University of South Bohemia
Faculty of Biological Sciences

Vegetation succession in quarries in the České středohoří Hills

Spontánní sukcesní procesy v lomech Českého středohoří

Ph.D. Thesis

Jan Novák

Supervisor **Prof. RNDr. Karel Prach, CSc.**
Department of Botany, Faculty of Biological Sciences, University of South Bohemia,
and Institute of Botany, Academy of Sciences of the Czech Republic

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Annotation. Vegetation succession in quarries in the České Středohoří Hills was studied. Investigations were focused on variability of vegetation succession in basalt quarries over landscape scale, influence of surrounding dry grassland on succession patterns and possibility of artificial sowing of target species on restoration disused basalt quarries. The results of this thesis suggest that restoration of abandoned quarries via spontaneous succession has been proposed as a cheap alternative to expensive technical reclamation.

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I hereby decleare that I worked out this thesis on my own using the cited literature only.

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Contens

Introduction

Introduction

Succession of vegetation can be generally regarded as a directional change in species composition over time, implying that one species or a group of species replace another one (Glenn-Lewin et al. 1992). Species composition changing during succession can be regulated by local factors (such as abiotic conditions, competition, disturbance) and regional factors (such as climate, history of landscape management, evolution and migration). Generally, the assembly of a local vegetation can be visualised as species passing through a series of filters, which represent historical and ecological constrains on the arrival and survival of organisms in a certain locality (Zobel 1997, Lawton 1999). Succession of vegetation is related to regional species pool and is connected with dispersal of species, mainly responsible for the assembly of local communities.

Investigating the variability provides possibilities which are not able to be achieved by even very detailed analysis of a limited number of sites. Seeking answers to questions such as those on divergence vs. convergence of succession on a broader spatial scale (Lepš & Rejmánek 1991), influence of different climate (Prach 1994), and the role of different species pools in the course of succession (Strykstra et al. 1998) is not possible without a broader geographical analysis of one type of succession. Moreover, an analysis of a large number of sites can produce insights that can be better applied in restoration ecology than those from only one or a few sites. It has been argued repeatedly that spontaneous succession is a suitable tool for restoration of various disturbed sites (Parker 1997; Harker et al. 1999; Prach et al. 2001)

Use of spontaneous vegetation succession in an ecosystem restoration program requires an existing knowledge base and application to specific aims. A target ecosystem should be set, including its expected structure and functions, in order to set clear aims for the particular restoration effort. The scientific debate oversetting restoration goals has tended to polarize. On one hand, a frequent aim is to return degraded biological communities to their original state and to re-establish self-regulatory natural processes. On the other hand, attempts to return damaged ecosystems to some kind of productive use or socially acceptable condition may be more realistic, a process that has been referred to as reclamation rather than restoration (Jordan et al. 1988).

Despite the enormous number of studies on vegetation succession, there are not many of them investigating the variability of succession over a larger landscape scale. Therefore I studied spontaneous succession in 56 basalt quarries spread over approximately 1800 km^2, in an volcanic hilly area in central Europe, where a distinct climatic gradient is known. The study area, named the České Středohoří Hills, is located in the northwestern part of the Czech Republic (latitude 50°34' – 50°48' N, longitude 13°41'-14°32' E). The area forms an elongated shape, running about 90 km from the southwest to the northeast. Three regions can be distinguished in the southwest-northeast direction and are characterised, besides climatic differences, by the occurrence of species belonging to different range types according to Meusel & Jäger (1992).

The České Středohoří Hills is a typical example of the central European landscape, where a great deal of habitat can be considered as arrested successional stages. Moreover, due to agricultural activities, the study area is largely affected by stone quarrying. Industrial quarrying of basalt was initiated in the 1920's and culminated in the 1980's in the region. There are now 56 basalt quarries in total, nine of them are still active.

In the first part of this thesis I am trying to answer the questions: (a) How does the vegetation succession differ among the quarries located in climatically different situations? (b) What are the differences in succession in particular habitats inside the quarries? (c) How typical is the participation of target species for species - rich grasslands, influenced by the surrounding vegetation?

The dry grasslands belong to the most valuable and rare habitats in central Europe (Ellenberg 1988). Most of present dry grasslands in central Europe are products of traditional non-intensive land use (Thomas, 1993; Bignal and McCracken, 1996; Wilmanns, 1997; Poschold et al., 2002). As intensive agriculture coupled with abandonment of less productive lands has replaced the traditional land use during the last decades, a considerable diversity of specialised plants and animals, whose survival depends on now-outdated management practices, faces extinction threats (Hillier et al., 1990; Van Swaay, 2002). The traditional non-intensive land use of the grasslands, i.e. extensive grazing and occasional cutting, has been recently practised only in some nature reserves under special management plans, and many of the remaining dry grasslands are gradually changing in the process of secondary succession (Kubíková et al. 1997). Moreover, since only small fragments of once extensive xerophilous grasslands remain in the region. Therefore it is increasingly argued that areas of protected lands should be augmented by restoration of unproductive and even degraded lands for conservation of biodiversity (Young, 2000; Beneš et al., 2003). Various types of post-industrial barrens, such as quarries, sand and gravel pits, mining dump heaps or old factory yards are particularly promising in this respect. Spontaneous colonisation of post-industrial

barrens by species of conservation interest has been reported for many organisms, whereas the supply of traditionally managed habitats transferable into reserves is steadily shrinking, the extent of restorable barrens increases, as abandoning of once-exploited sites is an inherent feature of an industrial economy (Schulz and Wiegleb, 2000). Quarries represent large and prominent landscape features and occupy larger areas than reserves in many regions. They may host valuable assemblages of both plants and animals.

Restoration of abandoned quarries via spontaneous succession has been proposed as a cheap alternative to expensive technical reclamation. However, the conditions channelling successional development in disused quarries towards specific vegetation are little known. In particular, there is minimum information to what extent the vegetation surrounding quarry sites influences the course of succession. In the second part of this thesis I am presenting the relevance of surrounding vegetation on the course of successional development in abandoned quarries. In studied area, the biotopes most valuable from the conservation point of view are semi-natural xerophilous grasslands. I tested the hypothesis that the distance of adjoining xerophilous grasslands and the proportion of the grasslands in quarry surroundings affect the vegetation of successional sites within the quarries. I studied the changes in plant species composition during succession in relation to the age of following site abandonment, and the distance and extent of xeric grasslands in the quarry vicinity.

The environmental site conditions of barren rock and debris, remained in the quarries, are expected to be rather extreme especially in initial stages of succession (Culen et al. 1998, Novak & Prach 2003). Besides the abiotic and other constraints, the arrival of some species before others may determine the next course of succession (van der Valk 1992, Tilman 1994).

In the studied area, the time of arrival and the rate of establishment of plants typical for the dry grasslands were recognized to influence whether a site will develop towards an open shrubby grassland, or towards continuous mesophilous scrubs and woodland. The occurrence of dry grasslands in a close vicinity of a quarry was decisive in this respect, thus dispersal limitation was expected to play a role (Novak & Prach 2003, Novak & Konvicka 2006). The main questions studied in the third section were: (a) Can the species typical for the dry grasslands be sown artificially to speed up succession towards restoration of the grasslands? (b) Are any differences in seedling recruitment and survival among climatically different regions?

To answer the question, I performed sowing experiments and followed seedlings recruitment and survival in the basalt quarries, located in three different climatic regions. I also intended to evaluate influence on weather fluctuations among years on seedlings establishment and survival.

The main goals of presented studies are to describe variability of successional changes over large geografical area, to attempt the demonstration of spontaneous succession as a suitable and effective tool for restoration of quarries.

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Paper I

Vegetation succession in basalt quarries: pattern over a landscape scale

Vegetation succession in basalt quarries: pattern over a landscape scale

Jan Novák[1] & Karel Prach[1,2]

[1] *Department of Botany, Faculty of Biological Sciences, University of České Budějovice, Branišovská 31, 37005 České Budějovice, Czech Republic*

[2] *Institute of Botany, Academy of Sciences of the Czech Republic, Dukelská 143, CZ-37982 Třeboň, Czech Republic*

Abstract. A spatio-temporal variation of vegetation during spontaneous succession was studied in 56 basalt quarries spread over 1800 km^2 in the České středohoří Hills (NW Czech Republic, Central Europe). Differences in the particular habitats inside a quarry, i.e. steep rocky slopes, bottoms and levels, dumps, and screes were considered. The habitats ranged in age from 1 to 78 yr since abandonment. Macroclimate (mean annual temperature and precipitation) significantly influenced the course of succession, which led to a formation of shrubby grassland, shrubby woodland or tall woodland. Participation of target species typical of steppe-like communities significantly depended on the occurrence of the communities in the vicinity, up to a distance of 30 m from a quarry. Disused quarries may become refugia for rare plant species. Spontaneous successional processes led in the reasonable time of ca. 20 yr to semi-natural vegetation. Thus, they can be successfully exploited in restoration programs scheduled for the disused quarries.

Keywords: Climatic gradient; Restoration; Species pool; Spontaneous succession; Target species.

Nomenclature: Hennekens (1995) for taxa; Oberdorfer (1992) for syntaxa.

Introduction

Despite the large number of studies on vegetation succession,there are not many of them investigating the variability of succession over a larger geographical area, except for Rydin & Borgegård (1991); Osbornová et al. (1990); Prach (1994); Csetcserits &Rédey (2001); Verhagen et al. (2001); and for limestone quarries Ursic et al. (1997) and Wheater & Cullen (1997). Investigating the variability provides possibilities which are not able to be achieved by even very detailed analyses of a limited number of sites. Seeking to answer questions such as those on divergence vs. convergence of succession on a broader spatial scale (Lepš & Rejmánek 1991), influence of different climate (Prach 1994), and the role of different species pools in the course of succession (Strykstra et al. 1998) is not possible without a broader geographical analysis of one type of succession. Moreover, an analysis of a large number of sites can produce insights that can better be applied in restoration ecology than those from only one or a few sites. It has been argued repeatedly that spontaneous succession is a suitable tool for restoration of various disturbed sites (Parker 1997; Harker et al. 1999; Prach et al. 2001), including stone quarries (Cullen et al. 1998). We had an opportunity to study spontaneous succession in 56 basalt quarries spread over ca. 1800 km^2, in an old volcanic hilly area in central Europe, where a distinct climatic gradient is known.

We asked: 1. How does the vegetation succession differ among the quarries located in climatically different situations? 2. What are the differences in succession in particular habitats inside the quarries? 3. How is the participation of target species, typical for species-rich grasslands, influenced by the surrounding vegetation?

Study area

The area, named the České středohoří Hills, is located in the northwestern part of the Czech Republic, Central Europe, 50°34' – 50°48' N, 13°41'-14°32' E (Fig.1). The altitudinal range is from 123 m a. s. l. at the bank of the River Elbe, up to 837 m a. s. l. at the top of the highest volcanic hill. The studied quarries are located between 160 and 610 m a.s.l. The area forms an elongated shape, running about 90 km from the southwest to the northeast, and was declared as a Protected Landscape Area by national law in 1976. Three regions can be distinguished in a SW-NE direction (Kubát 1970); they show differences both in climate and the occurrence of species belonging to different range types (Meusel &Jäger 1992).

The climate in the SW part (Region 1) shows continental features with only sporadic snow cover in winter and rather dry summers,with the lowest annual precipitation in the country. The region is characterized by the occurrence of species belonging to the Euro-Asian, and European meridional-submeridional-continental range types (Kubát 1970), e.g. *Stipa pulcherrima, Helictotrichon desertorum, Astragalus excapus* and *Artemisia pontica*. They occur in extensive vegetation patches of *Festucetalia valesiaceae*. The occurrence of *Quercetalia pubescenti-petraeae* vegetation is only sporadic and woodlands of *Fagetalia sylvaticae* do not occur there. The central part (Region 2) is equally warm, but wetter than Region 1. Thermophilous oak forests (*Quercetalia pubescenti-petraeae*) are typical natural vegetation.Patches of *Festucetalia valesiaceae* are numerous but smaller than in Region 1. Species with a submediterranean-(pontic) range, e.g. *Cornus mas, Quercus pubescens, Geranium sanguineum* are more abundant there.

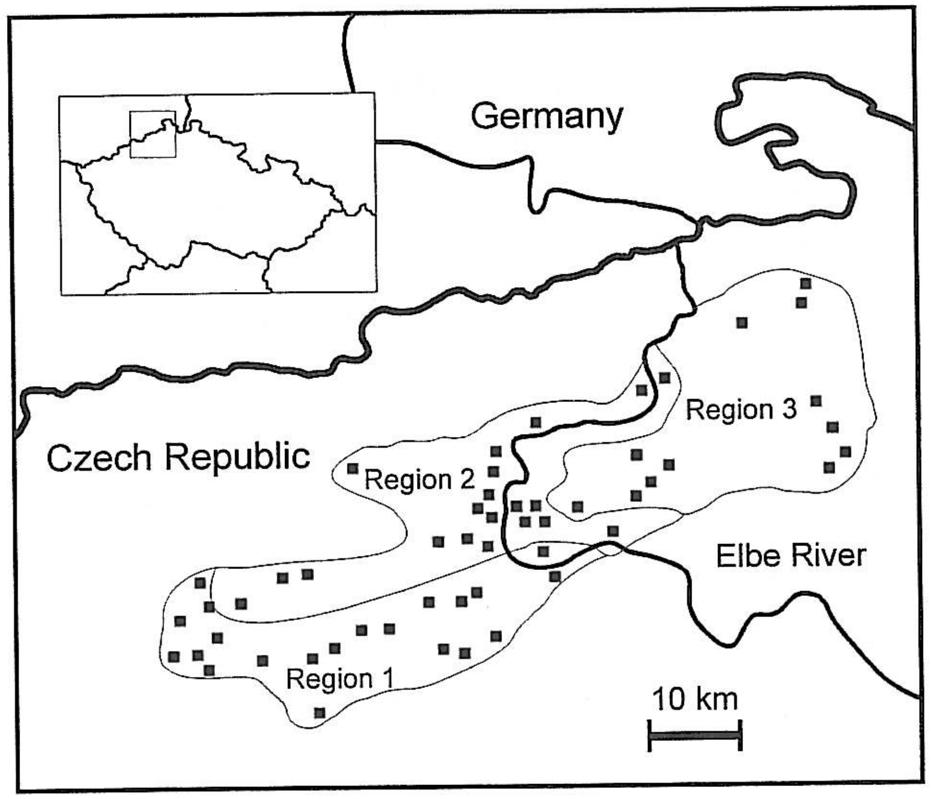

Fig. 1. Location of the studied basalt quarries. Three climatically different regions were delimited according to climatic characteristics (based on Kubát 1970).

The northeastern part (Region 3) is wetter and colder than the previous parts.There is an absence of plants of the continental range type. Species belonging to the submediterranean-(pontic) range type are sporadic.

Species of the Central-European range type e.g. *Quercus petraea, Corylus avellana, Galium odoratum* and *Brachypodium sylvaticum* are typical here. *Carpinion, Tilio-Acerion, Fagion* and *Arrhenatherion* prevail, while *Festucetalia valesiaceae* vegetation is rare. Characteristics are summarized in Table 1. Quarrying in the area started before World War II and culminated in the 1980s. Some quarries are still in use.

Methods

All available basalt quarries were considered if spontaneously re-vegetated sites occurred in a quarry. The history of each quarry was reconstructed on the basis of official records from the agencies exploiting the quarries or from the Administration of a Protected Land scape Area. Moreover, local people were consulted. The following particular habitats inside each quarry were considered: (1) steep rocky slopes (walls); (2) flat rocky and stony bottoms and levels; (3) dumps of various spoil material (disintegrated, fine-structured bedrock; low soil horizons); and (4) screes and debris at the foot of the walls. The habitats ranged in age from 1 to 78 yr since abandonment. Because exact dating was not possible in all cases,age categories were defined before data analyses started: Age 1: 1-3 yr old; Age 2: 4 -10 yr; Age 3: 11- 25 yr; Age 4: 26-40 yr; Age 5: >40 yr.

Phytosociological relevés of 5 m x 5 m were recorded in representative sites in each quarry, avoiding additionally disturbed sites, sites of unclear history or those being very fragmented and heterogeneous. We used the seven degree Braun-Blanquet scale (van der Maarel 1979) to estimate the cover of all species present (427 species together). The type of habitat (see above) was recorded. In total, 386 relevés were recorded with a mean number of seven relevés per quarry. The presence of natural xerotherm grasslands in the vicinity of a quarry (up to 30 m from the margin of a quarry) was recorded.

Mean annual temperature was obtained from Moravec & Votýpka (1997). 50-yr averages of mean annual precipitation and mean winter (X-III) precipitation were taken from the nearest meteorological station (Vesecký et al. 1960).

The vegetation data were analysed by multivariate methods in CANOCO version 4 (ter Braak &Smilauer 1998) and were not transformed. We expected unimodal relationships between species occurrence and time and therefore used DCA (length of the gradient of 5.9 SD) and CCA ordinations. For DCA, detrending by segments was used, and species with a weight from 5% were considered. For CCA, inter-sample distance by Hill scaling and unres -

Table 1. Characteristics of the climatic regions. The altitude ranges concern the studied quarries.

Region	Mean annual precipitation (mm)	Mean annual temperature (°C)	Typical natural vegetation	Frequent floristic elements	Altitude (m)	Number of quarries
1	460-500	8.1-9.0	*Festucetalia valesiacae*	Eurasian, continental	190-380	21
2	501-600	7.6-9.0	*Quercetalia pubescenti-petraeae*	Submediterranean - (Pontic) Central European	160-550	21
3	601-820	6.1-7.5	*Fagetalia sylvaticae*	Central European	290-610	14

tricted permutations (999) were used without forward selection, and p-values and F - ratio were calculated (ter Braak &Smilauer 1998).

Results

Changes in species composition

Except for steep walls, the succession of vascular plants starts in the studied quarries immediately after habitat creation. There are annual species which usually occur in the initial stages (Age 1) as dominants in most quarries disregarding the climatic region: *Arenaria serpyllifolia, Senecio vernalis, Lactuca serriola* and *Tripleurospermum inodorum*.

The initial stages are followed after 4 yr (Age 2) by annual and biennial species such as *Bromus tectorum, B. sterilis, Daucus carota, Trifolium arvense, Medicago lupulina,* and *Echium vulgare*, often accompanied by perennials such as *Poa compressa* and *Picris hieracifolia*. Several species occur only in the warmest Region 1, e.g. *Oxytropis pilosa*. On very rocky sites, such as the bottoms and levels, *Sedum album, Erysimum crepidifolium,* and *Verbascum lychnitis* occur also. *Tussilago farfara* appears early as a dominant on dumps with a higher proportion of fine-structured subsoil.

Gradually, after 10 yr (Age 3) perennial grasses and hemicryptophytes expand. *Arrhenatherum elatius* is a major dominant in all mesic habitats. *Dactylis glomerata, Lotus corniculatus, Hypericum perforatum, Inula conyza, Hieracium bauhinii, Echinops sphaerocephalus, Melilotus albus* and *Potentilla argentea* are also frequent. *Calamagrostis epigejos* is common on substrates with a higher content of clay. *Anthemis tinctoria, Convolvulus arvensis, Euphorbia cyparissias, Melica transsilvanica* and *Sanguisorba minor* are common on unstabilized debris and screes. Region 1 is characterized by the typical occurrence of 'steppe' species, e.g. *Koeleria macrantha, Artemisia campestris, Centaurea stoebe* and *Stachys recta.* Mesophilous species, e.g. *Poa nemoralis, Rubus idaeus* and young trees and shrubs of *Salix caprea, Betula pendula, Corylus avellana* and *Sambucus nigra*, are common in Region 3.

Trees, shrubs, sciophytes and nitrophytes expand after 25 yr (Age 4) in Regions 2 and 3, while heliophilous species decrease. Typical dominants for Region 2 are *Rosa canina, Sambucus nigra* and *Cornus sanguinea,* and young trees are becoming frequent, e.g. *Fraxinus excelsior, Acer campestre* and *Prunus avium. Betula pendula, Corylus avellana* and *Salix caprea* are very common in Region 3. The course of succession in the dry Region 1 is rather different. Grasses, such as *Festuca valesiaca* and *Bromus erectus,* and perennial herbs, e.g. *Thymus pannonicus, Salvia nemorosa* and *Scabiosa ochroleuca*, are typical for this age.

The oldest successional stages (Age 5) in Regions 2 and 3 are characterized by the gradual formation of a tree layer. *Fraxinus excelsior, Acer campestre, Crataegus* spp. are typical for Region 2 with the tree layer less closed. Heliophilous species such as *Fragaria viridis* and *Geranium sanguineum* are abundant. In the wettest Region 3, *Quercus petraea* and *Fraxinus excelsior* form the tree layer besides the already present *Betula pendula.* In the herb layer, nitrophilous and mesophilous species, such as *Geum urbanum, Impatiens parviflora, Campanula rapunculoides* and *Geranium robertianum* are common. In Region 1, the oldest stage resembles a 'shrubby steppe' with a higher occurrence of shrubs, especially *Prunus spinosa,* in wetter sites of the respective quarries. 'Steppe' species are represented especially by *Festuca valesiaca, Festuca rupicola, Elymus hispidus, Poa angustifolia, Bromus erectus, Dianthus carthusianorum* and *Scabiosa ochroleuca*. The oldest successional stages seem to be rather stabilized, so we expect further successional changes to be slow and mostly of a quantitative character.

Differences between habitats

Differences in the course of succession in the considered habitats are clearly evident from the results ob the DCA ordination presented in Fig. 2 (eigenvalue of axis 1 = 0.648, axis 2 = 0.459). Generally, the course ob succession seems to be divergent both among the regions and inside quarries within each region. The lowest within-quarry differences were found in Region 3, where the high humidity probably makes the habitats more uniform due to a higher participation of woody species in all the habitats. The differences among the particular habitats are more profound in the warmer and drier regions. Here, the dumps seem to be the most mesic sites, while the walls are most xeric. Quarry walls in Region 2 even appeared to be more xeric than dumps from Region 1. Succession on dumps is most rapid and slowest on

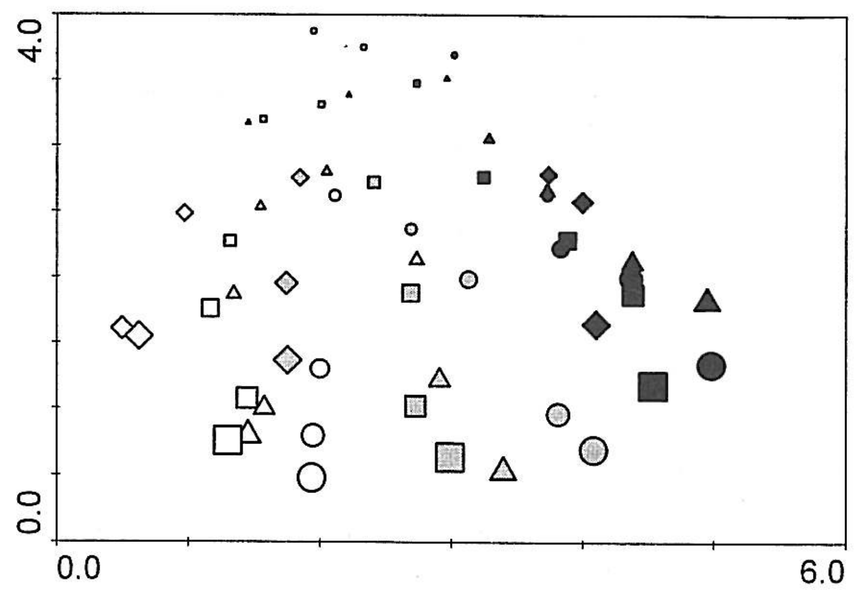

Fig. 2. DCA ordination of phytosociological relevés, grouped per habitat type,succesional stage and region. ▲- flat bottoms, ● - dumps, ■ - screes and debris at the foot of walls, ♦ - walls. The increasing size of symbols corresponds to 5 classes of sucessional age (1-3 yr; 4 -10 yr; 11 -25 yr; 26 -40 years; >40 yr). Region 1 - empty symbols; Region 2 - grey symbols; Region 3 - black symbols.

steep walls (the two youngest stages of walls are not represented here because there is no vegetation in that age). The positions of the centroids in Fig. 2 suggest that the early successional stages on walls lag ca. 10 yr behind: the 11 - 25 yr old stages are close to those of the 4-10 yr stages of other habitats,and later the delay can be even greater.

Influence of climate

The quarries were clearly arranged along the considered climatic gradients,i.e.mean annual temperature, mean annual precipitation,and mean winter precipitation, in the CCA ordination (Fig. 3).The quarries from the three regions were clearly separated ($p < 0.001$, $F = 11.054$). The eigenvalues of the first and second CCA axes were 0.497 and 0.186, respectively.

Influence of surrounding vegetation

The presence of natural or semi-natural xerotherm grasslands in the vicinity of a quarry has a significant (CCA, $p < 0.001$; $F = 10.331$) effect on the course ob succession (Fig. 4). The eigenvalues CCA axes 1 and 2 were 0.474 and 0.436 respectively. The differences are relatively small in the early stages of succession (Ages 1 and 2) when common ruderal species

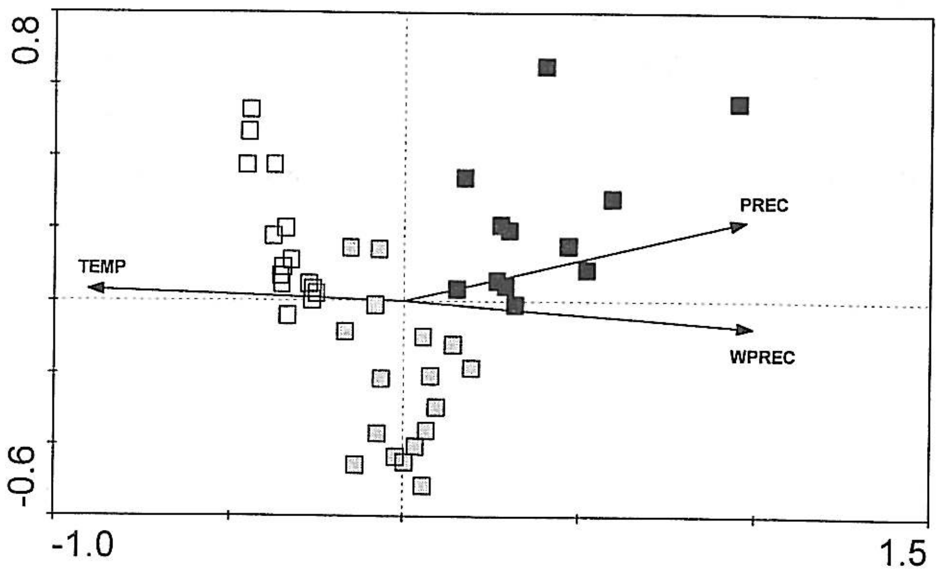

Fig. 3. CCA ordination biplot of quarries and climatic conditions. TEMP = Mean annual temperature; PREC = Mean annual precipitation; WPREC = Mean winter precipitation. Region 1 - empty symbols; Region 2 - grey symbols; Region 3 - black symbols.

are typical of all grasslands. However,with increasing successional age, the differences between quarries with and without xerotherm grasslands in their vicinity increase.

Discussion

Successional patterns

Studies on vegetation succession on a broader geographical scale can provide results which cannot be attained by any detailed study in one or a few sites: e.g. influences of macro-climate,and differences in species pool in the course of succession. Moreover, analysing a high number of sites, despite using rather robust methods, we obtained a much broader view on a particular type of succession, which can be used practically in restoration ecology. Unfortunately, there is still a lack ob such studies (Burrows 1990; Luken 1990; Glenn-Lewin et al.1992). We had a great advantage in our study that both the substratum (basalt) and the system of quarrying were similar in all studied sites. This enabled us to better recognize the effects of other factors in the course of succession.

The succession appears to be divergent both within and among quarries. Divergent succession trends on larger geographical scales have been reported several times ealier (Lepš & Rejmánek 1991; Prach 1994; Ursic et al. 1997) but at smaller scales, i.e. inside localities, succession tends to be convergent (Lepš & Rejmánek 1991). The opposite trend in the case of the studied quarries is probably caused by the fact that during the initial stages all habitats are colonized by a common set of ruderal species with a broad ecological amplitude (generalists). Later, more specialized species appear.

Despite the differences and the divergent status of succession among the habitats, the direction of succession inside a quarry is principally the same if life forms and dominant species are considered. There are more differences in the rate of succession, with a great delay of vegetation development on steep walls.

Successional divergence is also apparent in the physiognomy of vegetation in the three regions. The earlier stages are dominated everywhere by annual,biennial or perennial herbs whereas the late successional stages are dominated either by grasses, shrubs or trees (summarized in Fig.5). The proportion of woody species is generally higher in less extreme habitats, i.e. more humid in this case (Olsson 1987; Prach & Pyšek 1994).

Our study has shown that the course of succession is also dependent on the type of vegetation in the close vicinity. Even if the role of the surrounding vegetation in the process of colonization of disturbed sites has been repeatedly emphasized, there are only very few quantitative studies focusing on this topic (Zobel et al. 1998; Strykstra et al. 1998). It is known that species forming xerotherm grasslands are mostly dispersed over a short distance

(Grime et al.1988; Poschlod et al. 1996) and it is, therefore,not surprising that they are able to colonize the quarries only if they occur in their close proximity (Davis 1982). Recently, we conducted sowing experiments with dominant species from xerotherm grasslands and showed that these species are able to establish and grow in suitable habitats in any of the quarries. Their occurrence seems indeed to be limited mainly by dispersability (van der Valk 1992).

Implications for restoration practice

The results presented here demonstrate that spontaneous succession from bare quarries to semi-natural vegetation takes on average ca. 20 yr. Under certain conditions,i.e.if xerotherm grasslands are present in close vicinity to a quarry, even highly valuable communities may develop inside a quarry. These sites resemble natural steppe-like grasslands in species composition and physiognomy (Kubát 1970) and harbour rare and endangered species (see also Jefferson 1984). Several of such species find refugia even in younger stages (e.g. *Oxytro-*

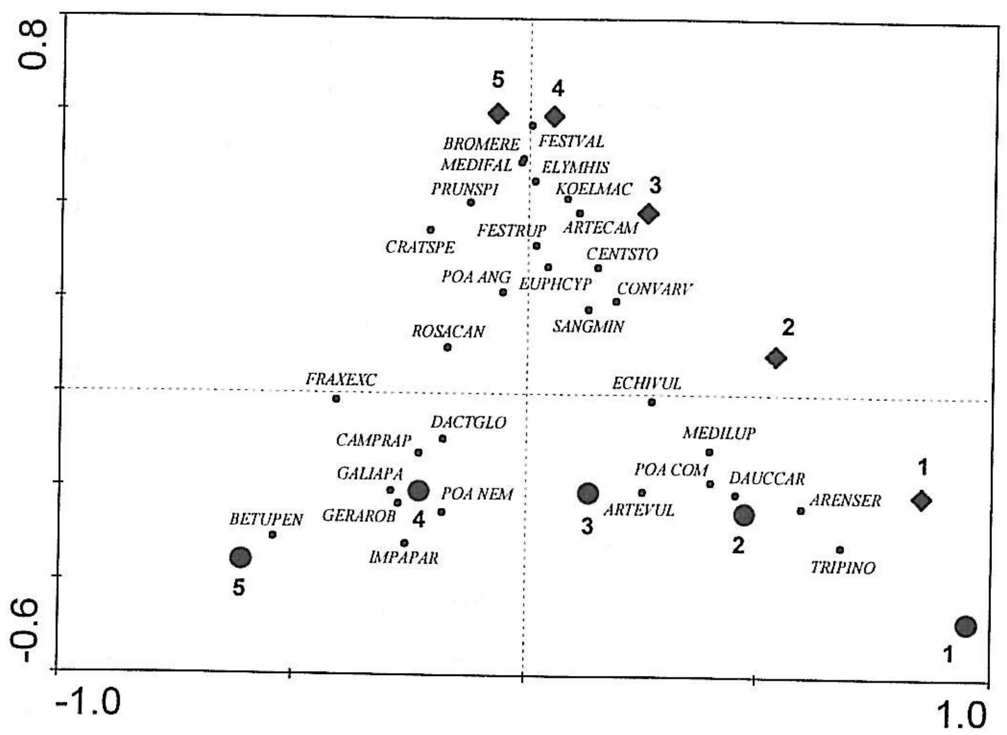

Fig. 4. CCA ordination of species and quarries,sorted according to the presence (♦) and absence (●) of xerotherm grasslands at a distance of up to 30 m from the margin of a quarry. Numbers 1-5 correspond to age categories. Species - represented with four letters from the genus and three from the species name - are mentioned in the text.

pis pilosa and *Erysimum crepidifolium*). Typical species from natural steppe-like grasslands that fail to establish naturally could be sown into suitable quarry habitats during restoration programs, thus accelerating and directing the succession (Luken 1990).

The intensity of quarrying in the region is decreasing but there are still several quarries operating. We recommend to include the preservation of at least some remnants of (semi)natural grasslands into the extraction schemes (if they still occur in the locality). We recommend also to eliminate the invasive *Robinia pseudacacia* from the surroundings in order to protect a quarry against invasion which we observed in several sites.

Generally, stone extraction is not appreciated in a Protected Landscape Area. However, under some future compromises, quarrying can be accepted if it respects the recommendations of ecologists. Our study showed that spontaneous succession can be a suitable, effective tool to restore quarries. This was found also in other studies on quarries (Davis et al.1985; Ursic et al.1997; Wheather &Cullen 1997) and does agree with general recommendations (Parker 1997; Harker et al.1999; Prach et al.2001; Perrow &Davy 2002).

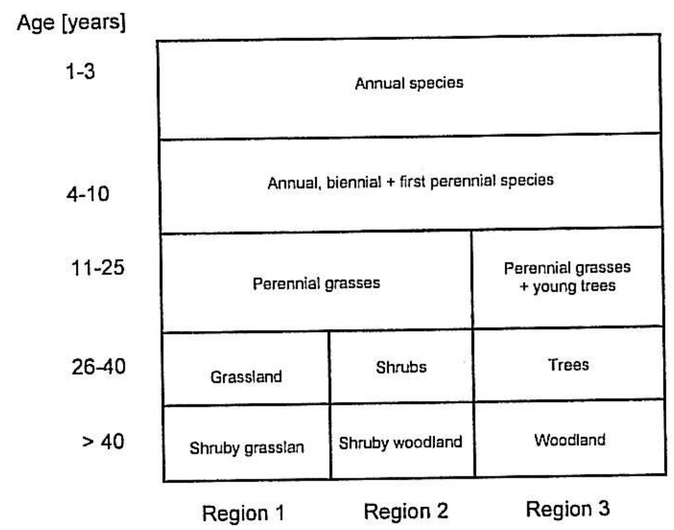

Fig. 5. Generalized scheme of succession in the basalt quarries in the three regions, based on the dominance of life forms and physiognomy of vegetation.

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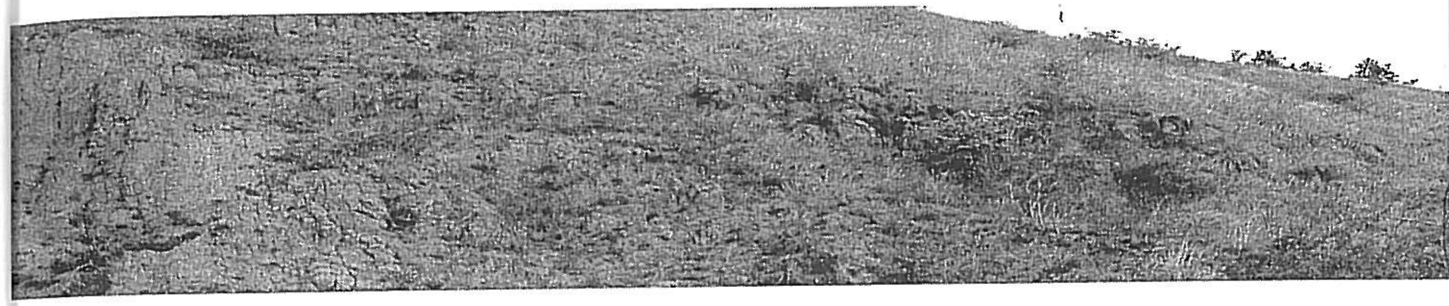
Paper II

Proximity of valuable habitats affects succession patterns in abandoned quarries



Proximity of valuable habitats affects succession patterns in abandoned quarries

Jan Novák[1], Martin Konvička[2]

[1] *Department of Botany, Faculty of Biological Sciences, University of České Budějovice, Branišovská 31, 37005 České Budějovice, Czech Republic*

[2] *Department of Ecology and Conservation, Institute of Entomology, Czech Academy of Sciences, Branišovská 31, 37005 České Budějovice, Czech Republic*

Abstract. The study tested the hypothesis that the composition of vegetation formed during primary succession in basalt quarries is affected by the distance to, and area of, conservation-valuable biotopes of surrounding xerophilous grasslands. The successional vegetation was recorded in 270 reléves collected in 34 quarries in the area of Ceske Stredohori Hills, Czech Republic. We used detrended correspondence analysis to visualise the relationship between successional vegetation, ages of individual sites, and distances to the closest xerophilous grasslands. Subsequent regression analyses of fidelities of individual reléves to the grassland alliances *Festucion valesiacae* and *Allyso-Festucion pallentis* corroborated the view that the probability of development of valuable habitats within the quarries decreased with distance to the closest grassland sites, and increased with their area. It also increased with successional age, but this effect was suppressed if quarry identity was considered as covariable in the regressions. Our results show that the valuable biotopes would eventually develop in quarries situated less than a hundred metres from adjoining xerophilous grasslands. We advocate that quarry operators pay attention to conservation management of biotopes that surround excavation sites, because maintaining valuable vegetation in the vicinity will eventually reduce costs of post-excavation restoration.

Keywords: Basalt quarry; Primary succession; Restoration; species pool; Xerophilous grasslands

Nomenclature: Kubat (2002) for taxa, Oberdorfer (1992) for syntaxa.

1. Introduction

Most of the xerophilous grasslands in Western and Central Europe are products of traditional non-intensive land use, including light grazing, small-scale hay cutting, occasional burning, and scrub removal for fuel purposes (Thomas, 1993; Bignal and McCracken, 1996; Wilmanns, 1997; Poschold et al., 2002). As intensive agriculture coupled with abandonment of less productive lands has replaced the traditional land use during the last decades, a considerable diversity of specialised plants and animals whose survival depends on now-outdated management practices face extinction threats (Hillier et al., 1990; Van Swaay, 2002).

One approach to battle this development is creation and active management of reserves, aimed on mimicking traditional land use (e.g., Bobbink and Willems, 1993; Pärtel et al., 1998; Dolek and Geyer, 2002). However, since only small fragments of once extensive xerophilous grasslands remain in many regions, the approach will ultimately reach the limits of available space. Therefore, it is increasingly argued that reserves should be complemented by restoration of unproductive and even degraded lands for conservation of biodiversity (e.g., Young, 2000; Benes et al., 2003). Particularly promising in this respect are various types of post-industrial barrens, such as quarries, sand and gravel pits, mining dump heaps or old factory yards (e.g., Davis, 1982; Cullen, 1998; Novák and Prach, 2003). They typically contain thin topsoil, which slows down forest growth and maintains the sites in arrested successional stages. Spontaneous colonisation of post-industrial barrens by species of conservation interest has been reported for many organisms, including plants (Wheater and Cullen, 1997; Prach and Pyšek, 2001), butterflies (Benes et al., 2003), beetles (Brandle et al., 2000), spiders (Bell et al., 2001) and birds (Bejcek and Tyrner, 1980). Whereas the supply of traditionally managed habitats transferable into reserves is steadily shrinking, the extent of restorable barrens increases, as abandoning of once-exploited sites is an inherent feature of an industrial economy (Schulz and Wiegleb, 2000). Hence, conservation use of localities exploited by industry offers a cheap and socially acceptable opportunity to augment the already small and fragmented areas of high quality biotopes in many regions (cf. Rosenzweig, 2003).

In this paper, we analyse spontaneous development of species-rich xerophilous grasslands in abandoned quarries. Quarries are large and prominent landscape features, which occupy larger areas than reserves in many regions. It has long been known that abandoned quarries may host valuable assemblages of both plants and animals (e.g., Usher et al., 1979; Jefferson, 1984). Recently, restoration of abandoned quarries via spontaneous succession has been proposed as a cheap alternative to expensive technical reclamation (Benes et al., 2003; Novak and Prach, 2003; Prach, 2003). However the conditions channelling successional development in disused quarries towards specific vegetation are little known. In particular, there is minimum information to what extent the course of succession is influenced by the vegetation surrounding quarry sites.

We studied the role of surrounding vegetation on the course of successional development in abandoned quarries within an ancient volcanic region of the Czech Republic. In this region, the biotopes most valuable from the conservation point of view are semi-natural xerophilous grasslands, protected by the ECC/EU Habitat Directive. We tested the hypothesis that the distance to adjoining xerophilous grasslands and the proportion of the grasslands in quarry surroundings affects the vegetation of successional sites within the quarries. We used an ordination technique to describe the changes in plant species composition during succession in relation to the age following site abandonment, and the distance and extent of xeric grasslands in the quarry vicinity. Then, we use regression techniques to assess the effect of surrounding grasslands upon the vegetation of successional sites.

2. Methods

2.1. Study area

The study was conducted within a 500 km^2 area situated in the České Středohoří Hills, located in the northwestern part of the Czech Republic, Central Europe, latitude 50°34'-50°48' N, longitude 13°41'- 14°32' E (Fig. 1). The altitude ranges from 180 to 420 m, the climate is mild with a low snow cover in winter, the mean annual temperatures range between 7.5 - 9 °C, and the annual precipitation is 500 - 600 mm (Kubat, 1970).

The landscape is a mosaic of deciduous forests, fields, hay meadows, human settlements and xerophilous grasslands. The forests, dominated by mesophilous oak-hornbeam and thermophilous oak woodlands, cover 30% of the landscape, whereas xerophilous grasslands (less then 5% of the landscape) are found either at steep and dry slopes unsuitable for forest growth, or at sites of former pastures.

2.2. Vegetation of xerophilous grasslands

Two types of semi-natural xerophilous grasslands occur in the area, closed-sward ones occurring on well-developed soils and open-sward ones occurring on rocky substrates. Central

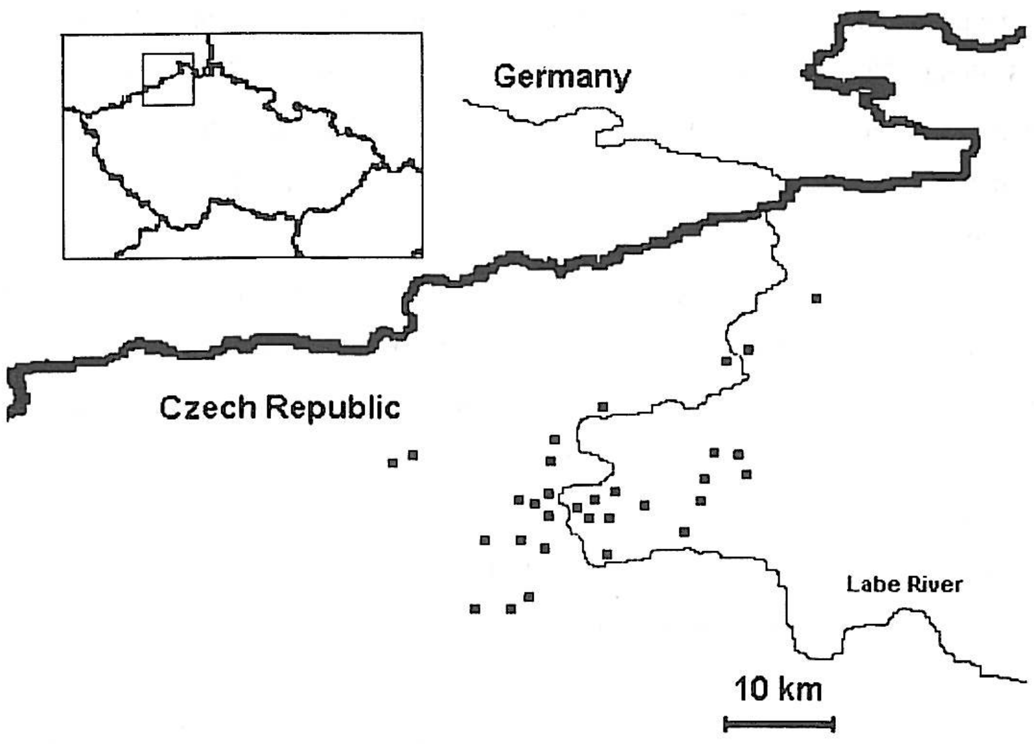


Fig. 1. Map of the study area showing its position in the Czech Republic and locations of the studied quarries.

European phytosociologists classify them as *Festucion valesiacae* and *Allyso-Festucion pallentis* alliances, respectively (Oberdorfer, 1992). A quantification of variation within these two alliances (Chytry and Tichy, 2003) showed that both are well-delimited, with 97.7 and 48.3% of species, respectively, being confined to them or rare in other alliances. The *Festucion valesiacae* alliance consists of species-rich formations dominated by thin-bladed tussock forming grasses, such as *Festuca valesiaca*, *Stipa* spp. and *Carex humilis*, accompanied by perennial herbs, such as *Potentilla arenaria*, *Eryngium campestre* and *Thymus pannonicus*, and spring ephemerals, such as *Arenaria serpyllifolia* or *Acinos arvensis*. Many of the species exhibit continental range types, reaching from Russian steppes to Central Europe. The formation is considered to be a relic from early post-glacial period, preserved owing to centuries-long grazing of domestic animals.

The *Alysso-Festucion* alliance is found on steep sun-exposed rocks and scree. The dominant grass is *Festuca pallens*, accompanied by hemicryptophytes, such as *Artemisia campestris*, *Aurinia saxatilis*, *Centaurea stoebe* and *Seseli osseum*, and by succulents including *Sedum album* and *Jovibarba globifera* (for details, see Chytry et al., 2001; Chytry and Tichy, 2003).

Industrial quarrying of basalt was initiated in the 1920s and culminated in the 1980s in the region. There are now 34 quarries in total, 9 of which are still active. Owing to the diverse landscape, none of the quarries is situated further than 4 km from a xerophilous grassland.

2.3. Data collecting

We sampled spontaneously re-vegetated sites in all 34 quarries present in the study region. In still operating quarries, freshly abandoned sites (1 year after excavation) were sampled. Within each quarry, we sampled vegetation by recording 5 m ×5 m phytosociological relevés of representative successional stages, using the seven-degree Braun-Blanquet scale (Braun-Blanquet, 1964) to estimate covers of all species of higher plants present. The collected data consisted of 270 relevés (mean per quarry = 8, S.D. = 6.5, median = 5), ontain5ing 393 species of higher plants (mean per relev′ e = 21, S.D. = 6.9, median = 20).

We used historical maps and information from quarry operators for dating successional age of the sampled sites. The age since cessation of quarrying ranged from 1-78 years. Because exact dating was not always possible, we used the following ordinal scale: (1) < 3 years, (2) 4-10 years, (3) 11-25 years, (4) 26-40 years, (5) > 40 years.

We located xerophilous grasslands surrounding the quarries by surveying the vicinity of each quarry aided by aerial photographs and detailed (1:5 000) topographic maps. The percentage proportion of the biotope in concentric circles around each relevé (up to 30, 31-100, 100-300 and more than 300 m from the relevé) was then recorded using the maps.

2.4. Statistical analyses

To visualise the effect of distance on succession, we used detrended correspondence analysis (DCA), an indirect ordination method that ordinates the positions of samples according to their species composition. Ages of individual relevés, and the distance of the relevés to the closest patches of xeric grasslands, were superimposed onto the ordination as supplementary environmental variables. We used CANOCO v. 4 (ter Braak and Smilauer, 1998), option "detrending by segments".

We used fidelity of individual rel′ eves (herein sample fidelity, Φ_R) towards the pre-defined vegetation alliances *Festucion valesiacae* and *Alysso-Festucion pallentis*, as a measure of similarity between the successional sites and the semi-natural grasslands. The analysis was based on species fidelities Φs or coefficients of association between individual species and the two above alliances. Fidelities of individual species of Czech flora towards all vegetation alliances were tabulated by Chytry and Tichy (2003) using empirical data stored in the Czech National Phytosociological Database, an immense source containing 54,310 reléves collected by 332 authors between 1922 and 2002 (Chytry and Rafajova, 2003).

The computing algorithm for species fidelity is,

$$\Phi_S = \frac{N \cdot n_P - n \cdot N_P}{\sqrt{n \cdot N_P \cdot (N-n)(N-N_P)}}$$

where N is the number of reléves in the database, N_p is the number of reléves in the particular vegetation unit p, n is the number of occurrences of the species in the database, and n_p is the number of occurrences of the species in p (Sokal and Rohlf, 1995; Chytry et al., 2002).

Based on the species fidelities, we computed sample fidelities Φ R for each of our reléves. We used the Φ s of individual species towards the alliances *Festucion valesiacae* and *Alysso-Festucion pallentis*, as givenby Chytry and Tichy (2003), entering middle values for species with a a fidelity towards both alliances. The computation was,

$$\Phi_R = \sum_{i,j} (\Phi_S \cdot N_S)$$

i.e., sum of species fidelities of all species present in the sample weighted by their perceptual abundances *Ns*. For species not considered as diagnostic for the two alliances, Φ_S were set to zero.

We than regressed the sample fidelities against the distance to surrounding xerophilous grasslands and their (arcsine transformed) percentual areas. The method was generalised linear modelling with assumed Poisson distribution of the response variable and log link (S-plus, 1999-2000). Then, we tested single-term relationships, and finally constructed a multiple-regression model based on forward stepwise selection procedure from all variables and their interactions. We then repeated the analysis with forcing quarry identity as a categorial co-variable onto the null model. This allowed controlling for pseudo-replication effect of multiple samples taken from one quarry, and for effects of such site-specific patterns as differences in altitude or climate.

3. Results

The course of succession in the quarries is visualised in Fig. 2. In early stages (< 4 years), there is little difference among the samples, which is evident from the short gradient on the horizontal axis, and all the early samples exhibit a strong fit of widespread annual weeds (e.g.,

Arenaria serpyllifolia, Conyza canadensis, Tripleurospermum inodorum). With increasing age, the samples diverge according to their distance to the xerophilous grasslands. Those in closest distances exhibit the strongest fit of characteristic steppe grasses and forbs

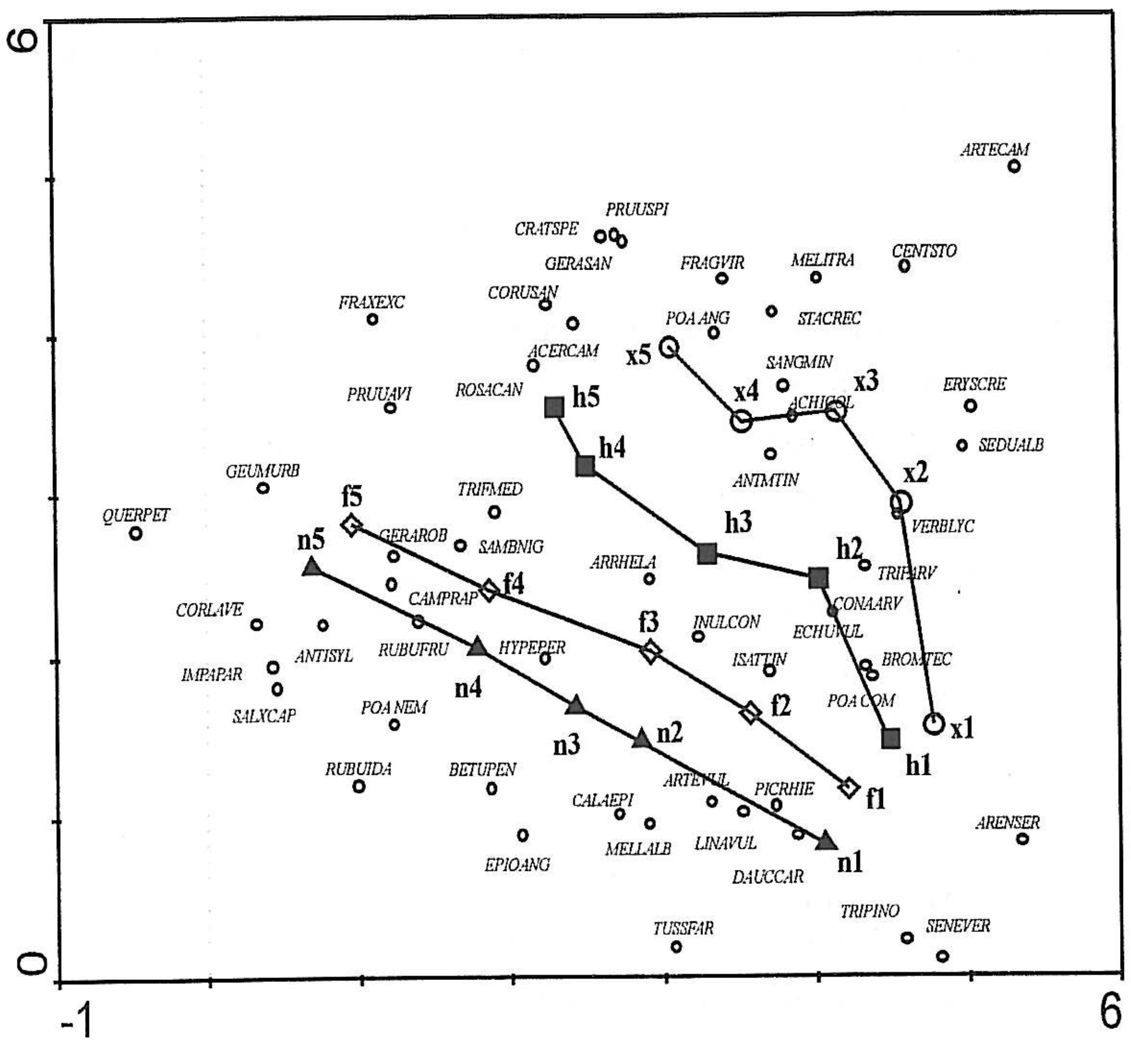


Fig. 2. Detrended correspondence analysis ordination diagram showing positions of species in samples collected from successional sites in basalt quarries. Successional age and distance to the closest xerophilous grassland were entered to the ordination as supplementary environmental variables. First and second canonical axes are shown. *Eigenvalues:* 1st axis, 0.67; 2nd axis, 0.49; sum of all eigenvalues, 2.71. The successional trajectories were created by connecting centroids of samples in particular successional age and distance class. The bold numbers accompanying the symbols delimit successional age: (1) < 3 years; (2) 4 -10 years; (3) 11 - 25 years; (4) 26 - 40 years; (5) > 40 years. The symbols indicate the distances to the closest xerophilous grasslands: (○) <30 m; (■) 30 -100 m; (◊) 150 -300 m, (▲) > 300 m.

(e.g., *Artemisia campestris, Festuca rupicola, Melica transsilvanica, Potentilla incana, Stachys recta*). This applies even to the latest successional stages. Here, however, the above species become accompanied by mesophilous herbs (e.g., *Fragaria viridis*), grasses (e.g., *Poa angustifolia*) and shrubs (e.g., *Prunus spinosa, Crataegus sp.*). Sites situated further from the xerophilous grasslands (with threshold at ca 100 m) are dominated by tall mesophilous grasses (e.g., *Arhenatherum elatius*) in middle-successional stage, and by mesophilous scrub (i.e., *Fraxinus excelsior*, *Betula pendula*, and grass *Brachypodium sylvaticum*) in the latest stages.

The values of sample fidelities were distinctly right-skewed, ranging from $\Phi_R = 0.0$ to 33.0 with mean = 3.0 and median = 2.0. Single-term regressions (Table 1) corroborated the role of distance to the nearest xerophilous grassland and of the area of the surrounding grasslands on the course of succession. Sample fidelities increased with increasing area of surrounding grasslands, which was the best predictor in terms of decrease of model deviance, and decreased with grassland distance. They also increased with successional age. When the (highly significant) effect of quarry entered the regressions as a covariable, the area and distance retained their effects, while the effect of successional age dissipated. This was expected, as individual quarries differed in ages.

Table 1. Single-term regressions of fidelities of vegetation samples recorded at successional sites within basalt quarries against distance to nearest xerophilous grasslands, and areas of the xerophilous grasslands surrounding the sites.

model	Regressions without covariable					Regressions containing covariable				
	d.f.	Dev[a]	qAIC[b]	*F*	*p*	d.f.	Dev.	qAIC	*F*	*p*
Null	269		1526.4							
Quarry						(-) 33, 236	55.3	814.4	9.6	***
Distance	↓ 1, 268	51.2	763.9	158.4	***	↓ 34, 235	7.0	683.7	44.2	***
Area	↑ 1, 268	55.7	683.9	304.4	***	↑ 34, 235	13.6	548.1	109.1	***
Age	↑ 1, 268	6.6	1444.6	16.0	***	34, 235	0.01	813.4	3.2	NS

Generalised linear models with assumed Poisson distribution of response variable. The darts (↓,↑) show directions of the relationships. Values of *F* and *p* are related to null model (y ~ +1) in regressions without covariable, and to model containing quarry as a categorical covariable in regressions with covariable.
*** $p < 0.0001$.
[a] Percentage deviance explained by the fitted model.
[b] Quasi-Akaike information criterion, weighting explained deviance by model complexity; the lower the value, the better and more parsimonious is model fit.

Table 2. Multiple-regression models of association of vegetation successional sites within basalt quarries to distance and area of adjoining xerophilous grasslands.

Model	d.f.	Deviance	AIC	*F*	*p*
Quarry identity not in the mode[a]					
+Area - distance + age +(distance x age) + (area x age)	5, 264	73.5	431.1	1117.5	***
Quarry identity as a covariable[b]					
+Area - distance + (area x distance)	3, 233*	18.2	506.1	42.4	***

Generalised linear models with assumed Poisson's distribution of response variable.
*** $p < 0.0001$.
[a]Deviance values and significance test computed against null model.
[b] Deviance and significance computed against a model containing covariable.

The multiple regressions pointed to the independent effects of area and distance on the composition of successional vegetation (Table 2). In addition, there were significant non-additive interactions between explanatory variables. In the model without covariable, the decrease of sample fidelities with increasing distance to xerophilous grassland was steeper in older quarries (distance x age in Table 2). Also, sample fidelities grew with area of surrounding grasslands rather monotonously at young sites, whereas at old sites they remained close to zero until a cutting value of some 40% of grasslands, and then steeply increased (interaction area x age in Table 2).

Controlling for quarry identity (by inclusion of covariable "quarry") pointed to a significant interaction between area and distance. If the grasslands were found within low distances, the fidelities grew linearly with grassland area, whereas in large distances (above ca 100 m) they remained low irrespective of grassland area (Fig. 3).

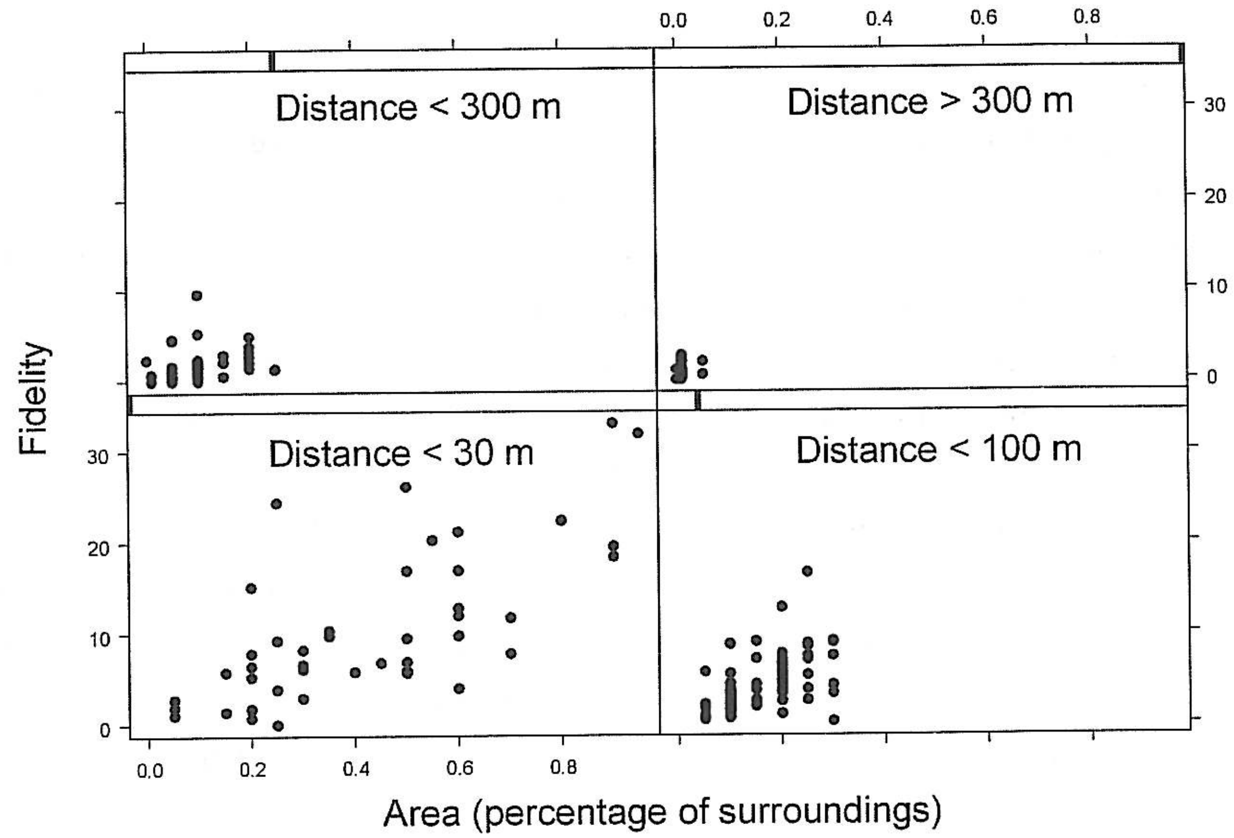


Fig.3. Trellis diagram showing the interaction effect of area of surrounding xerophilous grasslands and distance to the grasslands on fidelity of successional vegetation to vegetation formations of xerophilous grasslands (i.e., interaction Area x Distance from Table 2).

4. Discussion

4.1. Ecological interpretation

The course of succession in basalt quarries towards conservation-desirable xerophilous grasslands is strongly affected by the distance to the nearest grassland and the proportional share of the grasslands in quarry environs. Therefore, the plant assemblages colonising succession are not randomly drawn from the vegetation of the wider study area, but depend on the species pool within a close distance. This was expectable, as the probability that an organism arrives at a site during successsion is related to size and distance of source populations (Wilson, 1993), and the dispersal ability, quality and abundance of its propagules (Hansson, 1991; With and Crist, 1995; Strykstra et al., 1996; Hillebrand and Blenckner, 2002). However, the role of proximity of sources on the course of succession remains sparsely documented. A majority of studies that focused on the role of surrounding species pool on the successional development deal with secondary succession at such sites as abandoned fields (Foster et al., 2004) or newly planted woods (Butaye et al., 2002; Dupré et al., 2002). Studies focusing on primary succession are scarce, and studies dealing with industry-created primary succession sites are practically nonexistent (but see Kirmer and Mahne 2001, Campbell et al. 2003). By selecting quarries as a model system, we demonstrated the role of surrounding species pool on the course of primary succession, using a relatively large sample of sites situated on identical substrate and within an identical climatic region. The use of sample fidelities, as measures of association between successional sites and surrounding seminatural vegetation, facilitated simple and unequivocal testing of our hypotheses.

The arrival of some species before others determines the course of succession through shifts in competitive abilities (Lawton, 1987; Grace, 1987; Tilman 1994). In the studied area, the time of arrival and rate of establishment of plants characteristic for xerophilous grasslands determines whether a site will develop towards a biotope of high conservation value, or towards a mesophilous scrub (Novak and Prach, 2003). Whereas the extreme environmental conditions of barren basalt rock prevent establishment of woody species in early stages of succession, in later stages, the presence or absence of relatively competitive grasses determines whether woody plants would take over or not (Connell and Slatyer, 1977). Apparently, propagules of grassland species arrive earlier, and in larger amounts, if there are large grasslands in the surroundings.

A closer look into the plants recorded in the quarries that exhibited high fidelities to xerophilous grasslands allows distinguishing two distinct groups. One consisted of poor competitors that thrive at disturbed and/or rocky surfaces with minimum soil (e.g., *Erysimum crepidifolium*, *Sedum album*, *Acinos arvensis*). The other group included plants forming closed turf at sites with fully developed soils (e.g. *Festuca valesiaca*, *Koeleria macrantha*, *Stipa pennata*). Some representatives of the former group occurred even in quarries situated further from xerophilous grasslands, but were rare at older successional stages. In contrast, plants of the latter group occurred only at older stages that adjoined large tracts of xerophilous grasslands. The dichotomy is easily interpretable. Species of the former groups are good dispersers that can colonise the quarries even from relatively distant sources, but cannot withstand competition with later-arriving mesophilous species. The latter group, on the other hand, consists of poorer dispersers but better competitors (cf. Ellenberg, 1979; Grime, 1979).

Naturally, some woody cover would ultimately develop in all the studied quarries, except perhaps on steep rocks and screes (Ursic, 1997; Novák and Prach, 2003). This seemingly conflicts with the increase of fidelity with age observed in our analyses. The paradox is explicable by the limited range of quarry ages available in study area: none of the quarries was older than 80 years, whereas primary succession into woodlands may take centuries (Elias and Dias, 2004; Nishi and Tsuyuzaki, 2004). It is also notable that old quarries tended to be surrounded by larger xerophilous grasslands than young ones (grassland area and age were marginally significantly correlated, Spearman's $r = 0.12$, $t_{268} = 1.93$, $p = 0.054$), perhaps because it was easier for the past operators to begin excavations in grasslands and rocks than elsewhere.

Finally, it should be noted that the entire landscape surrounding the quarries had passed a substantial transformation during the last half-century due to decline of pasture land and the increase of forests (Barta, 1999; Sadlo and Pokorny, 2003). This will likely influence the course of future succession in some of the quarries studied. The average quarry abandoned some fifty years ago was surrounded by more xeric grasslands than an average quarry abandoned in the present. It can be expected that in recently closed quarries, spontaneous development of "mature" xerophilous grasslands (corresponding to the upper part of the ordination diagram in Fig. 2) will become increasingly rarer, unless a purposeful management changes the course. Instead, a majority of recent quarries may spontaneously develop more mesophilous vegetation.

4.2. Applied implications

Our findings may result into the paradoxical advice to locate new quarries next to biologically valuable sites, or, taken to the extreme, directly within reserves. This would be absurd: we do not call for sacrificing valuable biotopes to quarrying, and insist that new excavations should be located at lands with minimum conservation value, such as plantation forests or intensively farmed land. However, if there is a choice between locating a quarry near an existing xerophilous grassland or far from it, we advise the former alternative. Provided that a quarry will be ultimately restored via spontaneous succession (Prach, 2003), it will attain higher conservation value if located closely to valuable habitats.

It is equally important that high quality biotopes should persist in quarry vicinity in order to provide colonising propagules for eventual succession after cessation of quarrying. This highlights the importance of managing the areas surrounding active quarries. It is in the best interest of quarry operators to support such activities as non-intensive grazing, hay and shrub cutting, conservation burning or eradication of aggressive alien species at grasslands adjoining excavated sites (cf. Sutherland and Hill, 1995). The above activities may be prohibitively expensive for conservationists, but relatively cheap if compared with the budgets of excavating companies. For them, investments into the maintenance of high-quality vegetation around quarries may ultimately cut the costs of restoration after quarry closure.

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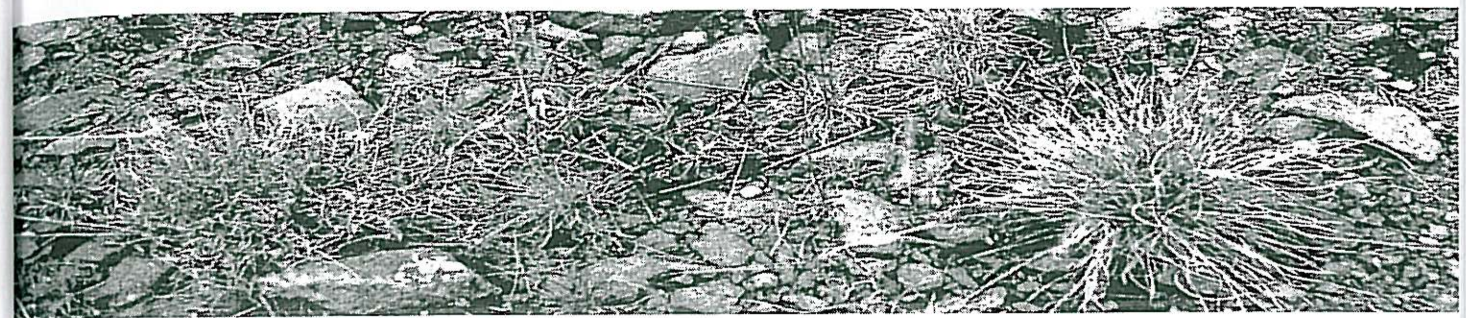
Appendix. Abbreviations of plant names appearing in Fig. 2.

ACERCAM	*Acer campestre*	INULCON	*Inula conisa*
ARENSER	*Arenaria serpyllifolia*	ISATTIN	*Isatis tinctoria*
ACHICOL	*Achillea collina*	IMPAPAR	*Impatiens parviflora*
ANRMTIN	*Anthemis tinctoria*	LINAVUL	*Linaria vulgaris*
ANTISYL	*Anthriscus sylvestris*	MELITRA	*Melica transsilvanica*
ARRHELA	*Arrhenatherum elatius*	MELIALB	*Melilotus albus*
ARTECAM	*Artemisia campestris*	POAANG	*Poa angustifolia*
ARTEVUL	*Artemisia vulgaris*	POACOM	*Poa compresa*
BETUPEN	*Betula pendula*	POANEM	*Poa nemoralis*
BROMTEC	*Bromus tectorum*	PICRHIE	*Picris hieracioides*
CAMPRAP	*Campanula rapunculoides*	PRUUAVI	*Prunus avium*
CRATSPE	*Crataegus* sp.	PRUUSPI	*Prunus spinosa*
CENTSTO	*Centaurea stoebe*	ROSUCAN	*Rosa canina*
CORNSAN	*Cornus sanguinea*	RUBUFRU	*Rubus fruticosus*
CONAARV	*Convolvulus arvensis*	RUBUIDA	*Rubus idaeus*
CORLAVE	*Corylus avellana*	QUERPET	*Qeurcus petrea*
DAUCCAR	*Daucus carota*	SALXCAP	*Salix caprea*
ECHUVUL	*Echium vulgare*	SAMBNIG	*Sambucus nigra*
ERYSCRE	*Erysimum crepidifolium*	SANGMIN	*Sanguisorba minor*
EPIOANG	*Epilobium angustifolium*	SENEVER	*Senecio vernalis*
EUPHCYP	*Euphorbia cyparissias*	SEDUALB	*Sedum album*
FRAGVIR	*Fragaria viridis*	STACREC	*Stachys recta*
FRAXEXC	*Fraxinus excelsior*	TRIFARV	*Trifolium arvense*
FESTRUP	*Festuca rupicola*	TRIFMED	*Trifolium medium*
GERASAN	*Geranium sanguineum*	TRIPINO	*Tripleurospermum inodorum*
GERAROB	*Geranium robertianum*	TUSSFAR	*Tussilago farfara*
GEUMURB	*Geum urbanum*	VERBLYC	*Verbascum lychnitis*
HYPEPER	*Hypericum perforatum*		

Paper III

Can artificial sowing of target species promote restoration in disused basalt quarries?



Can artificial sowing of target species promote restoration in disused basalt quarries?

Jan Novák[1)] and Karel Prach[1,2)]

[1)]*Department of Botany, Faculty of Biological Sciences, University of South Bohemia, Branišovská 31, CZ-37005 České Budějovice, Czech Republic;*

[2)]*Institute of Botany, Academy of Sciences of the Czech Republic, 37982 Třeboň, Czech Republic*

Abstract. Steppe-like dry (semi)natural grasslands are valuable and rare habitats in central Europe. In the study area (the Ceske Stredohori Hills, western part of the Czech Republic) they occur in fragments on southern slopes of volcanic hills, often in a vicinity of the quarries, which are numerous there. We performed sowing experiments and observed seedlings recruitment of six species, typical for the dry grasslands, in 9 basalt quarries located in 3 different climatic regions during 3 years. The sowing experiments were established in the young successional stages, 5-12 yr after quarrying was stopped. The objectives of the experiments were to evaluate (i) if seedlings recruitment and survival of the target species are possible, regarding the different climatic regions; and (ii) what is the influence of weather fluctuations among years on the seedlings survival.

Seedlings of all study species were able to recruit and survive in the early successional stages at least in some quarries. The species, except one, showed significant differences in recruitment among the climatic regions, with the best recruitment and survival in the driest and warmest region. Seedlings of two species did not recruit in the wettest and coldest region. All species survived in the driest and warmest region, while only one in the coldest and wettest region. The number of localities (floristic records) of particular species in the regions was the best predictor of the species germination and survival. Different weather conditions in the studied years significantly influenced recruitment of two species. It emerged, that the artificial sowing can be considered in restoration programs as a way how to restore dry grasslands in the disused quarries.

Keywords: Dry grassland; Quarries; Restoration; Seedlings recruitment; Seedling survival; Sowing experiments; Succession

Introduction

The dry grasslands belong to the most valuable and rare habitats in central Europe (Ellenberg 1988). Most of present dry grasslands in central Europe are, to a certain extent, products of a traditional non-intensive land use (Thomas, 1993; Bignal and Mc Cracken, 1996; Wilmanns, 1997; Poschold et al., 2002). They occur in fragments on southern slopes of volcanic hills in the studied area, the Ceske Stredohori Hills, in the western part of the Czech Republic. The traditional non-intensive land use of the grasslands, i.e. extensive grazing and occassional cutting, has been recently practised only in some nature reserves under special management plans, and many of the remaining dry grasslands are gradually changing in the process of secondary succession (Kubikova et al. 1997). Moreover, the study area is largely affected by stone quarrying, and the dry grasslands are often destroyed by the quarrying or survive in small patches in a vicinity of the quarries. Thus, their restoration should be a reasonable goal of reclamation activities in disused quarries.

The environmental site conditions of barren rock and debris, which remained in the quarries, are expected to be rather extreme, especially in initial stages of succession (Culen et al. 1998, Novak & Prach 2003). Besides the abiotic and other constraints, the arrival of some species before others may determine the next course of succession (van der Valk 1992, Tilman 1994). In the studied area, the time of arrival and rate of plants establishment typical for the dry grasslands were recognized to be influenced by the fact whether a site would develop towards open shrubby grassland, or towards continuous mesophilous scrubs and woodland. The occurrence of dry grasslands in a close vicinity of a quarry was decisive in this respect, thus dispersal limitation was expected to play a role (Novak & Prach 2003, Novak & Konvicka 2006). The main questions addressed in the study were: Can the species typical for the dry grasslands be sown artificially to speed up succession towards restoration of the grasslands? Are there any patterns in seedling recruitment and survival among climatically different regions? To answer the questions, we performed sowing experiments and followed seedlings recruitment and survival in the basalt quarries, located in three different climatic regions (Kubat 1970). We also intended to evaluate influence on weather fluctuations among years on seedlings establishment and survival. To carry out the experiments as close to natural conditions as possible we used the regional seed material and did not conduct laboratory or garden experiments which might give different results from those conducted in the field (Fenner 2000).

Material and methods

Study area

The area, named the Ceske Stredohori Hills, is located in the northwestern part of the Czech Republic, central Europe (50° 34′ – 50° 48′ N, 13° 41′ – 14° 32′ E). Three climatic regions can be distinguished along the southwest-northeast direction (Kubat 1970) and characterized, besides climatic differences, by the occurrence of species belonging to different range types, and different prevailing vegetation.

The climate in the southwestern part (Region 1) exhibits rather continental features with only sporadic snow cover in winter and rather dry summers, with the lowest annual precipitation in the country (460-500 mm). Mean annual temperature ranges between 8.1 and 9.0 °C. The region is characterized by the occurrence of species with rather continental range of occurrence (Meusel & Jäger 1992). They occur in comparably extensive vegetation patches of dry grasslands. The occurrence of termophilous oak woodland is also typical for the region.

The central part (Region 2) is equally warm, but wetter (501-600 mm) than Region 1. Termophilous oak woodland is typical natural vegetation and dry grasslands are numerous but smaller in their extent than in Region 1. There is a higher occurrence of plants with the submediterranean range of occurrence there.

The northeastern region (Region 3) is wetter (601-820 mm) and colder (6.1-7.5 °C) than the previous ones. There is nearly the absence of plants of the continental range type. Species belonging to the submediterranean range are sporadic. Dry grasslands are rare and beech forests represent prevailing natural vegetation (Neuhäuslova et al. 1998).

In the area, altogether 56 basalt quarries are located, where spontaneous vegetation succession was previously described (Novák & Prach 2003). Representative quarries were selected for the sowing experiments.

Sowing experiments

Six species, three forbs and three grasses, were selected to meet the following criteria: being typical for dry grasslands (Chytry and Tichy 2003, Oberdorfer 1992), producing sufficient amount of seeds of size and shape enabling easy collection and subsequent manipulation, and occurring in the area in sufficient number of localities. The following species were selected: *Atragalus excapus, Festuca valesiaca, Oxytropis pilosa, Silene otites, Stipa pennata* and *Stipa pulcherrima*. All the species are diagnostic species of the alliance of Festucion valesiaceae

(Chytry and Tichy 2003). Nomenclature follows Kubat et al. (2002). Seeds for each species in Region 2 were collected from two source populations.

The experiments were established in 9 disused basalt quarries, three in each climatic region. The age, since quarring was stopped, ranged between 5-12 yr. This successional age was chosen because this period appeared to be crucial for the next successional development of dry grasslands (see above). The sites for the experiments were situated on a flat quarry floor with homogenous substrate. In all cases the autochthonous substrate contained at least 10% of clayey particles and gravel size did not exceed 3 cm.

In each quarry, two blocks of six 1x1m plots were established. Randomized block design was used, and into the plots, particular species were sown, 100 seeds of each into three separated strips, in the late September 2000, 2001 and 2002, respectively. Numbers of seedlings were observed in the late April/early May and in the late September/early October from 2001 to 2004. In the case of *A. excapus* and *S. otites*, of which some seedlings germinated not only in the first but also in the subsequent seasons, it was not possible to calculate exactly the resulting balance between the newly emerged and died seedlings. Thus, the highest number of seedlings in the years was used as the number of emerged seedlings.

The years of observation differed in the weather conditions during the growing season. The year 2003 was very dry and warm, while 2001 and 2002 were wet. The following figures were obtained in the nearest meteorological station in Doksany (www.chmi.cz/meteo) for the growing seasons (IV-IX): 2001 – 15.2 °C, 454.5 mm; 2002 – 16.2, 417.9; 2003 – 17.0, 211.4; average (1961-1990) – 14.4, 308.3.

Data analysis

To assess whether germination and survival differed among species, years and regions, regarding also the number of localities (floristic records of the species) in the particular regions, and whether there were significant interactions among the factors, we used generalized linear models with Poisson's distribution of errors (S-Plus, 1999-2000). We first formulated a null model with numbers of seedlings, Y ~ +1. Then we constructed models including each of the explanatory variables separately, models with their additive combination, and model including all variables and their interaction. The models were compared with a null model using the Akaike information criterion (AIC; a balance between explanatory power and complexity; cf. Burnham and Anderson, 2002) and models with the lowest AIC value were considered as the best approximation of reality. Separate analyzes for

each species were performed using the same approach only in the case of germination because of data deficiency for survival.

The effects of number of localities were also assessed using GLM regressions, this time on square-root transformed response variable, gaussian distribution and identity link. Beside the number of localities, region and species were other potential predictors. All possible models containing number of localities were constructed and mutually compared using AIC.

Results

Germination and survival of the particular species and their cohorts during the experiment are evident from Fig. 1. Altogether, 1477 seedlings were available. Obviously not all seedlings emerged in the first season after sowing, seeds of some species germinated in the second and even the third year after sowing (*A. excapus* and *S. otites*). Some individuals of *A. excapus* and *O. pilosa* set flowers already in the third year after sowing in Region 1.

	Region 1			Region 2			Region 3		
	a	b	c	a	b	c	a	b	c
Astragalus excapus	133	99	49	13	6	11	0	0	0
Festuca valesiaca	303	198	93	207	103	49	66	31	2
Oxytropis pilosa	42	28	71	6	0	9	0	0	0
Silene otites	255	154	53	168	73	55	34	0	4
Stipa pennata	105	75	67	74	48	53	11	1	7
Stipa pulcherrima	34	23	62	22	11	54	4	0	4

Table 1. Seedling emergence, number of survival seedlings a number of localities in three climatic regions, calculated based on the maximum seedlings numbers reached during the observed period and the numbers in the last year of the experiment. a: seedling emergence, b: seedling survival, c: number of localities

The total numbers of emerged seedlings of the all cohorts, survived seedlings and localities of the respective species, recorded in the particular regions, are summarized in Table 1. If the seedlings emerged, their survival was rather high in Regions 1 and partly in Region 2. In Region 3, only *F. valesiaca* survived (disregarding one individual of *S. pennata,* four other species did not and two species did not even germinate.

All regions differed in numbers of localities ($F = 226.1$, $df = 2, 15$, $p < 0.001$), and numbers of emerging seedlings increased with number of localities (Spearman's $r = 0.64$, t

(16 d.f.) < 0.01). The numbers of surviving seedlings were closely correlated with numbers of emerged seedlings (Spearman's $r = 0.95$, t (16 d.f.) < 0.001).

Table 2. Results of regressions models of seedling emergence and seedling survival increased with number of localities, region and species.

germination	df	dev	AIC	F	P
Species	5, 12	232.57	396.1	2.82	0.07
Number of localities (Loc.)	1, 16	197.14	246.4	18.95	0.001
Region	2, 17	260.15	364.2	4.92	0.05
Locality + Species	6, 11	399.19	71.5	23.26	0.00001
Locality + Region	3, 14	234.90	307.6	5.60	0.01
Locality + Species + Region	8, 9	407.4454	69.64	19.745	0.0001
seedling survival					
Species	5, 12	134.49	467.3	1.38	0.29
Number of localities (Loc.)	1, 16	233.79	167.9	27.85	0.0001
Region	2, 15	196.95	239.6	8.63	0.01
Locality + Species	6, 11	325.18	97.6	13.88	0.001
Locality + Region	3, 14	235.30	208.7	8.27	0.01
Locality + Species + Region	8, 9	335.51	97.8	11.58	0.0001

As revealed by the GLM regressions (Table 2), both germination and seedling survival increased with number of localities. The numbers of germinating/surviving individuals differed regionally, being the highest in the warm and the lowest in the cold regions. For both germination and survival, the positive effect of number of localities were retained after including region and species to the models, that means the positive effect of the number of localities applied across regions and species. For germination, the third-order model including both species and region was superior of all models fitted, suggesting a regional effect on germinability that affected all species. For survival, second-order model (containing species but not region) performed slightly better according to AIC, and did not differ from a higher-order model containing both species and regions. Thus, although the species differed in germinability, this difference was not affected by regional differences.

Regarding the particular species, all generally germinated the best in the warmest and driest Region 1, and the worst in the coldest and wettest Region 3. *A. excapus* and *O. pilosa* did not germinate at all in Region 3 (Table 1). Except for *Stipa pulcherrima* and *Silene otites* the differences among the regions were significant (Table 3).

The best year for germination was in the most cases 2001, the worst 2003 (Fig. 1), but only *Silene otites* exhibited significant differences in the seedling recruitment among the

years, thus the species was more dependent on weather conditions in the particular years than the others. Difference in the case of *Stipa pennata* was marginally significant (Table 3).

	d.f.	Deviance[a]	AIC	*F*	*P*
Astragalus excapus (94 seedlings)	29		84.2		
Region	2, 27	52.1	49.9	12.75	***
Year	2, 27	3.4	99.2	0.41	N
Region + Year	4, 25	55.2	53.1	7.18	***
Region + Year + Interaction	**8, 21**	**84.1**	**23.9**	**14.46**	********
Festuca valesiaca (576 seedlings)	29		143.3		
Region	**2, 27**	**45.3**	**76.2**	**17.4**	********
Year	2, 27	2.4	169.6	0.29	N
Region + Year	4, 25	57.1	83.1	8.46	***
Region + Year + Interaction	8, 21	64.4	87.9	5.20	**
Oxytropis pilosa (48 seedlings)	29		68.2		
Region	2, 27	51.8	41.0	10.38	***
Year	2, 27	4.1	79.7	0.57	N
Region + Year	4, 25	57.0	41.9	6.59	***
Region + Year + Interaction	**8, 21**	**64.3**	**41.2**	**5.23**	******
Silene otites (336 seedlings)	29		235.2		
Region	2, 27	18.8	219.4	3.21	N
Year	2, 27	43.1	156.1	9.70	***
Region + Year	4, 25	61.9	122.5	9.10	***
Region + Year + Interaction	8, 21	70.8	115.5	7.00	***
Stipa pennata (190 seedlings)	29		119.5		
Region	2, 27	32.7	92.4	6.59	**
Year	2, 27	28.2	99.8	4.98	N
Region + Year	4, 25	60.9	60.8	10.21	****
Region + Year + Interaction	8, 21	74.8	49.9	8.78	****
Stipa pulcherrima (60 seedlings)	29		102.9		
Region	2, 27	11.9	108.6	1.33	N
Year	2, 27	23.1	95.9	2.81	N
Region + Year	4, 25	35.2	91.0	2.79	N
Region + Year + Interaction	8, 21	42.8	96.5	2.14	N

Table 3. Results of regressions models of seedling germination of the species regarding Region, Year and interaction Region x Year. N:nonsignificant; **: P < 0.01; ***: P < 0.001; ****: P < 0.0001
Generalized linear models with assumed Poisson's distribution of response variable;
[a] Percentage deviance explained by the fitted model.

Considering the interaction Region x Year, except *Stipa pulcherrima*, the species showed significant differences in seedlings recruitment, which indicates the weather conditions in the respective years were differently manifested in different regions.

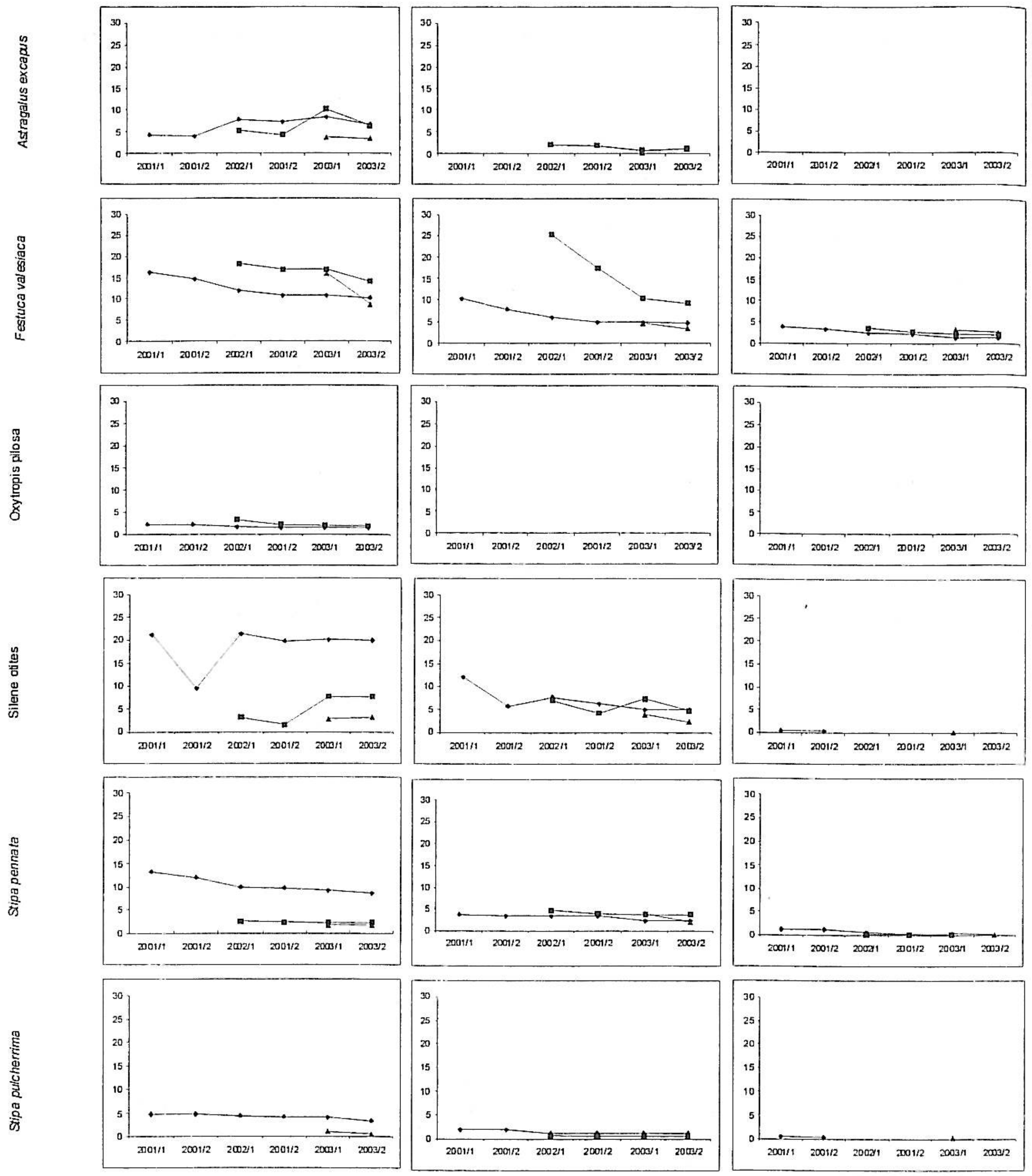


Figure 1. Percentage of germination and seedling survival of species sown in three subsequent years into the quarries in three climatically different regions.

Discussion

Although all the studied species are typical for late successional, or sub-climax vegetation (Ellenberg 1988, Oberdorfer 1992), they were able to grow in young successional stages (5-12 yr) in the basalt quarries, despite generally expected harsh abiotic site conditions in such quarries (Whisenant 1999). It seems, that the differences in abiotic site conditions between the young flat floor in the quarries do not differ so much from those on exposed southern slopes where (semi)natural remnants of the dry grasslands occur (Jenik and Rejmanek 1969, Slavikova 1983).

All the species germinated and survived best in the warmest and driest Region 1 where they frequently and naturally occur (Table 1) and the respective vegetation is typical for the region (Kubat 1970). Open shrubby grassland has spontaneously developed there in the quarries after some 20 years since quarring was stopped (Novak and Prach 2003). In Region 2, succession runs in the quarries towards close shrubby stands or woodland unless dry grasslands occur in the close vicinity (Novak and Prach 2003). Dispersal limitation was an evident factor in this region limiting the development of secondary dry grassland in the quarries (Novak and Konvicka 2006). Thus, seeding the respective species can potentially modify the successional development towards the restoration of the desirable dry grasslands. Moreover, the occurrence of the plant species typical for dry grasslands is important for rare insects in this region as demonstrated by Benes et al. (2003), which further advocates the restoration of the grasslands. The occurrence of dry grasslands in the wettest and coldest Region 3 is only very sporadic and small patches in extreme rocky sites harbor less number of species than in the previous regions (Kubat 1970). *A. excapus* and *O. pilosa,* which did not germinate in Region 3, have not been reported from the region (Kubat 1970, J. Novak, unpublished data). Only one species of those tested survived there in the experiment. It is evident, that the species and the respective vegetation are obviously there near their limit of occurrence and the results of our experiment correspond very well with the field observation of species occurrence in the area. It is interesting, that the number of localities (floristic records) was better predictor of seedling emergence and survival then the region itself in the sowing experiment. Thus floristic surveys may potentially help to predict success of species in restoration projects.

Rather great differences in seedling recruitment were observed between the years. Most species germinated best in 2001 and worst in 2003. The three subsequent years differed in climatic factors: 2001 and 2002 were wet, especially in summer, and 2003 was just opposite, i.e. very dry and hot in the growing season. It seems, that germination of the species typical for dry grasslands was limited by the dry season, and profited from the wet weather. Surprisingly, in the coldest and wettest Region 3, germination was not enhanced by the dry year. However, it must be mentioned that seed quality is influenced by weather conditions in the year of seeds forming (Fenner 2000), and thus germination ability cannot be simply attributed to the weather in the current year. Between-years variability implies, similar experiments and also practical sowing seeds in restoration projects should be conducted in several years to maximize germination and survival.

Adding seeds of target species into several stages to overcome dispersal limitation is a common restoration practice (Luken 1990, Perrow and Davy 2002), however seldom in quarries (e.g. Park 1982, Tichy 2005). Although spontaneous vegetation succession often proceeds towards acceptable vegetation, as we described earlier from the studied area (Novak and Prach 2003) and was also reported from quarries elsewhere (Ursic et al. 1997, Wheater and Cullen 1997, Jefferson 1984), the sowing can certainly speed up succession towards target stages and moreover, divert succession from less desirable to preferred stages.

Implications for restoration practice

Presented results are based on small-scale experiments, thus their extrapolation into a large-scale practical use must be done with caution. But the study clearly demonstrates that the late successional (or sub-climax) species can grow even in young successional stages in the quarries. It may be used, for example, in such situations when a valuable dry grassland is destroyed just by quarring. Then, seeds of valuable species may be collected before the destruction and sown in already abandoned parts of the same or in another quarry nearby, to form artificial refugee for the species. In our situation it may concern especially the rare and endangered species, namely *A. excapus, O. pilosa* and *S. pulcherrima*, the former is in the Red List and the others are rare in the country. Based on the results, such activities have sense only in the warm regions and not in the cold and wet ones. For a possible restoration of the dry grassland in the disused quarries, we recommend to sow the best survivor *F. valesiaca* as a keystone, dominant species of central European dry grasslands (Oberdorfer 1992). It may form a 'matrix' in restored grassland and other target species may be either sown artificially or they establish spontaneously if their seed sources are nearby. Our results indicate, that floristic records may be used as a tentative predictor of a relative performance of a species,

and thus to help in making decision if the species should or should not be used in restoration projects.

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Paper IV

Variabilita sukcesních změn vegetace v čedičových lomech Českého středohoří

Variability of vegetation succession in basalt quarries in the České středohoří Hills.

Variabilita sukcesních změn vegetace v čedičových lomech Českého středohoří

Variability of vegetation succession in basalt quarries in the České středohoří Hills

Jan Novák

Laboratoř archeobotaniky a paleoekologie, Katedra botaniky, Biologická fakulta, Jihočeská Univerzita České Budějovice, Branišovská 31, 37005 České Budějovice

Abstract. The succession of vegetation was studied in 56 basalt quarries in the area of České Středohoří Hills. The habitats ranged in age from 1 to 78 years since abandonment. The succession is rapid in all habitats but extreme ones, such as stone walls. In central Europe the spontaneous succession in basalt quarries often result to forest. Patches of treeless vegetation in quarries can be classified as *Festucion valesiacae* and *Allyso-Festucion pallentis*, which represent the most terget vegetation. Valuable biotopes can be predicted to develop in quarries situated less than 100 m from adjacent xerophilous grasslands. Quarry operators should pay attention to conservation management of surrounding biotopes, because maintaining valuable vegetation in the vicinity will eventually reduce costs of post-excavation restoration.

Keywords: Spontaneous succession; Target species, Basalt quarries, Restoration, České středohoří Hills.

Nomenklatura: Kubát (2002), Oberdorfer (1992).

Úvod

Těžba nerostných surovin významně pozměňuje vzhled krajiny a stává se často konfliktním tématem. Dřívější jednostranný pohled na lomy jako jednoznačně negativní vliv v krajině doznává alespoň v části vědecké obce změn. O významu opuštěných lomů jako důležitých center biologické diverzity v kulturní krajině je stále hlasitěji slyšet již od 80. let minulého století (Bradshaw et al. 1982, Ranson et Doody 1982, Jefferson 1984, Davis et al. 1985). Lomy jako významná refugia ohrožených druhů jsou zmiňovány i v řadě recentních českých publikacích (Novák 2002, Beneš et al. 2003, Novák and Prach 2003, Sádlo and Tichý 2003).

Směr a rychlost spontánní sukcese je ovlivněna především hlavními ekologickými faktory, jako jsou geologický podklad, klima, okolní vegetace a biotické interakce druhů, které jsou lokálně modifikovány vlhkostními poměry, charakterem substrátu a reliéfem daného místa v lomu. Mimo extrémní stanoviště, jako jsou např. stěny lomů, dochází během sukcese poměrně rychle k výrazným změnám přítomné vegetace. V České republice průběh spontánní sukcese v čedičových lomech obvykle směřuje k lesním biotopům (Novák and Prach 2003).

Průběh spontánní sukcese v čedičových lomech Českého středohoří

Průběh spontánní sukcese byl studován v 56 čedičových lomech Českého středohoří (Novák and Prach 2003). V těchto lomech se podařilo zachytit vývoj vegetace od jednoho roku do 78 let. Historie dané části lomu byla zjištěna ve spolupráci s těžebními společnostmi či pracovníky CHKO České středohoří. Vzhledem k tomu, že datování nebylo možné provést vždy zcela přesně, byla vegetace řazena do následujících věkových kategorií: a) 1-3 let; b) 4-10 let; c) 11-25 let; d) 26- 40 let; e) starší více než 40 let.

Spontánní sukcese v kamenolomech Českého středohoří začíná záhy po ukončení těžby. Iniciální stádia (1-3 let) jsou charakteristická řídkou vegetací jednoletých druhů (např. *Arenaria serpyllifolia, Senecio vernalis, Lactuca serriola, Tripleurospermum inodorum*). V následujícím sukcesním stádiu (4-10 let) se vedle jednoletých a dvouletých druhů (např. *Bromus tectorum, Trifolium arvense, Medicago lupulina, Daucus carota*) začínají objevovat i vytrvalé byliny a trávy (např. *Taraxacum* sp. div., *Picris hieracifolia, Poa compressa*). Na skalnatých stanovištích, jako jsou etáže a osypy lomů, jsou časté např. *Sedum album, Erysimum crepidifolium, Verbascum lychnitis. Tussilago farfara* je výraznou dominantou na

odvalech s vysokým zastoupením jílovitých částic. Několik druhů bylo nalezeno pouze v lomech Lounského středohoří, např. *Oxytropis pilosa*.

Následující období (11-25 let) je charakteristické přítomností zapojené vegetace s dominancí vytrvalých trav a bylin. Typickou dominantou mezických stanovišť je druh *Arrhenatherum elatius*, který provází např. *Daclylis glomerata, Lotus corniculatus, Hypericum perforatum, Inula conyza, Hieracium* cf. *bauhinii, Potentilla argentea*. Výraznou dominantou na substrátech s vyšším zastoupením jílovitých částic bývá *Calamagrostis epigejos*. Na nestabilních osypech a odvalech se v tomto sukcesním stádiu hojně vyskytuje *Anthemis tinctoria, Convolvulus arvensis, Euphorbia cyparissias, Melica transsilvanica* a *Sanguisorba minor*. České středohoří je známé výrazným klimatickým gradientem, např. průměrné roční srážky v Postoloprtech na Lounsku dosahují hodnot 450 mm, zatímco v České Kamenici, v severní části Verneřického středohoří, dosahují 820 mm (Vesecký et al. 1960). Tyto klimatické vlivy se projevují i na druhovém složení a průběhu spontánní sukcese v lomech stejného geologického podkladu. Vegetace v lomech Lounského středohoří je již v tomto sukcesním stádiu (11-25 let) charakteristická přítomností druhů xerotermních trávníků jako je např. *Koeleria macrantha, Artemisia campestris, Centaurea stoebe, Stachys recta* a *Achillea collina*. Ve Verneřickém středohoří jsou naopak běžné mezofilní a pasekové druhy jako např. *Poa nemoralis, Epilobium angustifolium, Rubus idaeus, Tanacetum vulgare* a juvenilní dřeviny, např. *Salix caprea, Betula pendula* a *Sambucus racemosa*.

Následující sukcesní stádium (26-40 let) je v regionu Verneřického a Labského středohoří typické výrazným nástupem dřevin, sciofytů a nitrofytů, zatímco heliofilní druhy zde ustupují. Pro Labské středohoří jsou typickými druhy *Rosa canina, Cornus sanguinea, Fraxinus excelsior, Acer campestre* a *Prunus avium*. Pro Verneřické středohoří jsou naopak charakteristické křoviny s *Corylus avellana, Betula pendula* a *Salix caprea*. V Lounském středohoří jsou v tomto sukcesním stádiu stále hojně zastoupeny druhy xerotermních trávníků jako např. *Festuca rupicola, Festuca valesiaca, Bromus erectus, Medicago falcata, Thymus pannonicus, Potentilla arenaria, Salvia nemorosa*.

Nejstarší existující sukcesní stádia (40 let a více) jsou v Labském a Verneřickém středohoří charakterická vyvinutým stromovým patrem. Méně zapojená vegetace s *Fraxinus excelsior, Acer campestre, Crataegus* sp. div. je typická pro Labské středohoří. Na stanovištích s nezapojeným keřovým a stromovým patrem jsou stále běžné heliofilní druhy, jako např. *Fragaria viridis, Geranium sanguineum* a *Securigera varia*. Vegetace v lomech Verneřického středohoří je charakteristická zapojeným stromovým patrem s přítomností *Fraxinus excelsior,* *Betula pendula* a *Quercus petraea*. V keřovém patře je hojná *Corylus avellana* a pro bylinné patro je typické zastoupení nitrofilních a mezofilních druhů jako např. *Geum urbanum, Geranium robertianum, Galium aparine, Impatiens parviflora, Anthriscus sylvestris, Campanula rapunculoides, Rubus fruticosus agg.* V Lounském středohoří mají nejstarší zjištěná sukcesní stádia charakter „křovinaté stepi" s hojným zastoupením *Prunus spinosa* a *Crataegus* sp. div. Hojněji zastoupené druhy xerotermních trávníků reprezentuje např. *Festuca valesiaca, Festuca rupicola, Elymus hispidus, Poa angustifolia, Bromus erectus, Dianthus carthusianorum* a *Securigera varia*. Mimo extrémní stanoviště, jako jsou např. stěny lomů či prudké jižní svahy, bude sukcese bez dalších zásahů i v Lounském středohoří pozvolna směřovat k lesní vegetaci.

Nejstarší zaznamenaná sukcesní stádia se zapojeným stromovým patrem se zdají být poměrně stabilizovaná a další sukcesní změny budou zřejmě probíhat pomaleji a budou mít především kvantitativní charakter.

Lomy jako refugia xerotermních druhů

V xerotermní travinné vegetaci je zastoupena řada reliktních druhů kontinentálních stepí, které byly v pozdním glaciálu velkoplošně rozšířeny v nížinách a pahorkatinách střední Evropy (Wilmanns 1997). Většina současných lokalit je však nepochybně sekundárního původu, vzniklá na místě původních teplomilných doubrav a dlouhodobě udržovaná pastvou, zejména ovcí a koz. Dnes se na většině lokalit nepase, s výjimkou těch rezervací, kde je pastva uplatňována jako součást ochranářského managementu. Jejich velikost je však pro přežití všech druhů vázaných na tyto biotopy malá.

Nápadným znakem druhové skladby jednotlivých sukcesních stádií v lomech českého a moravského termofytika je přítomnost řady diagnostických druhů xerotermní travinné vegetace svazu *Festucion valesiacae* a svazu *Allyso-Festucion pallentis*. V raně sukcesních stadiích čedičových lomů Českého středohoří se můžeme setkat např. s *Acinos arvensis, Androsacae elongata, Centaurea stoebe, Erysimum crepidifolium, Lactuca perennis, Medicago minima, Oxytropis pilosa, Petrorhagia prolifera, Polycnemum majus, Rapistrum perenne, Silene otites*. V čedičových lomech, kde těžba skončila před více než 40 lety, se vyskytuje např. *Adonis vernalis, Allium senescens* subsp. *montanum, Anthericum liliago, Artemisia pontica, Aster linosyris, Astragalus austriacus, A. excapus, Biscutella laevigata, Carlina acaulis* subsp. *caulescens, Clematis recta, Cotoneaster integerrimus, Elytrigia*

intermedia, Festuca pallens, Festuca valesiaca, Hypericum elegans, Melica transsilvanica, Orobanchae arenaria, Pulsatilla pratensis, Pseudolysimachion spicatum, Seseli hippomarathrum, Stipa capillata, S. pennata, S pulcherrima, S zalesskii, Verbascum phoeniceum (Novák 2002).

Vzhledem k tomu, že rozloha kamenolomů není zanedbatelnou částí krajiny, naskýtá se nám možnost využít spontánní sukcese v lomech pro vytvoření nových náhradních stanovišť.

Vliv blízké xerotermní vegetace na průběh sukcese

Vliv blízké xerotermní vegetace na průběh sukcese se pokusím dokumentovat na příkladu čedičových lomů Labského středohoří (Novák and Konvička 2006). Rozdíl mezi vegetací lomu s přítomností blízkého xerotermního trávníku či bez něj je u iniciálních sukcesních stádií (1-3 roky) relativně malý. V průběhu sukcese však dochází k výrazné diferenciaci v závislosti na vzdálenosti a velikosti plochy xerotermní vegetace. Nejsilněji se vliv xerotermní vegetace na průběh sukcese projevuje, vyskytuje-li se do vzdálenosti 30 m od vegetace v lomu. Sukcese na stanovišti vzdáleném více jak 100 m od xerotermní vegetace má víceméně mezofilní průběh.

Fidelita (věrnost) vegetace v lomu k vegetaci sv. *Festucion valesiacae* a *Allyso-Festucion pallentis* vzrůstá s rozlohou xerotermního trávníku a naopak klesá s jeho vzdáleností. U mladších sukcesních stádií fidelita vegetace v lomu roste s velikostí okolního xerotermního trávníku monotónně. Ovšem u starých sukcesní stádií je fidelita téměř nulová až do 40% zastoupení xerotermních trávníků v okolí, pak ale její hodnoty strmě stoupají.

Poměrně extrémní stanovištní podmínky některých iniciálních sukcesních stádiích zabraňují uchycení dřevin. Brzký příchod či absence relativně kompetitivních xerotermních trav rozhoduje, zdali bude průběh sukcese směřovat k tvorbě xerotermního trávníku či nikoliv. Jestliže v raně sukcesním stádium nebudou trávy xerotermních biotopů hojně zastoupeny, bude sukcese poměrně rychle směřovat k mezofilním křovinám. Diaspory trav se budou na lokalitě vyskytovat dříve a ve větším množství, jestliže se trávníky budou vyskytovat v blízkém okolí.

V sukcesních stádiích lomů se můžeme setkat se čtyřmi typy druhů přítomných v skalních a xerotermních travinných společenstvech:

1) snadno se rozšiřující druhy s nižší fidelitou ke stepní vegetaci (*Trifolium arvense, Arenaria serpyllifolia, Echium vulgare, Euphorbia cyparissias*). Tyto druhy jsou přítomné i v lomech od stepních biotopů dosti vzdálených.

2) slabý kompetitoři preferující iniciální stádia sukcese (např. *Erysimum crepidifolium, Sedum album, Centaurea stoebe, Acinos arvensis*). Tyto druhy se dobře rozšiřují a mohou lomy kolonizovat i z relativně vzdálenějších biotopů. V pozdějších sukcesních stádiích bývají velmi rychle nahrazeni kompetičně silnými mezofilními druhy.

3) druhy pozdějších stádií sukcese, které preferují stanoviště s již alespoň částečně vyvinutou půdou jsou (např. *Stipa* sp., *Festuca valessiaca, Koeleria macrantha*)

4) stepní druhy, které se do lomů šíří omezeně (např. *Carex humilis*).

Význam sukcese okolní vegetace lomů

Charakteristickým znakem Lounského a Labského středohoří je právě přítomnost xerotermních trávníků (Kubát 1970). Během posledních padesáti let však dochází k výrazným změnám krajinného rázu. Vedle intenzivního zemědělského hospodaření je nápadné postupné snižování pastvy a zároveň zvyšování zastoupení dřevin (Bárta 1999). Lomy, kde těžba byla ukončena před 50 lety, měly vlivem pastvy a hospodaření více xerotermní okolí, než jaké je mají lomy dnes. Nedojde-li k zásadní změně způsobu současného hospodaření, lze očekávat, že lomy budou fungovat především jako refugia raně sukcesních druhů a stepní druhy pozdějších sukcesních stádií se uplatní omezeněji, než tomu bylo dosud. Průběh sukcese v čedičových lomech českého termofytika bude vzhledem k současné mezofytizaci okolních biotopů asi rychleji směrovat k vegetaci zapojeného lesa.

Závěr

V současné době v naší republice převládají technické rekultivace (překrytí povrchu lomu zeminou a její osetí travní směsí a osázení dřevinami). Častým argumentem pro jejich aplikaci bývá např. zdlouhavý průběh spontánní sukcese či snaha zamezit šíření ruderálních druhů v krajině. Přítomnost ruderálních druhů v průběhu spontánní sukcese kamenolomů je však obvykle velmi krátkodobá a druhově omezená. Po 20 letech od ukončení těžby má většina lomů již značný biologický potenciál a relativně pomalejší rychlost sukcesních změn je třeba

vnímat spíše jako přednost. Lomy fungují jako refugia pro řadu dnes již vzácných raně sukcesních a strestolerantních druhů.

Druhová skladba vegetace je v průběhu sukcese značně ovlivněna přísunem diaspor, charakterem přítomných stanovišť a biotickými interakcemi druhů. Z tohoto pohledu nabývají na významu biotopy blízkého okolí a je velice důležité, aby přírodě blízké biotopy v blízkém okolí lomu byly zachovány. Prostředky určené na rekultivace lomu by bylo vhodné využít na údržbu kvality stávajících biotopů v jeho blízkém okolí, jako např. extenzivní pastvu, odstraňování dřevinného náletu a invazivních druhů (např. akátu) ze stepních trávníků, popř. i jejich maloplošné vypalování.

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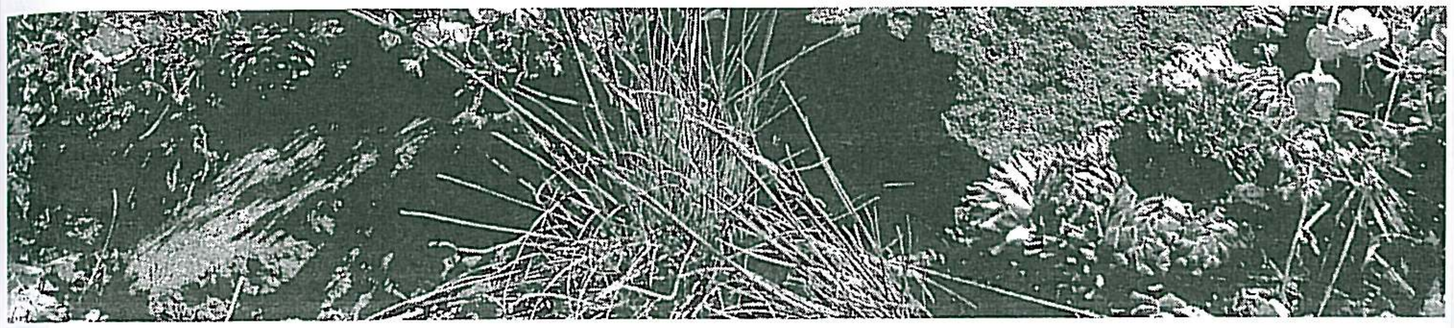
Paper V

Výskyt některých druhů rostlin v lomech Českého středohoří a dolního Poohří

Occurence of some plant species in quarries in the České středohoří Hills and in the lower Poohří



Výskyt některých druhů rostlin v lomech Českého středohoří a dolního Poohří

Occurence of some plant species in quarries in the České středohoří Hills and in the lower Poohří

Jan Novák

Katedra botaniky, Biologická fakulta, Jihočeská Univerzita České Budějovice, Branišovská 31, 37005 České Budějovice

Abstract. The České středohoří Hills and lower Poohří are traditional regions of exploitation of building stone - basalt, trachyt and some chalk sediments. Spontaneous succession is very acceptable for development of vegetation. The quarries are important refuge for many plants and animals. In the article I'm interesting in occurrence of some plants, which I consider as a phytogeografically important or rare.

Úvod

Jedním z projevů lidské činnosti je také těžba kamene. Vliv aktivního lomu na okolí, který se projevuje hlukem, prašností, destrukcí stávajících a tvorbou biotopů nových, je nesporný. Na druhou stranu ale nelze pohlížet na lomy jako na "nezhojitelné jizvy krajiny". Spontánní sukcese vede ve většině případů k porostům blížícím se svým druhovým složením polopřirozeným až přirozeným porostům této oblasti (Picket & Parker 1994, Prach et al. 1999). Lomy jsou vhodným útočištěm i pro relativně vzácné druhy rostlin, které jsou vázané na raně sukcesní stadia, skalní stěny a xerotermní bezlesí. Mnohdy jsou tyto relativně mladé biotopy z floristického hlediska zajímavější než okolní vegetace.

Cílem tohoto článku je upozornit na recentní nálezy některých druhů vyšších rostlin, které se vyskytují na těchto specifických biotopech.

Charakteristika území a metodika

Ve sledovaných lomech Českého středohoří se těžil a nadále těží bazalt či trachyt a v lomech dolního Poohří cenomanský pískovec a také čedič.

Z výskytu uvedených taxonů je patrný klimatický rozdíl mezi Lounským (spolu s dolním Poohřím) a Labským středohořím. I když je tato situace poměrně známá (Kubát 1970), jsou mnohdy tyto dvě části Českého středohoří chápány jako jeden floristický celek. Lounské středohoří a také i dolní Poohří jsou oblasti s poměrně kontinentálně laděným klimatem. Pro Labské středohoří je charakteristické méně extrémní „submediteránní" klima. Vzhledem k výskytu sledovaných druhů i v několika lomech severního okraje Podřipské a Perucké tabule byla studijní oblast rozšířena i o toto území. V článku uvádím i již známé, mnou potvrzené výskyty (např. *Carlina acaulis* subsp. *simplex* v lomu na Rané). Vybrané druhy rostlin, uvedené v článku, považuji za taxony fytogeograficky významné nebo vzácné.

Terénní výzkum jsem prováděl v roce 2000-2001. Nomenklatura uvedených druhů rostlin je dle Neuhäuslová, Kolbek (1982).

Přehled lokalit

1. Bečovský vrch: čedičový lom na J úpatí Bečovského vrchu 1,5 km Z od obce Milá
2. Bílinka: malý čedičový lom na J okraji Bílinky, km Z od Lovosic
3. Blšanský Chlum: čedičový lom 1,5 km J od Černčic
4. Boreč: trachytový lom na SSZ úpatí, 0,5 km JZZ od Režného Újezdu
5. Břvanský vrch, čedičový lom u Břvan
6. Červený Újezd:čedičový lom 500m SVV od Červeného Újezdu
7. Deblík: čedičové lomy na vrchu Deblík km JV od Církvic
8. Deblík, „Starý lom": čedičový lom nad železniční tratí u viaduktu, 1 km J od Církvic
9. Deblík, Hauberge: malý lom na J svahu Hauberge na JZ úpatí Deblíku, 900m J od Církvic, alkalický trachyt
10. Deblík, Kostelní vrch: malý lom na Z svahu Kostelního vrchu, 2 km SV od Libochovan, alkalický trachyt
11. Debus: čedičový lom 1 km SZZ od Prackovic
12. Dolánky: čedičový lom na SV okraji Dolánek, 2km Z od Bžan
13. Humenský vrch: malý čedičový lom 2 km Z od Keblice
14. Chloumek: malý čedičový lom 2 km Z od Břvan
15. Jezeř: malé čedičové lomy na J svahu
16. Jiřetín: malý čedičový lom 2 km S od Duban
17. Kamenná slunce: malý lom JV od Hnojmic
18. Kočka u Žitenic: malý čedičový lom JZZ od Žitenic
19. Kubačka: činný čedičový lom 500m S od Dobkoviček
20. Kvítel: malý čedičový lom na JZ úpatí Kvítele 1,5 km V od Třebenic
21. Libochovany: starý rulový lom 1,5 km J od Lobochovan
22. Mackovic skála: pískovcový lom na Holém vrchu mezi Přestavlky a Vrbkou, 2,5 km JV od Budyně nad Ohří
23. Ledvinův kopec („Ledviňák"): malý čedičový lom na JV úpatí Košťálova 600m S od nádraží Třebenice-město
24. Malý vrch: nižší z dvojice vrchů 400m SZ o Třtěna (kóta 246)
25. Mariánská skála: trachytový lom 300m V od stanice Ústí nad Labem – hlavní nádraží
26. Martiněves: starý pískovcový lom na SZ okraji Martiněvsi u Mšených Lázní
27. Medvědice: malý čedičový lom 100m Z od vrchu Klůček nedaleko Medvědic na SV úpatí Lipské hory
28. Měrunice: čedičový lom v SZ části vrchu Stříbrník 1 km Z od Měrunic, 5 km SZ od Libčevsi
29. Mojžíř: lom na Z svahu Kozího vrchu, alkalický trachyt
30. Moravany: lom mezi Moravany a Dolními Zálezly
31. Mšené Lázní: starý pískovcový lom 300 m JVV od nádraží
32. Neštěmice: čedičový lom nad silnicí 500 m V od železniční stanice Ústí nad Labem - sever
33. Obecní skála u Vrbky: starý pískovcový lom 1 km V od Vrbky u Budyně nad Ohří
34. Obecní vrch u Chudoslavic: malý trachytový lom 100m S od Chudoslavic
35. Písečný vrch: křemencový lom 2 km JZ od obce Milá
36. Podbradec: malý pískovcový lom v údolí Budyňského potoka 500m V od Podbradce
37. Podhájí: malý pískovcový lom v údolí Budyňského potoka 700m JVV od Roudníčku
38. Radobýl: čedičový lom na Z svahu Radobýlu 1 km od Žalhostic
39. Raná: dva čedičové lomy na SV a V svahu Rané
40. Rohatec: čedičový lom 1,5 km V od Křesina
41. Soutěsky: činný čedičový lom na okraji obce Soutěsky, 4 km od Benešova nad Ploučnicí
42. Stráž u Svinčic: čedičový lom na J okraji Svinčic, 3km V od Obrnice
43. Těchlovice: starý čedičový lom nad železniční tratí 1 km S od Těchlovic
44. Trabice: činný čedičový lom 2 km SZ od Libochovan na SZ svahu Trábice
45. Trmice: čedičový lom 150 m JV od obce
46. Týnecký Chlum: činný čedičový lom 800m SSV od Chraberců
47. Týnecký Chlum: malý čedičový lom na SV úpatí Týneckého Chlumu, 500m J od Mnichovského Týnce
48. Ústí nad Labem - Setuza: dva malé trachytové lomy JZ a Z části vrchu nad čistírnou Setuzy
49. Velká Kozí hůrka: malý čedičový lom 1 km JZ od Třebenic
50. Vinice: malý čedičový lom 1 km SSV od Křesína
51. Visálek: malý čedičový lom 1 km SSV od Křesína
52. Vrahožily: trachytový lom 300 m SSZ od Vrahožil asi km V od Rtyně nad Bílinou
53. Vraný: pískovcový lom nad Vranským potokem, 1 km V od obce Vraný
54. Vršetín: činný čedičový lom 2 km SZZ od Třebenic
55. Želenický vrch: dva trachytové lomy 800m od Želenic

Výskyt sledovaných druhů

Adonis aestivalis: 7, 19, 28.- *Allium senescens* subsp. *montanum*: 4, 25, 30, 32, 52, 55.- *Alyssum montanum*: 8, 23.- *Androsace elongata*: 2, 49.- *Anthericum liliago*: 4, 8, 12, 20, 22, 23, 26, 31, 39, 40.- *Anthericum ramosum*: 33.- *Artemisia pontica*: 1, 14, 16, 20, 22, 38, 39.- *Aster amellus*: 36.- *Aster linosyris*: 8, 14, 24, 35.- *Astragalus austriacum*: 13, 17, 20, 24, 31, 33, 35, 36, 38, 39, 40, 49.- *Astragalus excapus*: 13, 38, 39, 42.- *Astragalus onobrichis*: 31,36.- *Aurinia saxatilis*: 8, 22, 25, 28, 29, 43, 51.
Biscutella laevigata: 8, 29.
Campanula bononiensis: 8, 10, 30, 44.- *Carex humilis*: 5, 22, 23, 24, 31, 33, 35, 37, 38, 39, 42.- *Carex supina*: 8, 22, 53.- *Carlina acaulis* subsp. *Simplex*: 39.- *Cerasus mahaleb*: 13, 23, 54.- *Clematis recta*: 4, 30, 33, 44, 55.- *Corynephorus canescens*: 22.- *Cotoneaster integerrimus*: 4, 34, 42, 44, 47, 55.
Digitalis grandiflora: 4, 34, 55.

Elytrigia intermedia: 1, 3, 5, 8, 9, 10, 13, 15, 16, 17, 18, 20, 21, 22, 23, 24, 26, 27, 31, 33, 32, 33, 34, 37, 38, 39, 40, 41, 44, 49, 51, 53.
Festuca pallens: 4, 8, 9, 12, 19, 22, 38, 43, 46, 51.- *Festuca valesiaca*: 1, 3, 5, 7, 8, 9, 10, 13, 14, 15, 16, 17, 18, 20, 21, 23, 24, 31, 32, 37, 38, 39, 40, 42, 47, 49, 51.
Gagea arvensis: 27.- *Gentianella ciliata*: 31, 33.- *Geranium sanguineum*: 4, 7, 8, 10, 11, 19, 22, 25, 27, 30, 43, 44, 45, 52, 55.
Hypericum elegans: 40.- *Hypericum montanum*: 44,55.
Iris aphylla: 4.
Kohlrauschia prolifera: 1, 7, 8, 9, 10, 11, 12, 13, 19, 32, 38, 41, 43, 45, 46.
Lactuca perenis: 7, 8, 9, 11, 12, 19, 30, 32, 39, 45,46.- *Lathyrus linifolius*: 34.- *Logfia arvensis*: 7, 19.
Melampyrum arvense: 1, 4, 13, 18, 20, 22, 23, 24, 31, 33, 35, 36, 38, 39, 40,50.- *Melica transsilvanica*: 1, 3, 4, 5, 7, 8, 9, 11, 12, 13, 14, 15, 16, 18, 19, 20, 23, 25, 24, 26, 30, 31, 32, 36, 38, 39, 40, 40, 42, 45, 46, 48, 50, 51, 52, 54.
Oxytropis pilosa: 3, 13, 16, 17, 20, 23, 24, 35, 38, 39, 40, 46, 49, 51.- *Orobanche arenaria*: 38.
Peucedanum cervaria: 4, 8, 30, 33, 43, 55.- *Platenthera bifolia*: 33.- *Polycnemum majus*: 54.- *Pseudolysimachion spicatum*: 4,20, 22, 37, 38, 39. – *Pulsatilla pratensis*: 8, 23, 27, 38, 48.
Rosa gallica: 4, 8, 30.
Saxifraga rosacea: 4, 55. – *Seseli hippomarathrum*: 3, 8, 10, 15, 17, 18, 23, 24, 38, 39, 40, 42, 51.- *Sesleria albicans*: 29, 33.- *Silene otites*: 1, 8, 9, 12, 17, 20 23, 24, 31, 38, 39, 40, 42, 46, 47, 51. *Sorbus aria* agg.: 4, 7, 8, 34, 48, 55.- *Stipa capillata*: 1, 3, 5, 13, 14, 15, 20, 22, 23, 24, 26, 33, 35, 36, 37, 38, 39, 40, 42, 51, 53.- *Stipa joannis*: 2, 8, 24, 38, 39, 40.- *Stipa pulcherrima*: 24, 38, 39.- *Stipa glabrata*: 46.
Verbascum phoeniceum: 14, 38, 39, 51.

Diskuse

Spontánní sukcese vede ve většině případech k porostům charakterem se blížícím polopřirozené či přirozené vegetaci této oblasti. V opuštěných lomech vznikají refugia pro řadu dnes již vzácných raně sukcesních a strestolerantních druhů. V kulturní krajině bývají lomy jednou z mála možností kde je možné nalézt neeutrofní raná sukcesní stádia.

Rozloha kamenolomů je nezanedbatelnou částí krajiny. Naskýtá se nám zde možnost využít spontánní sukcese v lomech k vytvoření nových náhradních stanovišť pro dnes již vzácné a ohrožené druhy. Jako jediný více problémový druh (a to nejen opuštěných lomů, ale i např. xerotermních trávníků) považuji *Robinia pseudoacacia.* Vhodným zásahem by bylo odstranění akátu z okolí lomů. Tento zásah by významně ovlivnil disperzi jeho semen na dané lokalitě. Je však otázkou, nakolik a v jakém měřítku je tento zásah reálný.

Závěr

V článku se zabývám rozšířením 57 vyšších rostlin v lomech Českého středohoří a dolního Poohří. Pravděpodobně nejzajímavější je nález nové lokality *Stipa glabrata* v sukcesně starší , západní části lomu na Týneckém Chlumu nedaleko stožáru osvětlení nad cestou. Vzhledem k tomu, že tento lom je činný, je však budoucnost lokality poměrně nejistá. Za zmínku stojí i výskyty *Astragalus excapus, Biscutella laevigata, Carlina acaulis* subsp. *simplex, Oxytropis pilosa, Orobanche arenaria, Polycnemum majus, Saxifraga rosacea* a *Verbascum phoeniceum.*

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Conclusions

Conclusions

Despite the generally negative effect of quarrying on the landscape, if it exists, quarries may produce valuable vegetation. In this thesis is presented investigations of spontaneous succession in basalt quarries in the České středohoří Hills. Investigations of spontaneous succession in basalt quarries in the České středohoří Hills are presented in this thesis. In the first part (paper I) it is showed a spatio-temporal variation of vegetation during spontaneous succession in 56 basalt quarries.

In the second study (paper II) I tested the hypothesis that the composition of vegetation formed during succession in basalt quarries is affected by the distance of adjoining xerophilous grasslands and the proportion of the grasslands in quarry surroundings. Subsequent regression analysis of fidelities of individual relévés to the grassland alliances *Festucion valesiacae* and *Allyso-Festucion pallentis* corroborated the view that the probability of development of valuable habitats within the quarries decreased with distance of the closest grassland sites, and increased with their area. The study results show that the valuable biotopes would eventually develop in quarries situated less than 100 m from adjoining xerophilous grasslands. The course of succession in basalt quarries towards conservation-desirable xerophilous grasslands is strongly affected by the distance of the nearest grassland and the proportional share of the grasslands in quarry environs. In the study area, the time of arrival and rate of establishment of plants characteristics for xerophilous grasslands determine whether a site will develop towards a biotope of high conservation value, or towards a compact mesophilous scrub.

The landscape, surrounding the quarries, has passed a substantial transformation during the last half-century due to decline of pasture land and the increase of forests. This will likely influence the course of future succession in some of the studied quarries. The average quarry abandoned some fifty years ago was surrounded by more xeric grasslands than an average quarry abandoned in the present. It can be expected that in recently closed quarries, spontaneous development of "mature" xerophilous grasslands will become increasingly rarer, unless a purposeful management changes the course. Instead, a majority of recent quarries may spontaneously develop more mesophilous vegetation.

In the third section (paper III) the sowing experiments and seedlings recruitment of six species (*Atragalus excapus, Festuca valesiaca, Oxytropis pilosa, Silene otites, Stipa pennata* and *Stipa pulcherrima*) typical for the dry grasslands have been described. Seedlings of all study species were able to recruit and survive in the early successional stages at least in some quarries. The species, except one, showed significant differences in recruitment among the climatic regions, with best recruitment in the driest and warmest region. All species survived in the driest and warmest region, while only one in the coldest and wettest region. The number of localities (floristic records) of particular species in the regions was the best predictor of the species germination and survival. It appeared that the artificial sowing can be considered in restoration programs as a way how to restore dry grasslands in disused quarries.

Vegetation succession as a suitable and effective tool for restore basalt quarries is represented in the last section (paper IV and V). Disused quarries may become important refuge for many rare plants. Above all species appeared in younger stages (e.g., *Oxytropis pillosa* and *Erysimum crepidifolium*) can find refugia there. Surface area of quarries is a significant part of a landscape. There is a possibility of using the spontaneous succession in quarries to create new alternative site for the species which are rare and endangered nowadays.

At present the technical measures of restoration of quarries prevail in the Czech Republic. The results of this thesis suggest that restoration of abandoned quarries via spontaneous succession has been proposed as a cheap alternative to expensive technical reclamation. The directions and rate of succession are generally in relation to main environmental variables such as geology, climate, and surrounding vegetation, being locally modified by site moisture conditions, character of substratum, and relief in a particular site. Without extreme habitats as stone wall, there are a rapid vegetation changes during the course of succession. It is equally important that high quality biotopes should persist in quarry vicinity in order to provide colonising propagules for eventual succession after cessation of quarrying. This highlights the importance of managing the areas surrounding active quarries. It is in the best interest of quarry operators to support such activities as non-intensive grazing or eradication of aggressive alien species at habitats adjoining excavated sites.

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