School of Doctoral Studies in Biological Sciences

University of South Bohemia in České Budějovice
Faculty of Science

Spontaneous revegetation vs. forestry reclamation of mining sites on different spatial scales

Ph.D. Thesis

Mgr. Lenka Šebelíková

Supervisor: RNDr. Klára Řehounková, PhD.
Department of Botany, Faculty of Science, University of South Bohemia
in České Budějovice

České Budějovice 2018

This thesis should be cited as:

Šebelíková, L. 2018: Spontaneous revegetation vs. forestry reclamation of mining sites on different spatial scales. Ph.D. Thesis Series, No. 12. University of South Bohemia, Faculty of Science, School of Doctoral Studies in Biological Sciences, České Budějovice, Czech Republic, 158 pp.

Annotation

Spontaneously revegetated and forestry reclaimed post-mining sites were compared on the basis of chronosequence approach. The differences in the course of vegetation development, species composition and species richness were assessed. Key factors influencing species composition on forestry reclaimed post-mining sand and sand-gravel pits and the trajectories of vegetation development were determined. Possibilities and limitations of the use of forestry reclamation and spontaneous revegetation were defined.

Declaration [in Czech]

Prohlašuji, že svoji disertační práci jsem vypracoval samostatně pouze s použitím pramenů a literatury uvedených v seznamu citované literatury.

Prohlašuji, že v souladu s § 47b zákona č. 111/1998 Sb. v platném znění souhlasím se zveřejněním své disertační práce, a to v úpravě vzniklé vypuštěním vyznačených částí archivovaných Přírodovědeckou fakultou elektronickou cestou ve veřejně přístupné části databáze STAG provozované Jihočeskou univerzitou v Českých Budějovicích na jejích internetových stránkách, a to se zachováním mého autorského práva k odevzdanému textu této kvalifikační práce. Souhlasím dále s tím, aby toutéž elektronickou cestou byly v souladu s uvedeným ustanovením zákona č. 111/1998 Sb. zveřejněny posudky školitele a oponentů práce i záznam o průběhu a výsledku obhajoby kvalifikační práce. Rovněž souhlasím s porovnáním textu mé kvalifikační práce s databází kvalifikačních prací Theses.cz provozovanou Národním registrem vysokoškolských kvalifikačních prací a systémem na odhalování plagiátů.

České Budějovice, 29.11.2018

Lenka Šebelíková

Financial support

The presented work was supported by the Czech Science Foundation (GA ČR P505/11/0256, 17-09979S), RVO 67985939, and HeidelbergCement Group (QuarryLife Award).

Acknowledgements

I sincerely thank to my supervisor Klára Řehounková for her endless patience, help, advice, support, a lot of fun in the field, and her never ending enthusiasm.

My special thanks belong to Karel Prach and all co-authors and colleagues for their work.

I thank Keith Edwards for proofreading of the papers, and Robert West for language corrections of the Introduction and inspiring comments.

Last, but not least, I am also grateful to my husband, my family and my friends for their support and understanding in everyday life.

List of papers and author’s contribution

The thesis is based on the following papers (listed chronologically):

- Řehounková, K., Čížek, L., Řehounek, J., **Šebelíková, L.**, Tropek, R., Lencová, K., Bogusch, P., Marhoul, P., Máca, J. 2016. Additional disturbances as a beneficial tool for restoration of post-mining sites: a multi-taxa approach. Environmental Science and Pollution Research 23, 13745–13753 (IF = 2.80).

  LŠ participated at the data collection and compilation.

- **Šebelíková, L.**, Řehounková, K., Prach, K. 2016. Spontaneous revegetation vs. forestry reclamation in post-mining sand pits. Environmental Science and Pollution Research 23, 13598–13605 (IF = 2.80).

  LŠ collected the data, carried out the analyses, wrote the first draft of the manuscript, and participated in the writing of the final version of the manuscript.

- **Šebelíková, L.**, Csicsek, G., Kirmer, A., Vítovcová, K., Ortmann-Ajkai, A., Prach, K., Řehounková, K. 2018. Spontaneous revegetation vs. forestry reclamation - vegetation development in coal mining spoil heaps across Central Europe. Land Degradation and Development, accepted (IF = 7.27).

  LŠ participated at the data collection, did the data analyses and wrote the first version of the manuscript, participated on the writing of the final version and responded to reviewers’ comments during the revision process.

- **Šebelíková, L.**, Řehounková, K., Prach, K. Vegetation development of forestry reclaimed sand and sand-gravel pits: habitats in need or on a way towards more natural species composition? (manuscript).

  LŠ collected the data from forestry reclaimed sites, compiled them with data originally collected by KŘ, analysed them and wrote the first version of the manuscript and edited the comments of the co-authors.

Contents

INTRODUCTION

INTRODUCTION

SPONTANEOUS REVEGETATION VS. TECHNICAL RECLAMATION

In general, two main approaches to restoration of post-mining sites can be distinguished: spontaneous revegetation and technical reclamation. These two methods can be understood as the opposite ends of a continuum of restoration activities (Prach & Hobbs 2008; Prach et al., under review). **Spontaneous revegetation**, also called spontaneous succession or passive restoration, relies solely on natural processes without any human intervention after secession of activities which caused ecosystem degradation or destruction (Bradshaw 2000; DellaSala et al. 2003). In contrast, **technical reclamation** refers to restoration measures that substantially modify environmental conditions of the site to either ensure public safety (e.g. stabilization of surface, removal of pollutants) (Gatzweiler et al. 2001) or warrant possible future economic utilization of the site (Bungart et al. 2000; Pietrzykowski & Socha 2011). Technical reclamation often restores vegetation cover using surface leveling and enrichment of the substrate with a topsoil layer (Macdonald et al. 2015; Kaźmierczak et al. 2017) and subsequent planting or sowing of target species (Macdonald et al. 2015). In Central Europe, two main types of technical reclamation are prevailingly used: forestry and agricultural reclamation (Krümmelbein et al. 2012; CGS 2017). The result of both types of technical reclamation usually lead to productive monoculture stands (Pietrzykowski & Socha 2011; Boas et al. 2018; Vacek et al. 2018) resulting in site heterogeneity loss (Tropek et al. 2012; Frouz et al. 2018). Recently, forestry reclamation has increasingly aimed to use a more natural species composition of planted trees as a new approach, therefore establishing woodlands of more natural appearance and higher natural value (Csicsek et al. 2014; Macdonald et al. 2015). In many Central European countries, either pure spontaneous revegetation, or exclusively technical reclamation, is often taken into account.

Depending on specific conditions of the particular mining site, both approaches can be combined, and thus spontaneous revegetation can be manipulated to various degrees (Prach & Hobbs 2008; Holl & Aide 2011; Prach et al., under review). This method of **assisted** (or directed) **site recovery** can accelerate the vegetation development or mitigate the risk of erosion in post-mining sites (Kirmer & Mahn 2001; Alday et al. 2011; Baasch et al. 2012). Moreover, it can also suppress the expansion of undesirable species (i.e. expansive, competitive-strong, alien). For example, the native but competitive strong species *Calamagrostis epigejos* can form dense stands in disturbed sites (Baasch et al. 2012) and, thus, block the process of spontaneous revegetation as documented from several European countries (e.g. Wiegleb & Felinks 2001; Mudrák et al. 2010). However, assisted site recovery is only rarely used in the European restoration practice (but see Kirmer & Mahn 2001; Baasch et al. 2012), and technical reclamation is still prioritized (Schultz & Wiegleb 2000; Kasztelewicz 2014; CGS 2017).

There is a great inconsistency in the terminology of reclamation (Kaźmierczak et al. 2017; Cross et al. 2018). On the basis of a literature review (based on Web of Science, accessed in 2015), we found that it was sometimes difficult to distinguish between assisted site recovery and technical reclamation in particular studies because the authors used various terms with ambiguous meaning. Thus, for the purpose of the thesis, only forestry reclamation was taken into account because it is well defined in all of the studied regions. The term technical reclamation is used throughout the thesis in a more general way of meaning describing methods which use exclusively technical measures such as land relief shaping, soil restoration via amendments or topsoil layer spreading, and artificial planting or sowing of species.

Deciding which restoration method should be used in a particular case depends on the future utilization of the site. However, thorough planning of future land use of a mining site should take into consideration environmental conditions of the site, economic factors of the reclamation measures, and, last but not least, the social needs of the local communities (Masoumi et al. 2014; Prach et al., under review). On this basis, a wide spectrum of restoration goals can be found including restoration to the previous state, nature conservation, repurposing for recreation or timber production, or improvement of public safety (Masoumi et al. 2014; Mborah et al. 2016). Prach et al. (under review) identified six main factors which generally influence the decision about the proper restoration method used during mining site restoration: spontaneous revegetation, technical reclamation, or targeted active restoration, which involves a combination of both previous methods. The preference for spontaneous revegetation decreases with increasing degree of the stress of the site (e.g. extreme pH values, toxic levels of some compounds in the soil, extremely dry or wet sites, etc.), disturbance severity, area of the disturbed site, degree of the human impact in the surrounding landscape, and probability of immigration of alien and invasive species from site’s surrounding (Prach et al., under review). Spontaneous revegetation is preferred under intermediate levels of site productivity; whereas, in very low and highly productive sites, some restoration measures are necessary to restore the site to a desirable state (Prach et al., under review). Financial resources are the last factor considered by Prach et al. (under review) when determining which type of restoration activities should be employed. With no financial resources, spontaneous revegetation is the only way of restoration of a mining site. However, with sufficient financial resources available, the decision-making should take into consideration also ecological and social aspects of the restoration and carefully balance restoration activities to reach the desired target (Prach et al., under review). In general, the goal of any restoration project should be a creation of a sustainable ecosystem based on previous planning (Mborah et al. 2016).

There is a considerable imbalance between the number of studies and knowledge of vegetation development with respect to the two restoration methods, i.e. spontaneous revegetation and technical reclamation. Between the years 1945 and 2014, 513 studies on mining sites were published (based on Web of Science, accessed in 2015) out of which about three quarters (390) concerned technical reclamation; only about one fifth (101) dealt with spontaneous revegetation, and the rest (22) described assisted site recovery. Among the 101 studies on spontaneous revegetation, a vast majority (80) come from Europe, which reflects the fact that this topic has long been studied in detail in the Czech Republic (see references throughout the text). In contrast to this disproportion in numbers of studies on spontaneous revegetation and technical reclamation, the knowledge about the course of vegetation development and key factors involved in the process are incomparably better in spontaneously revegetated sites. The process of spontaneous revegetation has been studied in detail in various post-mining sites such as sand and sand-gravel pits (Borgegård 1990; Řehounková & Prach 2006, 2008), stone quarries (Ursic et al. 1997; Mota et al. 2003; Novák & Prach 2003; Novák & Konvička 2006; Trnková et al. 2010), extracted peatlands (Salonen 1994; Graf et al. 2008; Poulin et al. 2005; Bastl et al. 2009; Konvalinková & Prach 2010; González et al. 2013), and spoil heaps after coal mining (Prach 1987; Frouz et al. 2008; Piekarska-Stachowiak et al. 2014). Although there are a few studies describing methods and results of reclamation measures in a particular mining site (Koch 2007; Galiniak & Bik 2012; Hudeček et al. 2012) or in a mining district (Knabe 1964; Hüttl 1998; Ristović et al. 2010; Krümmelbein et al. 2012), the studies focused on vegetation development on technically reclaimed sites are extremely rare (but see Holl 2002; Vickers et al. 2012; Evans et al. 2013). Recently, an increasing number of studies has aimed to directly compare vegetation development on forestry reclaimed and spontaneously revegetated sites (Hodačová & Prach 2003; Pietrzykowski 2008; Mudrák et al. 2010; Woziwoda

& Kopeć 2014). Key factors affecting community composition, with respect to the two restoration methods, were assessed in multi-taxa studies (Tropek et al. 2010, 2012). Most of the studies on spontaneous revegetation of various post-mining sites are restricted to only one or several neighbouring localities in one region (but see e.g. Borgegård 1990; Skousen et al. 1994; Řehounková & Prach 2006; Konvalinková & Prach 2010), similarly to studies on comparison of the two restoration methods. There is a lack of studies describing vegetation development on forestry reclaimed sites and on the comparison of the two restoration methods on large spatial scales (i.e. country or landscape). Combination of small-scale and large-scale studies of vegetation dynamics in post-mining sites may also be useful for restoration practice. Small-scale studies describe successional trajectories in detail and can be used to test hypotheses formulated on broader scales.

FACTORS INFLUENCING VEGETATION DEVELOPMENT

Vegetation development in sites affected by mining of mineral resources is influenced by diverse factors. The major factor determining species composition is the **type of restoration** method used, i.e. spontaneous revegetation or forestry reclamation (Hodačová & Prach 2003; Tropek et al. 2010, 2012). **Age** of the site (i.e. time since site abandonment/reclamation) is another principal factor influencing the final species composition in spontaneously revegetated sites (Novák & Prach 2003; Trnková et al. 2010; Alday et al. 2012) as well as in forestry reclaimed sites (Holl 2002; Chen et al. 2018). In forestry reclaimed sites, the **species composition of the planted trees** plays a crucial role in the formation of understory vegetation (Mudrák et al. 2010; Chen et al. 2018; Rawlik et al. 2018). Furthermore, the vegetation pattern in spontaneously revegetated sites is significantly affected by **local site factors**, specifically site moisture, pH, nitrogen content of the substratum and soil structure, and **landscape factors**, namely close surrounding vegetation and macroclimate (see Prach & Řehounková 2006 for a review). There is, however, a lack of studies concerning the local site and landscape factors in forestry reclaimed sites.

Local site factors

Although it is often technically impossible to measure site **moisture** (i.e. water table depth) in post-mining sites, it is known to be the most important site factor affecting species composition (Řehounková & Prach 2006; Prach et al. 2013). Not only can site moisture play a crucial role in the participation of woody species during the course of spontaneous vegetation development (Řehounková & Prach 2006), it can determine vegetation differences in later successional stages (Prach et al. 2013). Forestry reclamation is restricted only to dry parts of the post-mining sites (Wiegleb & Felinks 2001), and afforestation of wet or shallow-flooded parts is extremely rare within Europe. Therefore, the gradient of moisture was not considered in any study on forestry reclaimed sites.

Substrate characteristics, particularly pH, nitrogen content, and substratum texture, play an important role in species composition and vegetation development in spontaneously revegetated post-mining sites (Wiegleb & Felinks 2001; Řehounková & Prach 2006; Frouz et al. 2008; Alday et al. 2011). These conditions may be very hostile for colonizing species in early stages of vegetation development (Bradshaw 2000; Alday et al. 2011). In forestry reclaimed sites, competition with unplanted herbaceous vegetation likely played a greater role than substrate conditions in the early stages of vegetation development (Evans et al. 2013). In metalliferous forestry reclaimed spoil heaps, the pH influenced vegetation composition of spontaneously established species (Szarek-Łukaszewska 2009).

Landscape factors

The surrounding vegetation of spontaneously revegetated mining sites proved to have high restoration potential (Borgegård 1990; Brändle et al. 2003; Novák & Konvička 2006; Kirmer et al. 2008; Řehounková & Prach 2008; Trnková et al. 2010; Kopeć et al. 2011; Kabrna et al. 2014). About one half of the plant species from the surrounding vegetation was also found inside spontaneously developing parts of lignite mining sites in Germany (Brändle et al. 2003). Borgegård (1990) found that 69 % of species occurring in old post-mining sand pits in Sweden were also present in the surrounding vegetation. About 74 % of target species colonized spoil heaps in the Czech Republic from the surroundings (Kabrna et al. 2014). In the post-mining sand and sand-gravel pits across the Czech Republic, about 70 % of target (i.e. grassland, woodland and wetland) species recorded in the surroundings of up to 100 meters appeared also inside sand and sand-gravel pits (Řehounková & Prach 2008). In acidic quarries in the same country, the proportion of target species found in the surroundings and inside the quarry reached 80 % (Trnková et al. 2010). Depending on a mining region and its landscape characteristics, between 65 and 89 % of plant species present in open cast mined sites in Germany occurred also in the distance up to 3 km (Kirmer et al. 2008).

The process of colonization and development to a target community in spontaneously revegetated sites is facilitated by the occurrence of (semi)natural vegetation in the immediate vicinity of the mining site (Novák & Konvička 2006; Řehounková & Prach 2008; Kopeć et al. 2011). On the contrary, in human-altered landscapes, undesirable plants, such as ruderals or aliens, are likely to colonize a particular mining site (Řehounková & Prach 2008). Tischew et al. (2014), however, found out that spontaneous revegetation facilitates the development to native plant communities with a low proportion of undesirable species (i.e. neophytes and invasive species) in former lignite coal mines, even if surrounded by cultural landscape. The key factor was a low proportion of invasive species in the surrounding of the post-mining site (Tischew et al. 2014). Alien species may block or change the trajectory of the successional pathway towards an undesirable state or can change the local site conditions (Walker & del Moral 2003; Yurkonis et al. 2005). In general, alien species can be found more frequently in young successional stages and their importance in the course of vegetation development, in most cases, gradually decreases (Rejmánek 1989; Bastl et al. 1997; Řehounková & Prach 2008). Some alien species, however, may become serious invaders during the process of spontaneous revegetation in mining sites. This is the case for *Robinia pseudoacacia* in some regions of Central Europe (Řehounková & Prach 2008; Tischew et al. 2014).

The surrounding vegetation plays a crucial role also in vegetation development in forestry reclaimed sites. Szarek-Łukaszewska (2009) documented fast, spontaneous colonization of 5-year-old forestry reclaimed metalliferous spoil heaps in southern Poland by a species from neighbouring preserved grasslands and woodlands. However, on older sites, the colonization, particularly with woodland species, was retarded due to the destruction of natural communities in the surrounding of the mining sites (Szarek-Łukaszewska 2009). Colonization of forestry reclaimed sites by native tree species from the surroundings may facilitate reforestation to the desired state making it more species-rich and similar to surrounding unmined forest vegetation (Holl 2002; Evans et al. 2013). Similarly to spontaneously revegetated sites, competitive-strong alien species are not desired to colonize the reforested sites because they may hinder successful reclamation towards a reference natural forest (Evans et al. 2013).

Although **macroclimate** seems to be very important explanatory variable for species composition in post-mining sites, there are only a few studies that considered its effect during spontaneous revegetation (Prach & Řehounková 2006; Prach et al. 2007). However, no study exists about this phenomenon from forestry reclaimed sites. Macroclimate, similarly to site moisture, may have an important influence on the local species pool. Climatic conditions can constrain or favour participation of particular species in the course of spontaneous vegetation development, which was documented for example for woody species in Central Europe (Novák & Prach 2003; Řehounková & Prach 2006).

RATE OF COLONIZATION OF POST-MINING SITES

Unfavourable local site conditions (e.g. lack of nutrients, poor stability and water retention of substrate, extreme surface temperature) in early successional stages may prevent many plant species from colonizing the site (Ash et al. 1994; Walker & del Moral 2003; Moreno-de las Heras et al. 2008) and change the speed of successional processes (Prach 2003). Colonization of post-mining sites is also highly influenced by the dispersal ability of species occurring in the surrounding landscape and by their distance to the site (Bradshaw & Chadwick 1980; Kirmer et al. 2008; Baasch et al. 2012; Tischew et al. 2014). Nevertheless, in most human-disturbed sites, the colonization process towards fully developed vegetation, through the processes of spontaneous revegetation, varied between 15 and 50 years (e.g. Bradshaw & Chadwick 1980; Prach 2003; Řehounková & Prach 2006; Tischew & Kirmer 2007; Trnková et al. 2010). A study of 16 successional seres from various human-altered sites revealed that continuous vegetation cover can be formed within 15 years since site abandonment (Prach & Pyšek 2001). This can be considered as a reasonable time from the restoration point of view (Prach 2003; Tischew & Kirmer 2007). The time period is comparable to forestry reclaimed sites where vegetation cover also requires some time to establish due to poorer survival of saplings in the first years after planting (varying from 31 % to 86 %). This is due to competition with herbaceous vegetation (Evans et al. 2013) or unfavourable conditions of the used topsoil material (Emerson et al. 2009). At the beginning, forestry reclamation can accelerate the vegetation development (Szarek-Łukaszewska 2009), but after about 15 years the situation changes in favour of spontaneously revegetated sites (Hodačová & Prach 2003). Within 10 to 15 years, forestry reclaimed sites may be colonized by native tree species, and continuous vegetation cover is formed (Holl 2002).

USE OF SPONTANEOUS REVEGETATION AND TECHNICAL RECLAMATION IN CENTRAL EUROPE

The necessity and effectiveness of the technical reclamation approach have been questioned in recent studies (e.g. Prach et al. 2013). Prach et al. (2011) proposed that spontaneous revegetation can be successfully implemented in 95–100 % of the area of post-mining sites. Nevertheless, technical reclamation is necessary under certain circumstances—for instance, site toxicity, risk of erosion or for production purposes (Tordoff et al. 2000; Gruenewald et al. 2007; Moreno-de las Heras et al. 2008; Prach & Hobbs 2008). Productivity and economic profit of post-mining sites is a frequent reason for technical reclamation. Pietrzykowski and Socha (2011) documented that aboveground tree biomass in Scots pine plantations (i.e. forestry reclamation) was higher in comparison with natural stands. In general, technical measures, such as substrate amelioration or creation of terrain variability, should be merely used to overcome local unfavourable conditions and provide the opportunity for restoring functional components of the ecosystem by spontaneous revegetation (King & Hobbs 2006; Prach & Hobbs 2008; Baasch et al. 2012). However, the legal support for using spontaneous revegetation in post-mining sites in Central Europe is still insufficient. For example, the Czech Mining Act requires reclamation of land affected by mining (Act No. 44/1988 Coll. on the Protection and Utilization of Mineral Resources). Reclamation of agricultural or forest land is governed by special Acts which demand reverting of the land to its original use (i.e. forest or agricultural land) (Act No. 334/1992 Coll. on the Protection of Agricultural Land Fund; Act No. 289/1995 Coll. on Forests). Thus, the creation of agricultural land or forest by sowing commercial seed mixtures or planting trees for commercial use are preferred reclamation measures currently accounting for 30, and 45 %, respectively, of the reclaimed mined area (CGS 2017). Scientists and practitioners have increasingly tried to promote that at least 20 % of the area of mining sites should be left to spontaneous revegetation (Řehounková et al. 2011), which is a reasonable compromise between land use policy and nature conservation. The new Amendment to the Act on the Protection of Agricultural Land Fund permits leaving up to 10 % of previously agricultural land for nature conservation after termination of mining. Regarding other Central European countries, in Poland, about 90 % of the area disturbed by mining activities is technically reclaimed (forestry, agricultural or hydric reclamation) and 10 % is designed for special reclamation such as municipal, educational, or artistic purposes (Kasztelewicz 2014) with no regards to nature conservation. The situation has recently changed in Germany. Nature conservation and recreation are currently regarded as full-fledged land-use options giving a chance for near-natural restoration (*sensu* SER 2004) (Schultz & Wiegleb 2000). Current reclamation schemes in Germany allow 15% of the land disturbed by mining activities to be spontaneously revegetated (Schulz & Wiegleb 2000; Wiegleb & Felinks 2001).

IMPORTANCE OF POST-MINING SITES FOR NATURE CONSERVATION

In general, spontaneously revegetated post-mining sites are typical of broad ecological gradients, particularly in moisture; temperature; and substrate characteristics, which favour coexistence of species from various ecological groups (Řehounková & Prach 2006; Kompała-Bąba & Bąba 2013; Prach et al. 2013). From the nature conservation point of view, open and nutrient-poor habitats are of great importance because they provide suitable persistent habitats for competitive-week species (e.g. Tischew & Kirmer 2007; Prach et al. 2013). For instance, sand and sand-gravel pits may offer alternative habitats for species adapted for low nutrient availability (Řehounková & Prach 2008). Similar results are documented also from stone quarries which may serve as secondary habitats for specialized and endangered xerophilous species (Novák & Prach 2003; Tropek et al. 2010). However, covering of the surface with nutrient-rich topsoil during technical reclamation causes habitat homogenization and brings diaspores of non-target species (Hall et al. 2010) often favouring ruderal and competitive-strong species over rare or specialized species (Mudrák et al. 2010; Tropek et al. 2010). In some cases, forestry reclaimed sites have been found to be less diverse in species richness in comparison with spontaneously revegetated ones (Hodačová & Prach 2003; Woziwoda & Kopeć 2014). In other cases, no clear differences in plant species richness between forestry reclaimed and spontaneously revegetated sites were observed (Pietrzykowski 2008; Tropek et al. 2010). Forestry reclaimed sites, however, have usually only negligible representation of rare or specialized species (Pietrzykowski 2008; Tropek et al. 2010, 2012).

SUBJECTS AND AIMS OF THE THESIS

Based on the above-mentioned facts (see Table 1 for summary), further comparison of spontaneously revegetated and forestry reclaimed sites with consideration of local site and landscape factors and detailed description of vegetation development in forestry reclaimed sites is justified. A better understanding of vegetation development in sites with different restoration status may contribute to current discussions on the need and effectiveness of forestry (or technical in general) reclamation in post-mining sites.

Table 1 Prevailing characteristics of spontaneous revegetation and forestry reclamation in Central Europe.

	Spontaneous revegetation	**Technical reclamation**
Process	natural	technical (surface modelling, topsoil addition,...)
Method	passive	active
Aim	improvement of ecosystem conditions	public benefits or productivity
Environmental conditions	heterogeneous	homogeneous
Target	open habitats, wetlands, dry grasslands, woodlands	productive monoculture stands
Species	rare and specialists	generalists
Conservation value	higher	lower
Production value	lower	higher
Vegetation cover	within 15 years	within 10–15 years
Applicability	potential in 95–100 % of the mining area	necessary under severe circumstances (toxicity, erosion, ...) or for production purposes
Threats	habitat loss through reclamation, competitive strong/expansive/alien species	failure of the reclamation measures
Knowledge on vegetation development	detailed studies	lack of knowledge

The presented thesis consists of four studies conducted on different spatial scales: (i) local scale—Cep II sand pit in Třeboňsko Protected Landscape Area, South Bohemia, Czech Republic (***Chapter I***); (ii) regional scale—sand pits in the Třeboňsko region, South Bohemia, Czech Republic (***Chapter II***); (iii) landscape scale (country) —sand and sand-gravel pits across the Czech Republic (***Chapter III***); and (iv) landscape scale (Central European) —spoil heaps after coal mining across Central Europe, i.e. Hungary, Czech Republic, Germany (***Chapter IV***). First three studies (***Chapters I–III***) were conducted in sand and sand-gravel pits because they are well defined and evenly distributed across the country. The last study (***Chapter IV***) was conducted in spoil heaps after coal mining across Central Europe because they are present in sufficient numbers in all three studied regions. The generalization of results obtained from sand pits and spoil heaps was justified by a previous study comparing 19 successional seres (i.e. type of mining/post-industrial site) from various human-disturbed habitats (Prach et al. 2014) in which the particular seres largely overlap, and the effect of the identity of the sere was not significant.

The main objective of the presented thesis was to address the above-mentioned gaps in the knowledge on forestry reclaimed post-mining sites with respect to vegetation development, comparison of trends with spontaneously revegetated sites, and assessment of conservation value. We particularly focused on the following issues: (i) to describe vegetation development in forestry reclaimed sites and identify key factors affecting species composition (***Chapter III***); (ii) to analyze differences in the course of vegetation development between the two restoration methods (***Chapter II*** and ***IV***); and (iii) to define possibilities and limitations of the use of forestry reclamation and spontaneous revegetation (***Chapter I*** and ***III***).

We hypothesized that vegetation development in forestry reclaimed sites proceed fast towards species-poor woodlands, and the main factors influencing species composition in these sites are age and cover of planted trees (***Chapter III***); both types of plots (i.e. spontaneous revegetation and forestry reclamation) develop towards woodlands but spontaneous sites host more plant species (***Chapter II*** and ***IV***); spontaneous sites have greater potential for nature conservation (***Chapter I*** and ***III***) with young open stages being the most valuable (***Chapter I***).

References

Act No. 44/1988 Coll. on the Protection and Use of Mineral Resources. https://www.mzp.cz/www/platnalegislativa.nsf/0F98B34F089A0137C12564EA003FAE03/%24file/Z%2044_1988.pdf (in Czech). Accessed 28 November 2018.

Act No. 334/1992 Coll. on the Protection of Agricultural Land Fund. https://www.mzp.cz/www/platnalegislativa.nsf/B9E6985E9AA11F98C12564EA003D3E04/%24file/Z%20334_1992.pdf (in Czech). Accessed 28 November 2018.

Act No. 289/1995 Coll. on Forests. http://www.mzp.cz/www/platnalegislativa.nsf/9DDEDC0DCB2D745AC1256FF50048540A/$file/OL-NV22_05_HOSTYNVRCHY-050502.doc (in Czech). Accessed 28 November 2018.

Alday, J. G., Marrs, R. H. & Martínez-Ruiz C. 2011: Vegetation succession on reclaimed coal wastes in Spain: the influence of soil and environmental factors. Applied Vegetation Science 14: 84–94.

Alday J. G., Marrs, R. H. & Martínez-Ruiz C. 2012: Soil and vegetation development during early succession on restored coal wastes: a six-year permanent plot study. Plant Soil 353:305–320.

Ash, H. J., Gemmell, R. P. & Bradshaw, A. D. 1994: The introduction of native plant species on industrial waste heaps: a test of immigration and other factors affecting primary succession. Journal of Applied Ecology 31: 74–84.

Baasch, A., Kirmer, A. & Tischew, S. 2012: Nine years of vegetation development in a postmining site: effects of spontaneous and assisted site recovery. Journal of Applied Ecology 49: 251–260.

Bastl, M., Kočár, P., Prach, K. & Pyšek, P. 1997: The effect of successional age and disturbance on the establishment of alien plants in man-made sites: an experimental approach. In: Brock, J. H., Wade, M., Pyšek, P., Green, D. [eds.]: Plant Invasions: Studies from North America and Europe. Backhuys Publishers, Leiden, pp. 191–201.

Bastl, M., Štechová, T. & Prach, K. 2009: Effect of disturbance on the vegetation of peat bogs with *Pinus rotundata* in the Třeboň Basin, Czech Republic. Preslia 81: 105–117.

Boas, H. F. V., Almeida, L. F. J., Teixeira, R. S., Souza, I. F. & Silva, I. R. 2018: Soil organic carbon recovery and coffee bean yield following bauxite mining. Land Degradation & Development 29: 1565–1573.

Borgegård, S. 1990: Vegetation development in abandoned gravel pits: effects of surrounding vegetation, substrate and regionality. Journal of Vegetation Science 1: 675–682.

Bradshaw A. 2000: The use of natural processes in reclamation – advantages and difficulties. Landscape and Urban Planning 51: 89–100.

Bradshaw, A. D. & Chadwick, M. J. 1980: The restoration of land: The ecology and reclamation of derelict and degraded land. Blackwell Scientific Publications, Oxford. 317 pp.

Brändle, M., Durka, W., Krug, H. & Brandl, R. 2003: The assembly of local communities: plants and birds in non-reclaimed mining sites. Ecography 26: 652–660.

Bungart, R., Bens, O. & Hüttl, R. F. 2000: Production of bioenergy in post-mining landscapes in Lusatia. Perspectives and challenges for alternative land use systems. Ecological Engineering 16: S5–S16.

CGS (Czech Geological Survey) 2017: Mineral Commodity Summaries of the Czech Republic (Statistical data to 2016). Gzech Geological Survey, Prague.

Chen, H. Y. H., Biswas, S. R., Sobey, T. M., Brassard, B. W. & Bartels, S. F. 2018: Reclamation strategies for mined forest soils and overstorey drive understorey vegetation. Journal of Applied Ecology 55: 926–936.

Cross, A. T., Young, R., Nevill, P., McDonald, T., Prach, K., Aronson, J., Wardell-Johnson, G. W. & Dixon, K. W. 2018: Appropriate aspirations for effective post-mining restoration and rehabilitation: a response to Kaźmierczak et al. Environmental Earth Sciences 77: 256.

Csicsek, G., Ortmann-né Ajkai, A. & Lóczy, D. 2014: Rekultivált meddöhányó fásításának vizsgálata a Mecsek-hegységben [Research of recultivated coal mining spoil heap in SW-Hungary]. Tájökológiai Lapok 12: 133–145.

DellaSala D. A., Martin, A., Spivak, R., Schulke, T., Bird, B., Criley, M., van Daalen, C., Kreilick, J., Brown, R., & Aplet, G. 2003: A citizen's call for ecological forest restoration: forest restoration principles and criteria. Ecological Restoration 21: 14–23.

Emerson, P., Skousen, J. & Ziemkiewicz, P. 2009: Survival and growth of hardwoods versus gray sandstone on a surface mine in West Virginia. Journal of Environmental Quality 38: 1821–1829.

Evans, D. M., Zipper, C. E., Burger, J. A., Strahm, B. D. & Villamagna, A. M. 2013: Reforestation practice for enhancement of ecosystem services on a compacted surface mine: Path toward ecosystem recovery. Ecological Engineering 51: 16– 23.

Frouz, J., Prach, K., Pižl, V., Háněl, L., Starý, J., Tajovský, K., Materna, J., Nalík, V., Kalčík, J. & Řehounková, K. 2008: Interactions between soil development, vegetation and soil fauna during spontaneous succession in post mining sites. European Journal of Soil Biology 44: 109–121.

Frouz, J., Mudrák, O., Reitschmiedová, E., Walmsley, A., Vachová, P., Šimáčková, H., Albrechtová, J., Moradi, J. & Kučera, J. 2018: Rough wave-like heaped overburden promotes establishment of woody vegetation while leveling promotes grasses during unassisted post mining site development. Journal of Environmental Management 205: 50–58.

Galiniak, G. & Bik, A. 2012: The reclamation of post-mining areas of Lubuski region (Poland) on example of Sieniawa lignite mine. Journal of Mining and Geoengineering 36: 179–187.

Gatzweiler, R., Jahn, S., Neubert, G. & Paul, M. 2001: Cover design for radioactive and AMD-producing mine waste in the Ronneburg area, Eastern Thuringia. Waste Management 21: 175–184.

Graf, M. D., Rochefort, L. & Poulin, M. 2008: Spontaneous revegetation of cutwaway peatlands of North America. Wetlands 28: 28–39.

Gruenewald, H., Brandt, B. K. V., Schneider, B. U., Bens, O., Kendzia, G. & Hüttl, R. F. 2007: Agroforestry systems for the production of woody biomass for energy transformation purposes. Ecological Engineering 29: 319–328.

González, E., Rochefort, L. & Poulin, M. 2013: Trajectories of plant recovery in block-cut peatlands 35 years after peat extraction. Applied Ecology and Environmental Research 11: 385–406.

Hall, S. L., Barton, C. D. & Baskin, C. C. 2010: Topsoil seed bank of an oak-hickory forest in eastern Kentucky as a restoration tool on surface mines. Restoration Ecology 18: 834–842.

Hodačová, D. & Prach, K. 2003: Spoil heaps from brown coal mining: technical reclamation versus spontaneous revegetation. Restoration Ecology 11: 385–391.

Holl, K. D. 2002: Long-term vegetation recovery on reclaimed coal surface mines in the eastern USA. Journal of Applied Ecology 39: 960–970.

Holl, K. D. & Aide, T. M. 2011: When and where to actively restore ecosystems? Forest Ecology and Management 261: 1558–1563.

Hudeček, V., Černá, K. & Adamec, Z. 2012: Utilization of result of trial seeding experimental plots in the course of rehabilitation of central tailing heap of Ján Šverma mine in Žacléř. Acta Montanistica Slovaca 17: 119–125.

Hüttl, R. F. 1998: Ecology of post strip-mining landscapes in Lusatia, Germany. Environmental Science and Policy 1: 129–135.

Kabrna, M., Hendrachová, M. & Prach, K. 2014: Establishment of target and invasive plant species on a reclaimed coal mining dump in relation to their occurrence in the surroundings. International Journal of Mining, Reclamation and Environment 28: 242–249.

Kasztelewicz, Z. 2014: Approaches to post-mining land reclamation in Polish open-cast lignite mining. Civil and Environmental Engineering Reports 12: 55–67.

Kaźmierczak, U., Lorenc, M. V. & Strzałkowski, P. 2017: The analysis of the existing terminology related to a post-mining land use: a proposal for new classification. Environmental Earth Sciences 76: 693.

King, E. G. & Hobbs, R. J. 2006: Identifying linkages among conceptual models of ecosystem degradation and restoration: towards an integrative framework. Restoration Ecology 14: 369–378.

Kirmer, A. & Mahn, E.-G. 2001: Spontaneous and initiated succession on unvegetated slopes in the abandoned lignite-mining area of Goitsche, Germany. Applied Vegetation Science 4: 19–27.

Kirmer, A., Tischew, S., Ozinga, W. A., von Lampe, M., Baasch, A. & van Groenendael, J. M. 2008: Importance of regional species pools and functional traits in colonization processes: predicting re-colonization after large-scale destruction of ecosystems. Journal of Applied Ecology 45: 1523–1530.

Knabe, W. 1964: Methods and results of strip-mine reclamation in Germany. The Ohio Journal of Science 64: 75–105.

Koch, J. M. 2007: Alcoa’s mining and restoration process in south Western Australia. Restoration Ecology 15 (Supplement): S11–S16.

Kompała-Bąba, A. & Bąba, W. 2013: The spontaneous succession in a sand-pit – the role of life history traits and species habitat preferences. Polish Journal of Ecology 61: 13–22.

Konvalinková, P. & Prach, K. 2010: Spontaneous succession of vegetation in mined peatlands: a multi-site study. Preslia 82: 423–435.

Kopeć, D., Zając, I. & Halladin-Dąbrowska, A. 2011: The influence of surrounding vegetation on the flora of post-mining area. Biodiversity: Research and Conservation 24: 29–38.

Krümmelbein, J., Bens, O., Raab, T. & Naeth, A. 2012: A history of lignite coal mining and reclamation practices in Lusatia, eastern Germany. Canadian Journal of Soil Science 92: 53–66.

Macdonald, S. E., Landhäusser, S. M., Skousen, J., Franklin, J., Frouz, J., Hall, S., Jacobs, D. F. & Quideau, S. 2015: Forest restoration following surface mining disturbance: challenges and solutions. New Forests 46: 703–732.

Masoumi, I., Naraghi, S., Rashidi-nejad, F, & Masoumi, S. 2014: Application of fuzzy multi-attribute decision-making to select and rank the post-mining land-use. Environmental Earth Sciences 72: 221–231.

Mborah, C., Bansah, K. J. & Boateng, M. K. 2016: Evaluating alternate post-mining land-uses: a review. Environment and Pollution 5: 14–22.

Moreno-de las Heras, M., Nicolau, J. M. & Espigares, T. 2008: Vegetation succession in reclaimed coal-mining slopes in a Mediterranean-dry environment. Ecological Engineering 34: 168–178.

Mota, J. F., Sola, A. J., Dana, E. D & Jiménez-Sánchez, M. L. 2003: Plant succession in abandoned gypsum quarries in SE Spain. Phytocoenologia 33: 13–28.

Mudrák, O., Frouz, J. & Velichová, V. 2010: Understory vegetation in reclaimed and unreclaimed post-mining forest stands. Ecological Engineering 36: 783–790.

Novák, J. & Konvička, M. 2006: Proximity of valuable habitats affects succession patterns in abandoned quarries. Ecological Engineering 26: 113–122.

Novák, J. & Prach, K. 2003: Vegetation succession in basalt quarries: pattern on a landscape scale. Applied Vegetation Science 6: 111–116.

Piekarska-Stachowiak, A., Szary, M., Ziemer, B., Besenyei, L. & Woźniak, G. 2014: An application of the plant functional group concept to restoration practice on coal mine spoil heaps. Ecological Research 29: 843–853.

Pietrzykowski, M. 2008: Soil and plant communities development and ecological effectiveness of reclamation on a sand mine cast. Journal of Forest Science 54: 554–565.

Pietrzykowski, M. & Socha, J. 2011: An estimation of Scots pine (*Pinus sylvestris* L.) ecosystem productivity on reclaimed post-mining sites in Poland (central Europe) using of allometric equations. Ecological Engineering 37: 381–386.

Poulin, M., Rochefort, L., Quinty, F. & Lavoie, C. 2005: Spontaneous revegetation of mined peatlands in eastern Canada. Canadian Journal of Botany 83: 539–557.

Prach, K. 1987: Succession of vegetation on dumps from strip coal mining, N. W. Bohemia, Czechoslovakia. Folia Geobotanica et Phytotaxonomica 22: 339–354.

Prach, K. 2003: Spontaneous succession in Central-European man-made habitats: What information can be used in restoration practice? Applied Vegetation Science 6: 125–129.

Prach, K. & Hobbs, R. J. 2008: Spontaneous succession versus technical reclamation in the restoration of disturbed sites. Restoration Ecology 16: 363–366.

Prach, K. & Pyšek, P. 2001: Using spontaneous succession for restoration of human-disturbed habitats: Experience from Central Europe. Ecological Engineering 17: 55–62.

Prach, K. & Řehounková, K. 2006: Vegetation succession over broad geographical scales: which factors determine the patterns? Preslia 78: 469–480.

Prach, K., Pyšek, P. & Jarošík, V. 2007: Climate and pH as determinants of vegetation succession in Central European man-made habitats. Journal of Vegetation Science 18: 701–710.

Prach, K., Řehounková, K., Řehounek, J. & Konvalinková, P. 2011: Ecological restoration of central European mining sites: a summary of a multi-site analysis. Landscape Research 36: 263–268.

Prach, K., Lencová, K., Řehounková, K., Dvořáková, H., Jírová, A., Konvalinková, P., Mudrák, O., Novák, J. & Trnková, R. 2013: Spontaneous vegetation succession at different central European mining sites: a comparison across seres. Environmental Science and Pollution Research 20: 7680–7685.

Prach, K., Řehounková, K., Lencová, K., Jírová, A., Konvalinková, P., Mudrák, O., Študent, V., Vaněček, Z., Tichý, L., Petřík, P., Šmilauer, P. & Pyšek, P. 2014: Vegetation succession in restoration of disturbed sites in Central Europe: the direction of succession and species richness across 19 seres. Applied Vegetation Science 17: 193–200.

Rawlik, M., Kasprowicz, M. & Jagodziński, A. M. 2018: Differentiation of herb layer vascular flora in reclaimed areas depends on the species composition of forest stands. Forest Ecology and Management 409: 541–551.

Rejmánek, M. 1989: Invasibility of plant communities. In: Drake, J. A., Mooney, H. A., di Castri, F., Groves, R. H., Kruger, F. J., Rejmánek, M., Williamson, M. [eds.]: Biological invasions: A global perspective. John Wiley & Sons, Chisester, pp. 369–388.

Ristović, I. M., Stojaković, M. P. & Vulić, M. I. 2010: Recultivation and sustainable development of coal mining in Kolubara Basin. Thermal Science 14: 759–772.

Řehounková, K. & Prach, K. 2006: Spontaneous vegetation succession in disused gravel-sand pits: Role of local site and landscape factors. Journal of Vegetation Science 17: 583–590.

Řehounková, K. & Prach, K. 2008: Spontaneous vegetation succession in gravel-sand pits: a potential for restoration. Restoration Ecology 16: 305–312.

Řehounková, K., Řehounek, J. & Prach, K. 2011: Near-natural restoration vs. technical reclamation of mining sites in the Czech Republic. University of South Bohemia in České Budějovice, České Budějovice, 112 p.

Salonen, V. 1994: Revegetation of harvested peat surfaces in relation to substrate quality. Journal of Vegetation Science 5: 403–408.

Schultz, F. & Wiegleb, G. 2000: Development options of natural habitats in a post-mining landscape. Land Degradation Development 11: 99–110.

SER (Society for Ecological Restoration International Science & Policy Working Group) 2004: The SER international primer on ecological restoration. Society for Ecological Restoration International, Tuscon, Arizona.

Skousen, J. G., Johnson, C. D. & Garbutt, K. 1994: Natural revegetation of 15 abandoned mine land sites in West Virginia. Journal of Environmental Quality 23:1224–1230.

Szarek-Łukaszewska, G. 2009: Vegetation of reclaimed and spontaneously vegetated Zn-Pb mine wastes in southern Poland. Polish Journal of Environmental Studied 4: 717–733.

Tischew, S. & Kirmer, A. 2007: Implementation of basic studies in the ecological restoration of surface-mined land. Restoration Ecology 15: 321–325.

Tischew, S., Baasch, A., Grunert, H. & Kirmer, A. 2014: How to develop native plant communities in heavily altered ecosystems: examples from large-scale surface mining in Germany. Applied Vegetation Science 17: 288–301.

Tordoff, G. M., Baker, A. J. M. & Willis, A. J. 2000: Current approaches to the revegetation and reclamation of metalliferous mine wastes. Chemosphere 41: 219–228.

Trnková, R., Řehounková, K. & Prach, K. 2010: Spontaneous succession of vegetation on acidic bedrock in quarries in the Czech Republic. Preslia 82: 333–343.

Tropek, R., Kadlec, T., Karešová, P., Spitzer, L., Kočárek, P., Malenovský, I., Baňař, P., Tuf, I. H., Hejda, M. & Konvička, M. 2010: Spontaneous succession in limestone quarries as an effective restoration tool for endangered arthropod and plants. Journal of Applied Ecology 47: 139–147.

Tropek, R., Kadlec, T., Hejda, M., Kočárek, P., Skuhrovec, J., Malenovský, I., Vodka, Š., Spitzer, L., Baňař, P. & Konvička, M. 2012: Technical reclamations are wasting the conservation potential of post-mining sites. A case study of black coal spoil dumps. Ecological Engineering 43: 13–18.

Ursic, K. A., Kenkel, N. C. & Larson, D. W. 1997: Revegetation dynamics of cliff faces in abandoned limestone quarries. Journal of Applied Ecology 34: 289–303.

Vacek, Z., Cukor, J., Vacek, S., Podrázský, V., Linda, R. & Kovařík J. 2018: Forest biodiversity and production potential of post-mining landscape: opting for afforestation or leaving it to spontaneous development? Central European Forestry Journal 64: 116–126.

Vickers, H., Gillespie, M. & Gravina, A. 2012: Assessing the development of rehabilitated grasslands on post-mined landforms in north west Queensland, Australia. Agriculture, Ecosystems and Environment 163: 72– 84.

Walker, L. R. & del Moral, R. 2003: Primary succession and ecosystem rehabilitation. Cambridge University Press, 442 p.

Wiegleb, G. & Felinks, B. 2001: Primary succession in post-mining landscapes of Lower Lusatia – chance or necessity. Ecological Engineering 17: 199-217.

Woziwoda, B. & Kopeć, D. 2014: Afforestation or natural succession? Looking for the best way to manage abandoned cut-over peatlands for biodiversity conservation. Ecological Engineering 63: 143–152.

Yurkonis, K. A., Meiners, S. J. & Wachholder, B. E. 2005: Invasion impacts diversity through altered community dynamics. Journal of Ecology 93: 1053–1061.

CHAPTER I

ADDITIONAL DISTURBANCES AS A BENEFICIAL TOOL FOR RESTORATION OF POST-MINING SITES: A MULTI-TAXA APPROACH.

Řehounková et al. 2016. Environ Sci Pollut Res 23: 13745–13753
https://doi.org/10.1007/s11356-016-6585-5

ADDITIONAL DISTURBANCES AS A BENEFICIAL TOOL FOR RESTORATION OF POST-MINING SITES: A MULTI-TAXA APPROACH

Klára Řehounková[1], Lukáš Čížek[1,2], Jiří Řehounek[3], Lenka Šebelíková[1], Robert Tropek[2,4], Kamila Lencová[1], Petr Bogusch[5], Pavel Marhoul[6] & Jan Máca[7]

[1] *Faculty of Science, University of South Bohemia, Branišovská 1760, 370 05 České Budějovice, Czech Republic*
[2] *Institute of Entomology, Biology Centre, Czech Academy of Sciences, Branišovská 31, 370 05 České Budějovice, Czech Republic*
[3] *Calla- Association for Preservation of the Environment, Fráni Šrámka 35, 370 01 České Budějovice, Czech Republic*
[4] *Faculty of Science, Charles University in Prague, Viničná 7, 128 44 Prague, Czech Republic*
[5] *Faculty of Science, University of Hradec Králové, Rokitanského 62, 500 03 Hradec Králové, Czech Republic*
[6] *Beleco, Slezská 125, 130 00 Praha 3, Czech Republic*
[7] *Na Potoce 276, 391 81 Veselí nad Lužnicí, Czech Republic*

Corresponding author: Klára Řehounková, email: klara.rehounkova@gmail.com

Abstract

Open interior sands represent a highly threatened habitat in Europe. In recent times, their associated organisms have often found secondary refuges outside their natural habitats, mainly in sand pits. We investigated the effects of different restoration approaches, i.e. spontaneous succession without additional disturbances, spontaneous succession with additional disturbances caused by recreational activities, and forestry reclamation, on the diversity and conservation values of spiders, beetles, flies, bees and wasps, orthopterans and vascular plants in a large sand pit in the Czech Republic, Central Europe. Out of 406 species recorded in total, 112 were classified as open sand specialists and 71 as threatened. The sites restored through spontaneous succession with additional disturbances hosted the largest proportion of open sand specialists and threatened species. The forestry reclamations, in contrast, hosted few such species. The sites with spontaneous succession without disturbances represent a transition between these two approaches. While restoration through spontaneous succession favours biodiversity in contrast to forestry reclamation, additional disturbances are necessary to maintain early successional habitats essential for threatened species and open sand specialists. Therefore, recreational activities seem to be an economically efficient restoration tool that will also benefit biodiversity in sand pits.

Keywords

Human-made habitats · Restoration ecology · Trampling management · Post-industrial sites · Biodiversity conservation · Sand mining

INTRODUCTION

Natural open and nutrient poor sandy biotopes, such as continental sand dunes or riverine banks, used to be relatively common components of some Central European regions (Jentsch & Beyschlag 2003; Riksen et al. 2006). Their total area has strongly decreased over the past few centuries as a consequence of both direct and indirect human impacts (Fanta & Siepel 2010). As unproductive bare land, the majority of sandy habitats were either afforested or extracted for sand; wet sandy sites were drained (Chytrý 2010). Simultaneously, these originally nutrient poor biotopes were affected by pasture cessation, rapid successional overgrowing accelerated by increased aerial N-deposition and the spreading of competitive eurytopic plants during recent intensive urbanisation (Walker & del Moral 2003). As a result, the inland dunes with open *Corynephorus* and *Agrostis* grasslands, for example, have recently shrank to a negligible area of 8.97 km^2 in the Czech Republic, i.e. ~0.01 % of the total area of the country (NCA CR 2013). Similarly, open low-growing stands of annual herbs on wet acidic sandy nutrient poor sites have nearly disappeared (Chytrý 2011), and recently, only several fragments of this vegetation type were recorded in a total area of 0.11 km^2 in the Czech Republic (NCA CR 2013). Such a situation has been reported throughout Europe, and thus, both dry and wet open sands are classified as priority habitats under the European Habitats Directive (European Commission 2015). Species specialised to the relatively extreme conditions of these habitats rank highly among the most threatened within the European fauna and flora (Jentsch & Beyschlag 2003; Heneberg et al. 2013; Tropek et al. 2013a).

Post-mining areas, mainly sand and gravel-sand mines, have been repeatedly revealed as crucial secondary habitats of many species highly specialised to sandy habitats (e.g. Řehounková & Prach 2008; Řehounková et al. 2011; Heneberg 2012; Heneberg & Řezáč 2014). Many threatened species successfully colonize extracted sites immediately after or even during mining (Řehounková & Prach 2010; Heneberg et al. 2013). Recent sand mining activities have affected ca. 96 km^2 (~0.1 %) of the Czech Republic (Starý et al. 2014), i.e. a much larger area than the remaining natural open sands. Therefore, such noticeable potential of sand and sand-gravel pits for conservation of the threatened communities of open sands needs to be realized through effective and evidence-based restoration.

The conservation potential of various post-industrial sites closely depends on the method of their restoration (e.g. Hodačová & Prach 2003; Tropek et al. 2010; Baasch et al. 2011). Current restoration practice predominantly prefers either economic or recreation interests over nature conservation while multi-use benefits still remain largely omitted (Prach & Hobbs 2008; Prach et al. 2011). Therefore, reclamation typically aims to prepare post-mining sites by the sowing of commercial species-poor seed mixtures or the planting of trees for commercial timber production, which in sand pits mostly consist of monocultures of *Pinus sylvestris* (Šebelíková et al. 2016). This is also mirrored in restoration-ecological research as many studies in Central Europe investigated the differences between forestry reclamation and spontaneous succession, i.e. revegetation by natural processes (e.g. Tropek et al. 2010; Harabiš et al. 2013; Woziwoda & Kopeć 2014; Šebelíková et al. 2016). Although most studies favoured spontaneous succession as a better approach for biodiversity conservation, it was also shown that successional overgrowing leads to the disappearance of the most precious open habitats within a few decades (Prach et al. 2014; Tropek et al. 2013b). The use of non-intensive disturbances, to decelerate succession or renew early successional stages, has already been shown to be an effective restoration management for post-industrial sites (Tropek et al. 2013b, Rich et al. 2015), but there is still a lack of evidence.

Sand and gravel-sand mines attract various recreational activities, such as swimming, angling or hiking causing additional disturbances. Such activities, especially if carried out by numerous people over a long period, cause disruption of the vegetation layer thereby maintaining bare plots. The noncohesiveness of the sandy substrate prevents its compaction by trampling, a negative consequence in other habitats (Kissling et al. 2009; Sikorski et al. 2013), and thus helps in maintaining the specific conditions of sandy habitats. As a result, many biotopes within sand pits remain in early successional stages for a long time with minimal (or even zero) costs. The majority of highly threatened species found in sand pits are specialised for these disturbed, early successional habitats (Lundholm & Richardson 2010; Tropek et al. 2010). Such species are thus optimal models to study the importance of additional modest human disturbances in restoration of various post-mining habitats. Considering the limited financial resources for biodiversity conservation even within protected areas, an unintentional low-cost restoration management technique applied to sand pits, as well as other post-industrial sites, could be the most effective practice. Tropek et al. (2013b), Harabiš and Dolný (2015), and Rich at al. (2015) alike found that various disturbances, including human trampling, are strongly beneficial for the biodiversity of black coal spoil heaps. On the other hand, to the best of our knowledge, no other study evaluated the effects of additional human disturbances on biodiversity in post-mining sites.

Therefore, we investigated how various commonly applied restoration approaches may benefit threatened sandy specialists. In this study, we compared the effects of additional disturbances caused by human trampling with the effects of forestry reclamation and spontaneous succession on communities of vascular plants and several taxonomic groups of arthropods in the abandoned parts of a large sand pit. We addressed the following questions: (i) which restoration approach is the most effective for biodiversity and the conservation of threatened and sand-specialised species; and (ii) are there any effects of site moisture or age on the conservation value of differently restored sites?

METHODS

Study area

The study was conducted in the Cep II sand pit within the Třeboňsko Protected Landscape Area (48°92"N, 14°87"E; 420–550 m a.s.l.; southwestern part of the Czech Republic). The mildly cold and wet area (mean annual temperature and precipitation of 8 °C and 650 mm, respectively) is a sedimentary basin with numerous wetlands, ponds and peat bogs influenced and remodelled by humans since the Middle Ages. A relatively large area of open sands, including large sand and gravel-sand beds and a few inland dunes, emerged along a dense local network of smaller rivers and streams. A majority of such habitats have disappeared as a consequence of afforestation and too advanced succession. However, the overwhelming area of open sands in the region has been maintained by sand excavation. Thus, utilization of the post-mining sandy habitats is thus necessary for biodiversity conservation.

In the studied sand pit (ca. 100 ha), Tertiary and Quaternary gravel-sand with bedrock formed by sand and clay layers of Cretaceous origin have been excavated since 1979. The recent mining activities are restricted to an approximately 1.5 ha area in the southern parts of the pit. Our research was carried out mainly on the banks of a single ~30 ha water body (maximum depth 12 m) formed by the mining. Larger parts of the sand pit have been forestry reclaimed by covering with previously scraped topsoil and afforested by Scotch pine (*Pinus sylvestris*) (Řehounková et al. 2011). Several smaller parts were restored by spontaneous succession. Being relatively close to a few villages and several towns, some of these areas are intensively used for recreational activities such as swimming or angling. They are thus additionally disturbed by human trampling, which further supports bank erosion, disruption of the upper substrate layers, suppression of vegetation cover and maintenance of microhabitat heterogeneity.

As a consequence, the lake sides are covered by a mosaic of spontaneously developed open sandy habitats with sparse vegetation cover maintained by additional disturbances, spontaneously established woodlands without additional disturbances, and forestry reclamations, i.e. monocultures. These represent the three prevailing approaches to restoration of sand mines in the country. In this mosaic, the described main habitats are distributed more or less irregularly along the bank of the water body. The sand pit is surrounded by species-poor pine plantations.

Data sampling

The data were collected in 18 sampling plots located in 18 patches of the three main restoration approaches found in the sand pit including: *spontaneous succession* (without any additional disturbances), *disturbed succession* (spontaneous succession with additional disturbances by recreation activities) and *forestry reclamation* (covering by a scraped fertile topsoil layer and afforested). Six discrete patches of each restoration approach were sampled. The period since mining ceased ranged from 14 to 21 years for all plots, and within each restoration approach. This time span corresponds to the middle successional stage (Prach et al. 2013). The history of each plot was reconstructed using official records of the mining company and by interviewing local administrators. Each plot was characterized by age since extraction, slope (0–15°), site moisture defined by water table (i.e. mean vertical distance of the centre of the plot surface to the water level of the sand pit water body; 0.3–15 m) and restoration approach.

The vegetation sampling was carried out in 2012. In July, percentage cover for each vascular plant species within a phytosociological relevé (5 × 5 m; Kent & Coker 1992) was recorded in the centre of each of the 18 sampling plot (in the littoral stands, the dimensions were adjusted to keep the total area of ca 25 m^2). Standard sampling of arthropods was conducted using a pitfall trap, a yellow pan (=Möricke) trap and standardised vegetation sweeping in each of the 18 sampling plots. Pitfall traps (plastic cups, diameter 9 cm, depth 15 cm, filled with 100 ml of 90 % ethylene glycol) were exposed from early April until mid-September and emptied every 2–3 weeks. Yellow pan traps (plastic bowls painted with a ‘taxi’ shade of yellow, 15 cm in diameter, filled with water with a drop of detergent) were placed near the pitfall traps for 3 days under suitable weather conditions (warm sunny days without wind) in April, May, June/July and August. Sweep samples (50 sweeps around each pitfall trap, net diameter 50 cm) were collected twice—in early July and late August.

Focal groups and species categorisation

We targeted vascular plants and five arthropod groups, namely spiders (Araneae), beetles (Coleoptera: focal families listed in Appendix), flies

(Diptera: focal families listed in Appendix), bees and wasps (Hymenoptera: Aculeata, except ants) and orthopterans (Orthoptera). For the analysis of group responses to environmental variables, the numerous and diverse material of Coleoptera was divided into subgroups differing in their life history: obligatory ground dwellers and obligatory/facultative vegetation dwellers (Table 1, Appendix).

The conservation value of the focal group communities was based on three indicators as follows: (i) *species richness*, (ii) *conservation value*, and (iii) *open sand specialization*. Species richness (i) was defined as the number of species within a given group per sampling plot. The conservation value (ii) followed the national Red Lists for vascular plants and particular groups of arthropods with the following categories: *highly endangered* (found as critically endangered or endangered in the national Red Lists), *slightly endangered* (vulnerable or near threatened), or *not endangered* (listed as least concerned or not listed in the Red Lists). Finally, for (iii), each species was classified as *obligatorily psammophilous* (restricted to open sand habitats), *facultatively psammophilous* (with optional occurrence on open sand habitats), or *sand indifferent*. The sand indifferent species were further subdivided as associated with grasslands, shrublands, woodlands, synanthropic (plants) or eurytopic (arthropods). Nomenclature, species habitat use and conservation status references, together with the lists of all recorded species with their categorisation, can be found in Appendix.

Statistical analyses

Multivariate analyses were conducted using Canoco for Windows 5 (ter Braak & Šmilauer 2012). The length of the gradients suggested a unimodal response of species (Šmilauer & Lepš 2014); thus, the differences in species composition (vascular plants and arthropods) were assessed using DCA. The species data were log-transformed, and rare species were downweighted. The effects of age, slope, site moisture, and restoration approach were quantified using CCA ordination. The forward selection procedure with all environmental variables was conducted using the Monte Carlo permutation test with 999 permutations; all significant variables ($P<0.05$) were selected.

For the analysis of species richness, the species numbers of the individual focal groups per plot were used as explained variables. For the analyses of conservation value and open sand specialisation, the numbers of individuals of each arthropod species per plot and total cover of each vascular plant species were weighted by their red-list status (highly endangered—2, slightly endangered—1, and not endangered—0) and open sand specialisation (obligatory psammophilous—2, facultative psammophilous—1, and sand indifferent species—0). Differences in all the three indicators among the restoration approaches were tested using a linear ordination method (RDA) as justified by the length of the gradient in DCA. The forward selection procedure with Monte Carlo permutation tests (999 permutations) was applied to analyse the effects of the individual environmental variables; all significant variables ($P<0.05$) were selected.

Differences in species richness, number of red-listed species and open sand specialists (obligatory psammophilous) of particular focal groups among differently restored sites were analysed using generalised linear models (GLM, quasi-Poisson model because of overdispersion) in R 3.0.2 (R Core Development Team 2014). The post-hoc comparisons among the restoration approaches were done by the Tukey HSD tests (package *multcomp,* function *glht*).

RESULTS

Altogether, we recorded 92 species of vascular plants and 314 species (1460 individuals) of arthropods (Table 1). Besides the sand-specialised species, only 16 grassland, 8 shrubland and 2 woodland species were included in the Red Lists. None of the recorded synanthropic species reached any red-listed status (Appendix).

Table 1 Diversities and abundances of the focal groups.

Taxonomic group	[a]**Species**	[a]**Individuals**	[a]**Red-listed species**	[a]**Open sand specialists**
Spiders (Araneae)	76	426	15	11
Beetles—ground dwellers (Coleoptera)	58	471	7	15
Beetles—vegetation dwellers (Coleoptera)	60	203	6	6
Flies (Diptera)	43	78	9	10
Bees and wasps (Hymenoptera: Aculeata)	65	181	25	54
Orthopterans (Orthoptera)	12	101	3	4
Vascular plants	92	–	6	12
Total	406	1460	71	112

[a] Total number of

The DCA ordination of sampling plots ($\lambda_1 = 0.611$, $\lambda_2 = 0.362$, Fig. 1a) clearly separated the sites restored by different approaches along the first axis: disturbed succession sites clustered on the right, the forestry reclaimed sites on the left and the spontaneous succession sites were in-between. The second axis corresponded to increasing site moisture. The correlation coefficient (R) between the site moisture of the sampled site and their score on the second ordination axis was 0.576 ($P<0.01$).

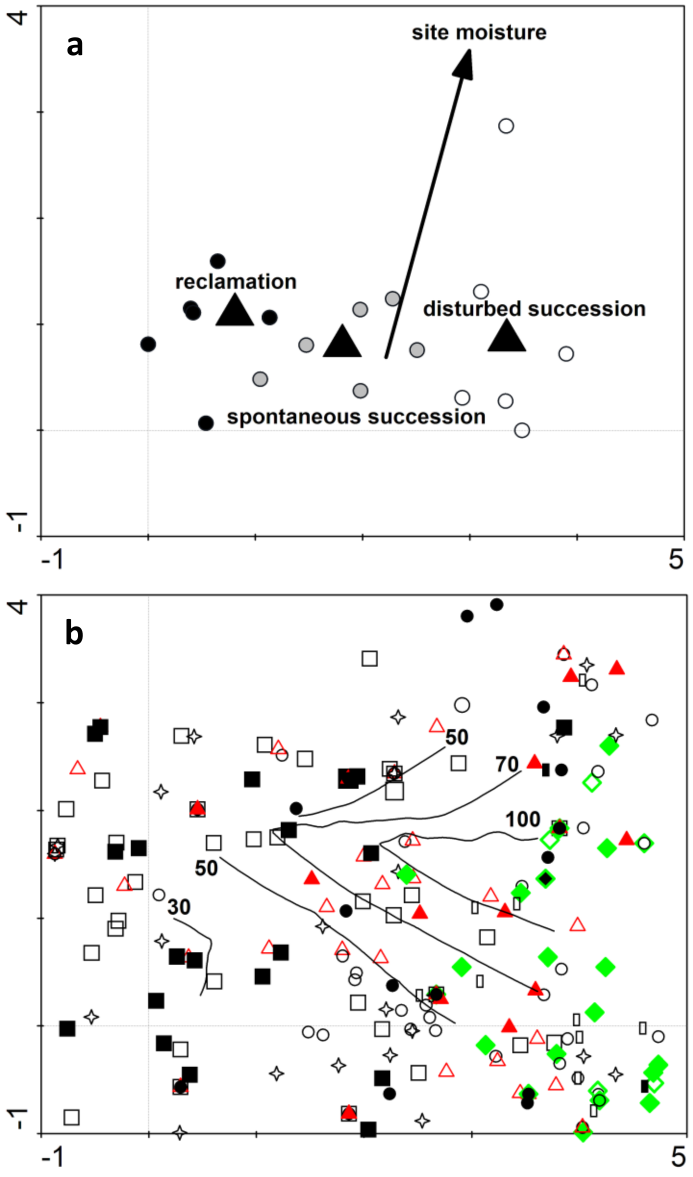

Fig. 1 DCA ordination of sampling plots (a) and species (b) according to different restoration approaches. The isolines (*loess curves*) demonstrate the total number of species per sampled plot (b). The *arrow* represent the significant environmental variable. Arthropods (*empty*), vascular plants (*full*). Species: threatened (*diamond*), synanthropic plants and eurytopic arthropods (*triangle*), open sand (*rectangle*), grassland (*circle*), woodland (*square*), shrubland (*star*, only arthropods were shown, no vascular plants occurred in this category). Restoration approach (shown by centroids): spontaneous succession—spontaneous succession without additional disturbances, disturbed succession—spontaneous succession with additional disturbances, reclamation—forestry reclamation, afforested sites with Scotch pine (*Pinus sylvestris*).

Table 2 Impact of different restoration approaches on total number of species, Red List species and sand specialists of particular focal groups. Significant differences between the three restoration approaches are marked in *bold* and by *different letters—the same letters* indicate homogeneous groups according to the Tukey HSD test, GLM (*P*<0.05). The average number of species for each focal group and standard deviation are shown.

Restoration approach	Focal groups						
	Spiders	BeetlesG	BeetlesV	Flies	Bees & wasps	Orthopterans	Vascular plants
Total number of species							
D	12.5±7.3	8.5±5.3	**11.7±5.6**^{a}	**7.2±4.4**^{a}	**9.0±8.7**^{a}	**4.5±1.0**^{a}	18.0±7.4
S	11.8±5.0	7.0±4.0	6.3±4.1^{ba}	2.7±1.2^{ba}	2.7±1.2^{ba}	1.7±1.8^{ba}	14.5±5.7
R	8.0±3.8	8.8±5.0	**3.3±1.5**^{cb}	**1.0±2.4**^{cb}	**1.0±2.4**^{cb}	**0.2±0.4**^{cb}	12.2±1.7
[a]Red List species							
D	1.7±2.3	**1.7±1.0**^{a}	1.2±1.0	**1.5±1.2**^{a}	**6.3±3.6**^{a}	**1±0.6**^{a}	**1.3±0.8**^{a}
S	2.0±2.3	0.8.±1.3^{ba}	0.8±1.0	0.3±0.8^{ba}	1.7±2.0^{ba}	0.3±0.5^{ba}	0.2±0.4^{ba}
R	0	**0**^{cb}	0	**0**^{cb}	**0**^{cb}	**0**^{cb}	**0**^{cb}
[a]Sand specialists							
D	**3.0±2.0**^{a}	**3.8±2.2**^{a}	0	**1.5±1.4**^{a}	**12.7±0.5**^{a}	**2.0±0.6**^{a}	**3.5±1.9**^{a}
S	2.0±1.4^{ba}	**1.2±1.8**^{b}	0	0.7±0.8^{ba}	**3.5±3.6**^{b}	0.8±1.17^{ba}	**1.5±1.2**^{b}
R	**0.7±0.8**^{cb}	**0.2±0.4**^{cb}	0	**0**^{cb}	**0.7±0.5**^{cb}	**0.2±0.4**^{cb}	**0.2±0.4**^{cb}

BeetlesG beetles—ground dwellers, *BeetlesV* beetles—vegetation dwellers, *S* spontaneous succession, *D* disturbed succession, *R* reclamation.

[a] Total number of

Analogous patterns emerged in the case of species selected according to their habitat use, conservation status and open sand specialization (Fig. 1b). The red-listed species were more frequent in the disturbed succession sites (53 grassland and open sand species in total) characterised also by most of the open sand-specialized species (Table 2). The red-listed species occurred substantially less frequently in sites revegetated through spontaneous succession (33 species, predominantly of grassland and a few shrubland species) and were almost missing in the forestry reclaimed sites (only one grassland species). The latter sites were dominated by common woodland species whilst disturbed sites were characterized by grassland species (Appendix). The community composition of spontaneously revegetated sites form a transition continuum in-between the other two. Shrubland species and synanthropic plants and eurytopic arthropods did not show any clear patterns in relation to restoration method. The disturbed succession sites were characterised by a higher number of species as the isolines show a decrease of species richness to the left side of the diagram through the spontaneous succession sites towards the forestry reclaimed sites (Fig 1b).

The CCA analyses (λ_1 = 0.592, λ_2 = 0.272) of vascular plant/arthropod species revealed significant relationships of two variables. Restoration approach explained 11.7 % of the model variation (F = 1.84, P<0.001) and site moisture 9.4 % (F = 1.52, P<0.05), whilst the effects of age and slope were insignificant (P>0.05).

The RDA analyses revealed the restoration approach as the only variable significantly affecting the conservation indicators. The species richness (RDA, λ_1 = 53.8, λ_2 = 0.227) of the focal groups was positively related to disturbed succession and partly also to spontaneous succession. Only the species richness of ground-dwelling beetles did not correspond to any of the restoration approaches (Fig. 2a, Table 2). Restoration approach, the only significant environmental variable, explained 53.8 % of the variability (*F* = 18.6, *P*<0.001).

The conservation values (RDA, $\lambda_1 = 0.408$, $\lambda_2 = 0.281$) of the focal groups were always positively associated with disturbed succession, and negatively to spontaneous succession and forestry reclamation. Spiders were the only exception, being equated rather to spontaneous than disturbed succession (Fig. 2b). Restoration approach, the only significant variable, explained 40.8 % of the variability (*F* = 11.4, *P*<0.001).

The open sand specialisation of the focal groups (RDA, $\lambda_1 = 0.401$, $\lambda_2 = 0.299$) was positively related to disturbed succession in all the focal groups, except for beetles dwelling on vegetation, which associated also to forestry reclamation (Fig. 2c). The analysis revealed only restoration approach as a significant variable, which explained 40.1 % of the variability (*F* = 10.73, *P*<0.0001).

The numbers of red-listed species and open sand specialists in the sites revegetated through different restoration approaches are shown in Table 2. In comparison to forestry reclaimed sites, the disturbed sites were more variable in the numbers of red-listed species (with the exceptions of spiders and vegetation dwelling beetles) and hosted a significantly higher number of species of all the focal groups except spiders, ground dwelling beetles and vascular plants. The disturbed sites also hosted significantly higher numbers of open sand specialists with the exception of vegetation dwelling beetles.

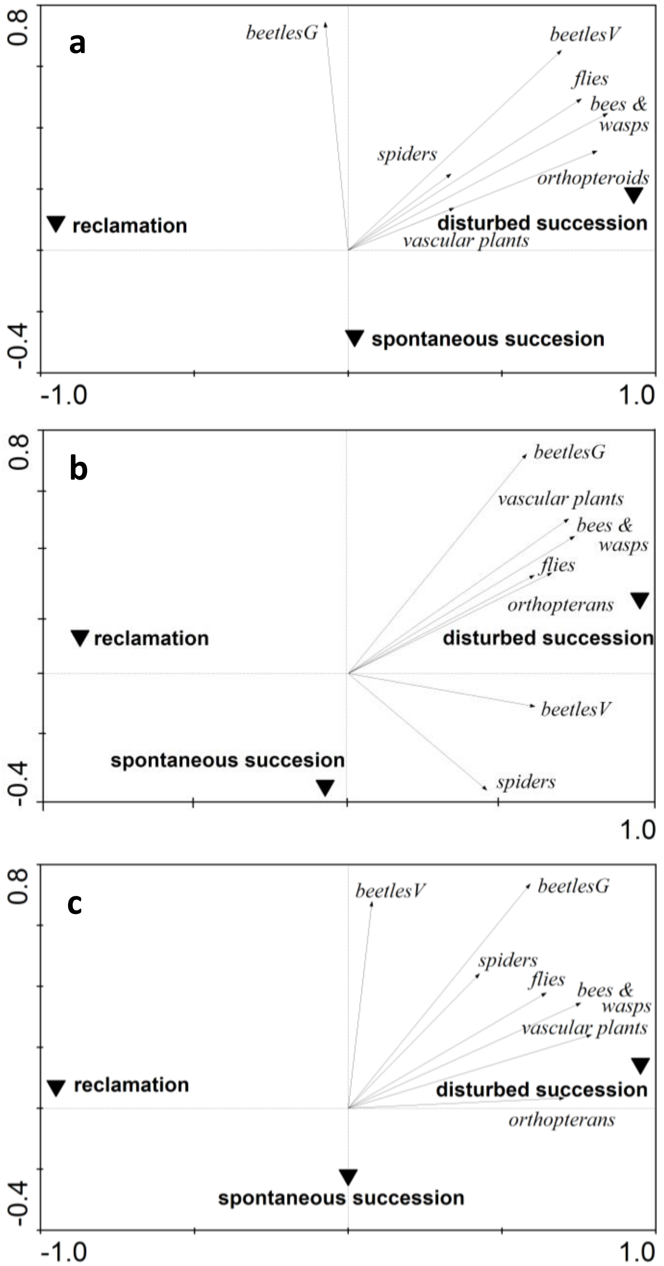

Fig 2 RDA ordination showing the conservation benefits of focal groups indicated by species richness, (a) conservation value and (b) and open sand specialists (c) in differently restored areas within the sand pit. Restoration approach (shown by *centroids*): spontaneous succession—spontaneous succession without additional disturbances, disturbed succession—spontaneous succession with additional disturbances, reclamation—forestry reclamation, afforested sites with Scotch pine (*Pinus sylvestris*). *BeetlesG* beetles—ground dwellers, *BeetlesV* beetles—vegetation dwellers.

DISCUSSION

Our study in the sand pit restored through spontaneous succession revealed that additional disturbances are crucial for long-term survival of the threatened biodiversity associated with open continental sands.

The spontaneously revegetated sites with additional disturbances caused by outdoor activities hosted ten- and fivefold higher proportion of threatened species and open sand specialists respectively in comparison to forestry reclaimed sites.

These findings suggest that intensive human trampling in noncohesive sandy substrate has the potential to substitute for the disturbance regime, either natural or mining, after excavation has ceased, in terms of maintaining heterogeneous habitats, including early successional stages. Moreover, the human trampling at the broader scale is spatially discrete in the sand pit. This is convincingly supported by the highly heterogeneous habitat specialisation of the most threatened species recorded in our study. The threatened species are specialised to a range of habitats; therefore, heterogeneity is supporting all these species. Besides the most important, endangered specialists of open sands (e.g. the wasp *Crabro scutellatus* and spider *Sitticus saltator*), we recorded various threatened species of natural river banks (e.g. the critically endangered spider *Arctosa cinerea*), steppe grasslands (e.g. the endangered spider *Micaria silesiaca* and endangered pompilid wasp *Evagetes pectinipes*), peat bogs and other wetlands (e.g. the vulnerable bee *Melitta nigricans*). Almost all these important species avoided afforested plots covered with topsoil layer, i.e. reclamations, which have been repeatedly found to decrease habitat heterogeneity in various post-mining sites (e.g. Prach & Hobbs 2008; Tropek et al. 2010).

Although spontaneous succession is usually considered as an effective restoration method for post-mining sites (Hodačová & Prach 2003; Mudrák et al. 2010; Tropek et al. 2010; Tropek et al. 2013b; Šebelíková et al. 2016), sooner or later, its positive effect will be depleted by vegetation overgrowing. In Central Europe, spontaneous succession in post-mining sites usually leads to development of dense vegetation cover within 10 years, resulting in woodland stages in about 20 years (Prach at al. 2011). Although such woodlands have a still much higher conservation value than that established through forestry reclamations (Mudrák et al. 2010), they cannot harbour the endangered species associated with early successional biotopes (Prach et al. 2014; Beneš et al. 2003; Tropek et al. 2013b).

Human trampling has been repeatedly shown to support conservation important communities of plants and insects in sand dune and steppe grasslands, and black coal spoil dumps (e.g. Kadlec et al. 2009; Čížek et al. 2012; Tropek et al. 2013b; Brunbjerg et al. 2014, Rich et al. 2015). On the other hand, several studies have recently documented negative impacts of trampling on various habitats leading to degradation of plant and animal assemblages (Kotze et al. 2012; Ballantyne & Pickering 2013; Pescott & Steward 2014). Although it is difficult to generalise on a few existing publications with different methodological approaches and contradictory results, any potential benefits of such disturbances will depend not only on the biotopes but also on type of substrate and life-histories of target species. In the case of open sands, the target biotope of sand mine restoration, the most conservation important species are usually highly adapted to regularly disturbed habitats. Plants are thus typically stress-tolerant, dependent on low nutrient supply and soil water content during summer (Jentsch & Beyschlag 2003), and generally are weak competitors (Grime et al. 1988). The specialised arthropods also have various adaptations to extreme conditions of the finely grained bare substrate (Fanta & Siepel 2010). The best example is bees and wasps which very often require sand for nesting (Macek et al. 2010), but the majority of sand specialists are not able to survive long-term in later successional habitats as well. For such species, additional disturbances seem to be the only solution for their effective local conservation (Olsson et al. 2014). In our study, the only exception was threatened spiders, which preferred spontaneous succession before disturbances. Such affinity of many threatened spider species to medium successional stages is already known (Tropek et al. 2014). On the other hand, even in this group, some of the most threatened species (such as the critically endangered *Arctosa cinerea*) indisputably needs the intensively disturbed plots.

A couple of studies have tested the effect of local site and landscape factors on species composition in abandoned sand pits (Borgegård 1990; Řehounková & Prach 2006). In this study, we focused only on a few local environmental factors, while other potentially important variables, such as soil texture, macroclimate and species pool characteristics, were not included because of the homogenity of the substrate and surrounding vegetation. Besides the restoration approach, no other recorded environmental factors showed any significant effect on the focal groups. The lack of any effect of plot age in our study is incongruent with other studies focused on vegetation succession in post-mining sites (Řehounková & Prach 2006; Trnková et al. 2010; Konvalinková & Prach 2010). On the other hand, the insignificant effect of the post-mining habitats age on arthropods has been repeatedly shown, as they are considered to reflect habitat conditions rather than its age (Beneš et al. 2003; Krauss et al. 2009; Tropek et al. 2013b). The lack of variability among the studied plots could have concealed the importance of plot age and slope inclination.

We are aware of the limitations of our case study for making any general conclusion concerning restoration recommendations. On the other hand, our study covers numerous threatened and/or sand specialised species belonging to several evolutionary different groups which showed similar general patterns. Further, we do not know of any other opportunity for such a comparison of additional disturbances with spontaneous additionally undisturbed succession and conventionally used forestry reclamation. Lastly, our results are from a single, but unusually large, locality with reasonably well-balanced spatial design of the individually managed plots. We thus believe that, in spite of all the limitations, our case study shows the potential use of the disturbed succession approach in post-industrial sites and will thus initiate its broader application and research. This is especially so, because, to the best of our knowledge, this is the first multi-taxa study focusing on disturbed succession as a restoration method in sand mines.

CONCLUSION AND IMPLICATIONS FOR PRACTICE

Our study demonstrates how a single, appropriately managed locality can harbour a rich spectrum of endangered species. Forestry reclamation is a costly restoration approach, causing rapid destruction of valuable habitats and loss of endangered species. Spontaneous succession is a low-cost and effective restoration method, but without additional disturbances, it led to the suppression of habitat heterogeneity which subsequently resulted in the decline of the most threatened specialists of early successional stages. Additional disturbances, such as trampling by human recreation activities, cause renewal of early successional habitats, maintain local habitat heterogeneity and thus support the long-term high conservation potential of sand mines.

Acknowledgement. The authors thank Keith Edwards for proofreading our English and Karel Prach and four anonymous reviewers for their comments. The study was supported by the following grants: the Czech Science Foundation (P505/11/0256, P504/12/2525), RVO 67985939, HeidelbergCement Group (Quarry Life Award 2012), the University of South Bohemia (04-168/2013/P) and University of Hradec Králové (SV 2117/2014). None of the funders had any influence on the study design, results and their interpretation.

References

Baasch, A., Kirmer, A. & Tischew, S. 2011: Nine years of vegetation development in a postmining site: effects of spontaneous and assisted site recovery. Journal of Applied Ecology 49: 251–260.

Ballantine, M. & Pickering, C. M. 2013: Tourism and recreation: a common threat to IUCN red-listed vascular plants in Europe. Biodiversity and Conservation 22: 3027–3044.

Beneš, J., Kepka, P. & Konvička, M. 2003: Limestone quarries as refuges for European xerophilous butterflies. Conservation Biology 17: 1058–1069.

Borgegård, S. O. 1990: Vegetation development in abandoned gravel pits: effects of surrounding vegetation, substrate and regionality. Journal of Vegetation Science 1: 675–682.

Brunbjerg, A. K., Svenning, J. C. & Ejrnæs, R. 2014: Experimental evidence for disturbance as a key to the conservation of dune grassland. Biological Conservation 174: 101–110.

Chytrý, M. (Ed) 2010: Vegetation of the Czech Republic 1. Grassland and heathland vegetation. Academia, Praha (in Czech).

Chytrý, M. (Ed) 2011: Vegetation of the Czech Republic 3. Aquatic and wetland vegetation. Academia, Praha (in Czech).

Čížek, L., Hauck, D. & Pokluda, P. 2012: Contrasting needs of grassland dwellers: habitat preferences of endangered steppe beetles (Coleoptera). Journal of Insect Conservation 16: 281–293.

European Commission 2015: Natura 2000: habitats directive sites according to biogeographical regions. http://ec.europa.eu/environment/nature/natura2000/sites_hab/biogeog_regions/ index_en.htm. Accessed 10 April 2016.

Fanta, J. & Siepel, H. (Eds) 2010: Inland Drift Sand Landscapes. KNNV Publishing, Zeist.

Grime, J. P., Hodgson, J. G. & Hunt, R. 1988: Comparative plant ecology. Allen & Unwin, London.

Harabiš, F. & Dolný, A. 2015: Odonates need natural disturbances: how human-induced dynamics affect the diversity of dragonfly assemblages. Freshwater Science 34: 1050–1057.

Harabiš, F., Tichánek, F. & Tropek, R. 2013: Dragonflies of freshwater pools in lignite spoil heaps: restoration management, habitat structure and conservation value. Ecological Engineering 55: 51–61.

Heneberg, P. 2012: Flagship bird species habitat management supports the presence of ground-nesting aculeate hymenopterans. Journal of Insect Conservation 16: 899–908.

Heneberg, P. & Řezáč, M. 2014: Dry sandpits and gravel-sandpits serve as key refuges for endangered epigeic spiders (Araneae) and harvestmen (Opiliones) of Central European steppes aeolian sands. Ecological Engineering 73: 659–670.

Heneberg, P., Bogusch, P. & Řehounek, J. 2013: Sandpits provide critical refuge for bees and wasps (Hymenoptera: Apocrita). Journal of Insect Conservation 17: 473–490.

Hodačová, D. & Prach, K. 2003: Spoil heaps from brown coal mining: technical reclamation vs spontaneous re-vegetation. Restoration Ecology 11: 385 – 391.

Jentsch, A. & Beyschlag, W. 2003: Vegetation ecology of dry acidic grasslands in the lowland area of central Europe. Flora 198: 3–25.

Kadlec, T., Vrba, P. & Konvička, M. 2009: Microhabitat requirements of caterpillars of the critically endangered butterfly Chazara briseis (Nymphalidae: Satyrinae) in the Czech Republic. Nota Lepidopterologica 32: 39–46.

Kent, M. & Coker, P. 1992: Vegetation description: a practical approach. Belhaven Press, London.

Kissling, M., Hegetschweiler, K. T., Rusterholz, H. P. & Baur, B. 2009: Short-term and long-term effects of human trampling on above-ground vegetation, soil density, soil organic matter and soil microbial processes in suburban beech forests. Applied Soil Ecology 42: 303–314.

Konvalinková, P. & Prach, K. 2010: Spontaneous succession of vegetation in mined peatlands: a multi-site study. Preslia 82: 423–435.

Kotze, D. J., Lehvävirta, S., Koivula, M., O'Hara, R. & Spence, J. R. 2012: Effects of habitat edges and trampling on the distribution of ground beetles (Coleoptera, Carabidae) in urban forests. Journal of Insect Conservation 16: 883–897.

Krauss, J., Alfert, T. & Steffan-Dewenter, I. 2009: Habitat area but not habitat age determines wild bee richness in limestone quarries. Journal of Applied Ecology 46: 194–202.

Lundholm, J. T. & Richardson, P. J. 2010: Habitat analogues for reconciliation ecology in urban and industrial environments. Journal of Applied Ecology 47: 966–975.

Macek, J., Straka, J., Bogusch, P., Dvořák, L., Bezděčka, P. & Tyrner, P. 2010: Hymenoptera of the Czech Republic. I. Aculeata. Academia, Praha (in Czech).

Mudrák, O., Frouz, J. & Velichová, V. 2010: Underestory vegetation in reclaimed and unreclaimed post-mining forest stands. Ecological Engineering 36: 783–790.

NCA CR 2013: Habitat mapping layer [electronic database]. Version 2013. Prague Nature Conservation Agency of the Czech Republic. The occurrence of natural habitat in the Czech Republic.

Olsson, P. A., Sjöholm, C. & Ödman, A. M. 2014: Soil disturbance favours threatened beetle species in sandy grasslands. Journal of Insect Conservation 18: 827–835.

Pescott, O. L. & Steward, G. B. 2014: Assessing the impact of human trampling on vegetation: a systematic review and meta-analyses of experimental evidence. PeerJ Preprints 2:e360.

Prach, K. & Hobbs, R. J. 2008: Spontaneous succession versus technical reclamation of disturbed sites. Restoration Ecology 16: 363–366.

Prach, K., Řehounková, K., Řehounek, J. & Konvalinková, P. 2011: Ecological restoration of central European mining sites: a summary of a multi-site analysis. Landscape Research 36: 263–268.

Prach, K., Lencová, K., Řehounková, K., Dvořáková, H., Jírová, A., Konvalinková, P., Mudrák, O., Novák, J. & Trnková, R. 2013: Spontaneous vegetation succession at different central European mining sites: a comparison across seres. Environmental Science and Pollution Research 20: 7680–7685.

Prach, K., Řehounková, K., Lencová, K., Jírová, A., Konvalinková, P., Mudrák, O., Študent, V., Vaněček, Z., Tichý, L., Petřík, P., Šmilauer, P. & Pyšek, P. 2014: Vegetation succession in restoration of disturbed sites in Central Europe: the direction of succession and species richness across 19 seres. Applied Vegetation Science 17: 193–200.

R Core Development Team 2014: R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna.

Řehounková, K. & Prach, K. 2006: Spontaneous vegetation succession in disused gravel-sand pits. Role of local site and landscape factors. Journal of Vegetation Science 17: 583–590.

Řehounková, K. & Prach, K. 2008: Spontaneous vegetation succession in gravel-sand pits: a potential for restoration. Restoration Ecology 16: 305–312.

Řehounková, K. & Prach, K. 2010: Life history traits and habitat preferences of colonizing plant species in long-term spontaneous succession in abandoned gravel sand pits. Basic and Applied Ecology 11:45–53.

Řehounková, K., Řehounek, J. & Prach, K. (Eds) 2011: Near-natural restoration vs. technical reclamation of mining sites in the Czech Republic. Faculty of Science USB, České Budějovice.

Rich, K., Ridealgh, M., West, S. E., Cinderby, S. & Ashmore, M. 2015: Exploring the Links between Post-Industrial Landscape History and Ecology through Participatory Methods. PLoS ONE 10: e0136522. doi:10.1371/journal.pone.0136522.

Riksen, M., Ketner-Oostra, R., van Turnhout, C., Nijssen, M., Goossens, D., Jungerius, P. D. & Spaan, W. 2006: Will we lose the last active inland drift sands of Western Europe? The origin and development of the inland drift-sand ecotype in the Netherlands. Landscape Ecology 21: 431–447.

Šebelíková, L., Řehounková, K. & Prach, K. 2016: Near-natural restoration vs. forestry reclamation in post-mining sand pits. Environmental Science and Pollution Research 23: 13598-13605.

Sikorski, P., Szumacher, I., Sikorska, D., Kozak, M. & Wierzba, M. 2013: Effects of visitor pressure on understory vegetation in Warsaw forested parks (Poland). Environmental Monitoring and Assessment 185: 5823–5836.

Šmilauer, P. & Lepš, J. 2014: Multivariate analysis of ecological data using CANOCO 5. Cambridge University Press, New York.

Starý, J., Sitenský, I., Mašek, D., Hodková, T. & Kavina, P. 2014: Mineral commodity summaries of the Czech Republic 2014. Czech Geological Survey, Prague.

ter Braak, C. J. F. & Šmilauer, P. 2012: CANOCO reference manual and user's guide: Software for ordination (version 5). Microcomputer Power, Ithaca.

Trnková, R., Řehounková, K. & Prach, K. 2010: Spontaneous succession of vegetation on acidic bedrock in quarries in the Czech Republic. Preslia 82: 333–343.

Tropek, R., Kadlec, T., Karešová, P., Spitzer, L., Kočárek, P., Malenovský, P., Baňař, P., Tuf, I. H., Hejda, M. & Konvička, M. 2010: Spontaneous succession in limestone quarries as an effective restoration tool for endangered arthropods and plants. Journal of Applied Ecology 47:139–147.

Tropek, R., Černá, I., Straka, J., Čížek, O. & Konvička, M. 2013a: Is coal combustion the last chance for vanishing insects of inland drift sand dunes in Europe? Biological Conservation 162: 60–64.

Tropek, R., Hejda, M., Kadlec, T., Spitzer, L. 2013b: Local and landscape factors affecting communities of plants and diurnal Lepidoptera in black coal spoil heaps: Implications for restoration management. Ecological Engineering 57: 252–260.

Tropek, R., Černá, I., Straka, J., Kadlec, T., Pech, P., Tichánek, F. & Šebek, P. 2014: Restoration management of fly ash deposits crucially influence their conservation potential for terrestrial arthropods. Ecological Engineering 73: 45–52.

Walker, L. R. & del Moral, R. (Eds) 2003: Primary succession and ecosystem rehabilitation. Cambridge University Press, Cambridge.

Woziwoda, B., Kopeć, D. 2014: Afforestation or natural succession? Looking for the best way to manage abandoned cut-over peatlands for biodiversity conservation. Ecological Engineering 63: 143–152.

Appendix

Lists of all recorded species with their memberships in individual categories and references to nomenclature, conservation status, open sand specialisation and habitat use.

Legend

***CS* —Conservation status**

HE	higly endangered (critically endangered or endangered in National Red Lists)
SE	slightly endangered (vulnerable or near threatened in National Red Lists)
-	not endangered (least concerned or not listed in the Red Lists)

***PS* —Psammophilous specialisation**

OP	obligatory psamophilous (restricted to open sand habitats)
FP	facultative psamophilous (with optional occurence at open sand habitats)
-	sand indifferent

Habitat use

OS —open sand	species restricted to open sands
GR —grassland	species restricted to grasslands
SH —shrubland	species restricted to shrublands or with optional occurence in shrubland and other open habitats
WO —woodland	with optional occurence in woodland habitats
SYN/EUR —synanthropic/eurytopic	habitat indifferent species

Restoration approach

S— Spontaneous succesion	spontaneous succession without any additional disturbances
D— Disturbed succession	spontaneous succession with additional disturbances
R— Reclamation	covered by a scraped fertile topsoil layer and afforested (*Pinus sylvestris*)

Spiders

Family	Species	Author	CS	PS
Agelenidae	*Coelotes terrestris*	(Wider, 1834)	-	-
	Histopona torpida	(C. L. Koch, 1837)	-	-
	Inermocoelotes inermis	(L. Koch, 1855)	-	-
	Tegenaria campestris	(C. L. Koch, 1834)	-	-
Amaurobiidae	*Amaurobius fenestralis*	(Ström, 1768)	-	FP
Araneidae	*Aculepeira ceropegia*	(Walckenaer, 1802)	-	-
	Araneus diadematus	Clerck, 1757	-	-
	Argiope bruennichi	(Scopoli, 1772)	-	-
	Gibbaranea bituberculata	(Walckenaer, 1802)	SE	-
	Hypsosinga pygmaea	(Sundevall, 1831)	SE	-
	Mangora acalypha	(Walckenaer, 1802)	-	-
Clubionidae	*Clubiona comta*	(C. L. Koch, 1839)	-	-
	Clubiona lutescens	Westring, 1851	-	-
	Clubiona subsultans	Thorell, 1875	-	-
	Clubiona terrestris	Westring, 1851	-	-
Corinnidae	*Phrurolithus festivus*	(C. L. Koch, 1835)	-	-
Dysderidae	*Harpactea lepida*	(C. L. Koch, 1838)	-	-
Gnaphosidae	*Drassodes pubescens*	(Thorell, 1856)	-	-
	Gnaphosa montana	(L. Koch, 1866)	SE	-
	Haplodrassus silvestris	(Blackwall, 1833)	-	-
	Haplodrassus soerenseni	(Strand, 1900)	-	-
	Micaria fulgens	(Walckenaer, 1802)	SE	-
	Micaria silesiaca	L. Koch, 1875	SE	FP
	Zelotes apricorum	(L. Koch, 1876)	-	-
	Zelotes petrensis	(C. L. Koch, 1839)	-	FP
Hahniidae	*Hahnia nava*	(Blackwall, 1841)	-	-
Linyphiidae	*Abacoproeces saltuum*	(L. Koch, 1872)	-	-
	Erigone atra	Blackwall, 1833	-	-
	Erigone dentipalpis	(Wider, 1834)	-	-
	Gongylidiellum vivum	(O. Pickard-Cambridge, 1875)	SE	-
	Linyphia triangularis	(Clerck, 1757)	-	-
	Neriene clathrata	(Sundevall, 1830)	-	-
	Oedothorax apicatus	(Blackwall, 1850)	-	-
	Walckenaeria alticeps	(Denis, 1952)	-	-
	Walckenaeria antica	(Wider, 1834)	-	-
	Walckenaeria mitrata	(Menge, 1868)	-	-
Liocranidae	*Agroeca brunnea*	(Blackwall, 1833)	-	-
Lycosidae	*Alopecosa pulverulenta*	(Clerck, 1757)	-	-
	Arctosa cinerea	(Fabricius, 1777)	HE	OP
	Arctosa leopardus	(Sundevall, 1833)	HE	-
	Aulonia albimana	(Walckenaer, 1805)	-	FP
	Pardosa alacris	(C. L. Koch, 1833)	-	-
	Pardosa amentata	(Clerck, 1757)	-	-
	Pardosa lugubris	(Walckenaer, 1802)	-	-
	Pardosa monticola	(Clerck, 1757)	-	-
	Pardosa prativaga	(L. Koch, 1870)	-	-
	Pardosa pullata	(Clerck, 1757)	-	-
	Pirata tenuitarsis	Simon, 1876	SE	-

Habitat use					**Restoration approach** (no. of indiv.)		
OS	**GR**	**SH**	**WO**	**SYN/EUR**	**S**	**D**	**R**
0	0	0	1	0	0	0	1
0	0	0	1	0	3	0	1
0	0	0	1	0	0	1	3
0	0	0	1	0	4	2	1
0	0	0	1	0	0	0	1
0	0	1	0	0	0	1	0
0	0	1	0	0	0	1	0
0	1	0	0	0	0	1	0
0	0	1	0	0	1	0	0
0	1	0	0	0	1	0	0
0	0	1	0	0	1	6	0
0	1	0	1	0	1	0	2
0	0	0	0	1	0	0	1
0	0	0	1	0	0	1	1
0	0	0	1	0	0	0	1
0	1	0	0	0	0	0	1
0	0	0	1	0	0	0	1
0	0	0	0	1	1	0	0
0	0	1	0	0	1	0	0
0	0	0	1	0	2	0	1
0	0	0	1	0	1	0	0
0	1	0	0	0	1	0	0
0	0	1	0	0	2	0	0
0	0	0	0	1	0	0	1
0	1	0	0	0	1	1	0
0	1	0	0	0	1	0	0
0	0	0	1	0	0	0	1
0	0	0	0	1	0	3	0
0	0	0	0	1	0	1	0
0	0	1	0	0	1	1	0
0	1	0	0	0	1	5	0
0	0	0	0	1	1	0	1
0	1	0	0	0	0	1	0
0	0	1	0	0	2	0	0
0	0	0	0	1	1	0	0
0	0	0	1	0	0	0	1
0	0	1	0	0	0	0	12
0	0	1	0	0	1	0	0
1	0	0	0	0	1	0	0
0	1	0	0	0	0	7	0
0	1	0	0	0	0	1	0
0	0	0	1	0	2	0	1
0	1	0	0	0	0	2	0
0	0	0	1	0	2	0	60
0	1	0	0	0	1	2	0
0	1	0	0	0	1	5	1
0	1	0	0	0	6	1	3
0	1	0	0	0	1	3	0

Family	Species	Author	CS	PS
Lycosidae	*Piratula hygrophila*	(Thorell, 1872)	-	-
	Piratula latitans	(Blackwall, 1841)	-	-
	Trochosa ruricola	(De Geer, 1778)	-	-
	Trochosa terricola	Thorell, 1856	-	-
	Xerolycosa miniata	(C. L. Koch, 1834)	-	FP
Oxyopidae	*Oxyopes ramosus*	(Martini & Goeze, 1778)	SE	-
Philodromidae	*Philodromus collinus*	C. L. Koch, 1835	-	-
	Tibellus oblongus	(Walckenaer, 1802)	-	-
Pisauridae	*Dolomedes fimbriatus*	(Clerck, 1757)	SE	-
	Pisaura mirabilis	(Clerck, 1757)	-	-
Salticidae	*Aelurillus v-insignitus*	(Clerck, 1757)	-	FP
	Evarcha arcuata	(Clerck, 1757)	-	-
	Evarcha falcata	(Clerck, 1757)	-	-
	Heliophanus flavipes	(Hahn, 1832)	-	-
	Phlegra fasciata	(Hahn, 1826)	-	FP
	Salticus scenicus	(Clerck, 1757)	-	-
	Sitticus caricis	(Westring, 1861)	SE	-
	Sitticus floricola	(C. L. Koch, 1837)	SE	-
	Sitticus saltator	(O. Pickard-Cambridge, 1868)	HE	FP
	Talavera petrensis	(C. L. Koch, 1837)	SE	FP
Sparassidae	*Micrommata virescens*	(Clerck, 1757)	-	-
Tetragnathidae	*Pachygnatha degeeri*	Sundevall, 1830	-	-
	Pachygnatha listeri	Sundevall, 1830	-	-
Theridiidae	*Robertus lividus*	(Blackwall, 1836)	-	-
Thomisidae	*Ozyptila atomaria*	(Panzer, 1801)	-	-
	Xysticus ulmi	(Hahn, 1831)	-	-
Zodariidae	*Zodarion germanicum*	(C. L. Koch, 1837)	-	FP
Zoridae	*Zora spinimana*	(Sundevall, 1833)	-	-

		Habitat use				Restoration approach (no. of indiv.)	
OS	**GR**	**SH**	**WO**	**SYN/EUR**	**S**	**D**	**R**
0	0	1	0	0	2	0	0
0	1	0	0	0	8	1	2
0	0	1	0	0	11	7	4
0	0	1	0	0	18	11	14
0	1	0	0	0	9	62	13
0	1	0	0	0	0	1	0
0	0	0	1	0	0	1	0
0	1	0	0	0	2	6	0
0	1	0	0	0	0	3	0
0	0	1	0	0	1	2	0
0	1	0	0	0	1	3	0
0	1	0	0	0	2	12	0
0	0	1	0	0	0	0	1
0	1	0	0	0	0	1	0
0	1	0	0	0	1	0	0
1	0	0	0	0	0	1	0
0	1	0	0	0	0	1	0
0	1	0	0	0	0	2	0
0	1	0	0	0	1	0	0
0	1	0	0	0	2	2	0
0	0	0	1	0	0	1	0
0	0	0	0	1	2	2	1
0	0	0	0	1	0	3	2
0	0	0	0	1	0	0	1
0	0	1	0	0	1	0	1
0	0	1	0	0	1	1	1
0	1	0	0	0	5	1	0
0	0	0	0	1	5	2	4

Beetles—ground dwellers

Family	Species	Author	CS	PS
Byrrhidae	*Byrrhus fasciatus*	(Forster, 1771)	-	FP
	Morychus aeneus	(Fabricius, 1775)	SE	OP
Carabidae	*Abax parallelepipedus*	Piller & Mitterpacher, 1783	-	-
	Abax parallelus	Duftschmid, 1812	-	-
	Acupalpus brunnipes	Sturm, 1825	SE	OP
	Acupalpus flavicollis	Sturm, 1825	-	FP
	Agonum fuliginosum	Panzer, 1809	-	-
	Amara aenea	DeGeer, 1774	-	-
	Amara communis	Panzer, 1797	-	-
	Amara fulva	O.F. Müller, 1776	SE	OP
	Amara plebeja	Gyllenhal, 1810	-	-
	Amara tibialis	Paykull, 1798	-	FP
	Bembidion bruxellense	Wesmael, 1835	-	-
	Bembidion femoratum	Sturm, 1825	-	-
	Bembidion illigeri	Netolitzky, 1914	-	FP
	Bembidion quadrimaculatum	(Linnaeus, 1761)	-	-
	Calathus erratus	Sahlberg, 1827	-	-
	Calathus micropterus	Duftschmid, 1812	-	-
	Carabus arcensis	Herbst, 1784	-	-
	Carabus auronitens	Fabricius, 1792	-	-
	Carabus hortensis	Linné, 1758	-	-
	Carabus nemoralis	Müller, 1764	-	-
	Carabus violaceus	Linné, 1758	-	-
	Cicindela hybrida	Linné, 1758	-	FP
	Cychrus caraboides	Linné, 1758	-	-
	Dyschirius globosus	(Herbst, 1784)	-	-
	Harpalus autumnalis	Duftschmid 1812	-	FP
	Harpalus rufipalpis	Sturm, 1818	-	FP
	Harpalus rufipes	(Degeer, 1774)	-	-
	Leistus ferrugineus	(Linné, 1758)	-	-
	Lionychus quadrillum	(Duftschmid, 1812)	SE	FP
	Loricera pilicornis	(Fabricius, 1775)	-	-
	Nebria brevicollis	Fabricius, 1792	-	-
	Oodes helopioides	(Fabricius, 1792)	-	-
	Oxypselaphus obscurus	(Herbst, 1784)	-	-
	Platynus assimilis	(Paykull, 1790)	-	-
	Poecilus lepidus	(Leske, 1787)	SE	FP
	Pterostichus aethiops	(Panzer, 1797)	-	-
	Pterostichus diligens	(Sturm, 1824)	-	-
	Pterostichus minor	(Gyllenhal, 1827)	-	-
	Pterostichus niger	(Schaller, 1783)	-	-
	Pterostichus oblongopunctatus	(Fabricius, 1787)	-	-
	Stenolophus mixtus	(Herbst, 1784)	-	-
	Syntomus foveatus	(Fourcroy, 1785)	-	FP
	Tachyura parvula	(Dejean, 1831)	-	FP
Elateridae	*Agriotes lineatus*	(Linnaeus, 1767)	SE	-
	Agriotes obscurus	(Linnaeus, 1758)	-	-
	Agrypnus murinus	(Linnaeus, 1758)	-	-

Habitat use					**Restoration approach** (no. of indiv.)		
OS	**GR**	**SH**	**WO**	**SYN/EUR**	**S**	**D**	**R**
0	1	0	0	0	0	2	0
0	1	0	0	0	45	21	0
0	0	0	1	0	0	1	1
0	0	0	1	0	0	1	1
0	1	0	0	0	0	4	0
0	1	0	0	0	0	2	0
0	1	0	0	0	0	0	4
0	0	0	0	1	0	2	0
0	0	0	0	1	1	0	0
1	0	0	0	0	0	2	0
0	0	0	0	1	0	0	1
0	0	1	0	0	0	2	0
0	1	0	0	0	0	1	0
0	1	0	0	0	0	1	0
1	0	0	0	0	0	1	0
0	1	0	0	0	1	0	0
0	0	1	0	0	48	34	4
0	0	0	1	0	5	33	8
0	0	0	1	0	1	0	1
0	0	0	1	0	0	0	6
0	0	0	1	0	0	0	8
0	0	0	1	0	2	0	5
0	0	0	1	0	2	0	1
1	0	0	0	0	1	6	2
0	0	0	1	0	0	0	6
0	0	0	0	1	6	3	4
1	0	0	0	0	0	1	0
0	0	1	0	0	0	1	0
0	0	0	0	1	1	0	0
0	0	0	0	1	0	0	2
1	0	0	0	0	1	4	0
0	0	0	0	1	0	0	1
0	0	1	0	0	0	2	1
0	1	0	0	0	0	0	1
0	0	0	0	1	0	0	1
0	0	0	0	1	0	2	0
0	1	0	0	0	1	0	0
0	0	0	1	0	0	1	0
0	1	0	0	0	0	1	0
0	1	0	0	0	1	0	0
0	0	0	1	0	12	7	47
0	0	0	1	0	1	0	6
0	1	0	0	0	0	2	0
0	1	0	0	0	1	4	0
1	0	0	0	0	0	1	0
0	1	0	0	0	0	1	0
0	1	0	0	0	1	0	0
0	1	0	0	0	0	1	0

Family	Species	Author	CS	PS
Geotrupidae	*Anoplotrupes stercorosus*	(Scriba, 1791)	-	-
	Trypocopris vernalis	(Linnaeus, 1758)	-	-
Scarabaeidae	*Aphodius prodromus*	(Brahm, 1790)	-	-
	Onthophagus ovatus	(Linnaeus, 1767)	-	-
Silphidae	*Nicrophorus humator*	Olivier, 1790	-	-
	Nicrophorus interruptus	Stephens, 1830	-	-
	Nicrophorus vespilloides	Herbst, 1784	-	-
	Oiceoptoma thoracicum	(Linnaeus, 1758)	-	-
	Phosphuga atrata	(Linnaeus, 1758)	-	-
Tenebrionidae	*Melanimon tibiale*	(Fabricius, 1781)	SE	OP

Habitat use					**Restoration approach** (no. of indiv.)		
OS	**GR**	**SH**	**WO**	**SYN/EUR**	**S**	**D**	**R**
0	0	0	1	0	5	0	15
0	1	0	0	0	12	0	3
0	0	0	0	1	0	1	0
0	0	0	0	1	0	2	0
0	0	0	0	1	0	0	1
0	0	0	0	1	0	0	2
0	0	0	0	1	5	0	23
0	0	0	1	0	0	0	8
0	0	0	1	0	3	0	2
1	0	0	0	0	2	1	0

Beetles—vegetation dwellers

Family	Species	Author	CS	PS
Anthicidae	*Notoxus monoceros*	Linnaeus, 1761	-	-
Buprestidae	*Anthaxia chevrieri*	Gory et Laporte, 1839	SE	FP
	Anthaxia godeti	Laporte de Castelnau et Gory, 1847	-	-
	Anthaxia helvetica	Stierlin, 1868	-	-
	Anthaxia quadripunctata	(Linnaeus, 1758)	-	-
	Anthaxia similis	(Saunders, 1871)	-	-
	Buprestis octoguttata	Linnaeus, 1758	SE	FP
	Trachys minutus	(Linnaeus, 1758)	-	-
Cerambycidae	*Pogonocherus fasciculatus*	(De Geer, 1775)	-	FP
	Stenurella melanura	(Linnaeus, 1758)	-	-
Chrysomelidae	*Agelastica alni*	(Linnaeus, 1758)	-	-
	Chrysolina fastuosa	(Scopoli, 1763)	-	-
	Clytra laeviuscula	Ratzeburg, 1837	-	-
	Cryptocephalus bipunctatus	(Linnaeus, 1758)	-	-
	Cryptocephalus ocellatus	Drapiez, 1819	-	-
	Galeruca tanaceti	(Linnaeus, 1758)	-	FP
	Gastrophysa polygoni	(Linnaeus, 1758)	-	-
	Linaeidea aenea	(Linnaeus, 1758)	-	-
	Lochmaea capreae	(Linnaeus, 1758)	-	-
	Oulema melanopus	(Linnaeus, 1758)	-	-
Coccinelidae	*Adalia bipunctata*	(Linnaeus, 1758)	SE	-
	Coccinella septempunctata	Linnaeus, 1758	-	-
	Coccinella quinquepunctata	Linnaeus, 1758	-	-
	Exochomus quadripustulatus	(Linnaeus, 1758)	-	-
	Harmonia axyridis	(Pallas, 1773)	-	-
	Hyperaspis campestris	(Herbst, 1783)	-	-
	Propylea quatuordecimpunctata	(Linnaeus, 1758)	-	-
	Scymnus frontalis	(Fabricius 1787)	-	-
	Scymnus nigrinus	Kugelann, 1794	-	-
Curculionoidea	*Acalyptus carpini*	(Fabricius 1792)	-	-
	Anthonomus phyllocola	(Herbst, 1795)	-	-
	Bagous tubulus	Silfverberg, 1977	SE	-
	Brachonyx pineti	(Paykull, 1792)	-	-
	Brachyderes incanus	(Linnaeus, 1758)	-	-
	Catapion seniculus	(Kirby, 1808)	-	-
	Curculio rubidus	(Gyllenhal, 1836)	SE	-
	Datonychus arquata	(Herbst, 1795)	SE	-
	Dorytomus dejeani	Faust, 1882	-	-
	Ellescus scanicus	(Paykull, 1792)	-	-
	Hylobius abietis	(Linnaeus, 1758)	-	FP
	Ischnopterapion virens	(Herbst, 1797)	-	-
	Otiorhynchus ovatus	(Linnaeus, 1758)	-	-
	Phyllobius arborator	(Herbst, 1797)	-	-
	Pissodes castaneus	(De Geer, 1775)	-	-
	Pissodes pini	(Linnaeus, 1758)	-	-
	Polydrusus cervinus	(Linnaeus, 1758)	-	-
	Polydrusus pallidus	Gyllenhal, 1834	-	-
	Protapion apricans	(Herbst, 1797)	-	-

Habitat use					**Restoration approach** (no. of indiv.)		
OS	**GR**	**SH**	**WO**	**SYN/EUR**	**S**	**D**	**R**
0	1	0	0	0	0	6	0
0	0	1	0	0	4	1	0
0	0	0	1	0	1	7	0
0	0	0	1	0	6	11	0
0	0	0	1	0	4	14	0
0	0	0	1	0	1	0	0
0	0	0	1	0	1	0	0
0	0	1	0	0	0	1	0
0	0	0	1	0	0	0	2
0	0	0	1	0	0	1	0
0	0	0	1	0	4	2	0
0	0	0	0	1	0	1	0
0	0	1	0	0	0	1	0
0	1	0	0	0	0	1	0
0	0	1	0	0	0	1	0
0	1	0	0	0	0	1	0
0	0	0	0	1	0	1	0
0	0	0	1	0	0	1	0
0	0	1	0	0	0	1	0
0	0	0	0	1	0	1	0
0	0	1	0	0	2	6	0
0	0	0	0	1	3	1	0
0	0	0	0	1	0	1	0
0	0	0	1	0	0	1	0
0	0	0	0	1	1	2	0
0	1	0	0	0	0	3	0
0	0	0	0	1	0	1	0
0	1	0	0	0	0	1	0
0	0	0	1	0	0	1	0
0	0	1	0	0	0	1	0
0	0	0	1	0	0	1	1
0	1	0	0	0	0	1	0
0	0	0	1	0	0	1	0
0	0	0	1	0	1	3	2
0	1	0	0	0	0	0	1
0	0	1	0	0	0	1	0
0	1	0	0	0	0	1	0
0	0	1	0	0	1	0	0
0	0	1	0	0	1	0	0
0	0	0	1	0	0	28	5
0	1	0	0	0	0	1	0
0	1	0	0	0	1	0	0
0	0	1	0	0	0	0	1
0	0	0	1	0	1	0	0
0	0	0	1	0	0	1	1
0	0	1	0	0	0	1	0
0	0	1	0	0	0	1	1
0	1	0	0	0	0	1	1

Family	Species	Author	CS	PS
Curculionoidea	*Protapion fulvipes*	(Geoffroy in Fourcroy, 1785)	-	-
	Rhinoncus bruchoides	(Herbst, 1784)	-	-
	Rhyncolus ater	(Linnaeus, 1758)	-	-
	Sitona lineatus	(Linnaeus, 1758)	-	-
	Sitona striatellus	Gyllenhal, 1834	-	-
	Sitona sulcifrons	(Thunberg, 1798)	-	-
	Strophosoma capitatum	(De Geer, 1775)	-	-
	Tachyerges pseudostigma	(Tempère, 1982)	-	-
Dasytidae	*Dolichosoma lineare*	(Rossi, 1792)	-	-
Oedemeridae	*Chrysanthia cf. geniculata*	Schmidt, 1846	-	FP
	Phyllopertha horticola	(Linnaeus, 1758)	-	-
Lagriidae	*Lagria hirta*	(Linnaeus, 1758)	-	-

Habitat use					**Restoration approach** (no. of indiv.)		
OS	**GR**	**SH**	**WO**	**SYN/EUR**	**S**	**D**	**R**
0	1	0	0	0	0	1	0
0	1	0	0	0	0	1	0
0	0	0	1	0	2	0	0
0	1	0	0	0	0	1	0
0	0	1	0	0	3	3	1
0	1	0	0	0	0	2	0
0	0	0	1	0	4	1	8
0	0	1	0	0	0	1	0
0	0	0	0	1	1	1	0
0	0	0	0	1	1	0	0
0	1	0	0	0	1	3	0
0	0	0	0	1	5	1	4

Flies

Family	Species	Author	CS	PS
Asilidae	*Dioctria hyalipennis*	(Fabricius)	-	-
	Lasiopogon cinctus	(Fabricius)	-	FP
	Neoitamus socius	(Loew)	-	-
	Neomochtherus pallipes	(Meigen)	-	-
	Rhadinus variabilis	(Zetterstedt)	HE	OP
Bibionidae	*Dilophus febrilis*	(L.)	-	-
Bombyliidae	*Anthrax varius*	Fabricius	SE	OP
Dolichopodidae	*Neurigona quadrifasciata*	(Fabricius)	-	-
	Sciapus sp.		-	-
	Xanthochlorus ornatus	(Haliday)	-	-
Drosophilidae	*Drosophila kuntzei*	Duda	-	-
Dryomyzidae	*Dryomyza flaveola*	(Fabricius)	-	-
	Neuroctena anilis	(Fallén)	-	-
Keroplatidae	*Antlemon brevimanum*	(Loew)	SE	-
Lauxaniidae	*Lauxania cylindricornis*	(Fabricius)	-	-
Muscidae	*Mesembrina meridiana*	(L.)	-	-
	Phaonia pallida	(Fabricius)	-	-
Platystomatidae	*Rivellia syngenesiae*	(Fabricius)	-	-
Psilidae	*Loxocera aristata*	(Panzer)	-	-
Rhagionidae	*Rhagio lineola*	Fabricius	-	-
Sarcophagidae	*Macronychia sp.*		-	FP
	Metopia argyrocephala	(Meigen)	-	OP
	Metopia staegerii	Rondani	SE	OP
	Sarcophaga carnaria	(L.)	-	-
	Sarcophaga similis	(Meade)	-	-
	Sarcophaga variegata	(Scopoli)	-	-
	Senotainia conica	(Fallén)	SE	OP
	Taxigramma hilarella	(Zetterstedt)	SE	OP
Scathophagidae	*Paralleloma medium*	(Becker)	-	-
Sciomyzidae	*Pherbina coryleti*	(Scopoli)	SE	-
Stratiomyidae	*Chloromyia formosa*	(Scopoli)	-	-
Syrphidae	*Chrysotoxum arcuatum*	(L.)	-	-
	Chrysotoxum bicinctum	(L.)	-	-
	Episyrphus balteatus	(De Geer)	-	-
	Eristalis tenax	(L.)	-	-
	Eupeodes corolae	(Fabricius)	-	-
	Helophilus pendulus	(L.)	-	-
	Helophilus trivittatus	(L.)	-	-
	Microdon analis	(Macquart)	SE	-
	Scaeva pyrastri	(L.)	-	-
	Volucella pellucens	(L.)	-	-
Therevidae	*Thereva microcephala*	Loew	-	FP
	Thereva marginula	Meigen	SE	FP

Habitat use					**Restoration approach** (no. of indiv.)		
OS	**GR**	**SH**	**WO**	**SYN/EUR**	**S**	**D**	**R**
0	0	1	0	0	1	0	0
0	1	0	0	0	1	1	0
0	0	1	0	0	1	1	0
0	0	1	0	0	1	0	0
1	0	0	0	0	0	1	0
0	1	0	0	0	0	5	0
1	0	0	0	0	0	1	0
0	0	0	1	0	1	1	1
0	0	0	1	0	0	1	0
0	1	0	0	0	0	0	1
0	0	0	1	0	0	0	2
0	0	1	0	0	2	0	0
0	0	0	1	0	0	1	6
0	0	0	1	0	0	1	0
0	0	1	0	0	1	2	0
0	1	0	0	0	1	0	0
0	0	0	0	1	0	1	1
0	1	0	0	0	0	1	0
0	1	0	0	0	0	1	0
0	0	0	1	0	0	1	0
1	0	0	0	0	0	1	0
1	0	0	0	0	1	0	0
1	0	0	0	0	1	0	0
0	0	0	0	1	1	1	0
0	0	0	0	1	1	0	0
0	0	0	0	1	1	0	0
1	0	0	0	0	1	6	0
1	0	0	0	0	0	1	0
0	0	0	1	0	0	1	0
0	0	1	0	0	0	1	0
0	0	0	0	1	0	1	0
0	0	1	0	0	0	1	0
0	0	1	0	0	0	1	0
0	0	0	0	1	1	3	1
0	0	0	0	1	0	1	0
0	0	1	0	0	0	4	0
0	0	1	0	0	1	0	0
0	0	1	0	0	0	2	0
0	1	0	0	0	0	0	1
0	0	1	0	0	0	2	0
0	0	1	0	0	0	1	0
0	0	1	0	0	0	1	0
0	1	0	0	0	0	1	0

Bees and wasps

Family	Species	Author	CS	PS
Ampulicidae	*Dolichurus corniculus*	(Spinola, 1808)	-	FP
Andrenidae	*Andrena carantonica*	Pérez, 1902	-	FP
	Andrena haemorrhoa	(Fabricius, 1781)	-	FP
	Andrena helvola	(Linnaeus, 1758)	-	FP
	Andrena nigroaenea	(Kirby, 1802)	-	FP
	Andrena nitida	(Müller, 1776)	-	FP
	Andrena praecox	(Scopoli, 1763)	-	FP
	Andrena vaga	Panzer, 1799	-	OP
Apidae	*Apis mellifera*	Linnaeus, 1758	-	-
Apidae	*Bombus jonellus*	(Kirby, 1802)	SE	FP
	Bombus pascuorum	(Scopoli, 1763)	-	-
	Bombus sylvestris	(Lepeletier, 1832)	-	-
	Bombus terrestris	(Linnaeus, 1758)	-	-
	Nomada flavoguttata	(Kirby, 1802)	-	FP
	Nomada fucata	Panzer, 1798	-	FP
	Nomada lathburiana	(Kirby, 1802)	-	FP
	Nomada rufipes	Fabricius, 1793	SE	OP
Chrysididae	*Cleptes pallipes*	Lepeletier, 1806	-	-
Chrysididae	*Hedychrum nobile*	Scopoli, 1763	SE	OP
	Trichrysis cyanea	(Linnaeus, 1761)	-	-
Crabronidae	*Alysson spinosus*	(Panzer, 1801)	SE	OP
	Bembecinus tridens	(Fabricius, 1781)	SE	OP
	Cerceris arenaria	(Linnaeus, 1758)	SE	OP
	Crabro scutellatus	(Scheven, 1781)	HE	OP
	Diodontus minutus	(Fabricius, 1793)	-	FP
	Gorytes laticinctus	(Lepeletier, 1832)	-	FP
	Nysson maculosus	(Gmelin, 1790)	SE	FP
	Nysson niger	Chevrier, 1868	HE	OP
	Oxybelus argentatus	Curtis, 1833	HE	OP
	Oxybelus bipunctatus	Olivier, 1812	SE	OP
	Oxybelus trispinosus	(Fabricius, 1787)	-	FP
	Passaloecus singularis	Dahlbom, 1844	-	-
	Philanthus triangulum	(Fabricius, 1775)	-	FP
	Tachysphex obscuripennis	(Schenck, 1857)	SE	OP
	Tachysphex pompiliformis	Panzer, 1805	-	FP
	Trypoxylon minus	Beaumont, 1945	-	-
Halictidae	*Halictus sexcinctus*	(Fabricius, 1775)	SE	FP
	Halictus tumulorum	(Linnaeus, 1758)	-	FP
	Lasioglossum aeratum	(Kirby, 1802)	SE	FP
	Lasioglossum leucozonium	(Schrank, 1781)	SE	FP
	Lasioglossum lucidulum	(Schenck, 1861)	SE	FP
	Lasioglossum malachurum	(Kirby, 1802)	-	FP
	Lasioglossum morio	(Fabricius, 1793)	-	FP
	Lasioglossum punctatissimum	(Schenck, 1853)	-	FP
	Lasioglossum rufitarse	(Zetterstedt, 1838)	SE	FP
	Lasioglossum zonulum	(Smith, 1848)	SE	FP

Habitat use					**Restoration approach** (no. of indiv.)		
OS	**GR**	**SH**	**WO**	**SYN/EUR**	**S**	**D**	**R**
0	0	1	0	0	0	1	0
0	0	1	0	0	0	1	0
0	0	1	0	0	0	1	0
0	0	1	0	0	0	1	0
0	0	1	0	0	0	3	0
0	0	1	0	0	0	1	0
0	0	1	0	0	0	1	0
1	0	0	0	0	0	1	0
0	0	0	0	1	0	1	0
0	0	0	1	0	1	4	0
0	0	0	0	1	0	1	0
0	0	0	1	0	1	0	0
0	0	0	0	1	1	2	0
0	1	0	0	0	1	0	0
0	1	0	0	0	0	1	0
0	1	0	0	0	1	0	0
1	0	0	0	0	1	0	0
0	1	0	0	0	1	0	0
1	0	0	0	0	0	5	0
0	0	0	0	1	0	1	0
1	0	0	0	0	0	1	0
1	0	0	0	0	0	1	0
1	0	0	0	0	0	7	0
1	0	0	0	0	0	2	0
1	0	0	0	0	0	1	0
0	0	1	0	0	0	1	0
1	0	0	0	0	0	5	0
1	0	0	0	0	0	2	0
1	0	0	0	0	0	6	0
1	0	0	0	0	0	1	0
1	0	0	0	0	0	1	0
0	0	1	0	0	1	0	0
1	0	0	0	0	0	3	0
1	0	0	0	0	3	22	0
1	0	0	0	0	0	1	0
0	0	0	0	1	4	3	0
1	0	0	0	0	0	2	0
0	1	0	0	0	1	0	0
0	1	0	0	0	1	0	0
0	1	0	0	0	0	3	0
1	0	0	0	0	0	2	0
0	1	0	0	0	0	2	0
0	1	0	0	0	0	2	0
0	1	0	0	0	0	2	0
0	1	0	0	0	0	1	0
0	1	0	0	0	0	1	0

Family	Species	Author	CS	PS
Halictidae	*Sphecodes longulus*	Hagens, 1882	SE	FP
Megachilidae	*Stelis minuta*	Lepeletier et Serville, 1825	SE	-
Melittidae	*Melitta nigricans*	Alfken, 1905	SE	FP
Pompilidae	*Anoplius concinnus*	(Dahlbom, 1843)	SE	OP
	Anoplius infuscatus	(Van der Linden, 1827)	-	FP
	Anoplius viaticus	(Linnaeus, 1758)	-	OP
	Arachnospila anceps	(Wesmael, 1851)	-	FP
	Arachnospila minutula	(Dahlbom, 1842)	-	FP
	Arachnospila trivialis	(Dahlbom, 1843)	-	FP
	Arachnospilla spissa	(Schiödte, 1837)	-	FP
	Episyron rufipes	(Linnaeus, 1758)	SE	OP
	Evagetes pectinipes	(Linnaeus, 1758)	HE	OP
	Pompilus cinereus	(Fabricius, 1775)	SE	OP
	Priocnemis hyalinata	(Fabricius, 1793)	-	FP
	Priocnemis perturbator	(Harris, 1780)	-	FP
	Priocnemis pusilla	Schiödte, 1837	-	FP
Sphecidae	*Ammophila sabulosa*	(Linnaeus, 1758)	-	FP
Vespidae	*Vespula rufa*	(Linnaeus, 1758)	-	-
	Vespula vulgaris	(Linnaeus, 1758)	-	-

Habitat use					Restoration approach (no. of indiv.)		
OS	**GR**	**SH**	**WO**	**SYN/EUR**	**S**	**D**	**R**
1	0	0	0	0	1	0	0
0	1	0	0	0	0	1	0
0	1	0	0	0	1	0	0
1	0	0	0	0	6	1	0
0	1	0	0	0	12	4	0
1	0	0	0	0	1	3	0
0	1	0	0	0	0	2	0
0	1	0	0	0	2	1	0
0	0	1	0	0	1	0	0
0	0	1	0	0	0	1	0
1	0	0	0	0	0	2	0
1	0	0	0	0	0	1	0
1	0	0	0	0	1	4	0
0	1	0	0	0	0	1	0
0	1	0	0	0	0	3	4
0	1	0	0	0	0	2	0
1	0	0	0	0	1	8	0
0	0	0	0	1	0	2	0
0	0	0	0	1	0	1	0

Orthopterans

Family	Species	Author	CS	PS
Acrididae	*Chorthippus biguttulus*	(Linnaeus, 1758)	-	-
	Chorthippus brunneus	(Thunberg, 1815)	-	-
	Chorthippus parallelus	(Zetterstedt, 1821)	-	-
	Chorthippus vagans	(Eversmann, 1848)	SE	FP
	Euthystira brachyptera	(Ocskay, 1826)	-	-
	Myrmeleotettix maculatus	(Thunberg, 1815)	SE	OP
Gryllotalpidae	*Gryllotalpa gryllotalpa*	(Linnaeus, 1758)	-	FP
Tetrigidae	*Tetrix bipunctata*	(Linnaeus, 1758)	SE	-
	Tetrix subulata	(Linnaeus, 1758)	-	-
	Tetrix tenuicornis	(Sahlberg, 1893)	-	-
	Tetrix undulata	(Sowerby, 1806)	-	FP
Tettigoniidae	*Tettigonia cf. viridissima*	Linnaeus, 1758	-	-

Habitat use					**Restoration approach** (no. of indiv.)		
OS	**GR**	**SH**	**WO**	**SYN/EUR**	**S**	**D**	**R**
0	1	0	0	0	2	9	0
1	0	0	0	0	0	5	0
0	1	0	0	0	1	0	0
1	0	0	0	0	0	4	0
0	1	0	0	0	0	4	0
1	0	0	0	0	4	9	0
1	0	0	0	0	1	2	1
1	0	0	0	0	2	0	0
1	0	0	0	0	0	3	0
1	0	0	0	0	2	1	0
1	0	0	0	0	8	42	0
0	0	0	0	1	0	1	0

Vascular plants

Species	Author	CS	PS
Agrostis canina	L.	-	-
Agrostis capillaris	L.	-	-
Agrostis scabra	Willd.	-	-
Agrostis stolonifera	L.	-	-
Alnus glutinosa	(L.) Gaertn.	-	-
Alopecurus geniculatus	L.	-	-
Anthoxanthum odoratum	L.	-	-
Avenella flexuosa	(L.) Drejer	-	-
Bellis perennis	L.	-	-
Betula pendula	Roth	-	-
Bidens frondosus	L.	-	-
Calamagrostis epigejos	(L.) Roth	-	-
Calamagrostis villosa	(Chaix) J. F. Gmel.	-	-
Callitriche palustris	L.	-	-
Calluna vulgaris	(L.) Hull	-	FP
Campanula rapunculoides	L.	-	-
Carex brizoides	L.	-	-
Carex canescens	L.	-	-
Carex leporina	L.	-	-
Carex pilulifera	L.	-	FP
Cirsium arvense	(L.) Scop.	-	-
Conyza canadensis	(L.) Cronq.	-	-
Cytisus scoparius	(L.) Link	-	-
Deschampsia cespitosa	(L.) P.B.	-	-
Elatine triandra	Schkuhr.	SE	-
Eleocharis acicularis	(L.) Roem. et Schult.	-	-
Eleocharis palustris	(L.) Roem. et Schult.	-	-
Epilobium angustifolium	L.	-	-
Epilobium lamyi	F. W. Schultz	SE	-
Epilobium palustre	L.	SE	-
Erigeron acris	L.	-	-
Festuca ovina	L.	-	FP
Festuca rubra	L.	-	-
Filago minima	(Sm.) Pers.	SE	FP
Frangula alnus	Mill.	-	-
Geum urbanum	L.	-	-
Glyceria fluitans	(L.) R. Br.	-	-
Gnaphalium sylvaticum	L.	-	-
Hieracium sabaudum	L.	-	-
Holcus lanatus	L.	-	-
Hypericum humifusum	L.	SE	FP
Hypochaeris radicata	L.	-	-
Juncus articulatus	L.	-	-
Juncus bufonius	L.	-	FP
Juncus bulbosus	L.	-	FP
Juncus effusus	L.	-	-
Juncus filiformis	L.	-	-
Juncus squarrosus	L.	-	-
Juncus tenuis	Willd	-	-

Habitat use					**Restoration approach** (total cover)		
OS	**GR**	**SH**	**WO**	**SYN/EUR**	**S**	**D**	**R**
0	1	0	0	0	0	5	0
0	1	0	0	0	2	5	+
0	0	0	0	1	2	+	0
0	1	0	0	0	0	+	0
0	0	0	1	0	+	1	7
1	0	0	0	0	+	0	0
0	1	0	0	0	0	+	0
0	0	0	1	0	17	+	5
0	1	0	0	0	0	r	0
0	0	0	1	0	86	5	30
0	0	0	0	1	+	+	0
0	0	0	0	1	8	3	+
0	0	0	1	0	2	0	1
1	0	0	0	0	+	0	0
1	0	0	0	0	6	+	+
0	0	0	1	0	+	0	0
0	0	0	1	0	+	+	2
0	1	0	0	0	1	+	0
0	1	0	0	0	+	+	0
0	1	0	0	0	0	1	0
0	0	0	0	1	r	+	0
0	0	0	0	1	+	+	0
0	0	0	0	1	12	+	0
0	1	0	0	0	0	+	0
1	0	0	0	0	r	0	0
1	0	0	0	0	+	0	0
0	1	0	0	0	r	0	0
0	0	0	0	1	1	r	+
0	0	0	0	1	0	+	0
0	1	0	0	0	+	+	0
0	1	0	0	0	0	+	0
0	0	0	1	0	0	1	0
0	1	0	0	0	0	+	0
1	0	0	0	0	+	1	0
0	0	0	1	0	0	0	5
0	0	0	1	0	r	0	0
0	1	0	0	0	2	+	0
0	1	0	0	0	+	+	0
0	0	0	1	0	1	0	0
0	1	0	0	0	+	0	0
1	0	0	0	0	0	1	0
0	1	0	0	0	3	15	0
0	1	0	0	0	+	0	0
1	0	0	0	0	+	0	0
1	0	0	0	0	3	+	0
0	1	0	0	0	17	10	r
0	1	0	0	0	+	0	r
0	1	0	0	0	+	0	0
0	0	0	0	1	+	10	0

Species	Author	CS	PS
Luzula campestris	(L.) DC.	-	-
Luzula luzuloides	(Lam.) Dandy et Wilmott	-	-
Luzula multiflora	(Ehrh.) Lej.	-	-
Luzula pilosa	(L.) Willd.	-	-
Lycopus europaeus	L.	-	-
Molinia caerulea	(L.) Moench.	-	-
Phragmites australis	(Cav.) Steud.	-	-
Picea abies	(L.) Karsten	-	-
Pilosella officinarum	L.	-	FP
Pinus sylvestris	L.	-	-
Plantago lanceolata	L.	-	-
Plantago major	L.	-	-
Populus tremula	L.	-	-
Potentilla erecta	(L.) Räuschel	-	-
Potentilla norvegica	L.	-	-
Pteridium aquilinum	(L.) Kuhn	-	-
Quercus robur	L.	-	-
Ranunculus flammula	L.	-	-
Ranunculus repens	L.	-	-
Robinia pseudoacacia	L.	-	-
Rubus fruticosus agg.	L.	-	-
Rubus idaeus	L.	-	-
Rumex acetosa	L.	-	-
Rumex acetosella	L.	-	FP
Salix caprea	L.	-	-
Salix cinerea	L.	-	-
Scorzoneroides autumnalis	(L.) Moench	-	-
Sedum sexangulare	L.	-	FP
Sedum spurium	M.Bieb.	-	-
Senecio sylvaticus	L.	-	-
Senecio viscosus	L.	-	-
Sorbus aucuparia	L.	-	-
Spergularia rubra	(L.) J. et C. Presl	-	FP
Tanacetum vulgare	L.	-	-
Taraxacum sect. Taraxacum	Kirschner, H. Øllgaard et Štěpánek	-	-
Trifolium repens	L.	-	-
Tussilago farfara	L.	-	-
Typha latifolia	L.	-	-
Vaccinium myrtillus	L.	-	-
Vaccinium vitis-idaea	L.	-	-
Verbascum chaixii ssp. austriacum	(R. et Sch.) Hayek	SE	FP
Veronica officinalis	L.	-	-
Viola reichenbachiana	Bor.	-	-

Habitat use					**Restoration approach** (total cover)		
OS	**GR**	**SH**	**WO**	**SYN/EUR**	**S**	**D**	**R**
0	1	0	0	0	+	+	0
0	0	0	1	0	0	+	+
0	1	0	0	0	+	+	0
0	0	0	1	0	0	+	+
0	0	0	1	0	+	1	0
0	1	0	0	0	1	+	+
0	1	0	0	0	50	35	0
0	0	0	1	0	2	1	7
1	0	0	0	0	+	+	0
0	0	0	1	0	112	15	280
0	1	0	0	0	0	r	0
0	0	0	0	1	0	+	0
0	0	0	1	0	4	1	4
0	1	0	0	0	0	r	+
0	0	0	0	1	0	+	0
0	0	0	1	0	+	0	+
0	0	0	1	0	2	0	7
0	1	0	0	0	0	+	0
0	1	0	0	0	0	+	0
0	0	0	0	1	1	0	0
0	0	0	1	0	6	0	+
0	0	0	1	0	0	0	1
0	1	0	0	0	+	0	0
1	0	0	0	0	0	+	0
0	0	0	1	0	16	10	2
0	0	0	1	0	0	1	0
0	1	0	0	0	+	+	r
1	0	0	0	0	+	0	0
0	0	0	0	1	+	0	0
0	0	0	1	0	+	0	0
0	0	0	1	0	0	+	0
0	0	0	1	0	0	0	1
1	0	0	0	0	0	+	0
0	0	0	0	1	0	0	+
0	0	0	0	1	0	+	0
0	1	0	0	0	0	+	0
0	0	0	0	1	+	r	0
0	1	0	0	0	2	0	0
0	0	0	1	0	15	+	+
0	0	0	1	0	1	+	+
0	1	0	0	0	+	0	0
0	1	0	0	0	0	+	0
0	0	0	1	0	+	+	0

References

nomenclature

bees & wasps	Bogusch O, Straka J. et Kment P. 2007: Annotated checklist of the Aculeata (Hymenoptera) of the Czech Republic and Slovakia. Komentovaný seznam žahadlových blanokřídlých (Hymenoptera: Aculeata) České republiky a Slovenska. Acta Entomologica Musei Nationalis Pragae suppl. 11: 1-300.
beetles	Löbl I and Smetana A (eds) (2003-11) Catalogue of palaearctic Coleoptera. Vols. 1-7. Apollo Boksellers, Vester Skerninge.
orthopterans	Eades, D.C.; D. Otte; M.M. Cigliano & H. Braun. *Orthoptera Species File* . Version 5.0/5.0. http://Orthoptera.SpeciesFile.org (accessed on 25.03.2015)
spiders	World Spider Catalog (2015) World Spider Catalog, version 16. Natural History Museum Bern. http://wsc.nmbe.ch (accessed on 28.03.2015)
flies	Fauna Europaea. http://www.faunaeur.org
vascular plants	Danihelka J, Chrtek J Jr & Kaplan Z (2012) Checklist of vascular plants of the Czech Republic. Preslia 84: 647–811

conservation status

bees & wasps	Farkač J, Král D, Škorpík M (eds) (2005) Červený seznam ohrožených druhů České republiky. Bezobratlí.— Red list of threatened species in the Czech Republic. Invertebrates. Agentura ochrany přírody a krajiny ČR, Prague (in Czech).
beetles	Farkač J, Král D, Škorpík M (eds) (2005) Červený seznam ohrožených druhů České republiky. Bezobratlí.— Red list of threatened species in the Czech Republic. Invertebrates. Agentura ochrany přírody a krajiny ČR, Prague (in Czech). Further, following experts were consulted: Dušan Čudan (Coccinellidae, Curculionidae), Oldřich Nedvěd (Coccinellidae
orthopterans	Farkač J, Král D, Škorpík M (eds) (2005) Červený seznam ohrožených druhů České republiky. Bezobratlí.— Red list of threatened species in the Czech Republic. Invertebrates. Agentura ochrany přírody a krajiny ČR, Prague (in Czech). Further, following expert was consulted: Pavel Marhoul
spiders	Kůrka, A., Řezáč M., Macek R., Dolanský J. (2015) Pavouci České republiky. Academia, Prague.
flies	Farkač J, Král D, Škorpík M (eds) (2005) Červený seznam ohrožených druhů České republiky. Bezobratlí.— Red list of threatened species in the Czech Republic. Invertebrates. Agentura ochrany přírody a krajiny ČR, Prague (in Czech). Further, following experts were consulted: Jaroslav Bosák (Asilidae), Zbyněk Kejval (Sarcophagidae), Karel Spitzer (Therevidae), Jan Máca (families left)

vascular plants	Grulich V (2012) Red List of vascular plants of the Czech Republic: 3rd edition. Preslia 84:631–645
habitat specialisation	
bees & wasps	Macek J., Straka J., Bogusch P., Bezděčka P., Dvořák L. et Tyrner P. 2010: Blanokřídlí České republiky. I - Žahadloví. Academia, Praha, 524 pp.
beetles	Following experts were consulted: Dušan Čudan (Coccinellidae, Curculionoidea), Aleš Bezděk (Scarabaaeidae, Geotrupidae), Oldřich Nedvěd (Coccinellidae), Zdeněk Kletečka (Buprestidae, Cerambycidae), Jiří Řehounek (Chrysomelidae),Josef Mertlik (Elateridae), František Grycz (Carabidae), Lukáš Čížek (Lagriidae, Oedemeridae, Dasytidae, Anthicidae, Silphidae, Tenebrionidae), MIlan Boukal (Byrrhidae)
orthopterans	Kočárek, P., Holuša, J., Vlk, R., Marhoul P. (2013) Rovnokřídlí České republiky. Academia, Prague.
spiders	Buchar, J. & V. Ruzicka. (2002) *Catalogue of Spiders of the Czech Republic.* Peres press, Prague. Nentwig, W., Blick, T., Gloor, D., Hänggi, A. & Kropf, C. (2014) Spiders of Europe. http://www.araneae.unibe.ch (accessed 21st June 2014). Kůrka, A., Řezáč M., Macek R., Dolanský J. (2015) Pavouci České republiky. Academia, Prague.
flies	Following experts were consulted: Jan Máca (Jaroslav Bosák (Asilidae), Zbyněk Kejval (Sarcophagidae), Karel Spitzer (Therevidae), Jan Máca (families left)
vascular plants	Chytrý M, Tichý L (2003) Diagnostic, constant and dominant species of vegetation classes and alliances of the Czech Republic: a statistical revision. Folia Fac. Sci. Nat. Univ. Masaryk. Brun, Biol. 108: 1–231 sandy specialisation: species were classified according thein affiliation to the vegetation classes typical of open sand and shallow soil (Koelerio- Corynephoretea, Sedo-Scleranthetea, Radiolion linoides), dry heathlands (Nardo-Callunetea) and oligotrophic standing waters (Isoëto -Nanojuncetea, Isoëto-Littorelletea), criterion according to Chytrý & Tichý (2003) was applied

CHAPTER II

SPONTANEOUS REVEGETATION VS. FORESTRY RECLAMATION IN POST-MINING SAND PITS.

Šebelíková et al. 2016. Environ Sci Pollut Res 23: 13598–13605
https://doi.org/10.1007/s11356-015-5330-9

SPONTANEOUS REVEGETATION VS. FORESTRY RECLAMATION IN POST-MINING SAND PITS

Lenka Šebelíková[1,2], Klára Řehounková[1,2], Karel Prach[1,2]

[1] *Department of Botany, Faculty of Science, University of South Bohemia, Branišovská 1760, 37005 České Budějovice, Czech Republic*
[2] *Institute of Botany, Academy of Sciences of the Czech Republic, Dukelská 135, 37982 Třeboň, Czech Republic*

Corresponding author: Lenka Šebelíková, e-mail: lenuskasch@gmail.com

Abstract

Vegetation development of sites restored by two different methods, spontaneous revegetation and forestry reclamation, was compared in four sand pit mining complexes located in the southern part of the Czech Republic, central Europe. The space-for-time substitution method was applied to collect vegetation records in 13 differently aged and sufficiently large sites with known history. The restoration method, age (time since site abandonment/reclamation), groundwater table, slope, and aspect in all sampled plots were recorded in addition to the visual estimation of percentage cover of all present vascular plant species. Multivariate methods and GLM were used for the data elaboration. Restoration method was the major factor influencing species pattern. Both spontaneously revegetated and forestry reclaimed sites developed towards forest on a comparable timescale. Although the sites did not significantly differ in species richness (160 species in spontaneously revegetated vs. 111 in forestry reclaimed sites), spontaneously revegetated sites tended to be more diverse with more species of conservation potential (10 Red List species in spontaneous sites vs. 4 Red List species in forestry reclaimed sites). These results support the use of spontaneous revegetation as an effective and low-cost method of sand pit restoration and may contribute to implementation of this method in practice.

Keywords

Afforestation · Mining · Passive restoration · Spontaneous succession · Vegetation

INTRODUCTION

There are two main methods for restoration of post-mining sites: (i) spontaneous revegetation and (ii) technical reclamation. The former method includes spontaneous ecological succession, i.e., spontaneous processes of species colonisation and establishment on a disturbed or newly created site, which can be also called passive restoration (Holl & Aide 2011). Spontaneous succession can be manipulated (directed or assisted succession) or not (Luken 1990). Technical reclamation usually attempts to vigorously improve environmental conditions of a site for further planting or sowing of some species, thus emphasizing possible future economic use of the site (SER 2004).

There are many papers describing spontaneous vegetation development in various post-mining sites (e.g., Novák & Prach 2003; Tischew & Kirmer 2007; Alday et al. 2012). Some of these concerned sand and gravel-sand pits (Borgegård 1990; Řehounková & Prach 2006, 2008). However, studies directly comparing spontaneous revegetation and technical reclamation are still scarce (Hodačová & Prach 2003; Pietrzykowski 2008; Mudrák et al. 2010; Tropek et al. 2010, 2012; Woziwoda & Kopeć 2014).

Mining of gravel-sand and sand is a worldwide activity (Walker 1999) extensively impacting the landscape. It has a long tradition in several regions of the Czech Republic (see Řehounková & Prach 2006) including that one under study. According to Czech law, disused mining sites must be reclaimed to their previous use, which is in most cases forest or agricultural land. Apart from the creation of artificial lakes as a result of mining under the groundwater table, forestry reclamation predominantly with Scots pine (*Pinus sylvestris*) is a widely used option in sand pits within the country (Řehounková et al. 2011). Although in some parts of the world, especially in the USA, forestry reclamation has recently aimed at achieving more natural composition of forest (Evans et al. 2013), the targets in central Europe are most often commercial monoculture forests that serve exclusively for production purposes (Pietrzykowski & Socha 2011). However, small parts of sand pits are sometimes left to spontaneous revegetation especially where it is not profitable to do forestry reclamation (e.g., close to the shoreline), being less accessible for heavy machinery or, exceptionally, where nature conservation is prioritized, especially within some protected areas (as for example our localities that are part of the Třeboňsko Protected Landscape Area). Although forests originated from technical reclamation usually exhibit a similar timber production value when compared to natural forests in the surroundings of mining sites (Pietrzykowski & Socha 2011), it has been documented that their nature conservation value is much lower (Pietrzykowski 2008). Therefore, passive restoration has been increasingly asserted among restoration ecologists as a viable alternative to technical reclamation also in sand pits (Prach et al. 2013).

Sand pits may serve as alternative habitats for specialists of open sandy habitats and acidic low-productive dry grasslands (Řehounková & Prach 2008). These include some of the most endangered species in the country (Grulich 2012). Their (semi-)natural communities are vanishing (Chytrý et al. 2010) due to successional changes after transformation of landscape management and eutrophication, artificial or spontaneous afforestation, or just mining.

The aim of this study was to evaluate vegetation development on spontaneously revegetated and forestry reclaimed sites. We especially asked the following questions: (i) How do spontaneously revegetated and forestry reclaimed sites differ in vegetation composition? (ii) What are the differences in participation of target species? (iii) What environmental factors determine vegetation changes? and (iv) Which restoration practice is the most effective in terms of conservation potential of sand pits?

METHODS

Study area

The study was conducted in 13 sand pits clustered into four large sand pit mining complexes located in the Třeboňsko Protected Landscape Area and Biosphere Reserve, southern part of the Czech Republic (48°49’-49°11’ N, 14°42’-14°57’ E). The altitude of the area is 457 m a. s. l. on average, the average annual temperature reaches 7.8 °C, and the average annual precipitation is roughly 570 mm. The area is filled with clay, sandy, and gravelly sediments originating from the Cretaceous-Quaternary period (Albrecht 2003).

All the studied sand pits were partly mined under the groundwater table, which resulted in the creation of artificial water bodies with extensive shores and slopes above. In almost all cases, the slopes were reclaimed mostly with Scots pine (*P. sylvestris*) with the non-native Red oak (*Quercus rubra*) being occasionally used. Some parts of the studied sand pits were left to spontaneous revegetation. The area of spontaneously revegetated sites was rather small compared to the forestry reclaimed parts. Information about the history of each sand pit was obtained from available literature sources (Řehounková et al. 2011) or mining company records. The area of an individual sand pit ranged from 13 to 161 ha. All studied sand pit complexes were prevailingly surrounded by commercial pine forests or arable land.

Sampling

Data about vegetation development in the sites restored by different methods, i.e., spontaneous revegetation and forestry reclamation, were collected during the 2012–2014 growing seasons. The space-for-time substitution method (Pickett 1989) was applied. Sampling plots were located in the centre of all available representative and homogeneous sites that were sufficiently large, not additionally disturbed (except from thinning in reclaimed sites), and with known history. Littoral and shallow flooded sites were not sampled because they are not afforested and because of the different trajectory of vegetation development (Řehounková & Prach 2006) which would not be comparable to forestry reclaimed sites.

Phytosociological relevés (5 m×5 m) were recorded estimating percentage cover of all vascular plant species present in different vegetation layers and the total cover of particular vegetation layers (Kent & Coker 1992). The size of the sampled plot was sufficient for recording all vegetation layers. The inclination in the middle of a particular plot and its aspect were also recorded. Groundwater table was roughly measured relative to the water level in the flooded part of the sand pit. In all cases, the open water table was close enough to the sampled plots to allow such estimations. The depth of the water table varied from 0.1 to 15 m below the surface in spontaneously revegetated plots and from 0.5 to 8 m below the surface on forestry reclaimed ones. The vegetation records were completed with the addition of six recorded in 2003 using the same method, because only a limited number of middle-aged spontaneous stages were available at the time of sampling.

Altogether, 84 vegetation records were obtained, 45 from spontaneously revegetated and 39 from forestry reclaimed sites. The successional age of the sampled plots ranged from 1 to 35 years on both types of plots. The plots were further classified into four successional stages: early (1–5 years, n = 17), young (6–10 years, *n* = 17), middle (11–20 years, *n* = 28), and late (21–35 years, *n* = 22).

Data analysis

All recorded species were classified according to their affinity to the following vegetation units: vegetation of open sandy sites and dry grasslands (hereafter target species), mesic and wet grassland (hereafter grassland species), woodland (hereafter woodland species) and ruderal and segetal vegetation (hereafter synanthropic species) (Ellenberg et al. 1991; Chytrý & Tichý 2003). Alien species, namely neophytes and invasive archeophytes (Pyšek et al. 2012), were classified as synanthropic regardless of their affinity. Determination of Red List species followed Grulich (2012). The species typical of open sandy sites and dry grasslands were considered as target species due to our expectation that sand pits may serve as alternative habitats for them. Target, grassland, and woodland species were considered as desirable, while synanthropic species were referred to as undesirable.

Relationships between vegetation and environmental data were analysed using multivariate methods in CANOCO 5 (ter Braak & Šmilauer 2012). Species of each plot were considered as response variables. Restoration method, age (time since abandonment/reclamation), water table, slope of the plot, aspect, and cover of planted *Pinus* in forestry reclaimed plots were used as environmental variables. Species data were logarithmically transformed and rare species were downweighted (Šmilauer & Lepš 2014). Detrended correspondence analysis (DCA) (length of the gradient of 5.5 SD units) and canonical correspondence analysis (CCA) were used because of the unimodal relationship. A redundancy analysis (RDA), standardized by response variables, was performed to test the effect of locality, i.e., sand pit complex, on other environmental variables. To separate the effect of locality, the identifier of plots situated in sites within the pits of the same mining complex was used as a covariable in the analyses. Forward selection was then conducted with all environmental variables. To assess the overall variation in species composition, DCA detrended by segments was used. Within CCA, the summarizing effects of explanatory variables provided independent (marginal) effects of individual environmental variables. Variation partitioning followed by a Monte Carlo permutation test with 499 permutations was then used to determine partial effects of these variables. Marginal effect reflects variability in the species data explained by a particular environmental variable used as the only explanatory variable, while partial effect is variability explained by this variable after separation of possible correlations with other environmental variables (Šmilauer & Lepš 2014). To assess the explanatory efficiency of environmental variables, variation explained by constrained axes in CCA was compared with variation explained by the same number of axes in DCA (Šmilauer & Lepš 2014).

The patterns of particular species groups (i.e., target, grassland, woodland, and synanthropic) were evaluated using principal components analysis (PCA) (length of the gradient 1.5 SD units) with a number of respective vascular plant species per sample used as response data. An RDA was then applied to evaluate the variability explained by the first axis. Species response curves of desirable and undesirable species within DCA were performed using logarithmically transformed cover of particular species groups (ter Braak & Šmilauer 2012).

Differences in species richness of particular species groups between spontaneously developed and forestry reclaimed sites were analysed using GLM methods in STATISTICA 10 (StatSoft 2010). Age of the plot was used as a covariable due to the unequal numbers of plots in different age categories.

RESULTS

Species pattern

The unconstrained ordination analysis (DCA, λ_1=0.5232, λ_2=0.3931) revealed that the pattern of species composition was influenced by the restoration method and successional age (Fig. 1). In forestry reclaimed sites, woodland species dominated during the whole course of vegetation development with typical dwarf-shrubs (*Vaccinium myrtillus*, *Vaccinium vitis-idaea*) in the undergrowth within older stages. Spontaneously revegetated sites were more variable in species composition hosting a number of synanthropic (*Tussilago farfara*, *Conyza canadensis*, *Digitaria ischaemum*) and grassland species (*Juncus effusus*, *Hypochaeris radicata*) in the early stages of vegetation development and more forest species (*P. sylvestris*, *Salix* sp., *Populus tremula*, *Avenella flexuosa*) in the later stages. Both trajectories converged, which is apparent in Fig. 2.

Participation of desirable and undesirable groups of species

A total of 189 vascular plant species were recorded. More than one half of the total number of species were non-target but desirable species (grassland and woodland); about one third were undesirable synanthropic species and the rest were target species (Table 1). Among the 61 synanthropic species, 16 were aliens (neophytes and invasive archeophytes), out of which 15 were found in spontaneous sites and 10 in forestry reclaimed sites. Moreover, 13 Red List species were recorded, 10 on spontaneously revegetated sites and 4 on forestry reclaimed sites. Out of the 13 Red List species, 6 species were target, 5 species were grassland, 1 species was woodland, and 1 species was synanthropic.

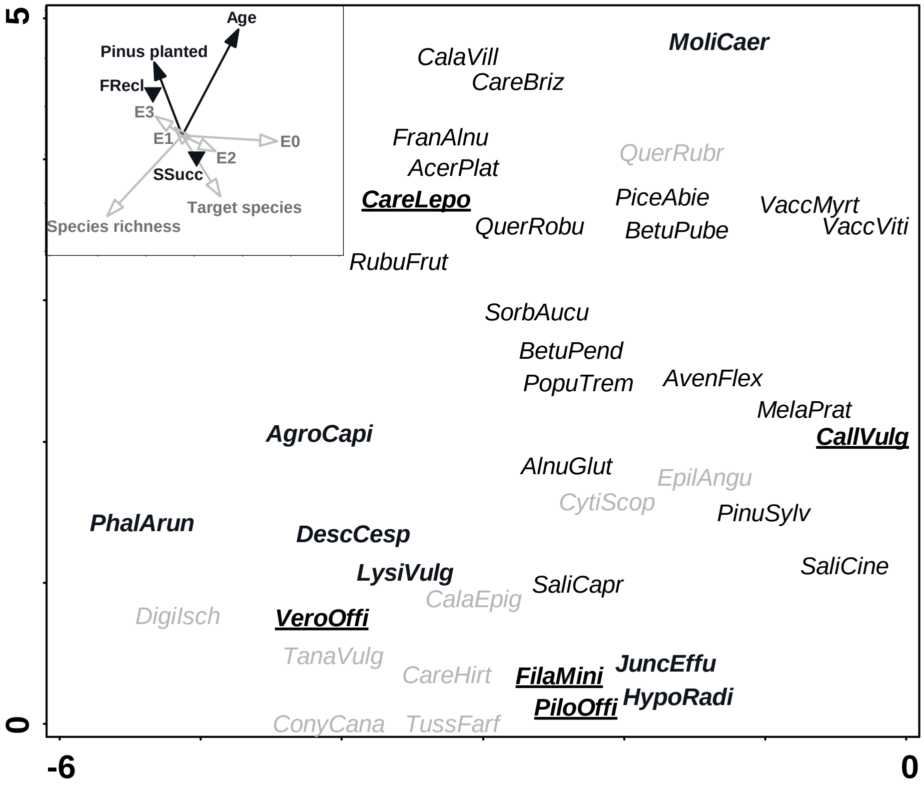

Fig. 1 DCA ordination of species. Species are classified according to their affiliation to particular vegetation units: open sandy sites and dry grasslands (*bold underlined*), mesic and wet grassland (*bold*), woodland (*black*), and synanthropic (*grey*). The *inset diagram* shows an ordination of environmental variables fitted as passive variables. Environmental variables significant in forward selection within further CCA analyses are shown in *black*. Restoration methods are represented by *centroids*: *SReveg* spontaneous revegetation, *FRecl* forestry reclamation. Cover of moss (*E0*), herb (*E1*), shrub (*E2*), and tree layer (*E3*); total number of species per sample (*Species richness*); and number of open sandy sites and dry grassland species per sample (*Target species*) are indicated by *grey arrows*. Abbreviations of species names are composed of the first four letters of the generic and species names; for full names, see Appendix. Only species with the highest weight (>1.1%) are shown.

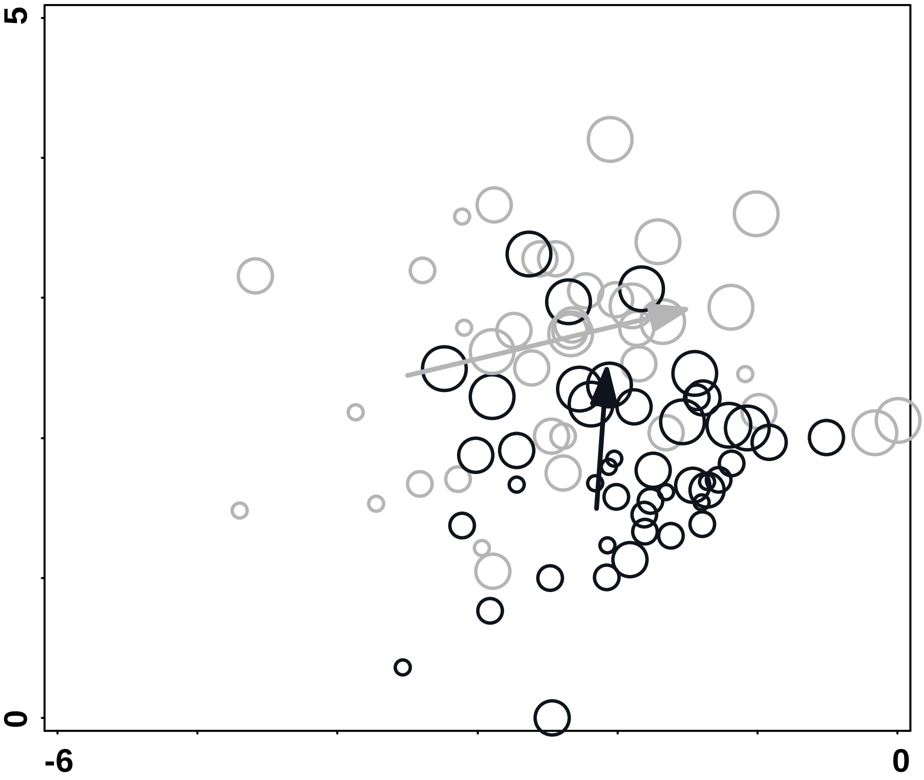

Fig. 2 DCA ordination of vegetation samples. The *increasing symbol size* corresponds to age categories (1–5, 6–10, 11–20, and 21–35 years). Spontaneous revegetation—*black circles,* forestry reclamation—*grey circles.* The *arrows* connect centroids representing the youngest and oldest age categories of spontaneously revegetated (*black*) and forestry reclaimed plots (*grey*) and thus show the main directions of succession.

Table 1 Species richness of particular species groups in plots restored by different methods.

Group of species	**Total SReveg**	**Total FRecl**	**Only SReveg**	**Only FRecl**	**Total**	**Average SReveg**	**Average FRecl**
Desirable							
Target							
Open sandy sites and dry grasslands	20 (10.6)	15 (7.9)	11 (5.8)	6 (3.2)	26 (13.8)	1.51±1.50	1.21±1.20
Non-target							
Grassland	42 (22.2)	32 (16.9)	20 (10.6)	10 (5.3)	52 (27.5)	2.93±2.76	1.95±2.16
Woodland	45 (23.8)	33 (17.5)	17 (9.0)	5 (2.6)	50 (26.5)	6.51±2.67	7.03±2.77
Undesirable							
Synanthropic	53 (28.0)	31 (16.4)	30 (15.9)	8 (4.2)	61 (32.3)	3.69±3.89*	2.15±2.18*
Total species richness	160 (84.7)	111 (58.7)	78 (41.3)	29 (15.3)	189 (100.0)	14.64±6.63	12.36±4.84

Numbers of species in particular species groups (target, grassland, woodland, synanthropic) found in the respective type of plot (total SReveg, total FRecl) and the respective numbers found exclusively on one type of plot (only SReveg, only FRecl) are shown. The proportion (%) of the total number of species found (189) is given in brackets. Average numbers of species per plot in a particular species group (average SReveg, average FRecl)±SD are given.

SReveg spontaneous revegetation, *FRecl* forestry reclamation.

*Significant ($P<0.05$) differences between spontaneously revegetated and forestry reclaimed sites (GLM; age was used as covariable).

There were about 1.5 times more species in the spontaneously revegetated sites in comparison with the forestry reclaimed sites, although this difference was not statistically significant ($F_{1,81}$=2.9957, P>0.05). Between-restoration method differences were significant only in the case of synanthropic species ($F_{1,81}$=4.7638, P<0.05) (Table 1), with higher numbers in spontaneous sites. Higher numbers were also recorded in spontaneous sites for other groups of species with the exception of woodland species. This basically corresponded with the results of the PCA where there were more target, grassland, and synanthropic species found in spontaneous sites whereas woodland species preferred forestry reclaimed sites (Fig. 3). In the respective constrained ordination analysis (RDA, λ_1=0.1667, λ_2=0.0073), the first axis explained 16.7 % and reflected age. The explanatory variables (i.e., restoration method, age, and cover of planted *Pinus*) explained 17.4 % of the total variation in the species data.

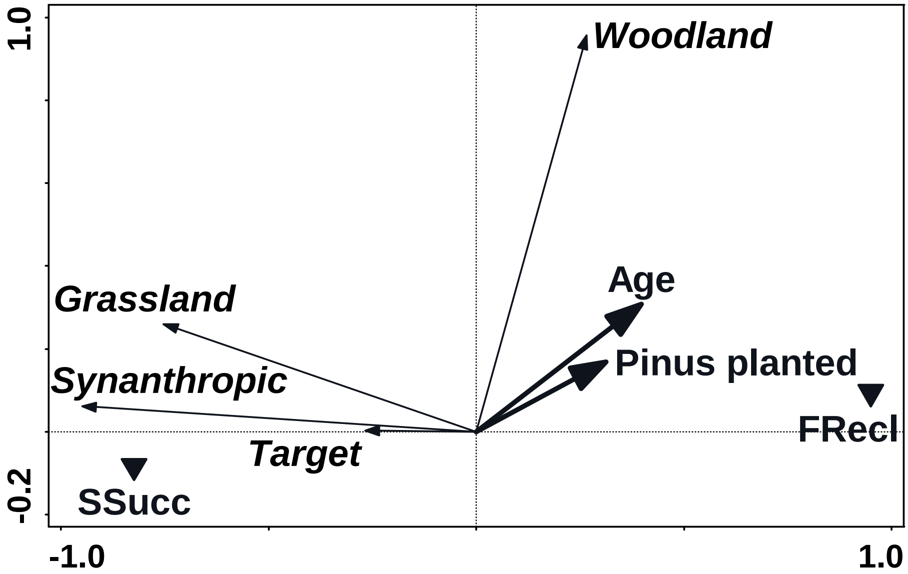

Fig. 3 PCA ordination of particular species groups (target, grassland, woodland, synanthropic) based on the numbers of species in a plot. Explanatory variables (age, cover of planted *Pinus*, and restoration method) were projected as passive variables. Restoration methods are represented by *centroids*: *SReveg* spontaneous revegetation, *FRecl* forestry reclamation.

Changes in the proportion of desirable (target, grassland, and woodland) and undesirable (synanthropic) species, and cover of planted *Pinus* during the course of vegetation development in sites restored by the different methods, are shown in Fig. 4. The cover of target, grassland, and synanthropic species decreased in both types of sites. The cover of grassland species in forestry reclaimed sites decreased rapidly within the first 15 years and remained negligible thereafter, while in spontaneous sites, they persisted for the whole study period. The cover of synanthropic species decreased very rapidly in forestry reclaimed sites, while they remained more or less stable in the early and young stages in spontaneous sites and then started to decrease, but increased again in the late stages of development. The cover of spontaneously established woodland species increased in both types of sites. In the forestry reclaimed sites, their cover was suppressed by the planted *Pinus* for the first two decades, but then the cover of planted *Pinus* decreased (due to thinning as a regular forestry practice), resulting in an increase in the cover of woodland species. In contrast, the cover of woodland species in spontaneously revegetated sites rather stagnated in the late stages of development.

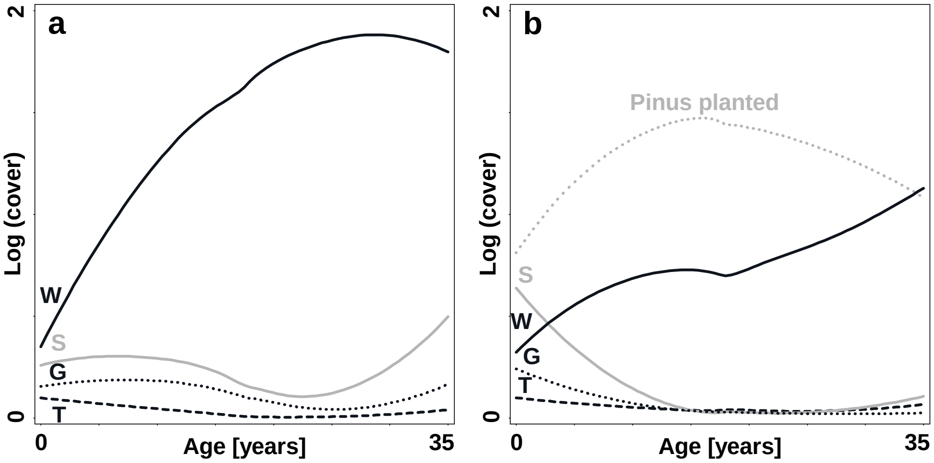

Fig. 4 DCA response curves of target (*T*), grassland (*G*), woodland (*W*), and synanthropic (*S*) groups of species for spontaneously revegetated (a) and forestry reclaimed (b) sites. For forestry reclaimed sites, cover of planted *Pinus* was also plotted. Response curves were fitted using a loess smoother model and reflect changing participation of the species groups in time.

Environmental factors

The CCA (λ_1=0.2564, λ_2=0.1924) revealed that significant environmental variables, i.e., restoration method, age, and cover of planted *Pinus*, explained 8.1 % of the total variation with the total explained variation accounting for 12.1 %. The largest amount of variability was explained by the restoration method (2.3 %, partial effect), while the smallest by cover of planted *Pinus* (1.0 %, partial effect). Both the partial and marginal effects of the environmental variables mentioned above were significant. The explanatory efficiency of the significant environmental variables was 46.81 %. Other environmental variables (water level, slope, and aspect of the plot) were not significant (Table 2).

The effect of locality on the other environmental variables was considerable, accounting for 14 % of the variability of the other environmental variables (*F*=4.4, *P*=0.002).

Table 2 Partial and marginal effects of environmental variables on species composition (CCA). Locality (i.e., identifier of plots belonging to the same sand pit complex) was used as a covariable. Partial effect—variability explained after separation of possible correlations with other variables; marginal effect—variability explained by a particular variable when used as the only explanatory variable.

	$\%_{partial}$	$F_{partial}$	$P_{partial}$	$\%_{marginal}$	$F_{marginal}$	$P_{marginal}$
Age	1.7	2.3	**	3.2	2.6	**
Restoration method	2.3	2.9	**	3.0	2.4	**
Water table	-	1.0	ns	1.0	0.8	ns
Slope	-	1.0	ns	1.0	0.8	ns
Aspect	0.8	1.6	*	1.8	1.5	ns
Pinus planted	1.0	1.8	*	1.9	1.6	*
Locality	3.0	1.8	**	6.5	1.8	**

% explained variation, *F* value of the *F* statistic, *P* probability level obtained by the Monte Carlo permutation test (499 permutations).

*P<0.05; **P<0.01; *ns* not significant.

DISCUSSION

The main trajectories of both forestry reclaimed and spontaneously revegetated sites converged towards woodlands. The dominant species on sandy soils in the area is Scots pine (*P. sylvestris*) (Chytrý et al. 2010), which can establish spontaneously on bare sandy substrates created by mining (Řehounková & Prach 2006). The fast colonization of bare sand is not surprising in this area, because of the character of the surrounding vegetation with a prevalence of commercial pine forests and a rather humid climate (Řehounková & Prach 2006). Thus, from this point of view, afforestation of abandoned sand pits is not necessary. As a consequence of the formation of the tree layer, either spontaneous or planted, there was a gradual decrease in the cover of species in the herb layer, similarly as in other mining sites (Hodačová & Prach 2003).

There was no significant difference in total species richness between the forestry reclaimed and spontaneously revegetated sites. This is in accordance with some studies where there were no significant differences in species richness; however, the representation of rare and specialized species was considerably lower in forestry reclaimed sites (Pietrzykowski 2008; Tropek et al. 2010, 2012). Nevertheless, in some other cases, forestry reclaimed sites were found to be significantly less species diverse in comparison with spontaneously developed ones (Hodačová & Prach 2003; Woziwoda & Kopeć 2014). Synanthropic species increased in the late stages of vegetation development on our spontaneous sites. This increase was caused by several synanthropic species with rather high covers in 28–35-year-old plots (namely *Calamagrostis epigejos*, *Urtica dioica*, *Q. rubra*), while the species were suppressed by dense canopy in reclaimed sites. However, we do not consider the species make any restoration problem, except the alien *Q. rubra* which may further expand in the future and, thus, should be eradicated.

The species pattern was significantly influenced by the restoration method (spontaneous revegetation or forestry reclamation) and age of the plot. Type of restoration method is the major factor determining species composition in post-mining sites (Hodačová & Prach; Tropek et al. 2010, 2012). In addition, age of the site (i.e., time since site abandonment/reclamation) also significantly influences the vegetation pattern, which was repeatedly shown for spontaneously revegetated (Trnková et al. 2010; Alday et al. 2012) and forestry reclaimed post-mining sites (Holl 2002; Brady & Noske 2010).

Surprisingly, site moisture did not significantly influence vegetation variability although it was found to be a crucial factor determining vegetation pattern in spontaneously revegetated sand pits (Řehounková & Prach 2006). To the best of our knowledge, no study comparing vegetation development on forestry reclaimed and spontaneously developed sites used site moisture/water table as an explanatory variable. Scots pine (*P. sylvestris*) is generally known to be extremely tolerant to site moisture (Ellenberg 1988), and its dominance probably masked the role of this variable. The other possible explanation is that the moisture gradient covered in this study was not as broad as in other studies (Řehounková & Prach 2006).

Forestry reclamation is often given priority over passive restoration, because it is assumed that it accelerates vegetation development (Zahawi et al. 2014). However, this effect may exhibit only a temporal character (Hodačová & Prach 2003), because colonization with native tree species and the formation of continuous vegetation cover on forestry reclaimed sites also require about 10 to 15 years (Holl 2002). In general, post-mining sites which have been restored with passive restoration methods are typified by having heterogeneous site environmental conditions, which are particularly important for the presence of species from various ecological groups (Řehounková & Prach 2006; Kompała-Bąba & Bąba 2013).

For nature conservation, open and nutrient-poor habitats are especially of great importance, because they provide suitable substitute habitats for competitively weak species (Novák & Prach 2003; Tischew & Kirmer 2007; Tropek et al. 2012). On the contrary, leveling of the surface and covering with nutrient-rich topsoil during forestry reclamation leads to habitat homogeneity and introduce diaspores of undesirable species favouring ruderal and competitively strong species over rare or specialized species (Řehounková et al. 2011). It is therefore desirable not to use forestry reclamation as the only possibility in post-mining sites but to try to maintain a mosaic of habitats from open bare substrates to shrubs and woody vegetation (Řehounková et al. 2016). Early successional stages in sand pits appear to host higher numbers of target species than later stages; thus, we suggest to arrest or even turn back the vegetation development towards the early stages of succession (Řehounková et al. 2016). The rather high financial inputs into forestry reclamation (in the studied sand pits about 50,000 € per hectare) can be partly invested into such restoration measures.

CONCLUSIONS

The restoration method, i.e., spontaneous revegetation or forestry reclamation, was the principal factor determining species composition. Although both types of sites developed towards forest, spontaneously revegetated sites were more species diverse in comparison with forestry reclaimed sites, especially in the number of target species, and thus exhibited higher conservation potential. This is particularly important for conservation of post-mining sand pits and implementation of passive restoration into practice as a common restoration strategy in areas not infested by alien species.

Acknowledgements. The study was supported by the grants GAČR P505/11/0256 and RVO 67985939. The authors thank Keith R. Edwards for doing the language revision of our manuscript and two anonymous reviewers for their comments.

References

Albrecht, J. 2003: Českobudějovicko. In: Mackovčin, P., Sedláček, M. (Eds) Protected areas of the Czech Republic, Volume VIII. Nature Conservation Agency of the Czech Republic and EkoCentrum Brno (In Czech).

Alday, J. G., Marrs, R. H. & Martínez-Ruiz. C. 2012: Soil and vegetation development during early succession on restored coal wastes: a six-year permanent plot study. Plant and Soil 353: 305–320.

Borgegård, S. 1990: Vegetation development in abandoned gravel pits: effects of surrounding vegetation, substrate and regionality. Journal of Vegetation Science 1: 675–682.

Brady, C. J. & Noske, R. A. 2010: Succession in bird and plant communities over a 24-year chronosequence of mine rehabilitation in the Australian monsoon tropics. Restoration Ecology 18: 855–864.

Chytrý, M. & Tichý, L. 2003: Diagnostic, constant and dominant species of vegetation classes and alliances of the Czech Republic: a statistical revision. Folia Facultatis Scientiarum Naturalium Universitatis Masarykianae Brunensis 108: 1–231.

Chytrý, M., Kučera, T., Kočí, M., Grulich, V. & Lustyk, P. 2010: Habitat catalogue of the Czech Republic, 2nd ed. Nature Conservation Agency of the Czech Republic, Prague (In Czech).

Ellenberg, H. 1988: Vegetation ecology of Central Europe. Cambridge University Press, Cambridge.

Ellenberg, H., Weber, H. E., Düll, R., Wirth, V., Werner, W. & Paulißen, D. 1991: Zeigerwerte von Pflanzen in Mitteleuropa. Scripta Geobotanica 18: 1–248.

Evans, D. M., Zipper, C. E., Burger, J. A., Strahm, B. D. & Villamagna, A. M. 2013: Reforestation practice for enhancement of ecosystem services on compacted surface mine: Path towards ecosystem recovery. Ecological Engineering 51: 16–23.

Grulich, V. 2012: Red List of vascular plants of the Czech Republic (3rd edition). Preslia 84: 631–645.

Hodačová, D. & Prach, K. 2003: Spoil heaps from brown coal mining: technical reclamation versus spontaneous revegetation. Restoration Ecology 11: 385–391.

Holl, K. D. 2002: Long-term vegetation recovery on reclaimed coal surface mines in the eastern USA. Journal of Applied Ecology 39: 960–970.

Holl, K. D. & Aide, T. M. 2011: When and where to actively restore ecosystems? Forest Ecology and Management 261: 1558–1563.

Kent, M., Coker, P. 1992: Vegetation description: a practical approach. Belhaven Press, London.

Kompała-Bąba, A. & Bąba, W. 2013: The spontaneous succession in a sand-pit—the role of life history traits and species habitat preferences. Polish Journal of Ecology 61: 13–22.

Luken, J. O. 1990: Directing ecological succession. Chapman and Hall, London.

Mudrák, O., Frouz, J. & Velichová, V. 2010: Understory vegetation in reclaimed and unreclaimed post-mining forest stands. Ecological Engineering 36: 783–790.

Novák, J. & Prach, K. 2003: Vegetation succession in basalt quarries: pattern on a landscape scale. Applied Vegetation Science 6: 111–116.

Pickett, S. T. A. 1989: Space-for-time substitution as an alternative to long-term studies. In: Likens, G. E. (Ed) Long-term studies in ecology: approaches and alternatives. Springer, New York.

Pietrzykowski, M. 2008: Soil and plant communities development and ecological effectiveness of reclamation on a sand mine cast. Journal of Forest Science 54: 554–565.

Pietrzykowski, M. & Socha, J. 2011: An estimation of Scots pine (*Pinus sylvestris* L.) ecosystem productivity on reclaimed post-mining sites in Poland (central Europe) using of allometric equations. Ecological Engineering 37: 381–386.

Prach, K., Lencová, K., Řehounková, K., Dvořáková, H., Jírová, A., Konvalinková, P., Mudrák, O., Novák, J., Trnková, R. 2013: Spontaneous vegetation succession at different central European mining sites: a comparison across seres. Environmental Science and Pollution Research 20: 7680–7685.

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

Řehounková, K. & Prach, K. 2006: Spontaneous vegetation succession in disused gravel-sand pits: role of local site and landscape factors. Journal of Vegetation Science 17: 583–590.

Řehounková, K. & Prach, K. 2008: Spontaneous vegetation succession in gravel-sand pits: a potential for restoration. Restoration Ecology 16: 305–312.

Řehounková, K., Řehounek, J. & Prach, K. 2011: Near-natural restoration vs. technical reclamation of mining sites in the Czech Republic. Faculty of Science USB, České Budějovice.

Řehounková, K., Čížek, L., Řehounek, J., Šebelíková, L., Tropek, R., Lencová, K., Bogusch, P., Marhoul, P. & Máca, J. 2016: Additional disturbances as a beneficial tool for restoration of post-mining sites: a multi-taxa approach. Environmental Science and Pollution Research 23: 13745–13753.

SER (Society for Ecological Restoration International Science & Policy Working Group) 2004: The SER International Primer on Ecological Restoration. Society for Ecological Restoration International, Tuscon.

Šmilauer, P. & Lepš, J. 2014: Multivariate analysis of ecological data using CANOCO 5. Cambridge University Press, New York.

StatSoft, Inc. 2010: STATISTICA (Data Analysis Software System), version 10. http://www.statsoft.com.

ter Braak, C. J. F. & Šmilauer, P. 2012 Canoco 5, trial version. http://www.canoco5.com.

Tischew, S. & Kirmer, A. 2007: Implementation of basic studies in the ecological restoration of surface-mined land. Restoration Ecology 15: 321–325.

Trnková, R., Řehounková, K. & Prach, K. 2010: Spontaneous succession of vegetation on acidic bedrock in quarries in the Czech Republic. Preslia 82: 333–343.

Tropek, R., Kadlec, T., Karešová, P., Spitzer, L., Kočárek, P., Malenovský, I., Baňař, P., Tuf, I. H., Hejda, M. & Konvička, M. 2010: Spontaneous succession in limestone quarries as an effective restoration tool for endangered arthropod and plants. Journal of Applied Ecology 47: 139–147.

Tropek, R., Kadlec, T., Hejda, M., Kočárek, P., Skuhrovec, J., Malenovský, I., Vodka, Š., Spitzer, L., Baňař, P. & Konvička, M. 2012: Technical reclamations are wasting the conservation potential of post-mining sites. A case study of black coal spoil dumps. Ecological Engineering 43: 13–18.

Walker, L. R. 1999: Ecosystems of disturbed land. Elsevier, New York.

Woziwoda, B. & Kopeć, D. 2014: Afforestation or natural succession? Looking for the best way to manage abandoned cut-over peatlands for biodiversity conservation. Ecological Engineering 63: 143–152.

Zahawi, R. A., Holl, K. D. & Reid, J. L. 2014: Hidden costs of passive restoration. Restoration Ecology 22: 284–287.

Appendix

List of full species names used in Fig. 1: *Acer platanoides* L., *Agrostis capillaris* L., *Alnus glutinosa* (L.) Gaertn., *Avenella flexuosa* (L.) Drejer, *Betula pendula* Roth, *Betula pubescens* Ehrh., *Calamagrostis epigejos* (L.) Roth, *Calamagrostis villosa* (Chaix) J. F. Gmel., *Calluna vulgaris* (L.) Hull, *Carex brizoides* L., *Carex hirta* L., *Carex leporina* L., *Conyza canadensis* (L.) Cronquist, *Cytisus scoparius* (L.) Link, *Deschampsia cespitosa* (L.) P. Beauv., *Digitaria ischaemum* (Schreb.) Muhl., *Epilobium angustifolium* L., *Filago minima* (Sm.) Pers., *Frangula alnus* Mill., *Hypochaeris radicata* L., *Juncus effusus* L., *Lysimachia vulgaris* L., *Melampyrum pratense* L., *Molinia caerulea* (L.) Moench, *Phalaris arundinacea* L., *Picea abies* (L.) H. Karst., *Pilosella officinarum* Vaill., *Pinus sylvestris* L., *Populus tremula* L., *Quercus robur* L., *Quercus rubra* L., *Rubus fruticosus* agg., *Salix caprea* L., *Salix cinerea* L., *Sorbus aucuparia* L., *Tanacetum vulgare* L., *Tussilago farfara* L., *Vaccinium myrtillus* L., *Vaccinium vitis-idaea* L., *Veronica officinalis* L.

CHAPTER III

VEGETATION DEVELOPMENT OF FORESTRY RECLAIMED SAND AND SAND-GRAVEL PITS: HABITATS IN NEED OR ON A WAY TOWARDS MORE NATURAL SPECIES COMPOSITION?

Šebelíková et al. (manuskript)

VEGETATION DEVELOPMENT OF FORESTRY RECLAIMED SAND AND SAND-GRAVEL PITS: HABITATS IN NEED OR ON A WAY TOWARDS MORE NATURAL SPECIES COMPOSITION?

Šebelíková Lenka[1], Řehounková Klára[1], Prach Karel[1,2]

[1] *Department of Botany, Faculty of Science, University of South Bohemia, Branišovská 1760, 37005 České Budějovice, Czech Republic*
[2] *Institute of Botany, Czech Academy of Science, Dukelská 135, 37982 Třeboň, Czech Republic*

Corresponding author: Lenka Šebelíková, e-mail: lenuskasch@gmail.com

Nomenclature: Danihelka et al. (2012)

Abstract

Restoration of post-mining sites has gained increasing attention in Central Europe. Until now, forestry reclamation has been a prevailing method used during mining sites restoration. Although many studies described the process and outcome of forestry reclamation, none described in detail the vegetation development from initial to late stages. Our study aimed to fill this gap focusing on vegetation description in forestry reclaimed post-mining sand and sand-gravel pits across the Czech Republic, identification of the effects of the surrounding vegetation on species composition in forestry reclaimed sites, and comparison of the conservation value of sites originating from forestry reclamation and spontaneous revegetation. In the early stages of vegetation development of forestry reclaimed sites, dry and mesic grassland species occurred even with some species belonging to the national Red List. After about 5 years, however, these species rapidly disappeared and were replaced by woodland species. In contrast, spontaneously revegetated sites hosted much more dry and mesic grassland species, as well as Red List species, which persisted during the whole study period (1–75 years). Although there was a large overlap in species composition between the forestry reclaimed and spontaneously revegetated sites, the study clearly demonstrated that the most valuable sites from a conservation perspective were destroyed within a few years by forestry reclamation. Therefore, spontaneous revegetation should be considered as a low-cost alternative method to forestry reclamation in post-mining sand and sand-gravel pits in Central Europe.

Keywords

Afforestation · Open sand specialists · Plant diversity · Restoration · Succession · Surrounding habitats

This chapter is a manuscript prepared for submission. The full version is archived by the Faculty of Science, University of South Bohemia in České Budějovice.

CHAPTER IV

SPONTANEOUS REVEGETATION VS. FORESTRY RECLAMATION - VEGETATION DEVELOPMENT IN COAL MINING SPOIL HEAPS ACROSS CENTRAL EUROPE.

Šebelíková et al. 2018. Land Degrad Dev, accepted

SPONTANEOUS REVEGETATION VS. FORESTRY RECLAMATION – VEGETATION DEVELOPMENT IN COAL MINING SPOIL HEAPS ACROSS CENTRAL EUROPE

Šebelíková Lenka[1], Csicsek Gábor[2†], Kirmer Anita[3], Vítovcová Kamila[1], Ortmann-Ajkai Adrienne[4], Prach Karel[1,5], Řehounková Klára[1]

[1] *Department of Botany, Faculty of Science, University of South Bohemia, Branišovská 1760, 37005 České Budějovice, Czech Republic*
[2] *Department of Ecology, Faculty of Sciences, University of Pécs, Ifjúság u.6., H-7624, Pécs, Hungary*
[3] *Department for Nature Conservation and Landscape Planning, Anhalt University of Applied Sciences, Strenzfelder Allee 28, 06406 Bernburg, Germany*
[4] *Department of Hydrobiology, Faculty of Sciences, University of Pécs, Ifjúság u.6., H-7624, Pécs, Hungary*
[5] *Institute of Botany, Czech Academy of Science, Dukelská 135, 37982 Třeboň, Czech Republic*
[†] *Current address: Institute of Ecology and Botany, Centre for Ecological Research, Hungarian Academy of Sciences, Alkomány u. 2-4., H-2163 Vácrátót, Hungary*

Corresponding author: Lenka Šebelíková, e-mail: lsebelikova@prf.jcu.cz

Abstract

Comparison of spontaneous revegetation and forestry reclamation can provide valuable information about the trajectories and rate of vegetation development applicable to restoration practice over broader geographical scales. In the current study, we sampled terrestrial vegetation in spontaneously revegetated and forestry reclaimed spoil heaps after brown coal mining differing in age in three regions across Central Europe (Germany, the Czech Republic and Hungary). The main objective was to compare the course of vegetation development and species richness between the two restoration methods over a large geographical scale. In all geographical regions, species richness was higher on spontaneously revegetated sites. Although the starting point differed across regions, trajectories to woodland development converged with time. In addition, spontaneous revegetation was comparably as fast as forestry reclamation in developing towards woodland. Spontaneous revegetation proved to be more valuable and cost-effective in terms of nature conservation and should be considered as an alternative restoration strategy to forestry reclamation in Central Europe.

Keywords

Central Europe · Forestry reclamation · Spoil heaps · Spontaneous succession · Species richness

This chapter is protected by copyright. This is the peer reviewed version of the following article: Šebelíková L, et al. Spontaneous revegetation versus forestry reclamation—Vegetation development in coal mining spoil heaps across Central Europe. Land Degrad Dev. 2018;1–9, which has been published in final format at https://doi.org/10.1002/ldr.3233. The full version of this chapter is archived by the Faculty of Science, University of South Bohemia in České Budějovice.

CONCLUSIONS

CONCLUSIONS

Understanding the processes and trajectories of vegetation development, and identifying key factors which influence the species composition in forestry reclaimed sites is an important contribution to the current knowledge, and is also crucial for cost-effective restoration of post-mining sites. It has long been discussed if forestry reclamation is necessary and under which circumstances. The key findings on the effectiveness of forestry reclamation should be taken into account during planning of a restoration project and decision-making processes of a particular post-mining site. We identified large gaps in the current knowledge on forestry reclamation with respect to vegetation development in post-mining sites which the presented thesis aimed to fill.

The presented thesis showed that woodlands originating from spontaneous revegetation were more valuable from a conservation perspective having higher species richness and diversity (***Chapter II*** and ***IV***). Forestry reclamation using a mixture of native broadleaved tree species provided a more natural result in species composition of spontaneously established higher plants approaching to spontaneous revegetation but it still considerably differed in species richness (***Chapter IV***). The finding that spontaneous revegetation created habitats having higher species richness and conservation value than forestry reclamation was also proved by previous studies (Hodačová & Prach 2003; Tropek et al. 2010, 2012). However, spontaneous revegetation provided only relatively short-term benefits for nature conservation. The natural processes direct towards woodlands closing open patches of a bare ground which represent the most valuable habitats from a conservation perspective. As a consequence, heliophilous rare and specialized species of plants and insects retreated over time. In this perspective, the disturbed succession (i.e. spontaneous revegetation repeatedly disturbed, for example, by recreational activities) proved to be the most effective restoration method (***Chapter I***). In the sand pits, additional disturbances can slow down or even arrest the process of vegetation succession for a long time providing habitats for species adapted to open sands (Heneberg et al. 2013; Heneberg & Řezáč 2014). Therefore, additional disturbances represented low-cost and long-term management. These valuable open sandy habitats were destroyed much faster (within ca 5 years) by forestry reclamation (***Chapter III***). After the initial and still relatively open stage of forestry reclamation, the canopy of planed *Pinus sylvestris* became dense causing a rapid decline in grassland species (both, dry and mesic) and allowing only woodland species to persist on the site.

There is a large evidence that vegetation in the surrounding of mining sites play a decisive role in species composition inside the spontaneously developing post-mining site (e.g. Kirmer et al. 2008, Řehounková & Prach 2008). The knowledge about the role of the surrounding vegetation in species composition in forestry reclaimed sites was limited. In the presented theses, we demonstrated that the surrounding vegetation, namely presence and proportion of dry grasslands and woodlands in the close vicinity, were important for species composition in the forestry reclaimed sites (***Chapter III***). However, the occurrence of dry grasslands was crucial only in the early stages of vegetation development because their participation inside the forestry reclaimed sites rapidly decreased over time. The occurrence of woodlands in the surrounding of the sand pits seemed to be less important for species composition inside the sand pits than the occurrence of dry grasslands which was explained by the low colonization ability of herbaceous woodland species (Onaindia et al. 2013).

Little was known about factors influencing vegetation development in forestry reclaimed sites. It was shown that age and restoration method were the most important factors affecting species composition regardless of the spatial scale (Table 1). The non-significant effect of age on the smallest spatial scale might be explained by a rather short range of age of the studied plots (14–21 years) or due to the fact that its effect was masked by other explanatory variables. Unlike our assumption, the cover of planted trees played a role in species composition only at the regional scale (Table 1).

Table 1 Summary of factors considered as influential for species composition on particular spatial scales. Significant factors are given in bold.

Scale	Method studied	Factors considered
Local	comparison	age, **restoration method**, water table, slope
Regional	comparison	**age**, **restoration method**, water table, slope, **cover of planted *Pinus***
Landscape (country)	forestry reclamation	**age**, **altitude**, cover of planted *Pinus*, **presence of dry grasslands**, **proportion of dry grasslands**, presence of woodlands, **proportion of woodlands**, proportion of synanthropic habitats
Landscape (Central Europe)	comparison	**age**, **restoration method**, slope, cover of planted species, **locality**

The presented thesis clearly demonstrated the importance of spontaneous revegetation of post-mining sites in Central Europe for the presence and persistence of rare and specialized species. Forestry reclamation maight host these species in the initial stages but these stages were rapidly overgrown by planted trees and the species of conservation potential vanished. However, further research on this topic is necessary to fully understand the processes of vegetation development in forestry reclaimed post-mining sites. On the basis of the current knowledge, spontaneous revegetation should be considered as an alternative method to forestry reclamation in the restoration of Central European post-mining sites. If forestry reclamation is unavoidable for legal or other reasons, the principal goal of the restoration project should be a creation of a mosaic of biotopes using both, spontaneous revegetation and forestry reclamation.

References

Heneberg, P., Bogusch, P. & Řehounek, J. 2013: Sandpits provide critical refuge for bees and wasps (Hymenoptera: Apocrita). Journal of Insect Conservation 17: 473–490.

Heneberg, P. & Řezáč, M. 2014: Dry sandpits and gravel-sandpits serve as key refuges for endangered epigeic spiders (*Araneae*) and harvestmen (*Opiliones*) of Central European steppes aeolian sands. Ecological Engineering 73: 659–670.

Hodačová, D. & Prach, K. 2003: Spoil heaps from brown coal mining: technical reclamation versus spontaneous revegetation. Restoration Ecology 11: 385–391.

Kirmer, A., Tischew, S., Ozinga, W. A., von Lampe, M., Baasch, A. & van Groenendael, J. M. 2008: Importance of regional species pools and functional traits in colonization processes: predicting re-colonization after large-scale destruction of ecosystems. Journal of Applied Ecology 45: 1523–1530.

Onaindia, M., Ametzaga-Arregi, I., San Seastián, M., Mitxelena, A., Rodríguez-Loinaz, G., Peña, L. & Alday, J. G. 2013: Can understorey native woodland plant species regenerate under exotic pine plantations using natural succession? Forest Ecology and Management 308: 136–144.

Řehounková, K. & Prach, K. 2008: Spontaneous vegetation succession in gravel-sand pits: a potential for restoration. Restoration Ecology 16: 305–312.

Tropek, R., Kadlec, T., Karešová, P., Spitzer, L., Kočárek, P., Malenovský, I., Baňař, P., Tuf, I. H., Hejda, M. & Konvička, M. 2010: Spontaneous succession in limestone quarries as an effective restoration tool for endangered arthropod and plants. Journal of Applied Ecology 47: 139–147.

Tropek, R., Kadlec, T., Hejda, M., Kočárek, P., Skuhrovec, J., Malenovský, I., Vodka, Š., Spitzer, L., Baňař, P. & Konvička, M. 2012: Technical reclamations are wasting the conservation potential of post-mining sites. A case study of black coal spoil dumps. Ecological Engineering 43: 13–18.

lenuskasch@gmail.com

Spontaneous revegetation vs. forestry reclamation of mining sites on different spatial scales.
Ph.D. Thesis Series, 2018, No. 12

Printed in the Czech Republic by Typodesign
Edition of 20 copies

University of South Bohemia in České Budějovice
Faculty of Science
Branišovská 1760
CZ-37005 České Budějovice, Czech Republic

Phone: +420 387 776 201
www.prf.jcu.cz, e-mail: sekret-fpr@prf.jcu.cz