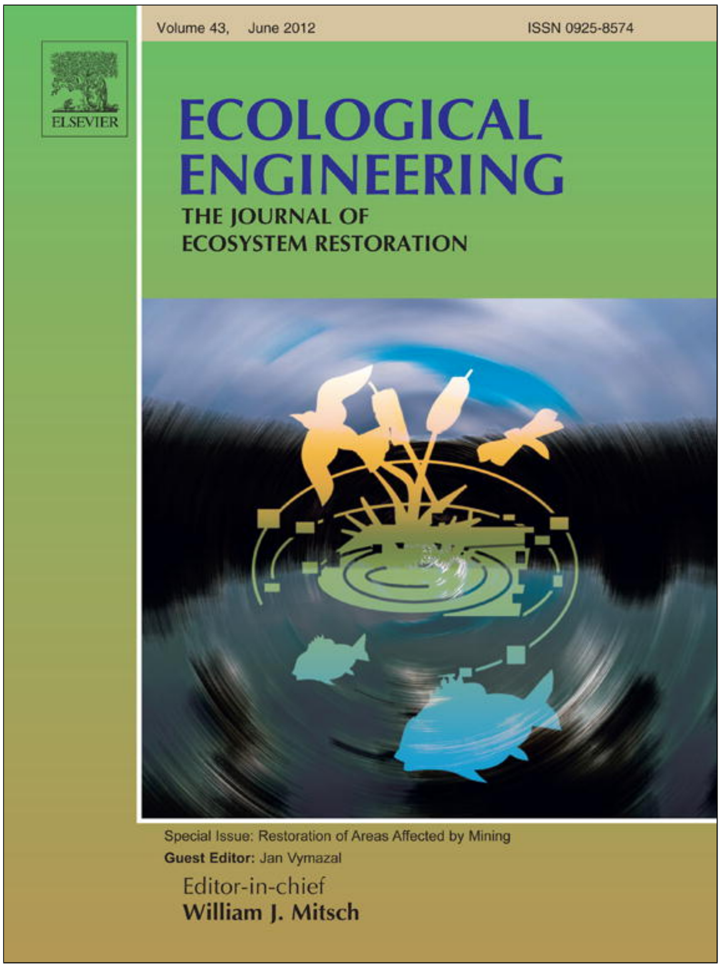
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Technical reclamations are wasting the conservation potential of post-mining sites. A case study of black coal spoil dumps

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ABSTRACT

Despite the increasing evidence that post-mining sites often provide biodiversity refuges in anthropogenically impacted landscapes, thus offering valuable analogues of natural habitats, technocratic methods still prevail over natural processes in restoration practice. Selection of the restoration approach, however, crucially affects the future conservation value of every site. As a contribution to recent debates, we studied the communities of vascular plants and seven arthropod groups (orthopteroids, spiders, leafhoppers, ground beetles, herbivorous beetles, true bugs, and butterflies and moths) colonising technically reclaimed versus spontaneously developed plots on black coal spoil dumps in the Kladno district, Czech Republic. In all studied groups, spontaneously developed sites hosted a high proportion of species of conservation concern, which were nearly absent from the technically reclaimed plots. Combined with existing single-taxon studies of diverse post-mining sites, and our previous similarly broad study of limestone quarries, our results provide strong evidence of the counterproductivity of costly technical reclamations of postindustrial sites with respect to biodiversity conservation. Relevant legislation should favour natural processes over technical reclamation when deciding the fates of post-mining localities. Technical reclamation should be reserved just for those cases of well-justified public concerns.

1. Introduction

Post-mining sites, an unavoidable consequence of the mining industry, cover almost 1% of the world's land (Walker, 1992) and represent important land forms in many regions. Recently, it has been repeatedly documented that their dry, rugged and often sparsely vegetated surfaces often host endangered species of declining unproductive and/or periodically disturbed biotopes (e.g., Schulz and Wiegleb, 2000; Benes et al., 2003; Krauss et al., 2009; Lundholm and Richardson, 2010), thus providing refuge and/or compensatory habitats for species that are rapidly declining from modern landscapes (Thomas et al., 1994; Dennis et al., 2004). On the other hand, the conservation potential of post-mining sites depends on their fate after the mining has been terminated (Prach and Hobbs, 2008; Tropek et al., 2010). The two most common contrasting approaches are (1) *technical reclamation*, typically comprising of covering the sites with fertile topsoil, sowing grass–herb mixtures and planting trees; and (2) *spontaneous succession* without any human intervention. Still rarely used is *directed succession*, when natural processes are actively influenced; e.g., through support of conservation-desired plants (by sowing or species-rich hay transferring), or suppressing invasive plants (Rydgren et al., 2010; Novak and Prach, 2010; Richardson et al., 2010).

Several recent papers, based on single-taxa (Hodacova and Prach, 2003; Holec and Frouz, 2005; Mudrak et al., 2010) and a broad multi-taxa study (Tropek et al., 2010), revealed that technical reclamation is both counterproductive for biodiversity, and

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economically costly. Simultaneously, the strongly positive effects of spontaneous and directed succession in diverse post-mining sites have been repeatedly showed (e.g., Bradshaw, 1997; Prach and Pysek, 2001; Wiegleb and Felinks, 2001; Benes et al., 2003). Despite this, the technical reclamations still prevail overwhelmingly (Prach and Hobbs, 2008; Prach et al., 2011), whereas non-technical restoration practices remain discouraged by national environmental laws (e.g., Schulz and Wiegleb, 2000; Prach and Hobbs, 2008; Prach et al., 2011). This situation is increasingly criticised by both non-governmental conservation groups and academia, advocating that it is both ethical and scientifically wiser to utilise the biodiversity conservation potential of once-exploited and subsequently abandoned localities (e.g., Rosenzweig, 2003; Prach et al., 2011; Tropek and Konvicka, 2011).

In this study, we compare the biodiversity conservation benefits of technical restoration versus spontaneous succession of black coal spoil dumps (after bituminous coal mining), a post-mining land form little appreciated in the conservation literature, using vascular plants and seven arthropod taxa. Our approach closely follows our previous study of limestone quarries (Tropek et al., 2010). Taken together, these studies should provide robust arguments for the ongoing legislative debates on the restoration of post-mining localities, and the utilisation of their conservation potential.

2. Methods

2.1. Study area

The study was carried out in the Kladno district, Central Bohemia, Czech Republic. It is a hilly, mildly warm and relatively dry (250–400 m a.s.l.; mean annual temperatures: 7–8.7 °C; annual precipitation: 450–500 mm) region covered by intensive farmlands, plantation forests, historically industrial (coal and steel) towns, and brownfields. The intensive land use and high degree of urbanisation (population density: 220 persons/km^2) resulted in severe degradation of natural habitats. The region thus represents many industry-dominated regions of Europe.

Until the 1990s, when the mines were closed, the Kladno district ranked among the most important black (bituminous) coal mining areas in the Czech Republic. As a side effect of the mining, 37 spoil dumps, forming either hills or hillsides, are scattered in a 100 km^2 area. Little reclamation was carried out in the past, but the recent closures are generating pressure for rapid technical reclamation of these localities. As a consequence, the majority of them are now partly reclaimed or technical reclamation is planned in the near future, mainly by a fertile topsoil covering supplemented by commercial grass-herb mixture sowing and/or trees planting. Only a few spoil dumps still stay abandoned for spontaneous succession outside these pressures.

2.2. Taxonomic groups and species categorisation

We targeted vascular plants, and seven arthropod taxa: orthopteroids (Orthoptera, Dermaptera, and Blattodea), spiders (Araneae), leafhoppers (Auchenorrhyncha), ground beetles (Coleoptera: Carabidae), herbivorous beetles (Coleoptera: Apionidae, Curculionidae, Dryophthoridae, Elateridae, Rhynchitidae), true bugs (Heteroptera), and day-active butterflies and moths (Lepidoptera) (see Appendix A for nomenclature references). The studied arthropods cover a broad diversity of life history features representing terrestrial invertebrates in general.

Besides *species richness*, we analysed the *conservation value* of the communities, based on the Czech Republic red lists (plants: Prochazka, 2001; arthropods: Farkac et al., 2005) distinguishing six ranked threat categories (EX – considered as extinct in the Czech Republic; CR – critically endangered; EN – endangered; VU – vulnerable; NT – near threatened; and LI – low interest, not threatened), and the *xeric specialisation* of the communities, according to the species' requirements for xeric habitats, distinguishing three ranked categories (ST – restricted to well-preserved xeric grasslands; XE – common xerothermophilous species; and GE – widespread generalists or species of non-xeric habitats). Appendix A lists these categories (including references) for all recorded species.

2.3. Data sampling

We targeted open habitats as one of the most endangered habitats in Europe (WallisDeVries et al., 2002; Cremene et al., 2005). Only three spoil dumps in the area contained larger (>0.2 ha) treeless parts, not affected by any technical reclamation uses for >20 years, appropriate as non-reclaimed treatments in this study. For comparison, three treeless plots of similar age reclaimed by topsoil covering and grass–herb mixture sowing were chosen. Summarizing, six study plots (ca 0.2–0.3 ha) were established, three technically reclaimed and three left to spontaneous succession, within five black coal spoil dumps (Table 1). Two differently restored plots were situated in the same spoil dump, the other ones were established in distinct spoil dumps. The minimum (Prago Tragy and Ronna) and maximum (Max and Theodor) distances between the studied spoil dumps were 1.3 and 6.1 km, respectively.

We closely followed the sampling protocol used by Tropek et al. (2010), including the numbers of samples taken the season, to achieve as high as possible comparability between the two types (black coal spoil dumps and limestone quarries) of post-mining sites. In the center of each plot, a line of five 3 m × 3 m quadrates, situated 2 m apart, was established. Within each quadrate, the percentage cover of all vascular plant species was estimated in June 2008. Arthropods were sampled using a standardized pit-fall trap (diameter 9 cm, depth 15 cm, containing 5% formaldehyde) per a quadrate, exposed from 7 May to 19 August 2008 and emptied four times during the study period, at approximately four-week intervals. The entire vegetation within each quadrate was swept on each day of the traps emptying and all arthropods were killed and preserved. The pitfall and sweeping material were sorted to target taxa and identified as to species. Butterflies and moths were recorded on two intersecting linear transects per plot (50 m/5 min; Kadlec et al., in press). Each transect was walked five times during the study season (7–8 May, 6 June, 2–4 July, 28–29 July, 19 August), between 9:30 and 16:30 CEST and under suitable weather conditions (>17 °C, sunny, no wind).

2.4. Statistical analyses

All analyses were computed in Canoco for Windows 4.5 (ter Braak and Smilauer, 2002). To compare *species richness*, *conservation value* and *xeric specialisation* between the two restoration methods (*METHOD*: reclamation vs. succession), a redundancy analysis (RDA) with Monte-Carlo significance testing (999 permutations, full model) was used. For *species richness*, the response variables were the numbers of species in the eight studied taxa, summed per plot. For *conservation value* and *xeric specialisation*, we weighted the numbers of individuals of all species in each taxon, recorded per plot, by the ranked values denoting the respective species' red-list status (EX – 5; CR – 4; EN – 3; VU – 2; NT – 1; LI – 0) and xeric specialisation (ST – 2; XE – 1; GE – 0). Orthopteroids and vascular plants, containing none and a single red-listed species, respectively, were excluded from the *conservation value* analyses.

Table 1
Characterisation of individual study plots.

Spoil dump	Restoration method	Coordinates	Age (years)[a]	Species[b]	Red-listed species[c]	Specialised species[d]
Max	Reclamation	50°09′27″N, 14°03′28″E	36	169	2	11
Mayrau – R	Reclamation	50°09′48″N, 14°04′59″E	35	216	4	11
Mayrau – S	Succession	50°09′46″N, 14°04′53″E	35	203	11	19
Prago Tragy	Reclamation	50°09′57″N, 14°07′36″E	20	121	0	6
Ronna	Succession	50°10′40″N, 14°06′57″E	26	200	6	17
Theodor	Succession	50°10′56″N, 14°08′09″E	73	202	16	32

[a] Age refers to the cessation of dumping.
[b] Total number of all recorded species of the target groups.
[c] Total number of all recorded species included in the national red lists (Prochazka, 2001; Farkac et al., 2005)
[d] Total number of all recorded species specialised to well-preserved xeric grasslands (see Appendix A for details).

Canonical correspondence analysis (CCA) was used to test the effects of restoration *METHOD* on the species compositions of samples. We used square-root transformation and downweighting of rare species options. For all taxa except vascular plants and butterflies and moths, the pitfall-trapped and swept material from each quadrate and visit were combined to form a sample. The Monte-Carlo permutation test (999 runs, full model) design reflected the spatiotemporal arrangements of the samples: quadrates were permuted as line transects and visits as time series. For butterflies and moths, the two transects per plot were permuted as freely exchangeable within each visit. For vascular plants, only the lines of quadrates formed the permutation design. Because these permutation designs do not allow for empty cells, we added a fictional species with abundance = 1 to each sample (cf. Leps and Smilauer, 2003).

3. Results

We recorded 93 species of vascular plants, 728 individuals/19 species of orthopteroids, 1780/100 spiders, 930/59 leafhoppers, 1379/68 ground beetles, 461/56 herbivorous beetles, 828/78 true bugs, and 472/49 butterflies and moths. Out of the 522 recorded species, 26 (~5% of the total) are included on the national red-lists and 52 (~10% of the total) are considered as specialists of well-preserved xeric grasslands or forest steppes (see Appendix A). Total numbers of all, red-listed and xeric grassland specialised species per individual studied plots are summarized in Table 1.

The *species richness* (Fig. 1a) of the spontaneously developed plots was considerably higher for orthopteroids and true bugs, slightly higher for butterflies and moths, spiders, vascular plants, and ground beetles, and slightly lower for leafhoppers and herbivorous beetles (1st axis variation = 33.3%, F = 1.996, p = 0.001). The *conservation value* (Fig. 1b) of all studied groups was higher in the spontaneously developed plots: considerably higher for leafhoppers and butterflies and moths, and slightly higher for herbivorous beetles, true bugs, ground beetles, and spiders (1st axis variation = 43.1%, F = 2.269, p = 0.001). Similarly, the *xeric specialisation* (Fig. 1c) of almost all targeted groups was higher in the spontaneously developed plots: considerably higher for spiders, true bugs, orthopteroids and herbivorous and ground beetles, while no visible effects for leafhoppers and butterflies and moths were found (1st axis variation = 39.2%, F = 2.581, p = 0.001). Therefore, all the analyses pointed to negative impacts of technical reclamation, while none of them revealed any negative impact of spontaneous succession, on *species richness*, *conservation value* or *xeric specialisation*.

The CCA analyses revealed significant effects of the restoration *METHOD* on community compositions of all sampled taxa (Table 2). Species of conservation concern (red-listed and xeric specialists combined) preferred spontaneous succession to technical reclamation (Fig. 2). Appendix A presents individual species responses as 1st axis scores.

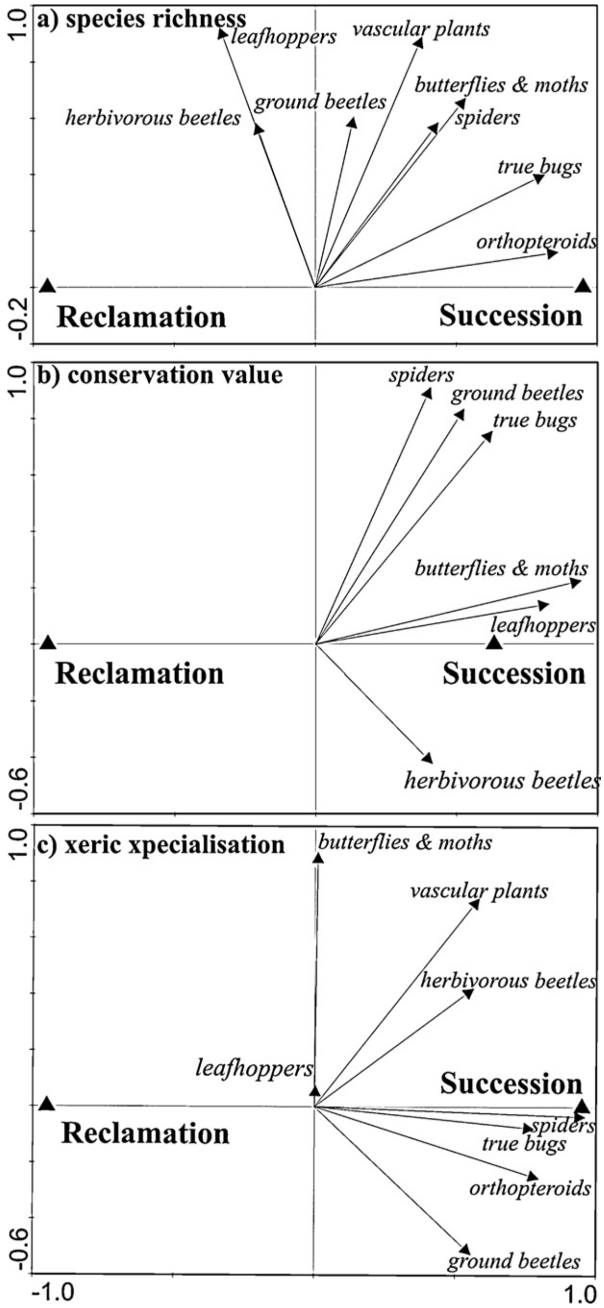

Fig. 1. Results of RDA ordination comparing differently restored black coal spoil dumps. (a) *Species richness* (number of species per plot); (b) *conservation value* (individuals recorded per plot weighted by their ranked red-list status); and (c) *xeric specialisation* (individuals recorded per plot weighted by ranked degree of xeric habitats requirements).

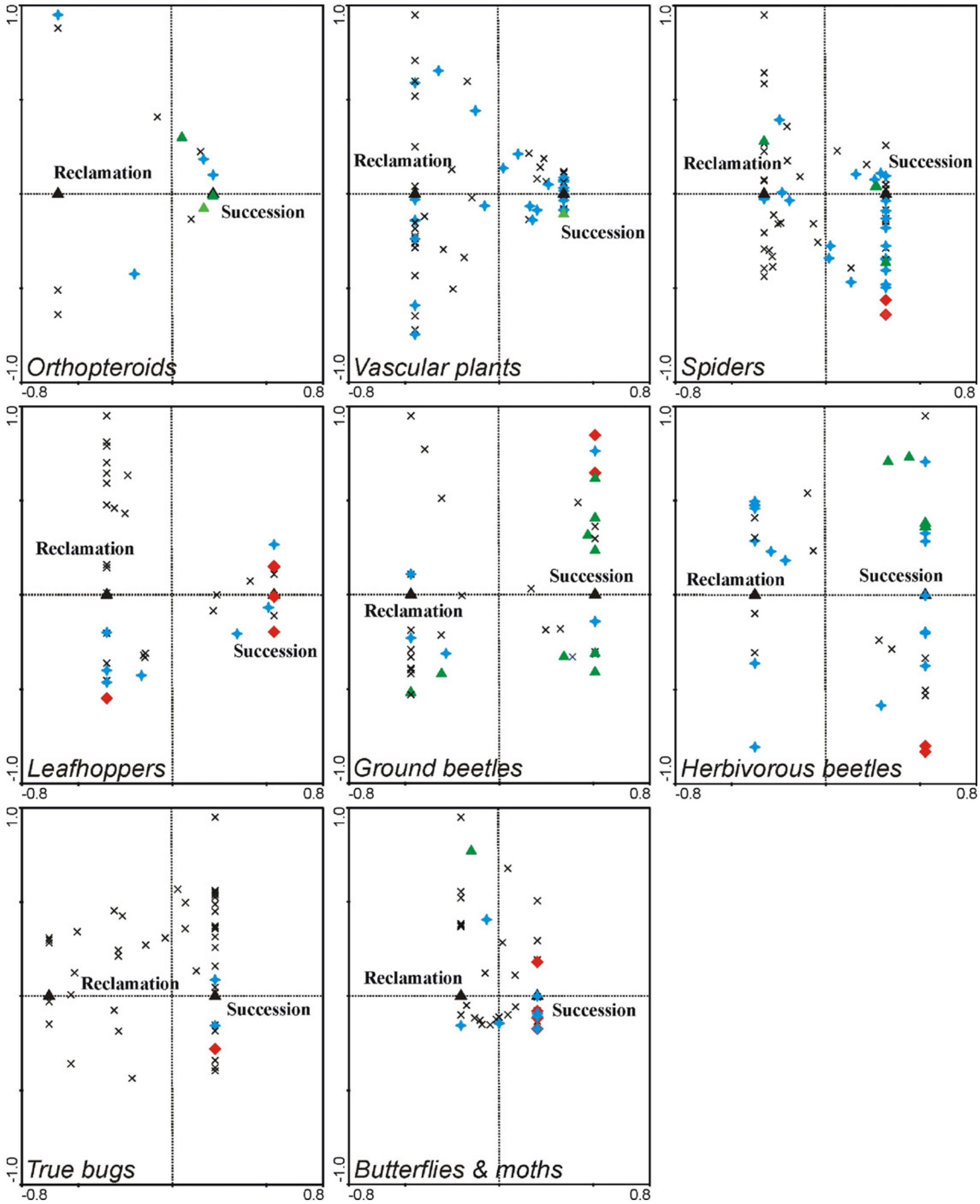

Fig. 2. CCA diagrams showing the relationships of vascular plants and seven studied arthropod groups to the restoration *METHOD*. Only species with the highest fits to the ordination models (>4%) are visualised. The symbols distinguish red-listed species (red diamonds), non red-listed species restricted to well-preserved xeric grasslands (green triangles), common xerothermophilous species (blue stars) and generalists plus species of non-xeric habitats (black crosses). See Table 2 for associated statistics and Appendix A for individual species' 1st axis ordination scores.

4. Discussion

In the heavily industrialised and agricultural Kladno district, a relatively high proportion of species colonising black coal spoil dumps are either nationally threatened, or represent xeric habitat specialists (see Table 1 and Appendix A). This illustrates a high conservation value of these land forms in the biologically depauperate landscape. Further, none of the studied groups of vascular plants and arthropods responded positively to technical reclamation, documenting that technical reclamation decreases the conservation value. Only leafhoppers and herbivorous beetles displayed slightly higher species richness in technically reclaimed plots, but threatened and xeric specialist representatives of these groups still inclined towards spontaneous succession, and the species traits such as rarity or decline should be primarily considered in conservation prioritisation (Thomas et al., 1994; Tropek et al., 2008).

We interpret our results by the starkly contrasting impact of the two restoration methods on the resulting habitats structure. Covering sites by fertile soil diminishes microtopographic heterogeneity and increases nutrients, as was shown in Tropek et al. (2010) in detail. These conditions disfavour stress-tolerant

Table 2
Results of the canonical correspondence analyses (CCA) of the restoration *METHOD* impact on the community composition of the studied taxa.

	1st axis F	1st axis eigenvalue	% Explained variation[a]
Orthopteroids	17.3***	0.33	12.8
Vascular plants	4.0***	0.51	12.6
Spiders	14.8***	0.47	11.1
Leafhoppers	11.3***	0.35	8.8
Ground beetles	10.3***	0.37	8.0
Herbivorous beetles	6.9***	0.24	5.5
True bugs	6.7***	0.31	5.4
Butterflies and moths	3.1***	0.22	5.0

[a] The variation in species data explained by the first ordination axis.
*** $P < 0.001$.

slowly growing plants, including rare xerothermophilous species (Prach et al., 1999), and this is further augmented by sowing mixtures of well-establishing competitive species. Following these arguments, we interpret the general negative response of vascular plants to technical reclamation in all analyses, consistently with the previous studies of limestone quarries (Tropek et al., 2010) and lignite spoil dumps (Hodacova and Prach, 2003; Mudrak et al., 2010).

The responses of prevailingly herbivorous arthropods (i.e., orthopteroids, leafhoppers, herbivorous beetles, true bugs, and butterflies and moths) are more complicated. The general preference of the red-listed species to spontaneous succession is consistent across all groups and corroborates the findings by Tropek et al. (2010). It could be easily attributed to the higher microhabitat heterogeneity of the spontaneously restored plots (e.g., Haddad et al., 2001; Tropek et al., 2010), and perhaps to a dependency of many endangered herbivores on stress-tolerant plants, many of which are declining (e.g., Dennis et al., 2004).

In terms of species richness, the technically restored plots hosted slightly richer communities of leafhoppers and herbivorous beetles. This pattern could be partly due to relatively low total species richness of the studied groups on the dumps, with a high proportion of the common generalists. Herbivorous generalists rarely appreciate the higher habitat heterogeneity of the spontaneously restored sites, preferring the higher productivity of technically reclaimed ones (Huston, 1979; Haddad et al., 2001). We also found no difference between leafhoppers and butterflies and moths communities, with regard to the restoration methods, in xeric specialisation. As the most specialised species of well preserved xeric grasslands preferred the spontaneously restored plots (Fig. 2), we explain this by non-significant patterns in less specialised xerothermophilous species. Xeric specialisation of these groups did not differ between restoration methods also in limestone quarries (Tropek et al., 2010) which would be caused by some unrevealed more general traits. Still, the overwhelming majority of individuals of highly specialised and/or endangered species preferred the spontaneous succession both in this study (Fig. 2) and in our previous study of limestone quarries (Tropek et al., 2010).

The communities of both prevailingly carnivorous groups (i.e., spiders and ground beetles) have positive affinities to the spontaneously restored plots in all analyses. While these results are in concordance with the limestone quarries study (Tropek et al., 2010) in case of spiders, ground beetles exhibited no significant response in the previous study. We interpret it by a higher proportion of the endangered and/or highly specialised ground beetles recorded on the black coal spoil dumps than in the quarries. As a rule, more specialised species of both groups require richly structured environments, provided by spontaneous succession but not by technical reclamation, which replaces structural diversity by uniformity (Prach and Hobbs, 2008; Mudrak et al., 2010; Tropek et al., 2010).

The evidence that black coal spoil dumps left to spontaneous succession offer great conservation potential thus corroborates our earlier multi-taxa study of limestone quarries (Tropek et al., 2010). While the limestone quarries study targeted a protected area, where colonisation by endangered species from a rich regional species pool was expected, the present study originated from an anthropically impoverished region with very few natural habitats. Both studies and multiple single-taxa comparisons of lignite spoil dumps (Hodacova and Prach, 2003; Holec and Frouz, 2005; Mudrak et al., 2010) document that in increasingly homogenised landscapes, post-mining features left to spontaneous succession provide surrogate habitats for sensitive and declining specialists (reviewed in Lundholm and Richardson, 2010).

Spontaneous vegetation succession in post-mining sites is remarkably slower, creating heterogeneous mosaics of microhabitats such as open rocks, sparse grasslands and xeric scrubs (e.g., Wheater and Cullen, 1997; Prach and Pysek, 2001; Tropek et al., 2010). This heterogeneity is crucial for the coexistence of multiple species, whose original environments, such as riverine gravel beds, landslides or nutrient-poor grasslands, have declined across Europe (e.g., Benes et al., 2003; Schulz and Wiegleb, 2000; Wenzel et al., 2006). The conservation value of spontaneously vegetated sites can be further augmented by such cheap interventions as sowing of conservation-desired plants from nearby natural habitats, and/or suppression of invasive and/or strongly competitive plants (Novak and Prach, 2010; Richardson et al., 2010). It follows that technical interventions such as levelling off sites, importing topsoil and sowing/planting fast growing plants should be avoided as hostile for biodiversity unless other public concerns (e.g., erosion risks, acid rock drainage, stream sedimentation, toxin leaks, public safety issues) outweigh it (Benes et al., 2003; Prach and Hobbs, 2008; Tropek et al., 2010). Admittedly, the available evidence mainly originates from densely populated temperate regions, where homogenisation of once-diverse land uses, rather than direct habitat loss, represents the greatest threat to biodiversity (e.g., Reif et al., 2009; Ekroos et al., 2010). The restoration goals might differ, e.g., in forested regions, where mining causes rapid attrition of otherwise intact land covers. Research on the conservation efficiency of various restoration methods from diverse regions is hence much needed. Still, we suppose that post-mining sites might offer valuable habitat surrogates in such long-cultivated regions as temperate and subtropical Asia, or regions with Mediterranean climate, where the biodiversity also long coexisted with traditional land use patterns (cf. Grove and Rackham, 2001; Katoh et al., 2009).

Even in temperate Europe, however, a strong discrepancy between the rapidly advancing knowledge and practical routines still exists. For reasons discussed elsewhere (Prach and Hobbs, 2008; Tropek et al., 2010; Lundholm and Richardson, 2010; Tropek and Konvicka, 2011), many national legislations strongly favour technical reclamation. No post-mining site is formally reserved for natural processes in the Czech Republic (Prach et al., 2011); only 15% of each mining region is reserved for spontaneous succession in Germany (Schulz and Wiegleb, 2000); and the situation is likely to be similar elsewhere (e.g., Ursic et al., 1997; Carrick and Kruger, 2007).

In summary, the conservation potential of post-mining sites, the low cost of directed successional processes, and the moral imperative to slow down the biodiversity decline all advocate for replacement of costly reclamation schemes by spontaneous succession processes wherever possible. At present, the necessary legal changes are being intensively discussed, and we hope that our results will strengthen the endeavours towards the more biologically benign restoration of post-mining sites.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.ecoleng.2011.10.010.

References

Benes, J., Kepka, P., Konvicka, M., 2003. Limestone quarries as refuges for European xerophilous butterflies. Conserv. Biol. 17, 1058–1069.

Bradshaw, A., 1997. Restoration of mined lands—using natural processes. Ecol. Eng. 8, 255–269.

Carrick, P.J., Kruger, R., 2007. Restoring degraded landscapes in lowland Namaqualand: lessons from the mining experience and from regional ecological dynamics. J. Arid Environ. 70, 767–781.

Cremene, C., Groza, G., Rakosy, L., Schileyko, A.A., Baur, A., Erhardt, A., Baur, B., 2005. Alterations of steppe-like grasslands in eastern Europe; a threat to regional biodiversity hotspots. Conserv. Biol. 19, 1606–1618.

Dennis, R.L.H., Hodgson, J.G., Grenyer, R., Shreeve, T.G., Roy, D.B., 2004. Host plants and butterfly biology. Do host–plant strategies drive butterfly status? Ecol. Entomol. 29, 12–26.

Ekroos, J., Heliola, J., Kuussaari, M., 2010. Homogenization of lepidopteran communities in intensively cultivated agricultural landscapes. J. Appl. Ecol. 47, 459–467.

Farkac, J., Kral, D., Skorpik, M. (Eds.), 2005. List of Threatened Species in the Czech Republic. Invertebrates. AOPK CR, Prague.

Grove, A.T., Rackham, O., 2001. The Nature of Mediterranean Europe: An Ecological History. Yale University Press, New Haven.

Haddad, N.M., Tilman, D., Haarstad, J., Ritchie, M., Knops, J.M.H., 2001. Contrasting effects of plant richness and composition on insect communities: a field experiment. Am. Nat. 158, 17–35.

Hodacova, D., Prach, K., 2003. Spoil heaps from brown coal mining: technical reclamation versus spontaneous revegetation. Restor. Ecol. 11, 385–391.

Holec, M., Frouz, J., 2005. Ant (Hymenoptera: Formicidae) communities in reclaimed and unreclaimed brown coal mining spoil dumps in the Czech Republic. Pedobiologia 49, 345–357.

Huston, M., 1979. General hypothesis of species-diversity. Am. Nat. 113, 81–101.

Kadlec, T., Tropek, R., Konvicka, M., in press. Timed surveys and transect walks as comparable methods for monitoring butterflies in small plots. J. Insect Conserv.

Katoh, K., Sakai, S., Takahashi, T., 2009. Factors maintaining species diversity in satoyama, a traditional agricultural landscape of Japan. Biol. Conserv. 142, 1930–1936.

Krauss, J., Alfert, T., Steffan-Dewenter, I., 2009. Habitat area but not habitat age determines wild bee richness in limestone quarries. J. Appl. Ecol. 46, 194–202.

Leps, J., Smilauer, P., 2003. Multivariate Analysis of Ecological Data Using CANOCO. Cambridge University Press, Cambridge.

Lundholm, J.T., Richardson, P.J., 2010. Habitat analogues for reconciliation ecology in urban and industrial environments. J. Appl. Ecol. 47, 966–975.

Mudrak, O., Frouz, J., Velichova, V., 2010. Understory vegetation in reclaimed and unreclaimed post-mining forest stands. Ecol. Eng. 36, 783–790.

Novak, J., Prach, K., 2010. Artificial sowing of endangered dry grassland species into disused basalt quarries. Flora 205, 179–183.

Prach, K., Hobbs, R.J., 2008. Spontaneous succession versus technical reclamation in the restoration of disturbed sites. Restor. Ecol. 16, 363–366.

Prach, K., Pysek, P., 2001. Using spontaneous succession for restoration of human-disturbed habitats: experience from Central Europe. Ecol. Eng. 17, 55–62.

Prach, K., Pysek, P., Smilauer, P., 1999. Prediction of vegetation succession in human-disturbed habitats using an expert system. Restor. Ecol. 7, 15–23.

Prach, K., Rehounkova, K., Rehounek, J., Konvalinkova, P., 2011. Ecological restoration of central European mining sites: a summary of a multi-site analysis. Landscape Res. 36, 263–268.

Prochazka, F., 2001. Black and red list of vascular plants of the Czech Republic—2000. Priroda 18, 1–166.

Reif, J., Storch, D., Vorisek, P., Stastny, K., Bejcek, V., 2009. Bird–habitat associations predict population trends in central European forest and farmland birds. Biodivers. Conserv. 17, 3307–3319.

Richardson, P.J., Lundholm, J.T., Larson, D.W., 2010. Natural analogues of degraded ecosystems enhance conservation and reconstruction in extreme environments. Ecol. Appl. 20, 728–740.

Rosenzweig, M.L., 2003. Win–Win Ecology: How the Earth's Species Can Survive in the Midst of Human Enterprise. Oxford University Press, New York.

Rydgren, K., Nordbakken, J.F., Austad, I., Auestad, I., Heegaard, E., 2010. Recreating semi-natural grasslands: a comparison of four methods. Ecol. Eng. 36, 1672–1679.

ter Braak, C.J.F., Smilauer, P., 2002. CANOCO Reference Manual and CanoDraw for Windows User's Guide: Software for Canonical Community Ordination (Version 4.5). Microcomputer Power, Ithaca, NY.

Schulz, F., Wiegleb, G., 2000. Development options of natural habitats in a post-mining landscape. Land Degrad. Dev. 11, 99–110.

Thomas, J.A., Morris, M.G., Hambler, C., 1994. Patterns, mechanisms and rates of extinction among invertebrates in the United-Kingdom. Philos. Trans. R. Soc. B 344, 47–54.

Tropek, R., Kadlec, T., Karesova, P., Spitzer, L., Kocarek, P., Malenovsky, P., Banar, P., Tuf, I.H., Hejda, M., Konvicka, M., 2010. Spontaneous succession in limestone quarries as an effective restoration tool for endangered arthropods and plants. J. Appl. Ecol. 47, 139–147.

Tropek, R., Konvicka, M., 2011. Should restoration damage rare biotopes? Biol. Conserv. 144, 1299.

Tropek, R., Spitzer, L., Konvicka, M., 2008. Two groups of epigeic arthropods differ in colonising of piedmont quarries: the necessity of multi-taxa and life-history traits approaches in the monitoring studies. Community Ecol. 9, 177–184.

Ursic, K.A., Kenkel, N.C., Larson, D.W., 1997. Revegetation dynamics of cliff faces in abandoned limestone quarries. J. Appl. Ecol. 34, 289–303.

WallisDeVries, M.F., Poschlod, P., Willems, J.H., 2002. Challenges for the conservation of calcareous grasslands in northwestern Europe: integrating the requirements of flora and fauna. Biol. Conserv. 104, 265–273.

Walker, L.R. (Ed.), 1992. Ecosystems of Disturbed Ground. Ecosystems of the World 16. Elsevier, Amsterdam.

Wenzel, M., Schmitt, T., Weitzel, M., Seitz, A., 2006. The severe decline of butterflies on western German calcareous grasslands during the last 30 years: a conservation problem. Biol. Conserv. 128, 542–552.

Wheater, C.P., Cullen, W.R., 1997. The flora and invertebrate fauna of abandoned limestone quarries in Derbyshire. Restor. Ecol. 5, 77–84.

Wiegleb, G., Felinks, B., 2001. Primary succession in post-mining landscapes of Lower Lusatia—chance or necessity. Ecol. Eng. 17, 199–217.