DOES EXPERIMENTAL NON-RECLAIMED SITES DIFFER FROM TECHNICALLY RECLAIMED AREAS IN THE RISK OF ARTIFICIAL BIRD NEST PREDATION?

A CASE STUDY IN RADOVESICKÁ SPOIL HEAP

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ABSTRACT

Areas left to natural development have been found to be sites with higher diversity and conservation value of local communities, including bird communities, compared to artificial reclamation of post-industrial areas. Most of the studies conducted so far have focused primarily on bird communities of post-mining areas, in terms of the diversity and richness of species. Our study dealt with bird nest predation on specific case of two experimental sites (20 and 32 ha) with more than a 20-year history of primary spontaneous succession established within the technical reclamation of the Radovesická spoil heap (approx. 1,200 ha, North Bohemia, Czech Republic). In the spring of 2018, we conducted a predation experiment using artificial nests (ground and elevated), installed within both succession areas and beyond, in the adjacent artificially reclaimed areas. We monitored the way of restoration and the distance of the nest placement from the succession-reclamation sites edge. The rate of predation was very high: 92.5 % in reclaimed area and 89.4 % in spontaneous successions. None of the observed factors analysed in the generalised linear model (GLM) have conclusively explained the risk of predation. The two experimental succession sites did not differ from the surrounding reclaimed sites in terms of the risk of predation, nor did they significantly influence predation risk on reclaimed sites. We believe that both relatively small and mutually isolated areas do not provide enough of an inner environment without or with at least a limited effect of predation pressure coming from adjacent reclaimed areas.

Keywords: predation risk, spontaneous development, technical reclamation, nest predator, matrix effect

INTRODUCTION

Bird nest predation is considered to be one of the major factors behind the decline of avifauna (e.g. Ricklefs, 1969 or Martin, 1993). It may cause a loss of up to 80 % of nests (Martin, 1993). Among other things, increased nest predation is due to landscape fragmentation (e.g. Donovan *et al.*, 1997; Stephens *et al.*, 2004). In addition to the direct loss of habitats or shrinking and deepening isolation of individual habitat patches (e.g. Wilcox & Murphy, 1985), the influence of the edge effects (Paton, 1994) is emphasised in ecotone between two adjacent habitats making the ecoton an "ecological trap" for the nesting birds that are exposed to higher predation pressure in the ecoton (Gates & Gysel, 1978; Chalfoun *et al*., 2002).

Reclamation of post-mining areas is aimed at restoring the landscapes disturbed or completely destroyed by extraction, including the restoration of functional and stable ecosystems (Hüttl & Gerwin, 2005; Macdonald *et al*., 2015). In addition to technical, agricultural, forestry or hydric reclamation, near-natural methods of restoration or even leaving at least part of the area to a natural spontaneous succession are being increasingly applied (e.g. Bradshaw & Hüttl, 2001; Hodačová & Prach, 2003; Tischew & Kirmer, 2007; Prach & Hobbs, 2008; Baasch *et al*., 2012). The landscape disturbed by mining activities creates new habitats that are immediately spontaneously occupied by plant, invertebrate and vertebrate colonisers (e.g. Prach & Pyšek, 2001; Bröring & Wiegleb, 2005; Kirmer *et al*., 2008). These succession areas are found to be sites with higher diversity and conservation value of local communities, as compared to artificial reclamation, especially the early stages of succession (Prach *et al*., 2011; Hendrychová *et al*., 2012; Hendrychová & Bogusch, 2016, Hendrychová *et al*., 2020).

The described phenomena are also valid for bird communities (Bejček & Šťastný, 1984). In terms of nature conservation, the early stages of succession, i.e. the open habitats without or with sparse vegetation cover are the most important (Clavero *et al*., 2011; Šálek, 2012). However, later succession stages are also valuable as they usually outperform technically reclaimed areas with their biodiversity (Hendrychová *et al*., 2009; Šálek, 2012). Most of the conducted studies focused on bird communities of post-industrial habitats mainly in terms of diversity and richness of species (e.g. Karr, 1968; Bejček & Šťastný, 1984; Hendrychová *et al*., 2009; Clavero *et al*., 2011; Šálek, 2012). Fewer studies (e.g. Purger *et al*., 2004 a, b) have dealt with nesting success or predation directly in post-industrial mining areas.

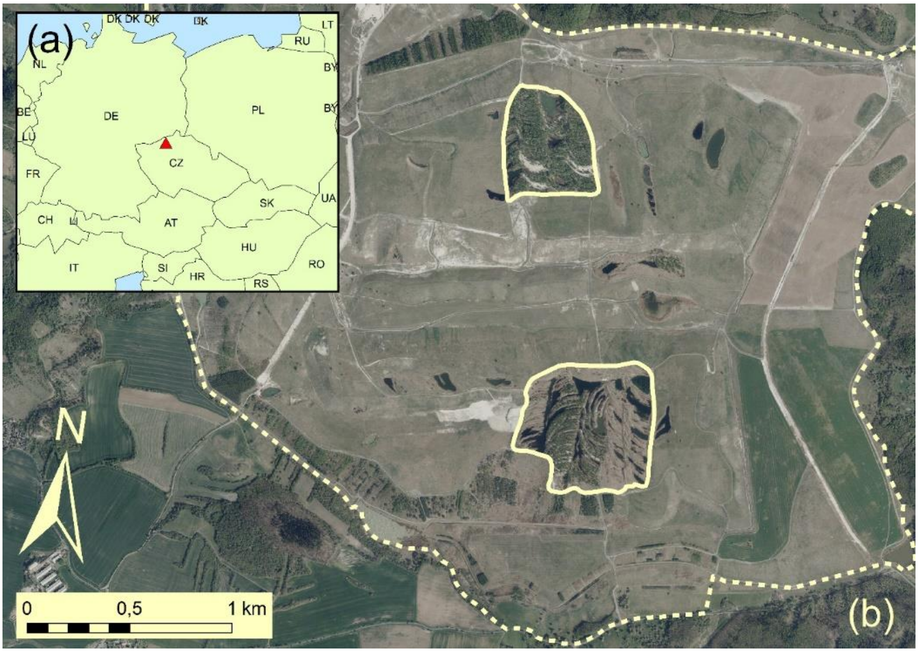
During a pilot research conducted in 2016, we recorded a very high predation rate 84.4 % (76 of 90, $p < 0.0001$) of experimental artificial bird nests in the Radovesická spoil heap a reclaimed post-mining locality in the Czech Republic. We also noted a possible positive effect of the present experimental succession areas. The predation rate in these areas reached 66.7 % (4 of 6, $p = 0.4142$), but due to the small number of nests located here, it was inconclusive (Novák, 2017). Therefore, two years later we focused directly on those experimental sites. The aim of this study was to investigate the relative risk of nest predation in the restored post-mining site primarily depending on the way of the restoration (spontaneous succession vs. technical reclamation). The intention was to find out whether the risk of nest predation on the successional areas differs from the risk of nest predation in the artificially reclaimed areas and whether the presence of succession areas may affect the risk of nest predation in artificially reclaimed areas.

MATERIAL AND METHODS

Study area

The study area is located on the Radovesická spoil heap (50°32'34.507"N, 13°49'53.891"E) situated in the Most Basin in Northern Bohemia in the Czech Republic, in the region affected by intensive lignite surface mining. Between 1964 and 2003, it was used to deposit overburden soils from the nearby surface mine. In total, almost 680 million m^3 of overburden, mainly sand-clay soils, were deposited here. The surface of the heap occupies an area of 1,200 ha. Since 1986, technical reclamation of the area has been gradually progressing. Surface landscaping has been carried out, as well as fertilisation of the upper layers of soils, road construction, drainage channels, erosion control measures and biological reclamation. Two mutually isolated research areas were left for continuing natural succession in the middle of the spoil heap: the southern area of 32 hectares since 1998; and the northern area of 20 hectares since 1990 (Figure 1). The smallest distance between the two areas is 833 m. The distance of the succession areas to the edge of the spoil heap is 278 m at the north and 551 m at the south. The wide vicinity of the succession areas is completely made up of agricultural or forestry reclamations with a levelled surface and dominant permanent grasslands established by sowing clover-grass mixtures poor in species, only minimally complemented by a young forest plantations. Solitary trees and small water bodies were left sporadically on grasslands during reclamation. In contrast with these large grassy plains, both succession areas have never undergone landscaping or fertilisation of the upper soil layers, and both have a very varied microrelief of the surface. It is composed of characteristic dunes, i.e. parallel strips of deposited spoil heap soil alternated with terrain depressions. A number of smaller and larger natural water bodies and wetlands have formed in these depressions. The "sharp" edge in between the technically reclaimed area and both succession areas is highlighted by the presence of service roads.

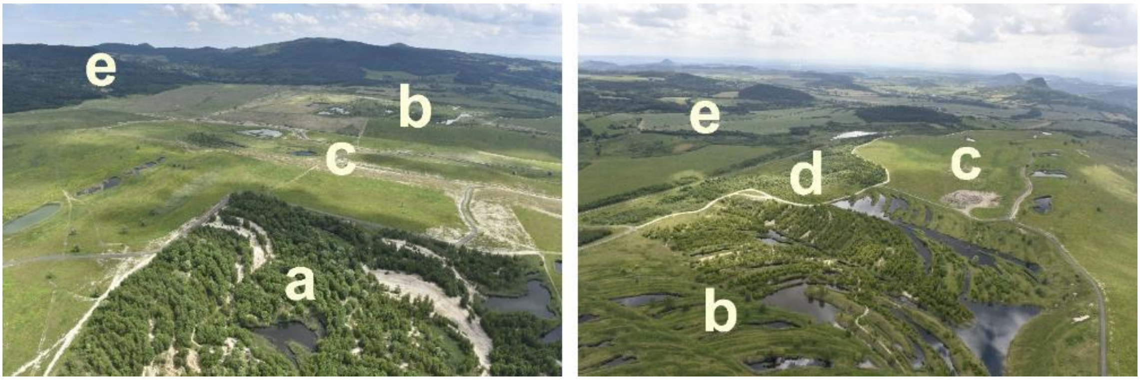
Fig. 1: Radovesická spoil heap location in the Czech Republic (a) and aerial map (b) with highlighted boundaries of the spoil heap (dashed line) and both non-reclaimed experimental sites (full line).



The naturally formed vegetation of succession areas has an open forest-steppe character with small vegetation free sites. Vertical and horizontal vegetation structure is very diversified (vegetation structure determined by remote sensing methods (LiDAR) and bird community of Radovesická spoil heap were also well described by Moudrý *et al.*, 2021). Spontaneously developing habitats are dominated by grows of European birch (*Betula pendula*), aspen (*Populus tremula*), goat willow (*Salix caprea*) and other shrubs. The bush grass (or also wood small-reed) (*Calamagrotidis epigejos*) is typical of grassy parts. Common reed (*Phragmites australis*) is often found in waterlogged depressions (Prach &

Pyšek, 2001; personal observation). The northern succession site is more covered with denser woody growth and contains some sandy sites without vegetation. The southern succession site has a character of more opened grasslands with dispersed woody growth and larger number of water bodies (Figure 2). Bird communities are represented by species typical of individual succession stages, complemented by other common species (Hendrychová *et al*., 2009). In total, 34 species including 14 species specially protected in the Czech Republic were found in succession areas (Šálek, 2012).

Fig. 2: Aerial photos of northern succession site (a), southern succession site (b), technical reclaimed areas be agricultural reclamation (c) or afforestation (d) and surrounding landscape (e).



Research design

We used artificial ground nests and, in the case of both succession areas with the presence of trees, even elevated nests. We consider the use of artificial nests to be justified alternative to natural nests, since we did not investigate the rate of nest predation in a particular bird species but rather the relative risk of nest predation depending on the post-mining area management (Major & Kendal, 1996; Pärt & Wretenberg, 2002; Zanette, 2002).

At the beginning of May 2018, we installed a total of 173 experimental nests: 80 in technically reclaimed areas; 46 (23 ground and 23 elevated) in the northern succession area, and 47 (25 ground and 22 elevated) in the southern succession area. The nests were housed in a total of 16 pre-defined line transects leading in various directions roughly perpendicular to the edge between the succession area and the technically reclaimed area. The nests were placed approximately at the edges and then further at different distances from the edge to the outside and inside of both succession areas (Paton, 1994; Reino *et al*., 2010). In the reclaimed areas, the remotest nest was located 509 meters from the edge. It was at a distance of only 218 m inside the succession areas, for spatial reasons. For easier searching, each site was labelled by sign in the form of a strip of unobtrusive colour, tied to a branch or a twig pinned in the ground at a distance of about 5 m from the installed nest (Major & Kendal, 1996).

Created nests very closely simulated the nests of birds nesting on the ground, such as Eurasian skylark (*Alauda arvensis*), whinchat (*Saxicola rubetra*) or tree pipit (*Anthus trivialis*), as well as the birds nesting in trees or bushes, such as Eurasian blackbird (*Turdus merula*), song thrush (*Turdus philomelos*) or Eurasian blackcap (*Sylvia atricapilla*). All species were observed in the study area (Šálek, 2012). The ground nests most often had the form of a shallow pit in the ground with a size of about 10 cm in diameter, laid out with local dry plant material. The elevated nests were made in advance as a shallow open dish with a diameter of about 10 cm, depth of about 5 cm, and an inner structure woven from metal wires, lined by a mixture of clay and dry grass, and wrapped with dry plant material. Each nest was filled with two eggs of Japanese quail (*Coturnix japonica*) and one plasticine egg of inconspicuous grey colour, corresponding to the quail egg in size and shape, allowed to detect predators through the imprints in the plasticine egg (Major & Kendal, 1996; Maier & Degraaf, 2000). The plasticine eggs were fixed in the ground nests with a 12cm nail pinched in the ground (with the head masked by plasticine) and attached to the nest structure with a wire in the case of the elevated nests made it difficult for the eggs to be removed from the nest (Suvorov *et al*., 2014). All materials and aids were allowed to ventilate in the open air for two weeks (Purger *et al*., 2004a) and we always used latex gloves to minimise the influence of human door transmission (Whelan *et al*., 1994; Reino *et al*., 2010; Sánchez-Oliver *et al*., 2014).

During the installation we made a photographic documentation of each nest with a nest concealment reading card (similar to Donovan *et al*., 1997). One photograph of the nest was taken from a height of about 1 m and another from a distance of about 5 m from four different, preferably mutually perpendicular directions, from an adult standing height. The concealment of the nests was optometrically detracted on a scale of 0 to 100 % (Remeš, 2005). In elevated nests, their height above the ground in cm was also registered.

The nests were exposed to predators for two weeks, which corresponds to the incubation period of many songbirds in the Czech Republic. Each nest was revisited after installation only for the check-up to reduce the effect of the observer and to keep its site hidden as far as possible from predators (Major, 1990). The fate of the nest was registered: (1) non-predated; (2) predated (if at least one of the eggs was taken away or damaged); (3) excluded from the research (if the nest was demonstrably destroyed by human activity). A possible predator of eggs and nests was determined in the taxonomic class of a mammal or a bird.

The data obtained was analysed in the R application, version 3.5.1 (R Development Core Team, 2018). We used the chi-squared test for goodness of fit to compare the difference between the numbers of predated and non-predated nests and between the number of nests predated by mammals or birds within one locality or one type of nest. To compare nest predation rates and the proportional representation of predators between the sites and between both types of experimental nests, Pearson's chi-squared test with Yates' continuity correction for 2 x 2 contingency tables were used. The average values of nest concealment in both types of environments were compared by a two-sample t-test. The probability of nest predation was analysed in a generalised linear model (GLM), in which the fate of the nest (1 = predated, 0 = non-predated) was the explained variable with binomial distribution. The relevance of the explanatory variables was tested by the chi-squared test. We have created two separate models for nests located in reclaimed areas and nests in succession areas. Both models consistently included explanatory variables of the smallest nest distance to the edge between the reclaimed and succession areas and the nest cover. In addition, the nest height above the ground was included in the GLM for nests installed in succession areas. A minimum probability level of p <0.05 was considered in all statistical analyses.

RESULTS

We collected data for a total of 152 experimental nests, including 67 in reclaimed areas and 85 in succession areas (Table 1). Although the rate of predation of experimental nests in succession areas was lower, it did not differ significantly from the rate of predation of experimental nests in reclaimed areas ($\chi^2 = 0.144$, $df = 1$, $p = 0.7046$). The predation rate did not differ significantly between both succession areas ($\chi^2 = 0.6684$, $df = 1$, $p = 0.4136$) nor was there a significant difference between the rate of predation of elevated and ground nests installed in succession areas ($\chi^2 = 1.016$, $df = 1$, $p = 0.3135$).

Table 1: Numbers of predated and non-predated experimental nests and the percentage of predation in each type of environment and depending on the nest height above the ground for nests installed in succession areas. Differences in the number of predated and non-predated nests were tested by the chi-squared test of good fit.

Nest site/type	*Number of predated nests*	*%*	*Number of non-predated nests*	*%*	χ^2	*df*	*p*
Reclaimed sites total	62	**92.5**	5	7.5	48.493	1	< 0.0001
Successional sites total	76	**89.4**	9	10.6	55.682	1	< 0.0001
- northern site	35	**85.4**	6	14.6	20.512	1	< 0.0001
- southern site	41	**93.2**	3	6.8	32.818	1	< 0.0001
- ground nests	41	**85.4**	7	14.6	24.083	1	< 0.0001
- elevated nests	35	**94.6**	2	5.4	29.432	1	< 0.0001

Table 2: Numbers and percentages of experimental nests divided according to their potential nest predators, depending on the type of research site and the nest height above the ground for nests installed in succession areas. Differences in the number of nests were tested by the chi-squared test of good fit.

	Aves		***Mammalia***				
Nest site/type	*Number of predated nests*	*%*	*Number of predated nests*	*%*	χ^2	*df*	*p*
Reclaimed sites total	23	**46.0**	27	**54.0**	0.320	1	0.5716
Successional sites total	55	**74.3**	19	**25.7**	17.514	1	< 0.0001
- northern site	21	**63.6**	12	**36.4**	2.455	1	0.1172
- southern site	34	**82.9**	7	**17.1**	17.780	1	< 0.0001
- ground nests	26	**65.0**	14	**35.0**	3.600	1	0.0578
- elevated nests	29	**85.3**	5	**14.7**	16.941	1	< 0.0001

We also determined a potential predator in 124 experimental nests (Table 2). Although mammals were slightly predominating in the reclaimed areas, the ratio between bird and mammal predators was almost balanced and did not differ significantly. In contrast, birds significantly dominated over mammals in the succession areas. The difference in the proportional representation of both taxonomic groups in each type of environment was statistically significant ($\chi^2 = 9.081$, $df = 1$, $p = 0.0026$). In the northern succession area, the predominance of birds over mammals was statistically insignificant, while in the southern area it was statistically significant. The proportional representation of individual taxonomic groups did not differ significantly between succession areas (χ^2 = 2.626, *df* = 1, *p* = 0.1051). For ground nests installed in succession areas, the predominance of bird predators was weakly inconclusive, while it was strongly significant in elevated nests. The difference in the proportional representation of predators was not as insignificant between the two types of nests (χ^2 = 2.974, *df* = 1, *p* = 0.0846)

The average value of nest concealment in reclaimed areas (36.7 %) was significantly lower than in nests located in succession areas (47.2 %) (*t* = -2.663, *df* = 150, *p* = 0.0086).

In both GLMs (Table 3), none of the observed predictors clearly demonstrated the predation of experimental nests.

Table 3: Separate generalised linear model for experimental nests located in reclaimed areas and succession areas. The parameters were tested by the chi-squared test.

	Estimate	*Std. Error*	*df*	*Deviance*	*p*
Reclaimed site nests					
Distance from the reclamation/succession edge	0.0007	0.0030	1	35.492	0.8046
Nest concealment	-0.0049	0.0178	1	35.508	0.7815
Successional site nests					
Distance from the reclamation/succession edge	0.0049	0.0065	1	54.645	0.4445
Nest concealment	0.0153	0.0193	1	54.693	0.4262
Nest height	0.0111	0.0079	1	56.436	0.1232

DISCUSSION

The studied succession areas represented habitats close to nature different from the surrounding predominantly agriculturally reclaimed area of the spoil heap, transformed into regularly managed grasslands. Therefore, we assumed that these different environments might differ in the risk of predation of artificial nests (e.g. Seitz & Zegers, 1993) or interact in one or both directions (regardless of whether positively or negatively) (Blitzer *et al*., 2012; Schneider *et al*., 2013). The succession areas could provide nesting birds with better vegetation cover for their nests and protection from predators, thereby, positively influencing the risk of nest predation (Götmark *et al*., 1995; Burhans & Thompson III, 2001; Weidinger, 2002; Whittingham & Evans, 2004). Or, on the contrary, they themselves could act negatively and be the source of predation pressure directed to their surroundings (Andrén, 1992; Söderström *et al*., 1998; van Der Vliet *et al*., 2008; Reino *et al*., 2010; Ludwig *et al*., 2012). We also considered the possible presence of an edge effect on the predation of experimental nests in the environment with a steep gradient in primary productivity on their divide (e.g. Angelstam, 1986).

Although the succession areas provided better cover for experimental nests compared to nests placed in reclaimed areas and the experimental nests placed there had lower predation rates, the difference between the predation levels found was not statistically significant. The predation rates found were very high in both types of studied sites (89.4 % and 92.5 %, respectively) compared to similar previous studies (see, for example; Paton, 1994), but not isolated (e.g. Sanchez-Oliver *et al*., 2014). However, none of the predictors investigated in the study, and primarily aimed at monitoring the potential interaction between the investigated sites explained the predation rate conclusively. The influence of succession areas on the predation of experimental nests located in their surroundings in a technically reclaimed area has not been proven. Although, according to the GLM, the probability of nest predation decreased slightly with proximity to succession areas, this tendency was very weak and inconclusive. Moreover, this dependence was also found in the opposite direction, i.e. from the edge of the succession sites into their interior. However, it was inconclusive even in this case. Thus, the influence of the edge effect at the interface of both environments was not detected (Andrén, 1995; Lahti, 2001; Batáry & Báldi, 2004). Rather than the management of the areas, the characteristics of the habitats and spatial relationships seem to explain the high risk of nest predation. The environment of the Radovesická spoil heap consists mainly of open grassland complemented by smaller areas of scattered greenery or young forest reclamation. Such an environment promotes a high number of predator prey (personal observation) such as rodents (*Rodentia*) or lagomorphs (*Lagomorpha*) (Hulbert *et al*., 1996). Higher prey rates can hence lead to an increased predator frequency and activity, and consequently increased nest predation (Vickery *et al*., 1992; Yanes & Suarez, 1996). The predation rate in the given habitat correlates with the abundance of nest predators in the habitat (Andrén *et al*., 1985). The high predator counts can then suppress or completely conceal the significant mutual influence between the neighbouring habitats, including the edge effect on their interface; the location of the nests farther from the edge does not reduce the risk of its predation (Renfrew *et al*., 2005). This applies in particular to bigger nest predators who are both trophic and habitat generalists and are able to enter diverse types of environments and move relatively freely between them (Gehring & Swihart, 2003). In addition to the food offer, the high local abundance of predators could be supported by the character of the heap as a relatively large area without a permanent human presence surrounded by a predominantly agricultural or urbanized landscape, attracting predators (and the prey) as their temporary or permanent habitat (refugia), mainly in inner islands of forest stands, including both successional sites (Müller *et al*., 2017).

The composition of presumable predators in both types of environments corresponded to the assumption of greater significance of bird nest predators in enclosed (e.g. forest) habitats, as birds seek prey visually. To be able to do this, they need elevated viewpoints, such as tree stands to search for prey (Angelstam, 1986; Paton, 1994; van Der Vliet *et al*., 2008). In the reclaimed areas, most of which were large-scale permanent grasslands, the ratio between birds and mammals was balanced (mammals even slightly dominated). However, in the succession sites formed by dominant natural succession wood forests, birds significantly predominated. Birds were also significant presumable predators of elevated nests (Söderström *et al*., 1998), which may be less accessible or even inaccessible to some mammalian species. (Ludwig *et al*., 2012). The inconclusiveness of the higher prevalence rate of elevated sites compared to the ground nests corresponds to the differing results of previous studies (e.g., Martin, 1993; Suvorov *et al*., 2014) and probably depends on the composition of the local nest predator community. When mammals are the dominant nest predators, ground nests are more predated and vice versa (Ratti & Rees, 1988).

Direct observations and signs of presence made it possible to define the range of potential bird nest predators active in the study area. Of the bird predators, it was mainly Eurasian jay (*Garrulus glandarius*), especially in forest stands in the territory of succession sites. In open habitats, there were common buzzard (*Buteo buteo*) and western marsh-harrier (*Circus aeruginosus*), which was tied to several artificial water reservoirs built during the operation and reclamation of the heap. Among mammals, it was a highly abundant wild boar (*Sus scrofa*), as well as red fox (*Vulpes vulpes*), European badger (*Meles meles*) and especially in forest stands European pine marten (*Martes martes*). Although we did not directly observe the species composition, the above list of nest predators corresponds well to the findings of other studies in Central Europe (e.g. Šálek *et. al*., 2004 or Purger *et al*., 2004b and other studies in Batáry & Báldi, 2004). Also predation of nests by other species of corvids (*Corvidae*) (van Der Vliet *et al*., 2008; Bravo *et al*., 2020) and small rodents could be expected (Remeš, 2005; Ludwig *et al*., 2012).

CONCLUSIONS

The succession sites represent two mutually isolated naturally predominantly forested areas, situated within artificially established and managed permanent grasslands. In fact, these are fragmented forest habitats within an agricultural landscape matrix. Based on the assumption that the technically reclaimed area is under great predation pressure, which was reflected in the high rate of predation of experimental nests located there, the succession areas themselves may be under the influence of their surroundings, i.e. under the influence of the landscape matrix (Forman, 1995; Poulin and Villard, 2011). Although they may offer an environment providing potentially better nesting shelter compared to open grasslands, we believe that the two relatively small and isolated (referring to the total area of the spoil heap) areas may not provide enough of an inward environment without or with at least a limited influence (e.g. by predation pressure), originating from adjacent reclaimed areas (Begon *et al*., 1986; Forman & Godron, 1986).

Our case study is the initial insight into the functioning of nest predation risk at reclaimed post-mining sites. It is appropriate to extend the experiment on other similar post-mining sites – preferably those that once again contain habitats with spontaneous succession within their territory.

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CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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