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# Succession of arthropods on xerothermophilous habitats formed by sand quarrying: Epigeic beetles (Coleoptera) and orthopteroids (Orthoptera, Dermaptera and Blattodea)

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ABSTRACT

European Commision suggested the remedying biodiversity damage should be achieved through restoration of the environment as a whole to its baseline condition. Here we provide the evidence on non-market goods gained when spontaneous succession is allowed at sites subject to previous sand or gravel-sand quarrying, arguing for estimation of the value of natural resources formed during the quarrying process and for their reflection in the restoration plans. We analyzed the assemblages of beetles and orthopteroids formed at xerothermophilous microhabitats subject to spontaneous succession for 2–5, 6–15 and >15 years, or formed at reclaimed sites within sandpits and gravel-sandpits in the Czech Republic, Central Europe. We collected a total of 7259 individuals from 401 species of beetles, and 2785 individuals from 43 species of orthopteroids. We found 62 red-listed species, among them eight CR species, including abundant *Psammodius asper* and *Zorochros meridionalis*; *Labidura riparia* (EN) was eudominant orthopteroid of early successional stages. Xerothermes subject to spontaneous succession hosted 95% of red-listed species found, whereas reclaimed sites hosted mostly the generalists and only 24% of red-listed species found. We identified 13 species specialized for drift sand (all beetles); most were present at xerothermes subject to intermediate or long-term succession. We identified 53 beetle and five orthopteroid species specialized for gravel-sand river terraces and xerothermophilous steppes. Striking 97% of red-listed beetles and 80% of red-listed orthopteroids found in the sandpits were absent in other comparable postindustrial habitats with fine-grained substrates. Sandpit xerothermes thus serve as important secondary strongholds for psammophilous beetles and orthopteroids.



## 1. Introduction

Quarrying of aggregates (sand, gravel-sand, gravel and crushed stone) forms the biggest branch of mining industry by production volume (Regueiro et al., 2002) and the most valuable non-fuel mineral commodity in the world (Menegaki and Kaliampakos, 2010). Contrary to the ore, fuel, coal and lignite mining, the aggregates quarrying does not lead to the exposition of toxic minerals, in particular heavy metals, and the newly formed habitats also do not suffer from low pH resulting otherwise, e.g., from the aeration of pyrite in lignite mines and associated spoil heaps. The negligible toxicity of such habitats should be considered an important factor because the previous research had already shown that the less toxic substrates are subject to faster colonization by various groups of arthropods, but such sites display also consistent trend from an open pioneer to a woodland community (Wanner and Dunger, 2002). The toxic substrates are considered an environmental and health hazard (Haynes 2009; Martinez et al., 2013; Bortey-Sam et al., 2015), and thus are usually subject to reclamation, and such habitats usually disappear after being overlaid with topsoil. Contrary to that, the presence of unreclaimed soil in sandpits and gravel-sandpits is not associated with adverse health effects except of possible emissions of silica dust particles from larger pits. When spontaneous succession is allowed, in most of the Central European sandpits and gravel-sandpits the succession leads to the woodland formation after ca. 20 years, whereas in very dry or wet places open vegetation develops, which is often highly valuable from the restoration and conservation point of view (Prach et al., 2014). Contrary to that, overlaying of the sandy soil and bedrock

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with the topsoil, fertilization with high doses of sludge or other similar measures lead to the impoverishment of the community structure, decrease of the diversity across multiple groups of organisms, and increase in the biomass of the generalist species (Andrés, 1999; Harabiš and Dolný, 2015). In this study, we focus on sandpit microhabitats stressed by drought, situated typically just above the quarry walls at any of the etages, or in the upper parts of talus slopes, where the succession towards the woodland is blocked by drought for up to several decades and thus steppe-like formations may evolve.

The time course of an establishment of beetle (Coleoptera) and orthopteroid (Orthoptera, Dermaptera and Blattodea) assemblages occupying the sandpits and gravel-sandpits were never analyzed systematically. Lönnberg and Jonsell (2012) analyzed recently the effects of sandpit area on the diversity of beetles in Sweden. Several transects located in disused sandpits were examined by Eyre et al. (2003), but the obtained specimens were analyzed together with those retrieved from other types of postindustrial sampling sites examined in course of their study. Beetles and other invertebrates adopting *Lipara*-induced reed galls in sandpits and gravel-sandpits were examined *in extenso* by Bogusch et al. (2016). Otherwise, there exist only several case studies, which examined beetles and/or orthopteroids (Eversham et al., 1996; Stüben and Wenzel, 1996; Hoekstra, 1998; Holuša and Vlk, 2003; Dvořák et al., 2010; Řehounková et al., 2012) in a single arbitrarily selected sandpit. Despite the conclusive data obtained on sandpit-associated beetles and orthopteroids are absent, recently published data suggested high importance of sandpits and gravel-sandpits for other groups of arthropods such as spiders (Heneberg and Řezáč, 2014), butterflies (Lenda et al., 2012) and hymenopterans (Heneberg, 2012; Heneberg et al., 2013, 2014). Large sandpits and gravel-sandpits also attract some vertebrate species, such as sand martins, gulls, bluethroats, or wheatears (Skórka et al., 2006; Heneberg, 2012). The beetles and orthopteroids were, however, studied in other post-industrial habitats, which were found to host numerous species of conservation interest and to serve as potential replacement habitats for a part of the xerothermophilous species, which are otherwise rare in the surrounding cultural landscape. The post-industrial habitats subjected to the analysis of their beetle and orthopteroid assemblages include limestone quarries (Balkenhol et al., 1991; Wheater and Cullen, 1997; Tropek et al., 2008, 2010; Novotná and Šťastná, 2012; Lucas et al., 2014), leucogranite quarries (Picaud and Petit, 2007), granite quarries (Tropek et al., 2008), quartzite quarry (Bétard, 2013), open-cast lignite mines and associated spoil-heaps (Neumann, 1971; Hejkal, 1985; Oelerich, 2000; Dunger et al., 2001; Wanner and Dunger, 2002; Bröring et al., 2005), lignite fly ash deposits (Tropek et al., 2015), strip lignite mines (Hawkins and Cross, 1982; Parmenter and MacMahon, 1987; Parmenter et al., 1991), spoil heaps resulting from underground black coal mining (Prymus, 1980; Vondřejc, 1994; Dolný, 2000; Pullmanová, 2006; Tropek et al., 2012; Hodecek et al., 2015), remnants of black coal mine shafts (McCravy and Willand, 2005), open-cast black coal mines (Bett et al., 2014), bauxite mines (Nichols and Burrows, 1985), urban brownfields (Small et al., 2003) and wastedumps (Baranová et al., 2015).

In this study, we aim to identify whether and at which time scale the habitats formed by sand and gravel-sand quarrying may serve as refuges for endangered beetles and orthopteroids associated otherwise with the Central European steppes, riverbank terraces and Aeolian sand dunes, all of which have nearly disappeared from the intensively cultivated Central European landscape. We focused prevalently on the dry steppe or forest-steppe-like habitats formed by sand or gravel-sand quarrying within both active and disused sandpits, which were not affected by recultivation efforts. Importantly, the laws of many countries requires the areas affected by quarrying be reclaimed as soon as possible to uniform arable land, forest plantations and other habitats with limited value for the nature conservation. The public is well aware of the value of habitats lost due to quarrying (Brown et al., 2011), but there is very limited awareness of the conservation value of habitats formed newly by quarrying (Heneberg, 2013; Sandberg and Wallace, 2013; Heneberg and Řezáč, 2014). This study thus aims to provide the first evidence on the role of habitats newly formed by sand and gravel-sand quarrying in the conservation of beetles and orthopteroids, providing background for estimating the value of non-market goods provided by near-natural restoration of the small-scale post-mining sites as are the sandpits and gravel-sandpits.

## 2. Material and methods

### 2.1. Study area and sampling sites

The study was carried out at 28 sandpits and gravel-sandpits distributed across the Czech Republic (48°39′–50°59′N, 12°19′–18°29′E), where we installed the traps into the patches of *Festuca* sand grasslands and other types of xerothermophilous habitats. The traps were installed at altitudes 163–477 m above sea level (mean 258 ± 93 m above sea level), and were distributed based on the space-for-time substitution paradigm proposed by Pickett (1989). Four groups of sampling sites were analyzed, three of them representing various length of spontaneous succession (2–5, 6–15 and >15 years), and the fourth one representing reclaimed sites of at least five years of age. The time spent since the cessation of sand quarrying at each respective sampling site was based on the extensive monitoring of sandpits performed by the first author in years 1992–2012 (Heneberg, 2013). Detailed description of examined sampling sites was provided by Heneberg and Řezáč (2014).

### 2.2. Sampling

At xerothermophilous habitats within each sampled sandpit or gravel-sandpit, we installed three to four pitfall traps. The traps were installed primarily within *Festuca* sand grasslands if present, and were exposed from 4 Mar to 22 Sep 2012. The traps were exposed for 20,447 trap-days, of which 2922 trap-days were exposed at early successional stages (2–5 years since quarrying cessation), 7334 trap-days were exposed at intermediate successional stages (6–15 years since quarrying cessation), 7162 trap-days were exposed late successional stages (>15 years since quarrying cessation), and 3029 trap-days were exposed at reclaimed sites formed >5 years before the sampling was performed. The traps consisted of polypropylene containers with upper diameter 120 mm and depth 80 mm (Obal Centrum, Sezemice, Czech Republic) filled up to three quarters with 20% ethyleneglycol or propyleneglycol supplemented with a mixture of ionic and anionic detergents and roofed with a 20 × 20 cm metal sheet colored with green or brown paint or were coated with sand grains bound in resin. The fixative was replaced every six to eight weeks, and the captured specimens were stored in 96% ethanol until processed.

### 2.3. Data analyses

The sampling was performed by Petr Heneberg. Obtained specimens were identified to species and collected by Petr Hesoun (beetles and orthopteroids) and Jiří Skuhrovec (weevils). The nomenclature of beetles was based on Koch (1992), Hůrka (1996), Laibner (2000) and Rheinheimer and Hassler (2010), and the nomenclature of orthopteroids was based on Holuša et al. (2013). The red-list status was assessed according to Farkač et al. (2005). The species included in the Czech red-list are termed as "red-listed" throughout the text, and include all species known as critically