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First evidence of the formation of secondary strongholds of threatened epigeic spiders (Araneae) in oligotrophic anthropogenic wetlands that form in sand pits and gravel-sand pits

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ABSTRACT

The absence of evidence regarding the ecosystem services of habitats affected by sand mining has had direct effects on the destiny of landscapes affected by human disturbances. Active sand pits and gravel-sand pits cover 0.1% of the study area, the Czech Republic. In many sand pits, various types of oligotrophic wetlands may form; these range from periodic pools to peat bogs and purposefully formed water bodies. In the present study, we aimed to provide the first conclusive evidence of ability of sand pit wetlands to serve as secondary strongholds for both common and threatened wetland-associated epigeic spiders. We examined 21 anthropogenic wetlands in Czech sand pits and gravel-sand pits using pitfall trapping (17,764 trap-days) for the presence of spiders, and characterized various abiotic variables and the cover and composition of plants in the analyzed microhabitats. We found 5,842 individuals from 224 spider species, including 52 Red-Listed species and one previously undescribed *Scutpelecopsis* sp. All types of examined anthropogenic wetlands were associated with low dominance and high entropy, with the least stable assemblages present in gravel-sand pit tailing ponds. The examined anthropogenic wetlands hosted 60% of the species that were previously found in (near-)natural wetlands within the study region, and hosted numerous species that were absent from (near-)natural wetlands. During the sampling period, four study sites were affected by severe June floods, which caused prominent changes in species-specific spider abundances but caused a disappearance of only a few species, including *Pardosa prativaga* and *Xerolycosa miniata*. Oligotrophic anthropogenic wetlands occurring in sand pits and gravel-sand pits serve as local biodiversity hotspots, and their value should be taken into consideration when planning restoration and rehabilitation of areas affected by sand and gravel-sand mining.

1. Introduction

Ecosystem services are traditionally viewed as services provided by natural or restored habitats (Evans et al., 2013, 2014; Cervelli et al., 2016; Lei et al., 2016). The recent ecosystem services paradigm suggests the inclusion of non-market goods, such as the biodiversity, with multiple attempts to provide market values for biodiversity offsets, debt-for-nature swaps and green investment products (Martín-López et al., 2014; Silvertown, 2015). However, comprehensive and consistent analyses of the ecosystem services provided by anthropized ecosystems are largely absent, although most ecosystems are indeed anthropized (Barot et al., 2017). Neglected value of ecosystem services in the assessment of the ecological value of anthropized ecosystems has already been shown to have led to a severe decrease in a population of sand martins in the Czech Republic, where they are, paradoxically, protected by law (Heneberg, 2013). Many such cases are likely to occur but are poorly documented. Only recent data regarding the biodiversity associated with anthropized ecosystems show the value of anthropized ecosystems for nature conservation. Modest changes in the technologies used may have strong effects on the associated biota, such as in the case of fly ash deposits, where many groups of invertebrates flourish (Tropek et al., 2013, 2016). However, such fly ash deposits are quickly disappearing from many European countries. In many countries, such as in the U.K., the disappearance of fly ash deposits is related to the decrease in the use of coal for power production. In other countries, such as in the Czech Republic, the fly ash deposits disappear from the landscape due to the implementation of new technologies that have replaced the production of fly ash with the production of energy gypsum (calcic sulphur), which is of little value for biodiversity when deposited. The absence of evidence regarding the potential ecosystem services of

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narrowly defined types of anthropogenic habitats has had direct effects on the destiny of landscapes that are affected by human disturbances.

The arachnofauna of anthropogenic habitats has received increasing attention over the past two decades. The papers relevant to the examined study area include Wilczek et al. (1997, 2005), Wilczek et al. (2005), Tropek and Konvička (2008), Tropek et al. (2012), Heneberg and Řezáč (2014), Košulič et al. (2014), and Tropek et al. (2014, 2016); others include, e.g., Courtney et al. (2010) Li et al. (2014), and Lowe et al. (2018). These studies have focused on the xerothermic habitats that often form on slopes and the upper berms of various types of quarries, mines, spoil heaps and fly ash deposits. However, human activities lead to the formation of a broad range of wetlands. Whether and to what extent recently formed anthropogenic wetlands can serve as secondary strongholds for spiders is unknown. Several studies have been performed in fish pond littorals, (Holec, 2000; Graham et al., 2003; Tropek, 2012; Avila et al., 2017). These habitats are anthropogenic wetlands too, although they formed several centuries ago. Based on the above-mentioned studies, it is clear that at least the fish pond littorals serve as important secondary strongholds for many spider species, some of which are present nearly exclusively at such sites (Řezáč et al., 2016).

To our knowledge, the only information regarding the presence of spiders in anthropogenic wetlands formed by mining, quarrying, and associated activities, such as spoil, ash or slug deposition, consist of studies that have examined some specific subset of host plants or specific spider species. In this regard, Bogusch et al. (2016) examined spiders that use the *Lipara*-induced galls that form on common reed *Phragmites australis* in 15 anthropogenic wetlands in gravel-sand pits, tailing ponds, stone quarries, colliery dumps and reclaimed lignite open-cast mines. They found 24 morphospecies, including several Red-Listed species. From a conservation point of view, of interest was the increased abundance of the critically endangered *Clubiona juvenis* in the material from anthropogenic wetlands compared to that from natural and near-natural wetlands. On the other hand, the endangered *Mendoza canestrinii* was completely absent from the material from anthropogenic wetlands but present in the control dataset (Bogusch et al., 2016). Tonkin et al. (2016) found that anthropogenic stress, quantified as a gradient of local land-use intensity, de-couples the links between spiders and carabid beetles, which likely share their resources. These links include predator-prey, competition and habitat associations. Many anthropogenic wetlands and anthropized wetland ecosystems suffer from pollution by heavy metals or surplus nitrogen. The spiders of different life strategies respond differently to these inputs (Maelfait and Hendrickx, 1998; Akamatsu and Toda, 2011), which highlights the need of knowledge on species composition of assemblages that develop at precisely specified types of anthropogenic wetlands. Thorough systematic studies of the overall spider diversity associated with anthropogenic wetlands are completely absent; some data can only be found in the grey literature, such as various surveys conducted for government authorities.

Oligotrophic wetlands of natural origin are increasingly rare across the Central European landscape and worldwide. Sand and gravel-sand quarrying often lead to the formation of large oligotrophic water bodies, and even in sand pits with dry bottoms, oligotrophic wetlands often form when quarrying reaches bottom clay- and silt-rich strata that are impervious to water. The enormous extent of sand and gravel-sand quarrying is reported worldwide (Menegaki and Kaliampakos, 2010). In the Czech Republic, where the present study was conducted, sand quarrying was actively conducted in 169 pits that spanned over 114 km^2 in 2007 according to Starý et al. (2008). In addition to the active sand pits, there are hundreds of sites, where quarrying had already ceased. Numerous studies suggest that many groups of organisms have found their secondary strongholds in oligotrophic wetlands formed in sand and gravel-sand pits; these organisms are either oligotrophic wetland specialists (plants – Křiváčková et al., 2006) or are negatively affected by increasing pressure from the fishing industry (amphibians – Vojar et al., 2016). Reports on invertebrates associated with sand and gravel-sand pit wetlands are scarce, and limited mostly to water beetles, mayflies and only rarely to other groups of invertebrates (Kehl and Dettner, 2003; Vad et al., 2012; Trnka and Rada, 2015). This causes negligible awareness of the conservation value of habitats that are newly formed by quarrying and mining, which is in contrast to the recognition of the value of habitat that is lost due to such activities (Heneberg, 2013; Sandberg and Wallace, 2013; Heneberg et al., 2014). Correspondingly, the conservation potential of newly formed habitats is poorly reflected in the laws of many countries, including the Czech Republic.

Sand and gravel-sand are relatively non-toxic compared to materials that are exposed at other sites affected by quarrying, mining and associated activities (Kapička et al., 1999; Zhao et al., 2007). We hypothesized that oligotrophic wetlands that form in sand and gravel-sand pits serve as secondary strongholds for both common and threatened wetland-associated epigeic spiders. Here we provide the evidence, which allows to test this hypothesis by comparing the presently obtained data with outcomes of previously conducted surveys of wetland-associated spiders, and which illustrates the variability of assemblages associated with the study habitats. The sampling was affected by severe floods, during which multiple rivers within the study area exceeded their 100-year flood flow rate. As we obtained the information on both the pre- and post-flood composition of analyzed spider assemblages, their comparison is also provided.

2. Material and methods

2.1. Study sites

We examined 21 sand pits and gravel-sand pits in the Czech Republic (48.82° – 50.44°N, 13.80° – 16.59°E), in which three main types of artificial wetlands have developed, representing the whole spectrum of artificial wetlands present in sand pits and gravel-sand pits within the study area. The examined sites included the following: 1) The tailing ponds of the sand pits and gravel-sand pits. This type of a tailing pond serves to the quarrying companies as the place where the clay and silt particles are retained after they are washed out of the quarried sand or gravel-sand. These tailing ponds do not suffer from the toxicity issues that are associated with other types of tailing ponds (power plant, heat plant or those that result from ore mining and processing). Three tailing ponds were examined in this study (Fig. 1, black circles). 2) Wetlands that were surrounded by open landscape. Six open wetlands were examined in this study (Fig. 1, light grey circles). 3) Wetlands surrounded or completely covered by forests. This type of habitat included both completely afforested sites and those that had formed along small artificial lakes that were completely surrounded by forest. Twelve afforested wetlands were examined in this study (Fig. 1, dark grey circles).

Basic abiotic characteristics of the study sites are provided in Table 1. Namely, we characterized the altitude, slope of the examined microhabitats, soil penetration resistance, soil shear strength resistance, and soil texture expressed as the share of soil grains of the sizes < 0.072 mm, 0.072–0.125 mm, 0.125–2.00 mm, 2.00–4.00 mm and > 4.00 mm. Most of the spider species are associated with sites of low penetration and shear strength resistance (Heneberg and Řezáč, 2014). Based on aerial photographs that were available at http://www.mapy.cz [accessed 28 Aug 2017], sixteen (76%) of the examined sand pits and gravel-sand pits were located at sites that were formed more than 10 years prior to the beginning of the study. Five sites (two open wetlands and all three tailing ponds) were formed between three and ten years ago. To our knowledge, no tailing ponds associated with sand pits or gravel-sand pits remained disused but not overlaid with topsoil for more than a decade, which is a problem also experienced in the case of disused fly ash tailing ponds, cf. Tropek et al. (2014, 2016). The methods used for the analyses of abiotic characteristics were described

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