Ecological Engineering 90 (2016) 278–284

Contents lists available at ScienceDirect

Ecological Engineering

journal homepage: www.elsevier.com/locate/ecoleng

Spontaneous succession on spoil banks supports amphibian diversity and abundance

Jiří Vojar[a,*], Jana Doležalová[a], Milič Solský[a], Daniela Smolová[a], Oldřich Kopecký[b], Tomáš Kadlec[a], Michal Knapp[a]

[a] Faculty of Environmental Sciences, Czech University of Life Sciences Prague, Kamýcká 129, Prague CZ 16521, Czech Republic
[b] Faculty of Agrobiology, Food and Natural Resources, Czech University of Life Sciences Prague, Kamýcká 129, Prague CZ 16521, Czech Republic

ARTICLE INFO

Article history:
Received 17 November 2014
Received in revised form 8 November 2015
Accepted 26 January 2016
Available online 16 February 2016

Keywords:
Biodiversity conservation
Landscape restoration
Open-cast coal mining
Post-mining habitats
Rana dalmatina
Technical reclamation

ABSTRACT

The ecological value and conservation potential of post-mining areas have been increasingly recognized by scientists and conservationists during recent decades. Especially valuable are sites left to spontaneous succession, which constitute habitats with high species diversity, or habitats that serve as refuges for threatened species. In contrast to several other taxa, there is a lack of such evidence for amphibians, despite the assumption that primary succession leads to a more suitable environment for amphibians than does technical reclamation. Therefore, we compared the effects of technical reclamation and spontaneous succession on amphibian presence, species richness, and abundance of the model species *Rana dalmatina* in technically reclaimed and unreclaimed sections of spoil banks in the Czech Republic's North Bohemian brown coal basin. We found that most recorded amphibian species, and *R. dalmatina* in particular, occurred predominantly within successional spoil bank sections. Apart from reclamation status, amphibians preferred partially vegetated ponds (5–75% vegetation cover) having gently sloping shores (<30°) and lower water conductivity. Mean species richness per pond (1.95 vs. 1.20), the proportion of ponds occupied by amphibians (88.5% vs. 69.4%), and the mean numbers of *R. dalmatina* clutches per pond (9.05 vs. 1.65) were significantly higher at unreclaimed sites compared to technically reclaimed sites. This study confirms the conservation value of post-mining sites for amphibians and evidences that sites left to spontaneous succession provide more suitable habitats for amphibians compared to technically reclaimed sites. Key habitat characteristics driving amphibian assemblages within post-mining sites are identified and guidelines for effective protection of amphibians in post-mining areas are proposed.

1. Introduction

The ecological value and conservation potential of such post-mining areas as sandpits, quarries, coal mines and spoil banks have been increasingly recognized among scientists and conservationists during recent decades. This applies mainly to sites left to spontaneous succession and which represent a fine mosaic of habitats with high species diversity (Hendrychová et al., 2008, 2009, 2012; Hodačová and Prach, 2003; Holec and Frouz, 2005; Mudrák et al., 2010; Prach and Pyšek, 2001; Wiegleb and Felinks, 2001) or habitats that are refuges for threatened species of vascular plants (Tischew et al., 2014; Tropek et al., 2010; Wheater and Cullen, 1997), terrestrial invertebrates (Hendrychová et al., 2008, 2012; Holec and Frouz, 2005; Mudrák et al., 2010; Prach and Pyšek, 2001; Wiegleb and Felinks, 2001), and vertebrates (Šálek, 2012). In contrast to those for other taxa, studies on aquatic or semiaquatic species are rare (but see Dolný and Harabiš, 2012; Harabiš et al., 2013). To our knowledge, in the case of amphibians, those studies taking place in post-mining areas are limited to investigation of the spoil bank colonization process (Galán, 1997) or to collection of faunistic records (Smolová et al., 2010; Vojar, 2006).

Spoil banks resulting from large-scale open-cast coal mining are typical of a specific type of heterogeneous environment (Doležalová et al., 2012). Terrestrial habitats at higher sections of spoil banks are accompanied by waterlogged and moisture-retaining areas with impermeable substrate in terrain depressions (Bejček, 1982). Many oligotrophic ponds with favorable habitat features have potential to become valuable refuges for numerous threatened aquatic and semiaquatic species (Harabiš and Dolný, 2011), including amphibians (Doležalová et al., 2012). According to Doležalová et al. (2012), technically unreclaimed (successional) sections of spoil banks are typical of a relatively high proportion of water area and higher

* Corresponding author.
E-mail address: vojar@fzp.czu.cz (J. Vojar).

http://dx.doi.org/10.1016/j.ecoleng.2016.01.028
0925-8574/

number of ponds than are those sections that have been technically reclaimed. The higher proportion of ponds occurring in unreclaimed sections is also partially vegetated, smaller, shallower, and with gentle shore slopes (Doležalová et al., 2012). During technical reclamation of spoil banks, primarily heterogeneous terrain is totally leveled, and instead of many various ponds only several large retention basins are created (Doležalová et al., 2012; Řehounek et al., 2010; Vojar, 2006). Therefore, larger and deeper ponds with steeper shore slopes and less vegetation cover prevail at reclaimed sites. The presumption is that primary succession leads to a more preferable environment for amphibians than does technical reclamation (Doležalová et al., 2012).

The aim of this study is to compare the effects of technical reclamation and spontaneous succession on amphibian diversity and abundance. In particular, we asked whether (i) mean species richness per pond, (ii) the proportion of ponds occupied by amphibians, and (iii) the mean numbers of clutches per pond of a selected model species, the agile frog *Rana dalmatina*, are higher at unreclaimed or at technically reclaimed sites. Furthermore, we analyzed the possible effects of habitat features on the presence of amphibians within selected water bodies (ponds). For the purpose of generalizing results and the possibility of their use in restoration practice, the study area covers most of the larger spoil banks situated in the Czech Republic's North Bohemian brown coal basin.

2. Materials and methods

2.1. Study area and pond selection

The study was conducted at 13 of 17 large spoil banks in the North Bohemian brown coal basin (see Supplementary Geospatial Data), the largest mining site in the Czech Republic and one of the largest in Europe (Vráblíková et al., 2008). Using orthophoto maps (Portal of Public Administration, 2014), ArcGIS 9.2 (ESRI, 2007), and field surveys, each spoil bank was classified according to reclamation status (successional vs. technically reclaimed) that directly affects spoil banks terrain heterogeneity and, therefore, the number of ponds there (Doležalová et al., 2012). If both technically reclaimed and successional sections were present at the same spoil bank, each such section was classified separately. In total, we distinguished 13 technically reclaimed and 6 unreclaimed sections. For a detailed description of the monitored spoil banks, see Doležalová et al. (2012). The age of all spoil banks varied between 10 and 50 years after heaping for unreclaimed spoil banks and after technical reclamation of spoil banks for reclaimed sections. We avoided the youngest spoil bank sections, because the newness of these sections could negatively affect amphibian diversity there. Spoil banks about 10 years of age could be colonized by most amphibian species in the region (Vojar, 2006).

During a systematic field survey of the spoil banks for water bodies in the beginning of April 2010, we found 890 water bodies and located these using GPS navigation. Of these, 196 were in 13 technically reclaimed sections and 694 were in 6 unreclaimed sections. For the comparison of amphibian presence, species richness and *R. dalmatina* abundance between reclaimed and unreclaimed sections, about 15 ponds were selected at random for each monitored spoil bank section. The reason for reducing the size of the pond sample was the impossibility to carry out precise amphibian surveys at all 890 ponds for all amphibian species. Spoil bank sections with fewer than six water bodies were excluded from the comparison because of a need to balance the numbers of ponds in particular spoil bank sections. In the end, 176 ponds in total were selected, of which 98 were within 7 technically reclaimed sections and 78 within 6 successional sections (Table 1). The total area of the 13 selected spoil bank sections was about 62 km^2.

2.2. Sampling of amphibian assemblages

At each of the 176 selected water bodies, two surveys were conducted by skilled researchers, the first in the middle of April 2010 and the second in the beginning of June 2010, under standard weather conditions (sunny or at most partly cloudy) during the daytime (10:00–18:00 CEST). Standard surveying techniques for the detection of amphibian occurrence (all monitored amphibian species) and abundance (only in case of *R. dalmatina*) were used (see Dodd, 2010; Heyer et al., 1994): (i) dip-netting, used particularly for larvae and adults of newts and tadpoles of all anurans; (ii) manual calling surveys, i.e. auditory monitoring for anuran males; (iii) visual encounter monitoring for adults of all anurans; and (iv) searching for clutches (egg masses). In case of *Salamandra salamandra*, we did not perform specific detection of the species (night surveillance) because of its evident absence on monitored spoil banks due to inappropriate environmental conditions there (Smolová et al., 2010; Vozenílek, 2000). A summary of methods

Table 1
Presence of amphibians on surveyed spoil banks. TR = technically reclaimed sections of spoil banks, TU = technically unreclaimed sections (=successional). Recl. = type of reclamation: T = technical, F = afforestation, A = agricultural, G = grass stands, S = successional; in cases of multiple types of reclamation, the order indicates the proportion of reclamation types on the spoil bank. N_{ponds} = number of surveyed ponds; N_{ponds_pres} = number of ponds with the presence of at least one amphibian species (percentage = N_{ponds_pres}/N_{ponds}); $N_{species}$ = total number of amphibian species found on the spoil bank; $N_{species\_mean}$ = mean number of species per pond on the spoil bank; SD = standard deviation; Species = amphibians species present on the spoil bank, *Bobo – Bombina bombina*, *Bubu – Bufo bufo*, *Buvi – Bufotes viridis*, *Livu – Lissotriton vulgaris*, *Pefu – Pelobates fuscus*, *Peri – Pelophylax ridibundus*, *Rada – Rana dalmatina*, *Rate – Rana temporaria*, *Trcr – Triturus cristatus*.

Name of spoil bank	Recl.	N_{ponds}	N_{ponds_pres} (%)	$N_{species}$	$N_{species\_mean}$ (±SD)	Species
	Technically reclaimed sections of spoil banks					
Čepirohy	T, A, F	14	9 (64.3)	6	1.1 ± 1.2	*Bobo, Livu, Pefu, Peri, Rada, Trcr*
Merkur	T, F, A	17	15 (88.2)	5	1.2 ± 0.6	*Bobo, Buvi, Livu, Peri, Trcr*
Pokrok	T, F, A, G	10	8 (80.0)	5	1.4 ± 1.1	*Bobo, Livu, Peri, Rada, Trcr*
Radovesická – TR	T, A, F	16	15 (93.8)	5	2.1 ± 1.3	*Bubu, Livu, Peri, Rada, Trcr*
Růžodolská – TR	T, F, G	22	11 (50.0)	4	0.7 ± 0.9	*Bobo, Livu, Peri, Rada*
Střimická	T, F, A	11	8 (72.7)	4	1.1 ± 1.1	*Bobo, Livu, Peri, Trcr*
Velebudická	T, F, A	8	2 (25.0)	4	0.6 ± 1.2	*Bobo, Livu, Peri, Trcr*
Overall in TR		98	68 (69.4)	8	1.2 ± 1.1	
	Technically unreclaimed sections of spoil banks					
Albrechtická	F, S	11	10 (90.9)	5	1.7 ± 1.0	*Bobo, Bubu, Livu, Peri, Rada*
Hornojiřetínská	F, S	16	15 (93.8)	7	2.6 ± 1.5	*Bobo, Bubu, Livu, Peri, Rada, Rate, Trcr*
Kopistská	F	15	13 (86.7)	5	2.2 ± 1.2	*Bobo, Livu, Peri, Rada, Trcr*
Radovesická – TU	S	13	12 (92.3)	5	1.6 ± 0.9	*Bubu, Livu, Peri, Rada, Trcr*
Růžodolská – TU	F, S	6	5 (83.3)	5	2.0 ± 1.5	*Bobo, Livu, Peri, Rada, Trcr*
Teplická	F	17	14 (82.4)	6	1.6 ± 1.4	*Bobo, Bubu, Livu, Peri, Rada, Trcr*
Overall in TU		78	69 (88.5)	7	2.0 ± 1.3	