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Conservation value of post-mining headwaters: drainage channels at a lignite spoil heap harbour threatened stream dragonflies

RNDr. thesis

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Annotation

In the work, we studied the biodiversity of dragonflies and damselflies (Odonata) at 53 sections (30 m) of an extraordinarily dense system of drainage ditches at a large lignite spoil heap in the Czech Republic. Using generalized linear models and canonical correspondence analyses we identified crucial factors affecting dragonfly communities and suggest implication for restoration ecology practise.

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Filip Tichanek has come with the research idea, has substantially contributed to its designing and planning, has fully organised the data sampling and analyses, and has substantially contributed to the results interpretations and the manuscript writing.

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ORIGINAL PAPER

Conservation value of post-mining headwaters: drainage channels at a lignite spoil heap harbour threatened stream dragonflies

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Abstract Headwaters and small streams are crucial components of riverine systems, harbouring many highly specialized and unique invertebrate species. Unfortunately, the overwhelming majority of the Central European lowland headwaters are channelized, eutrophicated and/or polluted, and many related species have become critically endangered. Artificial streams established to drain some post-mining sites supplement a network of headwaters and generally do not suffer from agricultural pollution. Nevertheless, the biodiversity and conservation potential of the streams at post-mining sites has never been evaluated. We studied the biodiversity of dragonflies and damselflies (Odonata) at 53 sections (30 m) of an extraordinarily dense system of drainage ditches at a large lignite spoil heap in the Czech Republic. We recorded 22 dragonfly species, of which eight are threatened according to the national Red List. Moreover, four of them are closely associated with the endangered environment of small streams. Overall diversity was generally low at very tiny and/or narrowed streams and was also strongly reduced by high water velocity, high bankside inclination and dominance of expansive common reeds. Sufficient cover of rather shallow sediment layers strongly supports the studied diversity indicators. We thus conclude that post-mining streams in drainage ditches could have a strong potential to offer secondary habitats for threatened headwater biodiversity. However, intermittent reed suppression and the establishment of gently sloping banks and a structured stream bottom are necessary measures for maximizing post-mining stream conservation.

Keywords Biodiversity conservation · Drainage ditches · Freshwater habitats · Odonata · Post-industrial sites · Restoration management

Introduction

Lowland headwaters (i.e. first- and second-order streams) harbour many unique and highly specialized species and thus substantially contribute to the freshwater biodiversity of Central Europe (Gomi et al. 2002; Meyer et al. 2007; Richardson and Danehy 2007; Clarke et al. 2008; Meyer and Wallace 2001; Wipfli et al. 2007). However, strong anthropogenic pressures (such as channelization and other stream remodelling, removal of natural obstructions from stream beds, organic and inorganic pollution, biological invasions, damming, and modifications of riparian zones) have resulted in a serious decline of headwater biodiversity (Muotka et al. 2002; Muotka and Laasonen 2002; Allan and Flecker 1993; Harding et al. 1998; Middleton 1999; Malmqvist and Rundle 2002). Changes of headwater biodiversity could be exemplified by Odonata (dragonflies and damselflies, hereinafter referred to as dragonflies), which is one of the best known groups of freshwater organisms (Kalkman et al. 2008; Simaika and Samways 2011). A substantial proportion of the endangered European dragonfly species are primarily associated with small streams and headwaters (Kalkman et al. 2008, 2010). In the Czech Republic, the seven dragonfly species primarily associated

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with headwaters and small streams constitute almost 10 % of the national dragonfly fauna (Dolný et al. 2007). All of them are nationally threatened (1 RE, 1 CR, 2 EN, 2 VU) except one species with deficient data (*Somatochlora meridionalis*; Hanel et al. 2005; Dolný et al. 2007). Therefore, restoration of the lowland headwater systems, together with conservation of the few remaining well-preserved small streams, should be an essential challenge for European conservationists.

Some artificial ditches in agricultural or urban landscapes are known to harbour rare plants and invertebrates (e.g. Vermonden et al. 2009; Herzon and Helenius 2008; Dorotovičová 2013; Chester and Robson 2013), including dragonflies (Harabiš and Dolný 2015; Dolný et al. 2007; Wildermuth 2008; Waldhauser and Mikát 2010), and they could be considered as headwater habitat surrogates. However, the majority of the Central European channels are strongly eutrophic with a simplified habitat structure and thus typically host poor communities of common generalist species (Janse and Van Puijenbroek 1998; Riis and Sand-Jensen 2001; Watson and Ormerod 2004; Petersen et al.1987; Muotka et al. 2002). The above-mentioned rarity of headwater dragonfly species, despite the relatively high numbers of drainage ditches across the Central European agricultural landscapes, also implies the generally low conservation potential of agricultural channels.

Drainage channels are also found in various post-industrial sites. The nutrient level of waters in post-industrial landscapes is usually much lower than in agricultural or (sub)urban landscapes (Harabiš et al. 2013; Harabiš and Dolný 2012; Dolný and Harabiš 2012). Similarly, various toxins used in agriculture, such as herbicides, are also absent from these streams. In addition, ordinary mowing of a substantial part of the ditch banks positively affects stream biodiversity (Naiman et al. 2005). On the other hand, extreme water chemistry (i.e. extreme conductivity and/or pH) and possible contamination from mining activities, which can strongly influence stream biota, is frequently documented from these sites (Mutz 1998; Michailova et al. 2012; Hopkins et al. 2013; Petty et al. 2013). In spite of such toxins and extreme chemistry, post-industrial sites have already been documented to be important refuges for endangered dragonflies of stagnant freshwaters, including pools in spoil heaps (Harabiš et al. 2013) and pools in mine subsidence (Dolný and Harabiš 2012; Harabiš and Dolný 2012). Rademacher (2011) and Hesoun and Dolný (2011) summarised numerous data on dragonflies at post-industrial sites and evidenced the occurrence of various threatened species of stagnant waters. Nevertheless, the biodiversity of drainage channels remains generally unexplored, except for studies of the critically endangered *Coenagrion ornatum* (Waldhauser and Mikát 2010; Harabiš and Dolný 2015). To the best of our knowledge, the only published study (Petty et al. 2013) comparing some environmental aspects (i.e. water chemistry, amphibian and invertebrate diversity) of permanent streams flowing in coal mines with natural headwaters (West Virginia, USA) revealed that artificial channels have a different water chemistry and similar species richness of both amphibians and invertebrates. However, there is no comprehensive study focusing on the biodiversity and conservation potential of streams in European post-industrial sites.

Our study is the first dealing with communities of freshwater invertebrates (dragonflies) inhabiting drainage channels of any European post-mining site (here, a lignite spoil heap). We posed the following main goals: (1) to determine the community composition of dragonflies colonising the drainage channels in the Radovesická lignite spoil heap; (2) to evaluate the conservation value of the artificial channels based on the occurrence of threatened small stream dragonflies; (3) to determine which environmental factors are the most important for the occurrence of endangered species. Finally, we suggest the implications of these findings for post-industrial site restoration.

Methods

Study area and sites

This study was carried out at the Radovesická spoil heap (North Bohemian lignite basin, Czech Republic, Central Europe). The North Bohemian lignite basin (mean annual temperature: 7–9 °C, annual precipitation: 500–620 mm, area: about 1100 km^2, mean altitude: 270 m a.s.l.) was historically covered by deciduous forests supplemented by relatively common open fens. The basin lies between two uplands—the Bohemian Uplands (České středohoří), covered mainly by xerothermic open habitats, thermophilous deciduous forests and agricultural areas; and the Ore Mountains (Krušné hory) with deciduous and coniferous forests and peatbogs. In past centuries, the North Bohemian basin has been an extensive agricultural region. Since the 19th century it has been significantly modified by opencast lignite mining, resulting in about 100 km^2 of large opencast lignite (brown coal) mines and 150 km^2 of spoil heaps formed mainly from tertiary clays (Harabiš et al. 2013; Štýs 1981). Therefore, today it is mainly a (post)mining, industrial (energetic and chemical industries) and urban landscape.

The Radovesická heap is a relatively large (ca 12.5 km^2; mean annual temperature: 8 °C, annual precipitation: 510 mm, altitude: 200–450 m a.s.l.) spoil heap after lignite mining, formed between 1964 and 2003, east of the town of Bílina (50.54°N, 13.83°E). It has recently been technically reclaimed (sensu Tropek et al. 2010, i.e. by remodelling of its surface, covering by nutrient-rich topsoil, and creating tree monocultures or artificial species-poor productive meadows). Only ca. 57 ha (~4.5 %) of the heap has been left for spontaneous succession so far (Vojar et al. 2012). As a part of the reclaimed plots, a dense network of channels, supplemented by more than 10 retention reservoirs, drains the entire spoil heap. This channel network is supplemented by an artificially channelized stream crossing the heap base, although it springs out of the heap. Except for ca. 10 km of permanent streams, the majority of the drainage channels are dried out except during the wettest seasonal periods or strong rains. Such a dense channel network is at least regionally unique, as all other spoil heaps in the study area have only a few, much shorter, drainage ditches. Hence, it offers a challenging model system for biodiversity studies with relatively high heterogeneity of environmental conditions among the streams.

Data sampling

Adult dragonflies and damselflies (Odonata) were recorded along the 53 study sites (30 m linear sections of channels) which were chosen as randomly as possible, with an effort to cover all habitats present within each channel and to avoid sections of temporary flow and steep slopes. Each section was sampled four times during the 2011 vegetation season (end of May, mid-June, mid-July, end of August). During each visit, each transect along the whole length of each section was walked three times (five times during the last visit because of the frequent occurrence of species difficult to detect or identify in late summer) to maximise detection. The transects were walked very slowly to enable careful searching and possible catching of all adult dragonflies above a stream and its nearest surroundings (2 m). All the data were sampled under optimal weather conditions (sunny, temperature above 20 °C, maximally mild wind) between 9:30 and 16:30 CEST. Abundance of each species was quantified using a semi-quantitative scale (0 = no individual; 1 = 1 individual; 2 = 2–5; 3 = 6–10; 4 = 11–20; 5 = 21–50; 6 = 51–100).

Environmental variables

We recorded 17 environmental characteristics (Table 1) that were sufficiently different across the study sites and likely to affect dragonfly community composition (following various odonatological studies, e.g. Rouquette and Thompson 2005; Hassall et al. 2011; Harabiš et al. 2013; and our field experience from post-industrial sites). The environmental variables were recorded during mid-July data sampling, except recording of *mowing*, which was performed between the third and fourth sampling periods. These included three variables describing attributes of the channel bankside, five variables describing stream parameters, two variables describing bottom sediment, five variables describing the character of emerged vegetation, and two variables describing water chemistry.

Statistical analyses

For each studied channel section, we quantified the *species richness* (i.e. number of all species recorded at least at two individuals in the study site) and *conservation value* of its dragonfly community. The conservation value of each section was established as the log-transformed average abundance of each species per site weighted by its Red List status (0—least concern (LC); 1—nearly threatened (NT); 2—vulnerable (VU); 3—endangered (EN); 4—critically endangered (CR); Tropek et al. 2010).

Effects of different environmental variables on the *species richness* and *conservation value* were tested by generalized linear models (GLM) with a log link function and assumed Poisson (species richness) and negative binomial (conservation value) distributions, using the below-cited software packages in R (R Development Core Team 2015). We used common visualization methods to detect non-linear relationships between response variables and predictors, to identify potential interactions between the predictors, and to view the data distribution of the predictors (XY plots, interaction plots and histograms). The environmental variables with distribution close to logarithmic (*bankside height*, *velocity*, *water depth*, *discharge*, *water depth heterogeneity*, *vegetation cover* and *vegetation heterogeneity*) were log-transformed to achieve additivity of their effects within the models. All continuous variables were standardized and centred. The environmental variables were selected by step-wise selection using AIC statistics (the *step* and *stepAIC* functions from the *MASS* package; Venables and Ripley 2002). The variables showing non-linear effects on the response variable (at XY plots) were included into step-wise selection with both, i.e. linear and second-order polynomial, predictors (i.e. *bankside inclination*, *velocity*, *discharge*, *sediment cover*, *short vegetation* and *Phragmites*; all the variables were the same for both *species richness* and *conservation value*), but only the predictor with higher ΔAIC was then included to the final models. Because the Moran's I tests of the models' residuals (the *ape* package; Paradis et al. 2004) were insignificant (*species richness* model: observed = −0.039, expected = −0.019, SD = 0.064, $P = 0.360$; *conservation value* model: observed = 0.080, expected = −0.019, SD = 0.064, $P = 0.119$) we did not consider spatial autocorrelations in our final models. Finally, we visualised the effects of each variable included into the final models

Table 1 List of recorded environmental variables, their way of evaluation and units

Variable	Definition and/or way of evaluation	Units
Bankside inclination	Visually estimated	Degrees
Bankside material	Nature of prevailing material	Nominal scale (artificial—concrete or other paving; natural—bare topsoil or natural vegetation)
Bankside height	Visually estimated	m
Velocity	Average value of three independent measures within each section	cm/s
Stream width	Average value of three independent measures within each section	Ranked scale (<40 cm, 40–80 cm, >40 cm)
Water depth	Average value of three independent measures within each section	cm
Water depth heterogeneity	Ratio between the highest and average measure of water depth	Absolute numbers
Discharge	Calculated from water depth, stream width and velocity	cm^3/s
Sediment cover	Visually estimated coverage, only sediments with depth >5 cm were considered	%
Sediment depth	Average value of three independent measures within each section, depth over 20 cm was recorded as 20 cm	cm
Vegetation cover	Visually estimated	%
Vegetation heterogeneity	Number of plant genera with >10 % relative cover, all grasses (except for *Phragmites* and *Glyceria*) were treated as a single "genus"	Absolute numbers
Short vegetation	Visually estimated relative cover of vegetation <0.5 m of height	%
Phragmites	Visually estimated relative cover of common reed	%
Mowing	Mowing of emergent vegetation recorded during fourth sample	Nominal scale (presence, absence)
Conductivity	Directly measured	µS/cm
pH	Directly measured	–

using the *effects* package (Fox 2003). The visualized effects were derived directly from the GLM analyses, but x-axes (predictors) were rescaled to the real values.

For testing effects of the environmental factors on the composition of dragonfly communities across the studied sections, we used the Canonical Correspondence Analysis (CCA) in CANOCO 5 (ter Braak and Šmilauer 2012). The significant environmental variables were selected using forward selection. For testing the significance of the individual variables as well as of the final model we used a Monte Carlo permutation test (with 9999 unrestricted random permutations under the reduced model). For avoiding the undesired influence of randomly recorded species, we excluded all singleton species from the analysis (Šmilauer and Lepš 2014).

Results

In total, we recorded 22 dragonfly species. From this number, eight species are threatened according to the national Red List (Hanel et al. 2005). Four of the threatened species (*Coenagrion ornatum*, *Orthetrum brunneum*, *O. coerulescens* and *Cordulegaster boltonii*) are known to be closely affiliated with small streams, and the first three were relatively common at the study site (see Table 2). Moreover, *C. ornatum* is included in the Appendix II of the Directive No. 92/43/EHS on the Conservation of Natural Habitats and of Wild Fauna and Flora ("Natura 2000"). An endangered dragonfly, *Sympetrum pedemontanum*, had not been previously recorded from the study region (Dolný et al. 2007).

The GLM (Table 3a) revealed *Phragmites* and *velocity* as the most important factors for the *species richness* model parsimony. The effect of *Phragmites* had a hump-shaped effect with the maximum *species richness* at intermediate (~40 % of cover) values, whereas *velocity* showed a negative effect, especially in higher values (Fig. 1a, b). *Bankside inclination, stream width* and *discharge* also substantially contributed to the model parsimony. *Bankside inclination* demonstrated humped-shaped relationships with the *species richness* with maximum values at about 25° (Fig. 1c). *Stream width* lower than 0.4 m was negatively associated with the *species richness*, whereas medium

Table 2 List of all dragonfly species recorded at the studied drainage channels

Species	CCA abbreviation[a]	Records[b]	Maximum abundance	Red list status[c]
Aeschna cyanea (Müller 1764)		1	1	LC
Anax imperator (Leach 1815)		1	1	LC
Calopteryx splendens (Harris 1782)		6	2–5	LC
Calopteryx virgo (Linnaeus 1758)		1	1	LC
Coenagrion ornatum (Selys 1850)	CoenOrna	23	21–50	CR
Coenagrion puella (Linnaeus 1758)	CoenPuel	31	21–50	LC
Cordulegaster boltonii (Donovan 1807)		1	1	VU
Enallagma cyathigerum (Charpentier 1840)		3	2–5	LC
Ischnura elegans (Vander Linden 1820)	IschEleg	19	6–10	LC
Ischnura pumilio (Charpantier 1825)	IschPumi	9	6–10	NT
Lestes barbarus (Fabricius 1758)		2	2–5	VU
Lestes sponsa (Hansemann 1823)		1	2–5	LC
Lestes viridis (Vander Linden 1825)		1	2–5	LC
Libellula depressa (Linnaeus 1758)	LibeDepr	9	6–10	LC
Orthetrum brunneum (Fonscolombe 1837)	OrthBrun	11	11–20	EN
Orthetrum coerulescens (Fabricius 1798)	OrthCoer	27	11–20	EN
Pyrhosomma nymphula (Sulzer 1776)	PyrhNymp	15	11–20	LC
Sympetrum dannae (Sulzer 1776)	SympDana	2	2–5	LC
Sympetrum pedemontanum (Müller in Allioni 1766)		1	2–5	EN
Sympetrum sanguineum (Müller 1764)		3	2–5	LC
Sympetrum striolatum (Charpantier 1840)	SympStri	5	2–5	NT
Sympetrum vulgatum (Linnaeus 1758)	SymVulg	8	2–5	LC

LC least concern, *NT* near to threatened, *VU* vulnerable, *EN* endangered, *CR* critically endangered (Hanel et al. 2005)

[a] Abbreviations used in the CCA diagrams

[b] Number of sites where the species was recorded

[c] Species status according to the national red list

values of 0.4–0.8 m had the highest *species richness* (Fig. 1d). *Discharge* showed positive linear association with the *species richness*. *Bankside height* showed a negative effect and *short vegetation* a positive effect on *species richness*; the effects of both were linear (Fig. 1f, g).

The *conservation value* (Table 3b) was most strongly associated with *bankside inclination* (Fig. 2a), but its effect was hump-shaped with the maximal values at about 30° of the slope. The relationship of *Phragmites* to the *conservation value* was almost steady in the low covers, but started to decrease rapidly with 40 % of cover (Fig. 2b). *Sediment cover* showed a strong positive effect at low values (up to ~60 %) only (Fig. 2c). On the other hand, *sediment depth* showed a negative relationship with the *conservation value* (Fig. 2g). The *conservation value* was positively associated with the relative cover of *short vegetation* and marginally also with *water depth*; all these relationships were linear (Fig. 2d, f). The GLM also revealed the lower *conservation value* at streams with *stream width* lower than 0.4 m (Fig. 3e).

The CCA (adjusted explained variation: 12 %, pseudo-F: 4, $P < 0.0001$) showed *vegetation cover* and *Phragmites* as the main factors determining species composition of the dragonfly communities at the study sites (Fig. 3). All of the red-listed headwater species avoided the channels overgrown by *Phragmites*. The individual threatened species, however, differed in their affinity to *vegetation cover*. Critically endangered *C. ornatum* favoured sites with higher vegetation cover, while endangered *O. brunneum* occurred in minimally vegetated sites. Endangered *O. coerulescens* did not show any apparent association to specific *vegetation cover*. Channels with a low *vegetation cover* were favoured by nearly-threatened *Sympetrum striolatum* and a few common generalists (e.g. *Libellula depressa*, *Sympetrum danae*). Higher *vegetation cover* was favoured by nearly-threatened *Ischnura pumilio*, as well as by a few common generalists (e.g. *Sympetrum vulgatum*). Two recorded individuals of endangered *Sympetrum pedemontanum* were found in a wide channel with a rich vegetation cover and a single recorded individual of

Table 3 Results of the generalized linear models explaining species richness and conservation value of dragonflies in the studied drainage channels. See "Methods" for the models details

	Variable[a]	Coefficient	SE	Z-value	*P*	ΔAIC[b]
a Species richness						
Model summary:	Velocity[1]	−0.518	0.234	−2.213	0.027	15.4
Null deviance:	Velocity[2]	−0.489	0.218	−2.243	0.025	
116 on 52 d.f.,	Phragmites[1]	0.326	0.155	2.103	0.035	16
Residuals deviance:	Phragmites[2]	−0.707	0.167	−4.242	<0.001	
26 on 41 d.f.,	Bankside inclination[1]	−0.424	0.163	−2.599	0.009	8.5
AIC of the model:	Bankside inclination[2]	−0.580	0.189	−3.074	0.002	
164.8	Stream width (0.4–0.8 m)	1.442	0.557	2.589	0.010	8.2
	Stream width (>0.8 m)	0.498	0.565	0.881	0.378	
	Discharge	0.464	0.169	2.737	0.006	5.7
	Bankside height	−0.189	0.105	−1.808	0.071	0.8
	Short vegetation	0.212	0.123	1.728	0.084	1.4
b Conservation value						
Model summary:	Bankside inclination[1]	−0.507	0.135	−3.764	<0.001	33.6
Null deviance:	Bankside inclination[2]	−0.909	0.161	−5.638	<0.001	
215 on 52 d.f.,	Phragmites[1]	−0.307	0.163	−1.880	0.060	12.0
Residuals deviance:	Phragmites[2]	−0.291	0.167	−1.745	0.081	
66 on 41 d.f.,	Sediment cover[1]	0.636	0.238	2.674	0.007	20.7
AIC of the model 303.1,	Sediment cover[2]	−0.578	0.223	−2.527	0.011	
Theta parameter: 4.57	Short vegetation	0.650	0.139	4.695	<0.001	18.7
	Stream width (0.4–0.8 m)	1.911	0.396	4.828	<0.001	20.3
	Stream width (>0.8 m)	1.637	0.380	4.313	<0.001	
	Water depth	0.245	0.107	2.285	0.022	3.3
	Sediment depth	−0.493	0.211	−2.333	0.020	3.9

[a] If the variable was fitted as a second-order polynomial function, the values for both linear([1]) and quadratic([2]) polynomial terms are listed

[b] Change of the AIC value of the final models after removing of individual variables

vulnerable *C. boltonii* was found in a sparsely vegetated channel.

Discussion

Biodiversity of post-mining drainage ditches

Our study brings clear evidence that headwaters of drainage channels in a spoil heap can have substantial conservation potential for threatened dragonflies, including a few important species closely associated with small streams (hereinafter called headwater species). Altogether, surveying streams at the single locality, we found 30 % of the national dragonfly fauna, including 22 % of species on the national Red List (Hanel et al. 2005). Moreover, some of the endangered species (mostly species of oligotrophic early-successional waters, such as *O. brunneum* and *S. pedemontanum*) are very rarely seen in the surrounding landscape (Dolný et al. 2007). Critically endangered *C. ornatum* and endangered *O. coerulescens* and *O. brunneum*, all specialised for headwaters, were highly abundant in the study; the first two mentioned species were among the most frequent species at the studied channels (Table 2). These findings fully corroborate with numerous other studies which have revealed post-industrial sites as refuges of both terrestrial (e.g. Beneš et al. 2003; Lundholm and Richardson 2010; Tropek et al. 2013) and aquatic (Dolný and Harabiš 2012; Harabiš and Dolný 2012, 2015; Harabiš et al. 2013) biodiversity. To the best of our knowledge, we bring the first evidence of a secondary surrogate habitat at any post-industrial site for headwater biodiversity.

Comparing our results with the study of dragonflies colonising freshwater pools in 8 spoil heaps of the same region (Harabiš et al. 2013), the drainage channels seem to have even a higher importance for biodiversity conservation than the pools. Although the numbers of species recorded in the pools at individual spoil heaps (average 16.3 ± 5.6) are comparable with the drainage channels, the numbers of threatened species at the pools per heap were substantially lower (average 3.5 ± 1.9; Harabiš et al. 2013) than in the presented study of drainage channels (22 species of dragonflies in the single spoil heap, 8 of them nationally threatened). Moreover, the channels hosted some of the most threatened species not recorded in the studied pools

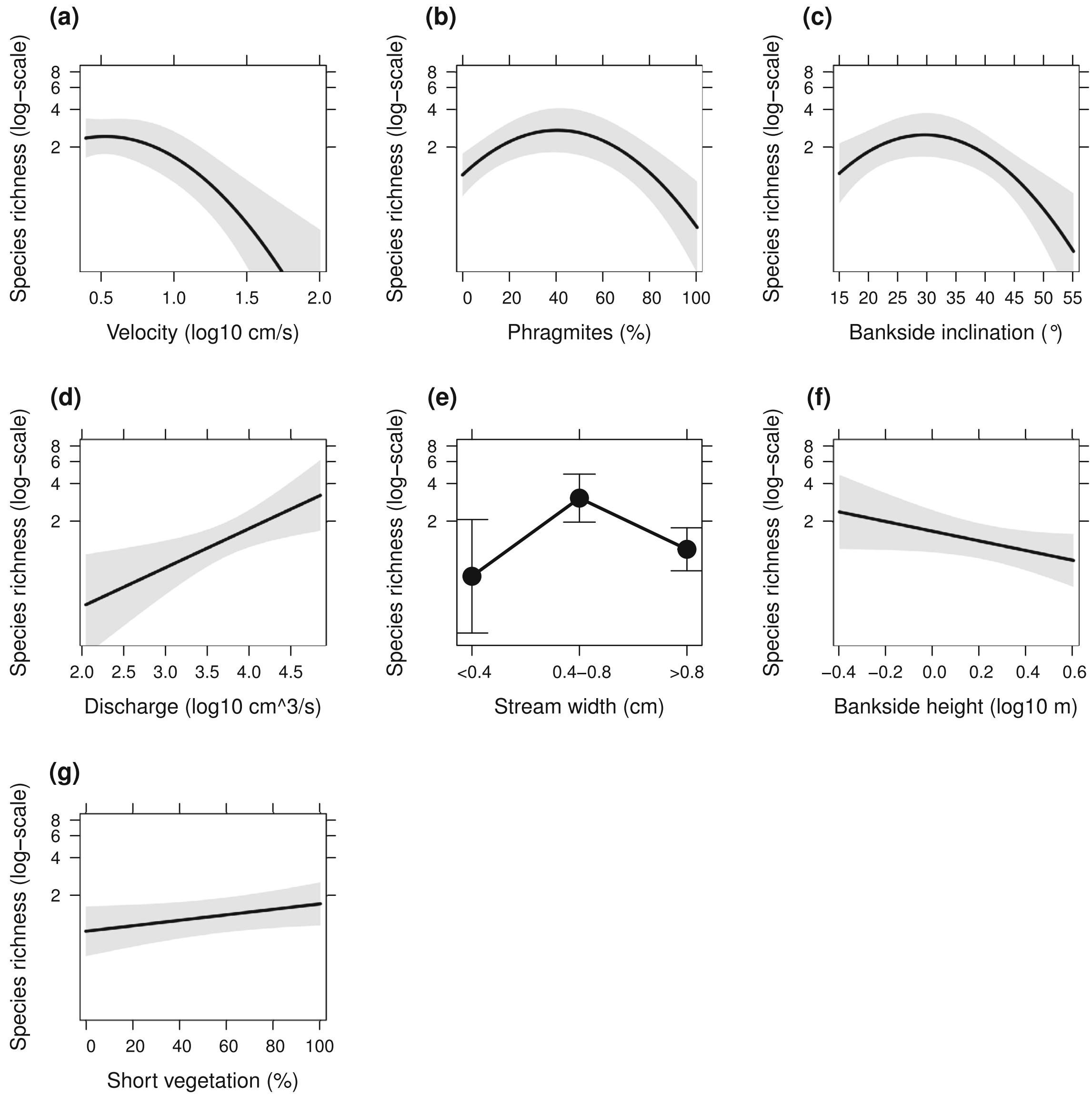

Fig. 1 Effects of the environmental variables included in the final model on the species richness of dragonfly communities in the studied channels predicted by the GLM. *Grey areas* indicate 95 % confidence intervals. See "Methods" and Table 3a for more details

(critically endangered *C. ornatum*, endangered *O. coerulescens*, *O. brunneum* and *S. pedemontanum*). Contrastingly, the pools offered habitats mostly for species with lower red-list status (NT, VU); only a single endangered species was found there (*Brachytron pratense*). In addition, the drainage channels harbour a unique ecological group of dragonflies specialized for small streams. Therefore, we conclude these channels are important freshwater components, contributing greatly to the regional biodiversity.

Environmental factors and management implications

The above-discussed high conservation potential of the drainage ditches for dragonflies strongly depends on several studied environmental factors. The negative effects of high bankside inclination and height can be related to shading of the water habitats, as well as reducing the aquatic-terrestrial linkage. Both have already been shown as key factors for stream biodiversity maintenance (Naiman et al. 2005; Rouquette and Thompson 2005; Pedersen et al. 2006; Remsburg et al. 2008). It is thus apparent that creation of lower and gentle banks will effectively support stream biodiversity.

The character of emergent vegetation has also been recognised as a key factor structuring dragonfly communities in various freshwater habitats (Schouten et al. 2008; Allen et al. 2010; Raebel et al. 2012; Harabiš et al. 2013). Channels overgrowing by common reed substantially decreased both the biodiversity indicators of the local dragonfly communities. Dense common reed vegetation

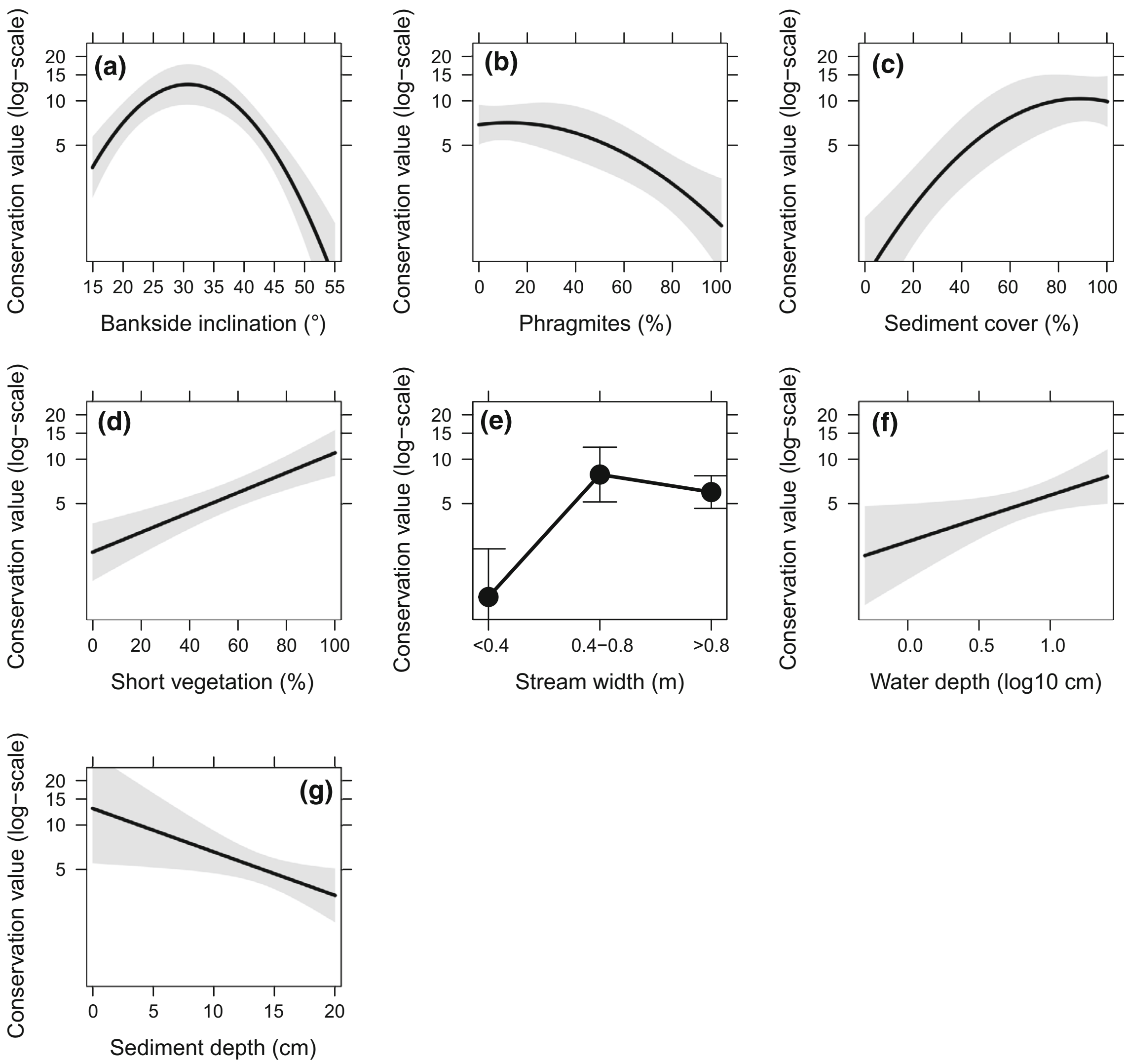

Fig. 2 Effects of the environmental variables included in the final model on the conservation value of dragonfly communities in the studied channels predicted by the GLM. *Grey areas* indicate 95 % confidence intervals. See "Methods" and Table 3b for more details

shades the stream and suppresses less competitive plants (Ailstock et al. 2001; Marks et al. 1994). Moreover, the dense common reed does not offer suitable oviposition sites for the majority of dragonfly species and simultaneously obstructs adults in their movement (Dolný et al. 2007; Painter 1998). On the other hand, richer and shorter vegetation, with only small patches of common reed, offer a more complex habitat for the majority of dragonfly species (Harabiš et al. 2013; Dolný et al. 2007), including the headwater specialists (Harabiš and Dolný 2015; Rouquette and Thompson 2005; Allen et al. 2010). We thus see the extensive suppression of the common reed as the most important management action to support the conservation potential of drainage systems at post-mining sites.

The revealed association of the conservation value with high cover of shallow sediments corresponds with several other studies documenting that sediments offer important shelters for many water invertebrates, including dragonfly larvae and their prey (Yarnell et al. 2006; Dolný et al. 2007; Harabiš et al. 2013; Harabiš and Dolný 2015). In general, too deep sediments suppress the microhabitat heterogeneity of stream bottoms and leads to more eutrophic and anaerobic conditions, as well as to reduction of the suitable freshwater habitat by decreasing the water level (Buffington and Montgomery 1999; Yarnell et al. 2006; Descloux et al. 2013; Burdon et al. 2013).

The dragonfly communities were also affected by stream architecture, namely by the flow depth, width, velocity and total discharge. Streams with higher water supply, and/or natural obstacles creating numerous pool structures, represent more heterogeneous environment offering suitable habitats for more dragonfly species, including the

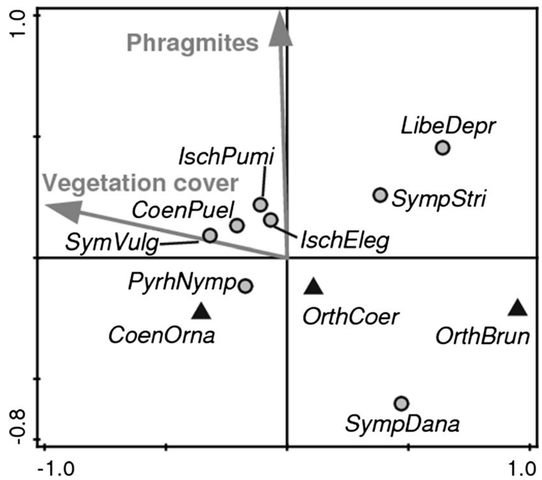

Fig. 3 An ordination diagram (CCA, variability explained by the model: 16 %, adjusted explained variability: 12 %, pseudo-F: 4, $P < 0.0001$) visualising affinities of individual dragonfly species to the significant environmental variables of the studied drainage channels. Only species best fitting the model (>4 %) are visualised. Legend to the species symbols: *black diamonds* threatened headwater species, *grey circles* all other species. See Table 2 for the individual species abbreviations and "Methods" for the environmental factors definitions

headwater species (Dolný et al. 2007). On the contrary, too high water velocity, frequently connected with simplified and narrowed bottoms, strongly supresses habitat complexity and makes the environment uninhabitable for the majority of species in the studied drainage system. Establishing streams with wider bottoms, structured by semi-natural obstructions locally decelerating flow, thus seem to be an efficient restoration tool (e.g. Pedersen et al. 2006, 2007).

Technical reclamation and freshwater biodiversity

Our results bring a new view to the ongoing debates on restoration of post-industrial biotopes. Recently, it has been recognized that technical reclamations destroy the conservation potential of terrestrial communities at post-mining sites, whereas spontaneous succession serves as a much more efficient restoration tool in terms of biodiversity protection (e.g. Hodačová and Prach 2003; Tropek et al. 2010, 2012, 2014; Mudrák et al. 2010; Hendrychová et al. 2012; Šálek 2012; Šebelíková et al. 2015). The only comparison of freshwater communities at differently restored sites (Harabiš et al. 2013) showed that stagnant freshwaters at technically reclaimed spoil heaps and at spontaneously developed sites are fully comparable in terms of the conservation value of dragonfly communities. Nevertheless, all the studied drainage ditches are fully artificial and lie exclusively in the technically reclaimed parts of the Radovesická spoil heap and they harbour even more threatened dragonfly species than any stagnant water there. Our study is thus the first suggestion that the highest conservation value of freshwater (dragonfly) communities is associated with technically reclaimed post-mining sites. On the other hand, it is necessary to admit that establishment of these channels in spoil heaps suppresses development of species-rich wetlands, except for a few cases in the water reservoirs' littoral zones (Hodačová and Prach 2003). With the current knowledge, we suggest careful combining of spontaneous succession with ecologically-engineered support of both flowing and stagnant freshwater and wetland habitats. Likewise, the newly established channels should be elongated as much as possible by building bends and meanders to maintain humidity in adjoining habitats and to increase the area of the stream itself.

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