Ecological Engineering 90 (2016) 438–446

Contents lists available at ScienceDirect

Ecological Engineering

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

High diversity of odonates in post-mining areas: Meta-analysis uncovers potential pitfalls associated with the formation and management of valuable habitats

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ARTICLE INFO

Article history:
Received 14 July 2015
Received in revised form
17 December 2015
Accepted 26 January 2016
Available online 20 February 2016

Keywords:
Biodiversity conservation
Odonata
Dragonfly
Habitat heterogeneity
Restoration
Spontaneous succession

ABSTRACT

A growing number of studies indicate high conservation potential of freshwater habitats occurring in post-mining areas. The overall diversity of these habitats depends on many factors, however, even a high diversity may diminish significantly over time. Therefore, it is difficult to identify and understand the importance of key habitat properties for diversity. Here I present analysis of three studies comparing the diversity of dragonflies and damselflies (Odonata). Each study was performed in different coal mining basins within the Czech Republic (a total of 94 sites). In this analysis, I used generalized linear mixed models and several multivariate methods to analyze the effects of a number of environmental characteristics such as depth, bottom substrate or bank slope, reflecting not only the current quality but also the succession and formation of individual pools. The occurrence of overall 14 nationally red listed species indicates the high conservation value of these habitats, while the 40 species found indicate that these areas contribute significantly to regional diversity. Species richness of individual pools was associated with habitat type (spoil heap vs. mine subsidence) and with several habitat variables, in particular the character of vegetation around aquatic habitats. In conclusion, the results indicate that diversity and species composition are significantly influenced by factors reflecting the formation and subsequent succession of pools. Effective conservation management should concentrate primarily on modifying pools' initial properties such as bottom substrate. Subsequent management should then sustain landscape dynamics, which means in particular to sustain minor disturbances that subsequently affect vegetation succession and prevent excessive overgrowing of expansive vegetation, as doing so is promoting the habitat heterogeneity which is essential to high biodiversity in these areas.

1. Introduction

Conservation biology is today facing the huge challenge of reducing the negative impacts of anthropogenic activities on biodiversity and halting the loss of sensitive species (Thomas et al., 1994). An overall effect of anthropogenically induced changes is exacerbated by the fact as individual phenomena often act synergistically (Fahrig, 2003; Travis, 2003). Anthropogenic activities such as mining and also their consequences are generally perceived as entirely negative, and therefore post-mining areas are regarded as degraded land which must be reclaimed (Prach and Pyšek, 2001). Recent studies have indicated, however, that the diversity of certain taxa in these areas can be very high and reclamation efforts can in turn lead to significant reduction of diversity (Tropek and Konvicka, 2012). One possible explanation for this situation is that reclamation efforts focus primarily on restoring historic abiotic conditions while ignoring the habitat requirements of individual taxa (Tropek and Konvicka, 2012; Tropek et al., 2010). Another explanation relates to higher environmental heterogeneity in non-reclaimed sites (Doležalová et al., 2012; Tropek et al., 2010). Thus, a question arises as to whether and under what circumstances the newly formed habitat can compensate for the enormous habitat loss caused by mining and other anthropogenic activities.

In comparison with smaller anthropogenic disturbances, mining has a significantly greater impact on abiotic and biotic components. In contrast to such valuable habitats as wetlands, mining areas often constitute a complete remodeling of the environment that substantially limits their recovery. There is no possibility in such cases to maintain the native species pools, and that means that succession processes basically start from a very initial stage (Prach and Pyšek, 2001; Suding et al., 2004). Precisely this should be taken into account during reclamation of these areas.

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http://dx.doi.org/10.1016/j.ecoleng.2016.01.070
0925-8574/

There exists a high risk of failure in efforts to recover entire complex ecosystems such as wetlands with all their functions or to establish entirely new complex habitats (Moreno-Mateos et al., 2012). Increasingly, research is documenting that initial environmental properties may significantly affect the diversity in these areas (Doležalová et al., 2012). Moreover, the initial features of a newly formed environment could significantly affect the subsequent succession process (Prach and Pyšek, 2001). From the viewpoint of nature conservation, therefore, it is highly desirable to understand those processes and initial habitat features which may significantly influence the diversity and conservation value of post-mining areas. A large part of the studies dealing with the diversity of post-mining areas have focused on species effect (e.g. Bröring and Wiegleb, 2005; Dolný and Harabiš, 2012; Harabiš et al., 2013; Šálek, 2012; Tropek et al., 2010).

It is assumed that individual species are differentially sensitive to individual habitat features and hence habitat specialists can be found on a given site only if the environment matches their habitat requirements (Aliberti Lubertazzi et al., 2009; Ball-Damerow et al., 2014; Suding et al., 2004). Dragonflies undoubtedly are among those taxa able to indicate very well the quality and conservation value of freshwater habitats (Bried and Samways, 2015; Foote and Rice Hornung, 2005; Kutcher and Bried, 2014; Oertli, 2008; Sahlén and Ekestubbe, 2001; Silva et al., 2010). Dragonflies have an amphibious life cycle, and their close association with the aquatic environment in the larval stage is completed with the possibility of escape in the adult stage (Corbet, 1999). Moreover, habitat requirements of odonates often reflect the quality of surrounding environments (Sahlén and Ekestubbe, 2001). Precisely these qualities make dragonflies very good indicators of ecosystem health and its change (Oertli, 2008; Raebel et al., 2011; Remsburg and Turner, 2009). A bit surprisingly, perhaps, recent studies have shown that diversity of odonates may be high in post-mining habitats even relative to that in some very valuable natural habitats such as fens or wetlands (Dolný and Harabiš, 2012; Harabiš et al., 2013). For several species, post-mining habitats constitute one of the last suitable habitats within a broad area (Harabiš and Dolný, 2015a). Even as diversity may vary greatly among habitats, it nevertheless can also change over a relatively short time (Harabiš and Dolný, 2015b, 2012), and this can significantly limit conservation of these areas. The aim of the present study is therefore to identify general patterns of odonate diversity across a wide range of aquatic habitats occurring in post-mining areas. I combined the data from three independent studies with the aims of (1) examining the diversity and species composition of assemblages in three major coal mining basins within the Czech Republic, (2) evaluating the effect of environmental variables positively/negatively influencing the diversity and conservation value of these secondary habitats, and (3) proposing appropriate management based upon a synthesis of this knowledge.

2. Methods

2.1. Study sites

Data were collected in the three largest areas within the Czech Republic where coal is mined. The North Bohemian lignite basin is a relatively large lowland area (about 1100 km^2, mean altitude 270 m a.s.l.) situated between the cold and wet Ore Mountains (Krušné hory) and the warm and dry Central Bohemian Uplands (České Středohoří) in the northwestern Czech Republic (Fig. 1). The climate in this area is relatively mild and dry (mean annual temperature: 7–9 °C, annual precipitation: 500–620 mm). The entire area is significantly affected by brown coal mining, which is extracted only through surface mining. Second, the Sokolov brown-coal basin, too,

Fig. 1. Locations of individual mining areas within the Czech Republic. From the total 94 sites were 56 sites located in the North Bohemian lignite basin, 18 mine subsidence pools in the Czech part of the Upper Silesian coal basin and 20 sites in the Sokolov brown-coal basin.

is significantly affected by brown coal mining. This area, covering about 100 km^2, is situated east of the cold and wet Ore Mountains. The climate in this area is also relatively mild (mean annual temperature: 7–8 °C, annual precipitation: 600–700 mm). The research area was located at an altitude of 443–600 m a.s.l. Brown coal is also mined here via surface methods, but subsurface (underground) mining had also been used in the past. Finally, the Upper Silesian coal basin is an area of about 5500 km^2 in Poland and the Czech Republic. Black coal in this area is deposited at a great depth and is therefore excavated exclusively by underground mining. The climate in this area is warm and relatively dry (mean annual temperature: 10.2 °C, mean annual precipitation 580 mm).

The individual attributes and further succession of newly formed aquatic pools is closely associated with the environmental conditions upon their initial formation, which are in turn closely related to the coal excavation method. Surface mining starts by removing a long strip of overlying soil and rock (the overburden) which covers the coal bed. The redundant overburden is deposited and thus creates a spoil heap. In terms of formation and recovery, the succession process on the spoil heap can be considered as primary. Aquatic pools arising in waterlogged terrain depressions can be very heterogeneous in size, covering an area of several meters up to several hundreds of meters. These pools may also significantly vary in depth (0.1–3 m) and their shape can be also very irregular. Development of biota on the spoil heap can be left to spontaneous succession or it may be affected by reclamation intervention (technical reclamation). Underground mining, meanwhile, leads to the creation of an extensive network of shafts and undermining of large areas. There is a gradual slump of upper layers, and this may result in the formation of terrain depressions on the surface. These depressions are successively inundated by rainwater and the infiltration of underground water, which leads to the formation of mine subsidence pools. This is a quite dynamic process, however, and ongoing subsidence of layers could even lead to extinction of the aquatic habitat.

The dataset for analysis was derived from three individual surveys that had been conducted according to a very similar sampling design. A total of 56 sites in the North Bohemian lignite basin had been sampled during 2010 (for details see Harabiš et al., 2013), 18 mine subsidence pools in the Czech part of the Upper Silesian coal basin during 2012, and 20 sites in the Sokolov brown-coal basin during 2014. Appendix A contains the locations and attributes of individual habitats. The minimum distance between sites was approximately 100 m.

2.2. Data sampling

Odonata (damselflies and dragonflies, hereinafter odonates) had been recorded during three visits from June to August (early June,