REVIEW

COLONIZATION OF POST-MINING LANDSCAPES BY AMPHIBIANS: A REVIEW

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Amphibians are in decline worldwide, due to their ecological requirements and their sensitivity to the quality of the environment. The chief causes of this phenomenon include destruction and changes to the landscape, as a result, e.g., of mining. In the territory of the present-day Czech Republic there was a problem, above all, of opencast brown-coal mining in northwest Bohemia. After the end of mining here, interesting habitats began to arise, which are gradually being colonized by organisms including amphibians. This study summarizes and synthesizes the literature on problems of succession of amphibians and other organisms, above all in locations affected by open-cast mining. Attention is also paid to species diversity of vertebrate communities during succession, questions of reclamation of these territories and amphibian conservation. It is not simply a matter of conserving individual ponds, but of dealing with the whole complex of ponds, including suitable terrestrial habitats, taking into account ecological considerations and the metapopulation dynamics of species. Unreclaimed spoil heaps, above all, offer a favourable environment. The study reveals that in many locations spontaneous succession brings higher species diversity of plant communities than in technically reclaimed territories. Although spontaneous succession is a much cheaper reclamation alternative, only technical reclamation is systematically used in the Czech Republic.

open-cast mining; spoil heaps; primary succession; species diversity; herpetofauna; technical reclamation; spontaneous succession

Amphibian decline and mining

There is a need for conservation of amphibians due to the considerable sensitiveness of this animal class to environment changes (e.g. Gibson, Freeman, 1997; Beja, Alcazar, 2003; Green, 2003) and the worldwide decline of their abundance (e.g. Wake, 1991; Houlahan et al., 2000; Carey, Alexander, 2003). The number of studies devoted to this problem has grown, especially in the last two decades (Semlitsch, 2003).

There are many reasons for amphibian decline. Collins and Storfer (2003) named six major reasons, the most significant and most investigated of which are destruction and changes in exploitation of landscape (Alford, Richards, 1999). In particular, open-cast mining operations replace the former dynamic equilibrium of vast landscapes (Hüttl, Gerwin, 2005). Large-scale mining is widely known from Australia, Russia, the U.S.A. and Central Europe, particularly Germany, Poland and the Czech Republic. In the Czech Republic these activities are concentrated in northwest Bohemia, where they have involved total destruction of the original ecosystem and changes in the surrounding areas (Sklenička, Lhota, 2002).

Major features of mining are open-cast mines and spoil heaps. The substrate of spoil heaps originating from the overlying earth of the brown seams (overburden) lack any life forms at the moment of stripping (Bejček, Šťastný, 1984). As soon as mining operations and reclamations are finished, these locations are taken over by plants and animals in the process of primary succession (Majer, 1989).

Spoil heaps are very suitable for the study of succession, since they are very easily identifiable and they are extensive territories with a known date of origin (Bejček, Šťastný, 1984). A study of succession on these territories provides a good opportunity to achieve a better understanding of their regular features, and to use the information acquired to protect habitats and the organisms living in them.

The goal of this review is to summarize and synthesize the literature on issues of the colonization of amphibians on spoil heaps and the variability of species diversity in their communities during this process. Attention is also paid to practical questions of amphibian conservation, and to the utilization of basic research for conserving these endangered species and their unusual, though often valuable habitats.

Succession – colonization of new habitats

One of the most significant features of a community is its variability in time. Changes in species composition, number of species and densities of populations show up

with repeated fluctuations, or the community gradually develops during succession (Krebs, 1985). Odum (1977) defined succession as the organized string of evolution of a community, with changes in its generic constitution and processes.

Studies of animal succession have much more often been carried out on a range of other habitats than on spoil heaps, e.g., mined peatbogs (Mazerolle, Cormier, 2003), newly formed ponds within conservation activities (Stumpel, van der Voet, 1998; Baker, Halliday, 1999), grazed grasslands (Zobel et al., 1997), dunghills (Gittings, Giller, 1998), fallows and abandoned fields (Siemann et al., 1999; Steffan-Dewenter, Tscharntke, 2001), sandpits (Taylor, Fox, 2001), territories affected by wildfire (Friend, 1993; Taylor, Fox, 2001), slag areas (Roy, Singh, 2003), restored wetlands (Petranka et al., 2003a, b), islands that have arisen through seismic activity (Thornton et al., 2001). From the beginning, greater attention has been paid to plants (Krebs, 1985). Among vertebrates, amphibians have been studied much more rarely than, e.g., birds or mammals (Galán, 1997).

The situation as regards spoil heaps is similar. Most studies concentrate on communities or populations of birds (e.g. Bejček, Tyrner, 1980; Bejček, Šťastný, 1982; Armstrong, Nichols, 2000; Balcerzak, Wood, 2003) and mammals (e.g. Halle, 1993; Rathke, Bröring, 2005). The study by Nichols and Nichols (2003) deals with all classes of amniotic vertebrates and ants. There have been several studies of how ants, together with other groups of invertebrates, colonize these locations (e.g. Majer, Nichols, 1998; Tajovský, 2001; Bröring, Wiegleb, 2005).

Among the minimal number of studies devoted to amphibians, mention should be made of the study by Nichols and Bamford (1985), who investigated herpetofauna on reclaimed areas after bauxite mining in Australia. Perhaps most comparable with the Czech Republic are the results of Galán (1997), who deals with the succession of amphibian and reptile communities on spoil heaps after lignite mining in northwest Spain. During the ten-year succession, 9 out of 13 kinds of amphibians and 6 out of 10 kinds of reptiles living in the surrounding areas appeared on the spoil heaps. The numbers for amphibians are very similar to the situation in the Czech Republic (Vojar et al., 2004). The first amphibian on Spanish spoil heaps was the midwife toad (*Alytes obstetricans*) and the Iberian green frog (*Rana perezi*) in the second year. The Iberian green frog is a species with broad habitat requirements with a similar ecology as the marsh frog (*Rana ridibunda*) (Arnold, Ovenden, 2002), which is common on spoil heaps in the Czech Republic soon after they have been filled (Vojar, Doležalová, 2003). The first species to reproduce on Spanish spoil heaps is the Portuguese painted frog (*Discoglossus galganoi*) and the natterjack toad (*Bufo calamita*), namely 5 years after the origin of the spoil heaps. This species, along with the green toad (*Bufo viridis*), is also in Czech conditions one of the first, with clutches registered already in the initial seral stages (Vojar, unpublished data). In the first three years, Galán (1997) mentions the occurrence of juvenile specimens only, which is again very similar to the settlement of the marsh frog, whose juveniles in the initial seral stages make up 88–100% of the population (Vojar, Doležalová, 2003). As in the studies on invertebrates (Siemann et al., 1999; Steffan-Dewenter, Tscharntke, 2001), the species diversity of communities of amphibians grew with the expansion of wetland and terrestrial vegetation.

Species diversity during succession

One of the many characteristics of a community that changes during succession is its diversity. This can be expressed by the number of species or indices, heterogeneity, organic components or also stratification and spatial distribution (Krebs, 1998). Species diversity should increase in connection with specialization of spatial and trophic niches (Odum, 1977). On the other hand, during this process there is an increase in the size of the organisms, the length and complexity of their life and interspecies competition, which are attributes that limit the number of species. Whether or not species diversity will increase during the process of succession depends on whether the growth of the number of possible niches outweighs the negative effects of growth of sizes and kinds of competition (Odum, 1977).

Margalef (1963, cit. Odum, 1977) presumes that species diversity will culminate in the early or middle seral stages. The results of Bejček (1981), who compares species diversity of communities of small mammals on 4 unreclaimed spoil heaps of ages 2–4, 7–9, 13–15 and 19–21 years conform with this. The highest values are found on locations 13–15 years old, and the oldest stages are characterized by indices of species diversity (Shanon-Wiener function) that are even lower than for areas 7–9 years after filling. Similar results were found in the study of succession of amphibians on 2–20 year old habitats on the Radovesická spoil heap (Vojar, unpublished data). In another study by Bejček and Šťastný (1984), species variety of bird communities continued to grow until the unreclaimed spoil heap was 25 years old. It is not without interest that these numbers plunged after forestry recultivation took place. Continuous growth of species diversity of amphibian and reptile communities on spoil heaps up to the age of 10 years was also found in the data of Galán (1997). A ten-year period is evidently too short for recording changes in this attribute, which is confirmed in the results of Bejček (1982). An increasing number of reptile and bird species was also discovered on reclaimed bauxite mines in Australia in connection with mounting heterogeneity of the environment (Nichols, Nichols, 2003).

It is quite evident that variety of one kind of organism is dependent on heterogeneity of habitats and other organisms, and this is in line with the general principles of succession (Odum, 1977). Steffan-Dewenter and Tscharntke (2001), who studied succession of bee communities on 1–5 year-old fallows, found that the species diversity of their communities is closely connected to diversity of flowering plants. The positive correlation of species diversity of invertebrates (arthropods) and plants in accordance with this principle was also demonstrated by Siemann et al. (1999) in his work on abandoned agricultural fields.

During succession, the proportion of individual species changes. The youngest seral stages are characterized by a low number of species and considerable dominance of one or just a few of them (e.g. Bejček, 1981, 1982). In mammals on the north Bohemian spoil heaps, the long-tailed field mouse (*Apodemus sylvaticus*) with 90–100% dominance is prevalent in the initial stages. Among amphibians on these locations, the green toad is prevalent (Vojar, unpublished data). Over a period of time, the representation of individual species equalizes, their numbers increase and at a certain seral stage one species again begins to gain a dominant position. For example, on 20-year-old unreclaimed locations over 80% of all caught individuals are the common vole (*Microtus arvalis*) (Bejček, 1982). The smooth newt (*Triturus vulgaris*) occupies a similar position in these stages (Vojar, unpublished data).

The early or middle seral stages are evidently some kind of transition between the clear-cut environmental conditions on spoil heaps in the initial or advanced phases of evolution. These stages usually play host to similar kinds of species as the oldest part of spoil heaps, when the dominant species have not yet shown so clearly. Indices of species diversity take into consideration the number of species as well as the evenness of the densities of individual populations (Krebs, 1998), so the resulting values are usually high for these succession stages (Vojar, unpublished data).

Management implications – technical reclamation versus spontaneous succession

Appropriately made reclamations of spoil heaps, or the absence of technical reclamation, have a great potential for enabling recolonization of organisms from the surrounding landscape. Monitoring of this process may bring a great deal of knowledge that can be used for reclamation and conservation of these territories.

Interesting information was gained, e.g., from an extensive study of more than 130 newly constructed ponds in Holland (Stumpel, van der Voet, 1998). Of 16 independent variables characterizing the ponds and their surroundings, the significant influences on species composition of amphibian communities were found to be distance from the nearest pond and suitable terrestrial habitats, the age of the basin, its depth, pH value and vegetation cover. Not only significant interactions between the variables were found, but also species-specific habitat requirements, which in addition change during evolution of the species. The rate of settlement in newly created ponds depended above all on their location, size, shape and distance from the nearest current population.

A comparison of newly created and older basins from the point of the presence or absence of species was made in Great Britain by Baker and Halliday (1999). The percentage of ponds occupied by amphibians was very similar between both groups (among 65–70%), unlike the species structure. Oldham (1999) in this connection presents estimates of the effect of density of basins in an agricultural landscape on the unit of area, which above all takes into account the possibility of amphibians migrating.

Among a whole series of similar studies, we mention a study of restored wetlands in Minnesota (U.S.A.), where the effect of the sizes and the isolation of individual wetlands was found in relation to species diversity in the observed communities (Lehtinen, Galatowitsch, 2001). Such studies form the basis for the elaboration of the conservation strategies, formulated, e.g. by Banks et al. (1994), Denton et al. (1997), Gibson and Freeman (1997), or Oldham et al. (2000).

Amphibian conservation should not involve simply conservation of the ponds themselves. Taking into account the ecology and metapopulation dynamics of species, it is necessity to protect the whole complex of ponds, together with suitable terrestrial habitats (Marsh, Trenham, 2001).

Under certain circumstances, such environments can originate on spoil heaps, mainly in technically unreclaimed locations with a rugged topography. On an impermeable subsoil of tertiary clays, which are the prevalent material of spoil heaps in the Czech Republic (Štýs, 1981), frequent sky ponds develop which are fed only by precipitation in landscape depressions. These locations, in particular, are instantly settled by organisms and within primary succession a fast expansion of plant and animal communities occurs.

If technical reclamation is carried out in an inappropriate way, irreversible changes may occur, and an ecosystem may be created that will damage or destroy communities (Vojar, unpublished data). Then the question arises, whether consistent technical reclamation should be carried out in all cases. Hodačová and Prach (2003) showed that in the oldest seral stages spontaneously revegetated spoil heaps have much higher species diversity with double the number of plant species than technically reclaimed sites. Apart from the cost savings, a further benefit of spontaneous succession is the satisfactory rate of colonization by species well adapted to the conditions in local sites. Technical reclamation is more justified where there are very adverse abiotic site conditions that must first be ameliorated, on intensively eroded sites where prevention of erosion is a priority, or on sites where production (timber, crops) is preferred (Prach,

2003). In all other cases, spontaneous succession is advocated as the preferable alternative to any technical reclamation. Unfortunately, technical reclamation is still the only approach considered in the present reclamation activities in the Czech Republic (Hodačová, Prach, 2003; Prach, 2003)

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Sukcese obojživelníků na územích ovlivněných těžbou: literární přehled.

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Vzhledem k ekologickým nárokům a citlivosti na kvalitu životního prostředí u obojživelníků dochází k jejich celosvětovému ubývání. Mezi hlavní příčiny tohoto jevu náleží destrukce a změny v krajině, reprezentované mimo jiné i těžbou nerostných surovin. V České republice jde především o povrchovou těžbu hnědého uhlí v oblasti

severozápadních Čech. Zároveň zde vznikají po ukončení těžby zajímavé biotopy, které jsou postupně osídlovány organismy včetně obojživelníků.

Práce zpracovává literaturu věnovanou problematice sukcese obojživelníků i ostatních organismů především na lokalitách postižených povrchovou těžbou nerostů. Pozornost je věnována také proměnlivosti druhové diverzity společenstev obratlovců v průběhu sukcese, otázkám rekultivace těchto území a ochraně obojživelníků. Ta by neměla být zjednodušována na ochranu jednotlivých vodních ploch, ale s ohledem na ekologii a metapopulační dynamiku druhů by se měla týkat celých komplexů vodních biotopů včetně vhodného terestrického prostředí. Takovéto prostředí nabízejí především nerekultivované výsypky. Ukazuje se např., že spontánní sukcese přináší na řadě lokalit druhově rozmanitější rostlinná společenstva než na technicky rekultivovaných plochách. I přesto, že jde zároveň o mnohem levnější rekultivační variantu, je u nás stále důsledně uplatňována pouze rekultivace technická.

povrchová těžba uhlí; výsypkové plochy; primární sukcese; druhová rozmanitost; herpetofauna; technická rekultivace; přirozená sukcese

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