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Seed bank development after the restoration of alluvial grassland via transfer of seed-containing plant material

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ABSTRACT

In the attempt to ensure long-term-conservation of flood meadows along the northern Upper Rhine transfer of seed-containing plant material was successfully applied since 2000. In this highly dynamic habitat, many typical plant species rely on a persistent seed bank for re-establishment after disturbance. But in contrast to the re-established above ground vegetation, seed bank composition remains unknown. Thus the main aims of the study were to elucidate the current seed bank composition and to assess patterns of seed and species traits. To this end we sampled above ground vegetation and seed bank on plant material plots and on control plots left to natural recruitment.

Although the seed bank was still dominated by agrestal and ruderal plant species, it already contained seeds of transferred species. Analyses revealed that on the plant material plots seed density of plant material species declined significantly with soil depth, just as similarity between above ground vegetation and seed bank declined. In contrast, the seed bank on control plots comprised significantly lower numbers of transferred species. We found a vertical pattern of seed bank composition: in general, the upper seed bank layer comprised more elongated and large seeds of long-lived, competitive species able to build up transient seed bank. The lower soil layer was dominated by seeds of short-lived, agrestal and ruderal species, producing small, round and long-term persistent seeds.

The present study shows that the build up of a seed bank typical of flood meadows is a time-consuming process. Thus restorative management in the early phase of vegetation development should focus on fostering high seed production of transferred species.

1. Introduction

Across Europe, large areas of species-rich grasslands have been lost through intensified management, abandonment and conversion into arable fields since the middle of the 20th century. Especially, flood meadows of the phytosociological alliances *Cnidion* and *Molinion* are habitats of many rare plant species and among the most threatened plant communities in Central Europe and subject to extensive conservation and restoration measures (Joyce and Wade, 1998). Therefore, they are protected by the Fauna Flora Habitat Directive of the European Union (92/43/ECC). Various restoration efforts in alluvial grasslands showed that the lack of available diaspore sources and seed dispersal limitations are the main obstacles for the re-establishment of alluvial grasslands (Bischoff, 2002; Vecrin et al., 2002; Donath et al., 2003; Bissels et al., 2004). In accordance to the general finding that the seed bank is a very limited resource for the re-establishment of

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species-rich plant communities (Bossuyt and Honnay, 2008), this was found to be true also in alluvial meadows (Hölzel and Otte, 2001; Bissels et al., 2005; Vecrin et al., 2007). In addition, flooding seems to have only limited effect on the transport of seeds of rare species along strongly confined rivers (Hölzel and Otte, 2001; Vecrin et al., 2007; Gerard et al., 2008). To overcome this dispersal limitation, transfer of freshly cut, un-dried biomass from species-rich meadows (plant material hereafter) has been successfully applied in the restoration of various grassland types (cf. Klimkowska et al., 2007), such as mesic grasslands (Jones et al., 1995; Molder, 1995), wet and fen meadows (Patzelt et al., 2001; Poschlod and Biewer, 2005; Rasran et al., 2006), calcareous grasslands (Pfadenhauer et al., 2000; Kiehl et al., 2006), sand grasslands (Kirmer and Mahn, 2001; Stroh et al., 2002) and flood meadows (Hölzel and Otte, 2003; Donath et al., 2007). Along the northern Upper Rhine, large-scaled (ca. 60 ha) restoration aimed at the re-establishment of rare flood meadows on former arable fields via transfer of seed-containing plant material (Hölzel et al., 2006; Donath et al., 2007). Four years after these measures were applied the restoration success was apparent, i.e., more than 100 transferred plant species, among these about 30 red listed species were successfully re-established (Donath et al., 2007).

In contrast to the development of the above ground vegetation, nothing is known about the current state of the soil seed bank of these restored grasslands. However, the seed bank is the main resource for several rare target species' re-establishment after disturbance of the above ground vegetation by floods. Although the dominant species of these flood meadows tend to have short-lived seeds, a relatively large proportion (approx. 40%) of typical flood meadow species build up a persistent seed bank (Hölzel and Otte, 2004a).

Seed bank succession has been studied in various habitats, e.g. during primary succession on land-uplift islands (Grandin and Rydin, 1998), during secondary succession in forests (Bossuyt et al., 2002), in heathlands (Mitchell et al., 1998; Pywell et al., 2002), in secondary forests on former grasslands (Milberg, 1995; Bekker et al., 1997; Kalamees and Zobel, 1998), in abandoned wet meadows (Jensen, 1998; Falinska, 1999), in dune slacks (Bossuyt and Hermy, 2004), in inland dune grassland (Matus et al., 2005) or in arable fields (Albrecht, 2005). Despite this large body of studies, the present study is one of the few that addresses seed bank development after the active introduction of typical grassland species (cf. McDonald et al., 1996). To this end, we characterized and compared soil seed banks of flood meadow restoration sites along the river Rhine both in plots with and without plant material application. Further, we related the soil seed bank to the above ground vegetation and explored the influence of species traits on seed bank development. In the current study, we addressed the following questions:

(i) To what extent do the transferred plant species build up a soil seed bank 5–6 years after the application of plant material?
(ii) Which traits of seeds and species may explain the composition of the soil seed bank?
(iii) Which conclusions can be drawn from our findings for restoration practice?

2. Materials and methods

2.1. Study area

The study area is situated in the Hessian part of the Holocene floodplain of the river Rhine about 30 km southwest of Frankfurt, Germany, in the municipal area of the City of Riedstadt. This region represents one of the last and most important strongholds of many rare and endangered alluvial grassland species in Central Europe (cf. Donath et al., 2003), among them even species of concern for Central European conservation, e.g. *Arabis nemorensis*, *Cnidium dubium*, *Iris sibirica* and *Viola pumila* (Schnittler and Günther, 1999). Some of the typical species are specialist plants with subcontinental distributions such as *Allium angulosum*, *C. dubium*, *Scutellaria hastifolia* and *V. pumila* (Hultén and Fries, 1986). The occurrence of this vegetation type is a consequence of the particular abiotic conditions in the area. Along with the strong seasonal and inter-annual fluctuations of the water level of the river Rhine goes a maximum amplitude of the ground-water table of more than 6 m (Bissels et al., 2005). The climatic conditions in the region are relatively warm and dry with a mean temperature of 10.3 °C and a mean annual precipitation of 580 mm (Müller-Westermeier, 1990). In conjunction with the hydrological and edaphic conditions, i.e., extremely fine-grained soils (clay content > 60%), this results in highly variable soil water potentials.

2.2. Sampling

Plots for the sampling of above and below ground vegetation were established at five restoration sites where flood meadows were re-established via transfer of seed-containing plant material in 2000 and 2001, respectively (for more information refer to Donath et al., 2007). All sites included in the current study were used as arable fields before restoration measures started. Therefore, the vegetation and seed bank at the sites comprised mostly agrestal or ruderal species and no typical flood meadow species (Bissels et al., 2005; Donath et al., 2007). Owing to a shortage of high-quality donor sites, only around 20% of the area of each restoration site was treated with plant material in stripes of approx. 10 m width.

To assess both the above and below ground vegetation composition 5–6 years after plant material transfer, we established five sampling plots (10 × 10 m) on the plant material stripes at each restoration site. To contrast the effects of plant material transfer on seed bank development with an untreated control, we established five additional sampling plots parallel to the plant material stripes. To avoid errors due to local carry-over of plant material to non treated areas, paired sampling plots with and without plant material transfer were separated by two meters.

On each of these 50 plots, we took 20 soil cores from 0–10 cm depth using a soil corer (3 cm diameter) along a regular sampling grid in late February 2006. To assess the vertical distribution of seeds in the soil, each soil core was divided into three sections: 0–1 cm, 2–5 cm and 5–10 cm (upper, medium and lower layer, respectively). The samples represent 141 cm^2 of the soil surface and 141 cm^3 (0–1 cm), 565 cm^3 (2–5 cm) and 706 cm^3 (5–10 cm), respectively, of the soil volume.