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Hay and seed transfer to re-establish rare grassland species and communities: How important are date and soil preparation?

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A B S T R A C T

European floodplain grasslands are threatened by land use intensification or abandonment. Hay transfer using plant material from species-rich reference communities may be a valuable tool to restore such grasslands. However, large differences in seed production periods and strong competition are still obstacles that limit the efficiency of hay transfer. Using continental Cnidion meadows (FFH habitat type 6440) as a model system, we tested the effect of cutting date and of soil disturbance intensity on community and target species for eight years in a full-factorial hay transfer experiment.

The cutting date treatments were early (June), late (October), combined and no hay. Soil disturbance included shallow, deep and no tillage prior to hay transfer. We estimated the plant cover on donor and restoration sites before and after hay transfer. We additionally counted the individual number of seven specialist species of Cnidion meadows considered as target species. In a sowing experiment, seedling establishment was recorded for a subset of target species and compared to establishment in the hay transfer experiment.

Hay transfer was successful in transferring target species but community structure was still quite different from the reference grassland. Target species were only transferred with late hay but early hay added several non-specialist species of Cnidion meadows. Strong competition by pre-existing vegetation prevented target species from establishing without soil disturbance but differences were small between shallow and deep tillage. In conclusion, a combination of early and late hay and moderate soil disturbance were the most appropriate treatments to restore Cnidion meadows.

1. Introduction

European floodplain grasslands are potentially diverse plant communities comprising many specialist plant species that do not or rarely occur in other grasslands (Joyce and Wade, 1998; Bischoff, 2002; Krause et al., 2011; Wesche et al., 2012). They are man-made but result from long-term traditional land use allowing an adaptation to this specific environment (Härdtle et al., 2006; Bischoff et al., 2009). However, recent changes in land use such as drainage, fertilization and the conversion to arable fields have degraded or destroyed these floodplain grassland communities (Hundt, 1996; Joyce and Wade, 1998; Krause et al., 2011). Specialists or indicator species have become rare and plant communities are usually protected now via European habitat directive such as the continental *Cnidion dubii* meadows (habitat type 6440, FFH, 92/43/EEC; European Commission, 2007). Cnidion meadows can be found in Central and Eastern European river valleys from the French-German border to South-Western Siberia including the Rhine, Elbe, Danube and Oder floodplains and its tributaries (Šeffer et al., 2008; Ludewig et al., 2014).

In the Eastern German Elbe valley, intensification was particularly strong from the 1960s to 1980s since the former German Democratic Republic (GDR) aimed at self-sustainable food production resulting in a high conversion to arable land and increased livestock densities (Hundt, 1996; Warthemann and Reichhoff, 2001). After German reunification in 1990, agri-environment schemes were introduced to restore former species richness. The major objective of these schemes was to reduce fertilization and related grazing or cutting frequency to the traditional extensive level

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through land use contracts with farmers. However, restoration success was poor in grasslands that did not include remnant populations of specialist floodplain grassland species (Bischoff, 2002; Bischoff et al., 2009). Grassland restoration is often dispersal limited and may be unsuccessful if source populations are too far away (Bischoff, 2000; Donath et al., 2003; Bischoff et al., 2009).

To overcome dispersal limitation, an active introduction of grassland species propagules has been suggested by several authors (Kiehl et al., 2010; Scotton et al., 2012). The use of seed mixtures involves propagation in stock by commercial producers. Seeds of less common species such as specialists of floodplain grasslands are usually not available. The transfer of hay collected in close-by reference communities may be a cost-efficient alternative to seed production (Kiehl et al., 2010). Although different techniques have been used to concentrate seeds in the cuttings, the transfer of green fresh hay is still the most widespread method and has also been successfully tested in floodplain grasslands (Donath et al., 2007; Edwards et al., 2007; Klimkowska et al., 2007; Engst et al., 2016).

Two problems may, however, limit the success of floodplain grassland restoration by hay transfer. First, seedling recruitment may be hampered by pre-existing grassland swards of already established species (Donath et al., 2007; Pywell et al., 2007; Schmiede et al., 2012). Due to the higher nutrient and water availability, productivity and interspecific competition are much higher than in dry or calcareous grasslands (Bischoff et al., 2009; Kiehl et al., 2010). In the Rhine valley, restoration by hay transfer was therefore more efficient starting from bare soil (arable fields) than from established grasslands (Donath et al., 2007). In the latter case, soil or sward disturbance may be required to improve restoration success (Schmiede et al., 2012).

Second, the phenology of floodplain grassland species is quite different resulting in different ripening periods. Early species may have already shed seed when late species start to produce seeds resulting in incomplete species assemblages if hay is only cut once (Kiehl et al., 2006; Edwards et al., 2007). Multiple transfers with plant material harvested at different dates are required to include early and late fruiting species but the thicker litter layer of multiple transfers may hamper germination (Kiehl et al., 2006; Scotton et al., 2012).

In this study, we used a full factorial experiment to test the influence of soil preparation and of harvest date on the efficiency of green hay transfer. While Schmiede et al. (2012) obtained similar seedling establishment for deep tillage by ploughing than for medium disturbance by rotovation, Schnoor et al. (2015) recommend rotovating rather than ploughing in calcareous grassland restoration. We used shallow and deep soil tillage to evaluate the need for sward opening or destruction prior to hay transfer. We combined these soil tillage treatments with hay transfer at different dates. Most specialist species of Cnidion meadows only produce seeds in late summer following regrowth after the first cut (Šeffer et al., 2008; Warthemann et al., 2009). Other typical but more widespread species flower much earlier and shed seeds before summer. We tested an early transfer corresponding to a traditional first cut, an early autumn transfer corresponding to a late second cut and a multiple transfer combining both. We hypothesised that specialist Cnidion species best establish from a late hay transfer whereas a full species set can only be obtained by transferring early and late hay. We additionally sowed hand-collected seeds of four specialist species to analyse seedling recruitment more in detail and to compare establishment from sown seeds and from hay.

We present classical community-based comparisons of reference and restoration grasslands but we focus on the re-establishment of target species populations because the protection of these species is a major aim of Cnidion meadow conservation. We specifically analyse the following research questions: i) Is hay transfer a suitable method to restore subcontinental floodplain grasslands and is it as efficient as hand sowing? ii) Can specialist (=target) species of Cnidion meadows be established and do their populations increase in the long run? iii) What is the best harvest time for transfer and are multiple transfers required? iv) Does previous soil disturbance improve re-establishment?

2. Material and methods

2.1. Study site

The experimental site is part of the "Neue Wiesen" grassland area 5 km west of Dessau (51°51′09.9″N, 12°08′45.5″E). In the 1970s, large parts of this area were ploughed and re-sown using a species-poor grass mixture, followed by a period of intensive grassland use until the breakdown of the former GDR in 1989 (Warthemann et al., 2009). Since 1993, most of these grasslands have been under agri-environment schemes excluding fertiliser use, soil tillage and re-sowing. At the beginning of our experiment, after fourteen years of restoration, on average 21 species were found in 50 m^2 plots but re-colonisation by target species specialised on Cnidion meadows was very low. Only some *Silaum silaus* individuals occurred before hay transfer (5% of the plots, mean cover: 0.025%). The area is frequently inundated in spring after snowmelt in the surrounding mountain ranges, but flooding may also occur during summer following heavy rainfall in large parts of the river catchment. The site is only 1.25 m above the level of the next channel connecting the area with the Elbe River (Bischoff et al., 2009). Ground water levels may still decrease to 1.5 m below the surface during summer. pH-values are about 6.4, plant available N (ammonium, nitrate), P and K contents of the soils are 0.5 mg100 ml^{-1}, 4.4 mg 100 ml^{-1} and 10.4 mg 100 ml^{-1}, respectively. The grassland is usually mown twice a year, mid-June and early September.

A close-by (1 km) Cnidion meadow of the same altitude was used as a reference and donor site for hay transfer. Seven target species described as regional specialist species of this plant community (Schubert et al., 2001) were identified on the reference site: *Allium angulosum*, *Cnidium dubium*, *Galium boreale*, *Pseudolysimachium longifolium*, *Sanguisorba officinalis*, *Selinum carvifolia* and *Silaum silaus*. Compared with a large-scale analysis of 33 grassland6s in the same region (Bischoff et al., 2009), only one target species (*Serratula tinctoria*) was missing.

2.2. Experimental design

2.2.1. Green hay transfer

The experiment was set up in June 2007 using a randomised block design. Each of the five replicate blocks comprised twelve treatment combinations and two replicates of each treatment combination resulting in 24 plots per block and 120 plots in total. Plot size was 5 m × 10 m. Prior to hay transfer the three soil disturbance treatments were established. Shallow tillage was realised using a rotary harrow that cuts rhizomes at the soil surface (10 cm) but not in deeper soil layers. A deep cultivator was used to destroy below-ground plant organs to a depth of 20–25 cm by deep tillage. One third of the plots were left undisturbed (control). At the following day (18 June, early transfer), hay was cut in a close-by reference community (1 km) and directly (without drying) transferred to the restoration plots (green hay). For this purpose, a bar-mower suction combination was used throwing the hay automatically on a loader wagon. The green hay was manually spread to the early hay and the combined hay plots representing half of the block area. In two of the five blocks, wild boar grubbing in deep and shallow tillage plots resulted in a second unintended soil disturbance. Hay transfer was repeated at 4 October 2007 by spreading the harvested material (210 g m^{-2}) to the late hay and the combined hay plots resulting in four different hay transfer treatments: no hay (control), early hay, late hay and combined hay. The position of the twelve treatment combinations was randomised within blocks. Hay was collected from a reference site that was four times larger than the sum of the recipient plots (donor-recipient area ratio 4:1) resulting in a transferred layer of 596 g hay per m^2 (air-dried before weighing).

2.2.2. Transfer of hand-collected seeds

One week after the late hay transfer, hand-collected seeds of four target species were sown to three additional plots in each block. To avoid cross contamination a buffer strip of 2 m separated sowing and hay