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Re-introduction of target species into degraded lowland hay meadows: How to manage the crucial first year?

Henriette John*, Sandra Dullau, Annett Baasch, Sabine Tischew

Anhalt University of Applied Sciences, Department of Nature Conservation and Landscape Planning, Strenzfelder Allee 28, 06406 Bernburg, Germany

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ABSTRACT

In grassland restoration, the first year after species re-introduction by sowing in former species poor grasslands is a crucial period for the restoration progress. Despite the preparation of the restoration site by ploughing or grubbing, the establishment window is usually open for only a short time period and germination as well as establishment of the sown target species is often hampered by dense vegetation stands and related low above-ground light-availability. However, concepts how to manage freshly sown sites differ widely. In the Elbe lowland plain (Saxony-Anhalt, Germany), we tested the effects of three different cutting treatments (cut once, twice, three times), three nitrogen fertilization treatments (120 kg N ha^{-1} yr^{-1}, 60 kg N ha^{-1} yr^{-1}, without fertilization), rolling versus no rolling as well as species-trait affiliation on the establishment of sown target species in a species-poor, grass-dominated hay meadow using a split-split-plot design. Eighteen target species were sown into ploughed and grubbed plots in autumn. In the following year, individuals of each sown species were counted in microplots before the first and after the last cutting date. The treatment effects as well as the species-trait affiliation were tested using generalized linear mixed models and principal component analysis.

Cutting three times significantly enhanced the number of established target species compared to cutting once showing the importance of biomass removal after species re-introduction into productive hay meadows. Compared to control plots, the 120 kg N ha^{-1} yr^{-1} fertilization led to a lower number of established target species as well as individuals, whereas moderate fertilization did not hamper the establishment success significantly. Rolling did not show a significant effect. In addition, species traits, such as the potential to build large hemirosettes close to the ground, specific leaf area, and species height are good predictors for the establishment success under the different treatments.

1. Introduction

Species-rich mesophilic grasslands are considered as endangered habitats throughout Europe, thus identified as an essential objective of general interest, for example, within Natura 2000 network (Council Directive 92/43/EEC). Major threats are intensification or conversion to arable land on the one hand and abandonment of management on the other hand (Bakker and Berendse, 1999; Dengler et al., 2014; Lindborg and Eriksson, 2004; Walker et al., 2004). Lowland hay meadows (habitat type 6510) have especially strongly declined since 1950 in Germany (Briemle et al., 1999), but also in other European counties (e.g. Öster et al., 2009b; Walker et al., 2004). Therefore, they are a focus of restoration projects throughout Europe (e.g. Lepš et al., 2007 for European grasslands, Germany: Buchwald et al., 2007; Conrad and Tischew, 2011; UK: Edwards et al., 2007; Pywell et al., 2002; Walker et al., 2004; Norway: Rydgren et al., 2010; Sweden: Öster et al., 2009b).

In grassland restoration, the first year after species introduction seems to be the most crucial period. Young seedlings are extremely sensitive to different biotic as well as abiotic factors resulting in a high loss rate (Fenner, 1987; Grubb, 1977). However, as shown by Öster et al. (2009b), a high first-year recruitment of sown species is very important for long-term establishment and therefore for the restoration outcome. It is thus a question how to manage this crucial first year to achieve high establishment rates of introduced species.

Particularly if a major part of farmed grassland is embedded into restoration schemes, restoration projects are often confronted with farmers demands. Because lowland hay meadows represent major forage sources for livestock feeding, farmers stipulate that the restoration sites are sufficiently productive and provide hay with a good forage quality already in the restoration phase. This

* Corresponding author.
E-mail address: he.john@loel.hs-anhalt.de (H. John).

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would imply to fertilize restoration sites (mainly with nitrogen), cut them twice a year as well as roll them using large machinery, like under traditional grassland management practices. The question is, how would this affect the establishment of introduced target species? On the one hand many grassland restoration projects cut their restoration sites only once a year (Hölzel and Otte, 2003; Jongepierová et al., 2007; Török et al., 2010; van der Putten et al., 2000) or even refrain from cutting in the early restoration period (Nordbakken et al., 2010; Rydgren et al., 2010). A relatively low biomass production is given as one argument for this management (Hölzel and Otte, 2003). Other arguments may be the fear of increasing soil compactness by cutting with large machinery (Schäffer et al., 2007), which can reduce seedling establishment (Török et al., 2011) or the disturbances caused by cutting. On the other hand some restoration studies have demonstrated that frequent cutting already in the first year can have positive effects on seedling establishment (Hofmann and Isselstein, 2004; Lawson et al., 2004). In particular, on sites with high soil nutrient contents seedlings of less competitive species can be suppressed by an increase in aboveground biomass and therefore increased light limitation for understory species (Borer et al., 2014; Hautier et al., 2009). Thus, frequent cutting may be a useful measure to reduce negative competition effects particularly in the first crucial year of establishment and on more productive sites (Borer et al., 2014; Lawson et al., 2004). Furthermore, effects of fertilization on seedling establishment might also be different depending on the intensity of biomass removal, i.e. cutting time and frequency. Therefore, testing the effects of different mowing regimes in combination with different nitrogen fertilization treatments is highly relevant for restoration practice, but has rarely been tested (Foster et al., 2009; Jones and Hayes, 1999; Smith et al., 2003). Apart from cutting and fertilization, rolling represents a further common management measure in Europe particularly practiced on former fen sites which are currently used as hay meadows. Rolling is mostly practiced in spring for soil consolidation and frost crack closing. There is little knowledge on the effects of rolling on the establishment of freshly sown species (e.g. Harper et al., 1965). It is a question whether rolling damages seedlings and if the soil consolidation reduces suitable micro sites for seed germination.

In order to allow for generalization independent of site-specific species, species traits may be good predictors of establishment success under different management practices (Kahmen and Poschlod, 2008; Pywell et al., 2003). This approach was already successfully applied in several studies on grassland restoration (Andrade et al., 2014; Bissels et al., 2006; Öster et al., 2009a), but not yet used for a systematic analysis of integrated fertilization and cutting treatments.

In the present study, a field experiment was conducted to test under practice-oriented on-site conditions the effects of relevant management treatments in different combinations on the performance of target species in the crucial first year after sowing, especially on the number of target species and individuals as well as composition of target species. Since small-scale heterogeneity of soil parameters are supposed to be a common feature of large-scale restoration sites (Baer et al., 2004; Maestre et al., 2003), we also included selected soil parameters into our analysis. We hypothesized that (1) a high cutting frequency in the first year after sowing is important for the establishment success of the sown target species on productive grassland sites, (2) high nitrogen fertilization inhibits target species establishment but moderate nitrogen fertilization might not impede sown target species, and (3) rolling damages seedlings and thus reduces the establishment rate. We further hypothesized that (4) specific species traits are good predictors for species-specific establishment success under the different treatments.

2. Materials and methods

2.1. Study site

The study site was located in the Wulfener Bruch, which is part of a large lowland plain area of the Elbe River in the center of the German federal state of Saxony-Anhalt (11°58′ E, 51°50′ N) with an altitude of about 52 m above sea level. The area is characterized by a continental climate with mean annual precipitation of about 500 mm and mean annual air temperature of 9 °C (climatologic station: Köthen, period: 1961–1990, DWD, 2015).

The study site was a former half-bog, but, as in many other regions, the site was long-since drained and used as a hay meadow. The soils are gley soils with high organic matter content (14.3%) and therefore of high fertility. The total nitrogen content of the soil is about 0.7 ± 0.3%, available phosphorous (DL extraction) 11.6 ± 7.5 mg per 100 g soil and pH (0.01 M $CaCl_2$) of 6.5 ± 0.7. The high nutrient level is due to intensive use during the times of the former GDR (high fertilization with slurry, several cuts per year). After German reunification, the meadow has been extensively managed (no fertilization, only one cut per year). This former management resulted in species poor stands (18.3 species per 16 m^2) with a clear dominance of grasses and a dense vegetation structure, as well as high litter accumulation. The meadow can be characterized as a species-poor lowland hay meadow (Arrhenatherion, Habitats Directive code 6510) which shows some features of an alluvial meadow (Cnidion, code 6440).

2.2. Study design

We used a split-split-plot design with four blocks (replications) to study the effects of different treatments on the number and individuals as well as composition of target species in the first year after sowing (Table 1). The cutting treatment was the main treatment of each block, split by the fertilization treatment (split-plot treatment) which was additionally split by the rolling treatment (split-split-plot treatment). All possible combinations of these single treatments resulted in 18 different management treatments. For each of the 18 treatments and their replications a sample plot with a size of 4 m × 4 m was installed (altogether 72). Interspaces between sample plots were about 12 m to avoid reciprocal interference of the different fertilization treatments and to facilitate the use of large machinery for mowing and rolling. The cutting height was about 10 cm and cuttings were subsequently removed within one week. The nitrogen fertilizer (urea) was spread by hand only within the 4 m × 4 m sample plots. Rolling was carried out using machinery typically used by the local farmers for this purpose (manufacturer Güttler GmbH Germany, prismatic roll, width: 6 m, mass: about 3 t).

All treatments represent typical management practices for this region. Cutting once represents the management practiced over the last 20 years at the study site, but came under criticism because of the unsatisfactory results in terms of the loss of many typical meadow species, particularly low-competitive forbs. Cutting twice is nowadays applied at nature conservation grasslands and cutting three times is mostly practiced at sites where farmers need high amounts of forage for cattle. With regard to the fertilization treatments, no fertilizers are used at nature conservation grassland sites where the soil should be impoverished or where atmospheric nitrogen input is high, while 60 kg N ha^{-1} yr^{-1} are often used in already developed species-rich lowland hay meadows and alluvial meadows where atmospheric nitrogen input is low. Fertilization with 120 kg N ha^{-1} yr^{-1} is a typical practice if a high hay quality is required. Rolling is typically used at drained half-bog sites for soil consolidation and frost crack closing as explained above.

All sample plots were ploughed and grubbed before sowing at the beginning of September 2011 and were afterwards sown with