Urban Forestry & Urban Greening 9 (2010) 43–47

Contents lists available at ScienceDirect

Urban Forestry & Urban Greening

journal homepage: www.elsevier.de/ufug

Successful creation of species-rich grassland on road verges depend on various methods for seed transfer

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ARTICLE INFO

Keywords:
Germination
Restoration
Secondary succession
Seed bank
Seedling recruitment

ABSTRACT

This study focused on a suite of vascular plant species (six herbs and two grasses) common to traditionally managed, species-rich grasslands in Western Norway. We assessed the suitability of two species transfer methods (seed sowing and soil seed bank) for restoration of species-rich grassland on a newly established road verge. We compared the species' frequencies one and three years after they were sown on a naked, newly created road verge with their frequencies in aboveground vegetation and soil seed banks of comparable, local grasslands. Species frequencies in the aboveground vegetation differed significantly from those in the seed banks. Moreover, the frequencies in the seed banks differed from those recorded one year after sowing, and the frequencies in the aboveground vegetation differed from those recorded three years after sowing. *Avenula pubescens* and *Knautia arvensis*, found in more than 25% of the aboveground grassland plots, did not germinate from any of the seed bank samples. *Festuca rubra*, *Galium verum*, *Pimpinella saxifraga* and *Silene vulgaris* were more frequent in the aboveground plots than in the seed bank samples. *Pimpinella saxifraga*, *Galium verum* and *Lychnis viscaria* emerged quite well both from sown seeds and from the seed bank. *Avenula pubescens* was frequent in the aboveground vegetation, but did not germinate from sown seeds. Six species established well from seeds, and most increased in frequency in the sown plots from the first to the third year. No species was found in the sown plots only, but three years after sowing, three species were more frequent in the sown plots than in the aboveground vegetation of donor grassland plots. Our fine-scale, point-to-point study demonstrates that different restoration methods produce widely differing species composition even when the donor material is identical. We propose that different substrates and a combination of establishment methods (sowing and hay transfer) are needed as supplements to seed banks to re-establish species-rich grassland.

Introduction

The development of road systems, construction of new roads and widening of existing road systems leads to fragmentation of landscapes and often affects biodiversity on several scales (Whisenant, 1999; Nicolau and Asensio, 2000). The area of roads has increased in the modern cultural landscape, and a combination of more intensive management of some areas of traditional semi-natural grassland and abandonment of others has led to a decline in the area and species richness of these habitats during the last sixty years (e.g. Bekker and Berendse, 1999; Kålås et al., 2006). Because many of the semi-natural grassland species have few alternative habitats in the modern cultural landscape, there is an increasing need to create new habitats that are suitable for them. Road verges make up significant areas that need to be vegetated to prevent erosion and improve the aesthetic quality of the landscape, and it has been suggested that properly managed road verges and embankments could partly replace the grassland habitats lost in recent decades, serving as substitute habitats and dispersal routes (Tikka et al., 2001; Auestad et al., 2008).

Verges are commonly hydroseeded with non-indigenous grasses, usually resulting in a monotonous green lawn (Skrindo and Pedersen, 2004). During the last ten years, restoration ecologists have shown increasing interest in the use of local genotypes and indigenous species to re-establish vegetation (Sackville Hamilton, 2001; Walker et al., 2004). Three methods are more or less commonly used to establish indigenous vegetation: (i) in situ germination of seeds collected in surrounding areas (Mortlock, 2000), (ii) germination from the topsoil seed bank (i.e. seeds, spores, or vegetative regeneration; Skrindo and Pedersen, 2004), and (iii) hay transfer (Kiehl et al., 2006).

When seeds from local habitats are used to steer the development of vegetation cover in a desired direction, the local

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doi:10.1016/j.ufug.2009.10.004

species composition should be used as a basis for selecting which species to use (Wells, 1990; Cousins and Lindborg, 2004). Experimentally adding seeds either to existing populations (seed augmentation) or to unoccupied sites (seed introduction) usually increases species density, as the presence of diaspores is likely to be a major contributor to the number and abundance of species (Primack and Miao, 1992; Ehrlén and Eriksson, 1996; Zobel et al.; 2000; Tofts and Silvertown, 2002). Also, sowing a seed mixture may significantly reduce the abundance and number of naturally colonising species, thus making it easier to control weed species (Lawson et al., 2004).

Topsoil removed before road construction and later returned to the new road verge contributes viable seeds of indigenous species, as well as plant nutrients and microfauna (Skrindo and Pedersen, 2004; Bakker et al., 2005). In disturbed habitats, the seed bank is usually an important source during restoration (Bakker et al., 1996; Thompson et al., 1997; Pärtel et al., 1998), often contributing more than 40% of vegetation cover (Kalamees and Zobel, 2002; Pakeman and Small, 2005). Previous land use and habitat type determine whether it is desirable species or those considered as weeds that emerge from the soil seed bank. In addition, environmental factors (e.g. vegetation cover, landform, microslope) may affect the relationship between standing vegetation and the soil seed bank (Westbury et al., 2006). Seed bank studies have often been used for assessing the abundance of seeds in local soil and thus the potential for restoration without addition of external seeds (Bossuyt and Hermy, 2003). Unless the availability of grassland species is increased by sowing or other methods of seed addition, it is unlikely that herb-rich grasslands will develop on areas with naked soil (Pywell et al., 2002; Hölzel and Otte, 2003), not least because the distance between seed source and target area often limits the availability of immigrant seeds (Poschlod et al., 1998; Kirmer and Mahn, 2001; Novák and Prach, 2003).

In the present study we focused on eight vascular plant species often found in traditionally managed grasslands in Western Norway. Our aim was to assess the suitability of this group of species in the establishment of species-rich grassland on a new road verge. We did this by comparing the frequencies of these eight species recorded one and three years after they were sown on a naked, newly created road verge with frequencies of the same species in aboveground vegetation and soil seed banks of local grasslands. To our knowledge no other studies have combined information from sowing experiments with data from aboveground vegetation and seed banks. Information on the presence of species in the soil seedbank and their abundance in the aboveground vegetation can help to explain revegetation patterns.

Materials and methods

Study sites

The seed sowing experiment was conducted at Borgund (61°3′N, 7° 49′E) in Lærdal, Sogn og Fjordane county, Western Norway, in a newly established road verge (total area about 0.5 ha). We collected seeds at three local donor grasslands in the Lærdal valley (Molde, Nese and Stuvane), positioned 16, 9 and 3 km down the valley from Borgund, respectively. The donor grasslands varied in size from 2.8 to 7.5 ha, and were situated at altitudes from 35 to 420 m. The experimental site and the donor grasslands were all positioned in the southern boreal, slightly continental region (Moen et al., 1999), had low annual precipitation of 500 mm (Førland, 1993), and annual mean temperature of ca. 5.9 °C (Aune, 1993) for the normal period 1961–90. All sites were situated on terraces formed in glacifluvial deposits (Klakegg et al., 1989). At the Borgund site, a top layer of soil with mean pH 6.1 was added (a mixture of about 80% gravel and sand and 20% local soil from nearby arable fields). The bedrock consisted of Precambrian gneisses, except for Nese, where it was gabbro (Klakegg et al., 1989). Information on the management history and ecology of the donor grasslands is given by Auestad et al. (2008). The seed bank in the soil used at the experimental site at Borgund was not studied. However, species abundance data from 80 sample plots recorded during the first three years of the experiment is presented in a parallel study in which we compare different methods of establishing herb-rich grassland vegetation (Rydgren et al., unpublished results).

Donor grasslands and vegetation recording

At each of the three donor grassland sites (Molde, Nese and Stuvane), we recorded the species abundance of vascular plants in June–July 2004 as presence/absence in 36 randomly positioned sample plots (0.5×0.5 m) that spanned the range of local environmental variation. Nomenclature of vascular species followed Lid and Lid (1994), and Muller (1978) was used for seedling determination.

Species from donor grasslands selected for seed germination

We selected eight grassland species common to the vegetation of species-rich, traditional grasslands in the area (Ref. Auestad et al., 2008). Seeds from these species were harvested in July and August 2004, and sown on the new road verge at Borgund in September the same year. We carefully collected seeds for the sowing experiment, deliberately choosing large and healthy looking seeds to ensure maximum viability. We used 25 seeds per plot for the six herb species (*Galium verum* L., *Knautia arvensis* (L) Coulter, *Lychnis viscaria* L., *Pimpinella saxifraga* L., *Potentilla argentea* L. and *Silene vulgaris* (Moench) Garcke) and 125 seeds per plot for the two graminoids (*Avenula pubescens* (Hudson) Dumort and *Festuca rubra* L.). Such sowing rates have been found to be successful in other studies (e.g. Pakeman et al., 2002). All sown species are perennials that can spread clonally as well as by means of seeds (clonal growth most often by below-ground stems; cf.Klimeš and Klimešová (1999)).

At Borgund, seeds from each of the three donor grasslands were mixed and sown together in three plots randomly positioned within each of the five replicates (blocks), giving a total of 15 plots (each 0.5×0.5 m). The abundance of the eight species was recorded as presence/absence in late July–early August 2005 and 2007.

As part of the management regime, all vegetation in the five blocks at Borgund, including the sown plots, was cut in mid-August 2006 and 2007 (second and third year), after the vegetation analysis.

Seed bank experiment, donor grasslands

Soil seed bank samples (5 cm deep) were collected a few cm outside each plot in all three donor grasslands on 5 September 2005 using a soil corer with a diameter of 5 cm. Two cores from each plot were sampled, merged and stored in darkness at 5 °C for three weeks for vernalisation. The soil from each plot was concentrated using the methods of ter Heerdt et al. (1996) and evenly spread over commercial potting soil in separate seed trays measuring $10\,\text{cm} \times 15\,\text{cm}$, at a thickness not exceeding 0.5 cm. The seeds were germinated for 17 weeks (after which no new seedlings appeared) under a light and temperature regime of 16 h