Flora 205 (2010) 179–183

Contents lists available at ScienceDirect

Flora

journal homepage: www.elsevier.de/flora

Artificial sowing of endangered dry grassland species into disused basalt quarries

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ARTICLE INFO

Article history:
Received 22 October 2008
Accepted 16 March 2009

Keywords:
Dry grassland
Quarries
Restoration
Seedlings recruitment
Seedling survival
Sowing experiments

ABSTRACT

Steppe-like dry (semi) natural grasslands are valuable and endangered habitats in central Europe. In the study area (the České středohoří Hills, Czech Republic), they occur in fragments on southern slopes of volcanic hills, often in the vicinity of quarries, which are numerous there. We performed sowing experiments and observed seedling recruitment of six species, typical for the dry grasslands, in 9 basalt quarries located in 3 different climatic regions over 3 yr. The sowing experiments were established in young successional stages, 5–12 yr after quarrying was stopped. The objectives of the experiments were to evaluate: (i) if seedling recruitment and survival of the target species are possible regarding different climatic regions and (ii) what is the influence of weather fluctuations among years on seedling survival. Seedlings of all studied species were able to recruit and survive in the early successional stages at least in some quarries. The species, except one, showed significant differences in recruitment among the climatic regions, with the best recruitment and survival in the driest and warmest region. Seedlings of two species did not recruit in the wettest and coldest region. All species survived in the driest and warmest region, while only one did so in the coldest and wettest region. Different weather conditions in the studied years significantly influenced recruitment of two species. The number of localities (floristic records) of particular species in the regions was the best predictor of species germination and survival. Thus a traditional floristic survey may help to predict success of species in restoration projects. It emerged that artificial sowing can be considered in restoration programs as a way of contributing to restoration of dry grasslands in disused quarries.

Introduction

Dry grasslands belong to the most valuable and rare habitats in central Europe (Ellenberg, 1988). Most of the present dry grasslands in central Europe are, to a certain extent, products of a traditional non-intensive land use (Bignal and Mc Cracken, 1996; Poschlod and Wallis De Vries, 2002; Thomas, 1993; Wilmanns, 1997). They also occur in fragments on southern slopes of volcanic hills in the studied area, i.e. the České středohoří Hills in the Czech Republic. The traditional non-intensive land use of the grasslands, i.e. extensive grazing and occasional cutting, has been recently practiced only in some nature reserves under special management plans, and many of the remaining dry grasslands are gradually changing in the process of secondary succession (Kubíková et al., 1997). Moreover, the study area is largely affected by stone quarrying, and dry grasslands are often destroyed by the quarrying or survive only in small patches in the vicinity of quarries. Thus, their restoration should be a reasonable goal of reclamation activities in disused quarries.

The environmental site conditions of barren rock and debris, which remained in the quarries, are expected to be rather extreme, especially in the initial stages of succession (Cullen et al., 1998; Novák and Prach, 2003). Besides the abiotic and other constraints, the arrival of some species before others may determine the course of succession (Tilman, 1994; van der Valk, 1992). In the studied area, the time of arrival and rate of plant establishment typical for the dry grasslands were recognized to be influenced by whether a site would develop towards open shrubby grassland or towards continuous mesophilous scrubs and woodland. The occurrence of dry grasslands in close vicinity of a quarry was decisive in this respect; thus dispersal limitation was expected to play a role (Novák and Konvička, 2006; Novák and Prach, 2003).

Based on the previous investigations, the main questions addressed in the present study were: Can the species typical for the dry grasslands be sown artificially to speed up succession towards restoration of the grasslands? Are there any patterns in

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doi:10.1016/j.flora.2009.03.003

seedling recruitment and survival among climatically different regions? To answer these two questions, we performed sowing experiments and followed seedling recruitment and survival in basalt quarries located in three different climatic regions (Kubát, 1970). We also intended to evaluate the influence of weather fluctuations among years on seedling establishment and survival. A regional seed material was used to carry out the experiments as close to natural conditions as possible. No laboratory or garden experiments were conducted as these might give different results from those conducted in the field (Fenner, 2000).

Material and methods

Study area

The České středohoří Hills are located in the northwestern part of the country (50°34′–50°48′N, 13°41′–14°32′E). Three climatic regions can be distinguished along the southwest–northeast direction (Kubát, 1970) and characterized, besides climatic differences, by the occurrence of species belonging to different range types and different prevailing vegetation.

The climate in the southwestern part (Region 1) exhibits rather continental features with only sporadic snow cover in winter and rather dry summers, having the lowest annual precipitation in the country (460–500 mm). Long-term mean annual temperature ranges between 8.1 and 9.0 °C. The region is characterized by the occurrence of species with a rather continental range of occurrence (Meusel and Jäger, 1992). They occur in comparably extensive vegetation patches of dry grasslands. The occurrence of thermophilous oak woodland is also typical for the region.

The central part (Region 2) is equally warm, but wetter (501–600 mm), than Region 1. Thermophilous oak woodland is typical natural vegetation and dry grasslands are numerous but smaller in their extent than in Region 1. There is a higher occurrence of plants with a submediterranean range of occurrence.

The northeastern region (Region 3) is wetter (601–820 mm) and colder (6.1–7.5 °C) than the previous ones. Plants belonging to the continental-range type are nearly absent. Species belonging to the submediterranean range are sporadic. Dry grasslands are rare and beech forests represent the predominant natural vegetation (Neuhäuslová, 1998).

Altogether, there are 56 basalt quarries located in the area, where spontaneous vegetation succession was previously described (Novák and Prach, 2003). Representative quarries were selected for the sowing experiments.

Sowing experiments

Six species, three forbs and three grasses, were selected to meet the following criteria: being typical for dry grasslands (Chytrý and Tichý, 2003; Oberdorfer, 1992), producing sufficient amount of seeds of a size and shape enabling easy collection and subsequent manipulation and occurring in the area in a sufficient number of localities. The following species were selected: *Astragalus exscapus, Festuca valesiaca, Oxytropis pilosa, Silene otites, Stipa pennata* and *Stipa pulcherrima*. All of the species are diagnostic species of the alliance of *Festucion valesiacae* (Chytrý and Tichý, 2003). Nomenclature follows Kubát et al. (2002). Diaspores for each species were collected from two source populations in Region 2.

The experiments were established in 9 disused basalt quarries, three in each climatic region. The age since quarrying was stopped ranged between 5 and 12 yr. This successional age was chosen because this period appeared to be crucial for the successional development of dry grasslands (see Novák and Prach, 2003). The sites for the experiments were situated on flat quarry floors with homogenous substrate. In all cases, the autochthonous substrate contained at least 10% clayey particles and gravel size did not exceed 3 cm.

In each quarry, two blocks of six 1×1 m plots were established using a randomized block design. Particular species were sown into each plot with 100 seeds of each species in three separate strips used in three subsequent years, in late September 2000, 2001 and 2002, respectively. Seedling numbers were observed in late April/early May and in the late September/early October from 2001 to 2004. In the case of *A. exscapus* and *S. otites*, of which some seedlings germinated not only in the first but also in the subsequent seasons, it was not possible to calculate exactly the resulting balance between the newly emerged and dead seedlings. Thus, the highest number of seedlings in each year was used as the number of emerged seedlings.

Weather conditions during the growing season differed in the years of observation. The year 2003 was very dry and warm, while 2001 and 2002 were wet. The following figures were obtained from the nearest meteorological station in Doksany (www.chmi.cz/meteo) for the growing seasons (IV–IX): 2001 – 15.2 °C, 454.5 mm; 2002 – 16.2 °C, 417.9 mm; 2003 – 17.0 °C, 211.4 mm; average (1961–1990) – 14.4 °C, 308.3 mm.

Data analysis

To assess whether germination and survival differed among species, years and regions, regarding also the number of localities (floristic records of the species extracted from the regional literature and herbaria and completed by own observations) in the particular regions and whether there were significant interactions among the factors, we used generalized linear models with Poisson's distribution of errors (S-Plus, 1999–2000). We first formulated a null model with numbers of seedlings, $Y \sim +1$. Then models were constructed including each of the explanatory variables separately, models with their additive combination and a model including all variables and their interaction. The models were compared to a null model using the Akaike information criterion (AIC; a balance between explanatory power and complexity; cf. Burnham and Anderson, 2002); models with the lowest AIC value were considered as the best approximation of reality. Separate analyses for each species were performed using the same approach only in the case of germination because of data deficiency for survival.

The effect of number of localities was also assessed using GLM regressions, this time on a square-root transformed response variable, Gaussian distribution and identity link. Besides number of localities, region and species were other potential predictors. All possible models containing number of localities were constructed and mutually compared using AIC.

Results

Germination and survival of the particular species and their cohorts during the experiment are shown in Fig. 1. Altogether 1477 seedlings germinated. Obviously, not all seedlings emerged in the first season after sowing; seeds of some species germinated in the second and even the third year after sowing (*A. exscapus* and *S. otites*). Some individuals of *A. exscapus* and *O. pilosa* set flowers already in the third year after sowing in Region 1.

The total number of emerged seedlings of all cohorts, survived seedlings and localities of the respective species, recorded for the particular regions, are summarized in Table 1. If the seedlings emerged, their survival was rather high in Region 1 and partly in