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Restoration of hay meadows on ex-arable land: commercial seed mixtures vs. spontaneous succession

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Abstract

In many areas of Europe there are policies to restore former arable land to grassland. In practice, this usually involves the use of commercial seed mixtures. The abundance of all vascular plants species in 35 ex-arable fields, sown with a commercial seed mixture or spontaneously revegetated, was studied in one landscape area to compare two methods of grassland restoration. Species abundance was also evaluated in the close surroundings of the fields. Data were processed using multivariate (ordination) and univariate statistics. Period of time since abandonment, size of the field and type of grassland restoration (sown vs. spontaneously revegetated) had a significant influence on vegetation. However, for the target meadow species, the type of restoration did not exhibit any influence. After about 20 years the contribution of meadow species that had established spontaneously in the studied fields was similar to that of their surroundings. We concluded that artificial sowing on ex-arable land is not necessary to develop semi-natural grasslands if (i) there are sources of appropriate diaspores in the immediate surroundings, (ii) the site is not very rich in nutrients and (iii) farmers do not need grass production immediately. In these situations and over this timescale natural regeneration would allow substantial savings of money and labour.

Keywords: agriculture management, grassland, rate of succession, species pool, vegetation

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Introduction

In the second half of the twentieth century many meadows and pastures all over Europe were converted to arable land. However, in the past two decades there have been various activities to return some arable land back to grassland in response to policies to reduce the intensity of agricultural management (Walker *et al.*, 2004; Bakker and van Diggelen, 2006). In the Czech Republic, secondary grasslands in the 1950s occupied about 1 200 000 ha, which represented approximately 13% of the country's land area. About one-third was lost due to ploughing or succession of woody species following abandonment. Since 1990, about 260 000 ha of arable land have again been converted to grassland (Jongepierová, 2008).

There are three possible methods to convert arable land to grassland: (i) using commercial seed mixtures, (ii) using regional seed mixtures, and (iii) to rely upon spontaneous succession (Partel *et al.*, 1998; Bakker and van Diggelen, 2006; Jongepierová *et al.*, 2007; Prach *et al.*, 2007a; Jongepierová, 2008). All three types of grassland restoration must be followed by appropriate further management, that is, by cutting or grazing or both, to protect a site against the expansion of either woody species or competitive and dominant forbs (Bakker, 1989). From the ecological point of view, the aim of restoration activities should be the creation of semi-natural, species-rich grassland (Jongepierová, 2008). Using species-poor commercial seed mixtures is still the prevailing practice, though these mixtures often contain non-native species and genotypes which do not fit very well with the local environmental conditions.

The alternative approach of spontaneous unassisted establishment of species usually selects a species composition that is well adapted to the site conditions (Prach and Hobbs, 2008). A set of colonizing species is predominantly determined by abiotic and biotic site conditions and by the local species pool (Zobel *et al.*,

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1998). The number of species, and the species which ultimately reach a target site by their diaspores, depends on the characteristics of the diaspores, availability and behaviour of the dispersal vectors, and the composition, abundance and proximity of local seed sources (Díaz *et al.*, 1998; Ozinga *et al.*, 2005).

We had the opportunity to study ex-arable fields that had been sown using a commercial seed mixture and also fields that had spontaneously revegetated in a landscape where sufficient numbers of both fields were available. Thus, it was possible to compare the two methods of grassland restoration. We asked the following questions: (i) how fast does semi-natural grassland develop on ex-arable fields, either after sowing or by spontaneous succession? (ii) are there differences in species composition between sown and spontaneously revegetated grass fields? and (iii) how important is the surrounding vegetation for the restoration of grassland?

Methods

Study sites

The research was conducted in 35 abandoned arable fields in a submontane landscape in the southern part of the Czech Republic, in cadasters of three small villages: Dolní Kožlí (49° 03′N, 13° 56′E), Chlumany (49° 04′N, 13° 58′E) and Budkov (49° 04′N, 13° 59′E). Fields were within an altitude range of 550–850 m a.s.l.

The climate is temperate with mean annual precipitation between 500 and 1000 mm depending on altitude. The mean annual temperature is between 6 and 7°C (Anonymous, 2007).

All available fields with a known history were considered. Their successional age ranged from 1 to 50 years and was determined by interviewing owners. The size of the fields varies between 0·2 and 34 ha and was measured with ArcView 3·2 (ESRI, 1996).

Of the 35 former arable fields, 26 had been sown with commercial seed mixtures and nine had been left to spontaneous succession. All the fields were subsequently managed by mowing, grazing or a combination of both. The commercial mixture used contained the following species: *Agrostis capillaris*, *Festuca pratensis*, *Festuca rubra*, *Lolium multiflorum*, *Lolium perenne*, *Poa pratensis*, *Trifolium pratense* and *Trifolium repens* (nomenclature follows Kubát *et al.*, 2002). Sowing rates were between 30 and 35 kg ha^{-1} sown. The proportions of each of the constituent species in the mixtures varied between 5 and 20%.

The fields under study were surrounded by a mosaic of small woodlands, permanent semi-natural grasslands and arable fields that were still in use. The semi-natural grasslands occurred in the surroundings up to 100 m from each field. Soil is moderately fertile with pH between 5 and 6; however, detailed soil analyses are not available.

Data collection

In June and July 2008, all vascular plant species were recorded in the whole fields and in the adjacent area up to a distance of 100 m from the field margins. Species abundances were estimated using the semi-quantitative scale according to Braun–Blanquet (Kent and Coker, 1992): 1 – very rare, 2 – rare, 3 – scattered, 4 – common and 5 – very common.

Data analysis

Changes in total species composition were analysed using multivariate ordination methods in Canoco for Windows (Ter Braak and Šmilauer, 2002). Ordinal abundance data from each field census were used as response data in the ordination. Age, size of field and methods of grassland restoration (seed mixtures vs. spontaneous succession) were considered as environmental variables.

Data were subjected first to detrended correspondence analysis (DCA) in order to assess the overall variation pattern in species composition. The environmental variables were projected passively onto the ordination diagram. DCA by segments revealed a gradient of 2·39 SD units but, because of the character of the data, collected in different fields, we preferred to utilize unimodal methods (Lepš and Šmilauer, 2003). Canonical correspondence analysis (CCA) was then used to evaluate the species–environment relationships. Environmental variables were evaluated for their marginal and partial effects to determine the amount of explained variability by individual predictors (Lepš and Šmilauer, 2003). The significance of each variable was evaluated using the Monte Carlo test (with 499 permutations). The management types, that is, spontaneous succession and seed mixtures were used as dummy variables. Only species with the highest weight and fits to ordination axes are shown in the diagrams.

The recorded species were classified into three classes: meadow species, ruderal species and other species, following their affiliation to the respective vegetation units (Chytrý and Tichý, 2003). The numbers of meadow and ruderal species, as well as the age and size of the fields, were log transformed before analyses. Effects of management, field size and age of the field on species number were analysed by ANCOVA using STATISTICA 6·0 (StatSoft, Inc., 2001) software. Field size and management method were used as covariates if the effect of age was analysed, and field size and age if the effect of management was considered.

The Czekanovski similarity index was calculated for each field using the numbers of meadow species occurring in the field and its vicinity. The ordinal species abundance was considered (Kent and Coker, 1992). Data on species similarity (Czekanovski index) were analysed using ANCOVA with age and field size as covariates.

Results

A total of 234 vascular plant species were recorded in the studied abandoned arable fields and in their surroundings. There were 166 species that occurred both in the fields and their surroundings, six species were found only in the fields and sixty-two species were only in the surroundings. The respective figures for meadow species were as follows: 70 species occurred in the fields and their surroundings, five species occurred only in the fields and twelve only in the surroundings. Most meadow species (92% on average) that were found in the field were also recorded in their 100 m surroundings.

Detrended correspondence analysis (Figure 1) revealed a clear pattern in species composition reflecting the successional age. Some annual species were typical for initial stages (1–3 years), that is, *Veronica arvensis*, *Myosotis arvensis* and *Stellaria media*. Some of the perennial ruderal species recorded, such as *Rumex obtusifolius*, *Taraxacum* sect. *Ruderalia*, *Cirsium arvense* and *Elytrigia repens,* were also typical for the initial stages. Other perennial species, such as *P. pratensis*, *A. capillaris*, *Dactylis glomerata* and *Trifolium hybridum* gradually increased their coverage from the initial stages. Non-ruderal perennial grasses and forbs were important, except in the initial stages (4–10 years), in middle (11–29 years) and late successional stages (>30 years). Typical species of the early and middle stages were represented mainly by *Arrhenatherum elatius, Alopecurus pratensis, Holcus lanatus, Trisetum flavescens, Ranunculus repens* and *Cerastium holosteoides*. In the late stages, *Alchemilla vulgaris* agg., *Leucanthemum vulgare* and *Leontodon hispidus* were also important. For later successional stages, spontaneously established species were more typical than species that had originated from the seed mixture. Among the sown species, only *P. pratensis* attained average abundance equal to 3 (scattered) after 10 years; other species were only rare (2) or very rare (1). *Lolium multiflorum* and *L. perenne* gradually disappeared completely.

The CCA analysis showed that 45% of the variability ($F = 1{\cdot}863$, $P = 0{\cdot}002$) was significantly explained by age, size of fields and type of grassland restoration. Both partial and marginal effects of each of these environmental factors were significant (Table 1). Inflation

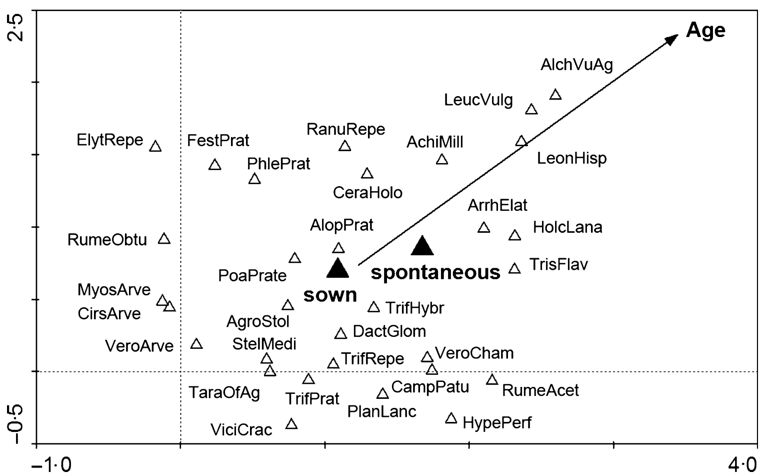

Figure 1 The ordination of species (detrended correspondence analysis, abundance ordinal data used) with age as the passive environmental variable. Fields sown by seed mixture or spontaneously revegetated are represented by centroids. Abbreviations of species names: AgroStol – *Agrostis stolonifera*, AchiMill – *Achillea millefolium*, AlchVuAg – *Alchemilla vulgaris* agg., AlopPrat – *Alopecurus pratensis*, ArrhElat – *Arrhenatherum elatius*, CampPatu – *Campanula patula*, CeraHolo – *Cerastium holosteoides*, CirsArve – *Cirsium arvense*, DactGlom – *Dactylis glomerata*, ElytRepe – *Elytrigia repens*, FestPrat – *Festuca pratensis*, HolcLana – *Holcus lanatus*, HypePerf – *Hypericum perforatum*, LeonHisp – *Leontodon hispidus*, LeucVulg – *Leucanthemum vulgare*, MyosArve – *Myosotis arvensis*, PhlePrat – *Phleum pratense*, PlanLanc – *Plantago lanceolata*, PoaPrate – *Poa pratensis*, RanuRepe – *Ranunculus repens*, RumeAcet – *Rumex acetosa*, RumeObtu – *Rumex obtusifolius*, StelMedi – *Stellaria media*, TaraOfAg – *Taraxacum officinale* agg., TrifHybr – *Trifolium hybridum*, TrifPrat - *Trifolium pratense*, TrifRepe – *Trifolium repens*, TrisFlav – *Trisetum flavescens*, VeroArve – *Veronica arvensis*, VeroCham – *Veronica chamaedrys*, ViciCrac – *Vicia cracca.*

Table 1 Environmental variables with their marginal and partial effects on the species composition in the fields using the canonical correspondence analysis ordinations.

Environmental variable	F_{marg}	P_{marg}	$\%_{marg}$	F_{part}	P_{part}	$\%_{part}$
Field age	2·211	0·002	18·8	2·043	0·002	17·1
Size	1·92	0·02	16·4	1·844	0·03	15·1
Type of grassland restoration	1·542	0·012	13·3	1·46	0·012	11·9

All effects were significant ($P < 0·05$).

factors were low in all analyses, and therefore correlations between environmental variables were small (Ter Braak and Šmilauer, 2002).

According to the results of the ANCOVA (Table 2), the number of meadow species significantly increased over time, while the apparent decrease in number of ruderal species was not significant (see also Figure 2). The effect of type of grassland restoration on the numbers of meadow and ruderal species was also not significant. There were no differences between the number of ruderal and meadow species in sown and naturally revegetated grass fields.

Surrounding vegetation exhibited a great effect on species composition of vegetation in the abandoned fields. Results of ANCOVA showed that the Czekanovski similarity index between species composition in a field and in its surroundings significantly increased with the age of the field ($F_{16,16} = 15·26$; $P = 0·0000$). Field size and management were used as covariates. After some 20 years, the contribution of meadow species present in a particular field and its surroundings were nearly identical as the Czekanovski similarity index increased up to 0·95 or more (Figure 3).

Discussion

All fields, either when restored using commercial grass seed mixtures or if left to spontaneous succession, developed towards semi-natural grasslands after approximately 10 years. It is necessary to begin regular cutting soon after abandonment to prevent the establishment of woody species which represent the usual successional dominants in central Europe in abandoned fields when they are left without intervention (Osbornová *et al.*, 1990; Prach *et al.*, 2007b). Regular cutting also supports the establishment and expansion of grasses at the expense of perennial forbs (Bakker, 1989).

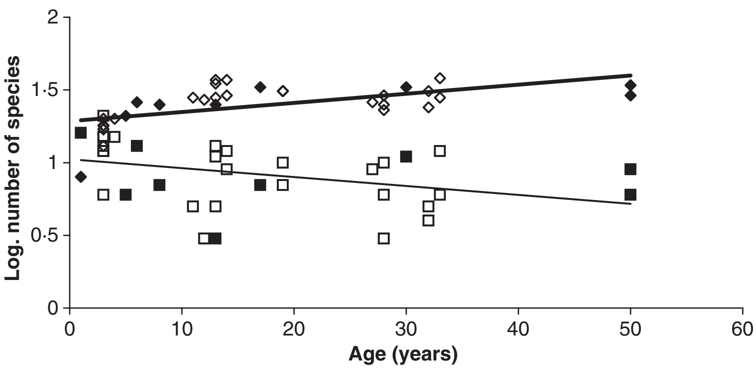

Figure 2 Relationships between the number (logarithmic scale) of ruderal (thin line) and meadow (thick line) species and the age of fields. Empty symbols represent sown and full symbols spontaneously revegetated fields.

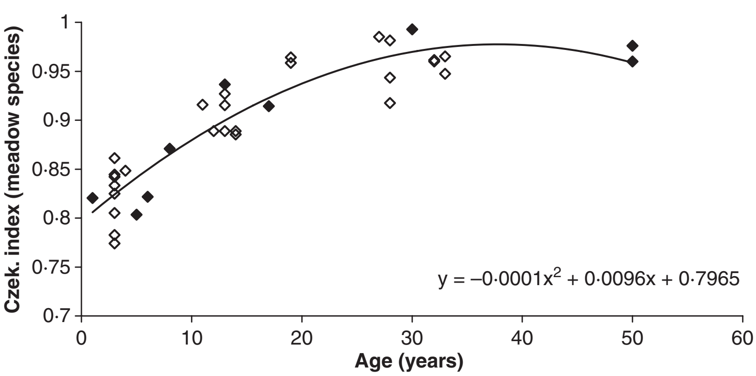

Figure 3 The dependence of the Czekanovski similarity index (calculated for meadow species in the field and its surroundings) on the age of field. Empty symbols represent sown and full symbols spontaneously revegetated fields.

Table 2 ANCOVA. The effects of age and the type of grassland restoration (spontaneously revegetated or sown) of fields on the number of meadow species and ruderal species.

	Field age (covariates: type of grassland restoration and field size)		Type of grassland restoration (covariates: age and field size)	
	$F_{17,15}$	P	$F_{1,31}$	P
Meadow species	13·399	0·0000	0·005	0·943
Ruderal species	1·802	0·129	0·825	0·371

An important finding in our study was that the fields did not differ, according to whether they were sown or not, in the contribution of species typical of semi-natural grasslands (Figures 2 and 3, Table 2). The type of grassland restoration had a significant effect only on the total species composition analysed using ordination methods (Table 1) but it was obvious that this was caused by the differences in species composition in early stages of the studied fields. Thus, in terms of practical management to restore diverse grasslands, there is the potential to save a substantial amount of money and labour if artificial sowing is not applied. If seeding must take place, for instance if farmers have an immediate requirement to use the field for grassland production, it is advocated that commercial seed mixtures should be replaced by seed mixtures with species of local origin (Jongepierová, 2008). Another important finding was that most of the sown species decreased rapidly during succession, and some of them disappeared totally. Sown species dominated only in the early stages of succession and they were later replaced by spontaneous colonists. Comparing the position of the respective centroids in Figure 1 it may be speculated that the competitive sown species, such as *Lolium* spp. and *F. pratensis*, in the case of this study, may even retard the spontaneous establishment of some less competitive meadow species (Jongepierová *et al.*, 2007).

In considering the restoration of grassland on ex-arable land we must decide what vegetation we wish to have. The prevailing economic situations often do not require the restoration of highly productive swards (Brower and van der Straaten, 2002), and therefore swards of low production and species-rich grasslands should be targeted (Bakker and van Diggelen, 2006). Fertilization of fields should be avoided because in most cases there is a negative relationship between site productivity and species richness, except on extremely nutrient-poor sites (Crawley *et al.*, 2005). However, such nutrient-poor sites were not included in the study area. Sites with moderately fertile soil, as in the case of those included in this study, are generally more species rich and present conditions that are more favourable for the immigration of local ecotypes than highly productive sites (Grime, 2001) and are thus suitable for restoration of semi-natural grasslands.

According to the results of the CCA, age since abandonment exhibited the highest explained variability of all the environmental variables that were considered. This finding was in accordance with results of most other studies on vegetation development on ex-arable land (Osbornová *et al.*, 1990; Bonet and Pausas, 2004; Ruprecht, 2005; Prach *et al.*, 2007b). The studied fields did not appear to differ greatly in terms of their environmental conditions such as site moisture and nutrients, which may mask the role of successional age (Szabó and Prach, 2009). The size of abandoned fields was another environmental factor that had a significant effect on vegetation pattern (Table 1). This might be explained by the easier colonization of small fields by propagules from their surroundings and by more rapid vegetation development in small fields than in large ones (Dovčiak *et al.*, 2005).

It seems that propagule sources in close vicinity to any disturbed site are usually decisive for species establishment, particularly of the late-successional species which are often considered as targets in restoration activities. The late-successional species mostly represent rather specialized groups of species with lower dispersal capability, whereas generalists, which are often present among early successional species, frequently belong to easily dispersed species, which can colonize a site from a longer distance (Grime, 2001). Thus the meadow species considered as targets in our study belong to the specialists often with specific dispersal vectors (Kahmen and Poschlod, 2008). The distance of 100 m used in our study was selected considering the time required for the fieldwork and earlier findings when this distance appeared as sufficient to include nearly all colonizing species (del Moral and Eckert, 2005; Řehounková and Prach, 2008). This distance also appeared to be sufficient in the present study.

A weakness of the present study was the imbalance between the number of sown and spontaneously revegetated grass fields. This may limit the general validity of some conclusions. This situation was unavoidable given the landscape of the particular geographic area when all available fields of known history were included. However, the main conclusion, that artificial sowing in ex-arable land was not needed to restore semi-natural meadows, was not biased by the sampling design.

Finally, the answers to the questions posed in the introduction are: (i) that semi-natural grasslands developed on the ex-arable fields after approximately 20 years; (ii) fields restored by spontaneous succession or sowing by commercial seed mixtures did not differ in the participation of target meadow species and (iii) after the two decades, species composition in a particular field was nearly identical to that in its close surroundings considering the target meadow species. This indicates the decisive role of the surrounding vegetation in the restoration of semi-natural grassland on ex-arable land.

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