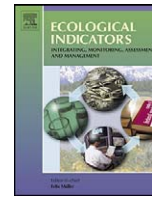
Ecological Indicators 11 (2011) 724–733

Contents lists available at ScienceDirect

Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind



Short communication

# Rapid restoration of a species-rich ecosystem assessed from soil and vegetation indicators: The case of calcareous grasslands restored from forest stands

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ARTICLE INFO

*Article history:*
Received 5 January 2010
Received in revised form 26 April 2010
Accepted 17 June 2010

*Keywords:*
Calcareous grasslands
Restoration monitoring
Soil conditions
Species composition

ABSTRACT

Calcareous grasslands have long been recognized as biodiversity hotspots in Europe. However, in recent decades these ecosystems have seen rapid decline. In Belgium, more than 100 ha of calcareous grasslands have been restored from oak coppices and pine forests since the 1990s. The aim of the present study was to provide a quantitative assessment of the success of these restoration efforts, using two sets of indicators: one related to soil conditions, the other related to vascular plant communities. Soil conditions were evaluated by comparing soil samples from pre-restoration forest stands, restored grasslands (3-age classes: 2–4 years; 5–8 years, and 10–15 years) and reference grasslands. The analysis revealed no significant differences in soil N, P, and K contents between pre-restoration forests and restored and reference grasslands. We observed a decrease in the mineralization rate indicators in both pre-restoration forests and recent grassland restorations, which was resorbed in older restorations. Floristic surveys revealed that plant species composition of older restorations was most like reference grasslands. However, some differences in species composition persisted after 15 years. Moreover, a few rare species did not colonize restored grasslands despite a close seed source. Non-recolonization by a set of species expected on calcareous grasslands may be due to dispersal limitation and higher cover by native invasive grasses in restored parcels. These results were discussed in term of implications for management.



## 1. Introduction

In the face of destruction and fragmentation of natural and semi-natural habitats, protection and management of the remaining (semi-)natural habitat fragments is no longer sufficient to ensure the long-term viability of all elements contributing to biodiversity. Consequently, habitat restoration has become a necessity to recreate functional ecological networks (Jongman and Pungetti, 2004). This approach serves to restore patches of degraded or destroyed habitat by accelerating or skipping successional stages. This is accomplished by directing ecosystem development towards a specific community structure or ecosystem type (Bakker and Berendse, 1999; Jordan et al., 1987). However, habitat restoration can be cost prohibitive and efforts to restore natural communities must demonstrate their success in reaching target ecosystems (Fagan et al., 2008). Hence, quantitative indicators are needed to evaluate the efficiency of restoration practices and to improve future restoration projects (e.g. Holl and Cairns, 2002; Samu et al., 2008). Ideally, these indicators may address different components of the restored ecosystem.

Habitat restoration is of vital importance in temperate semi-natural calcareous grasslands, and has received considerable attention in recent years. Those ecosystems are considered one of the richest in biodiversity in temperate regions (Prendergast et al., 1993; WallisDeVries et al., 2002) and the most species-rich plant communities in the world at a small scale (<10 $m^2$) (Willems, 2001). Once widespread over Europe, calcareous grasslands have undergone dramatic fragmentation since the end of the 19th century. Following the abandonment of the traditional agro-pastoral systems that were responsible for their extension, these communities have been replaced by arable land, trees plantations, or have undergone spontaneous encroachment and succession to forest communities (Poschlod and WallisDeVries, 2002). The maintenance and enhancement of calcareous grassland networks is now recognized as a priority in European biodiversity conservation policies, as reflected in the Habitat Directive 92/43/EEC.

Restoration success depends primarily on two factors, the reformation and maintenance of suitable environmental conditions and the recolonization capacity of target species (Perrow and Davy, 2002; Piqueray and Mahy, in press). Soil conditions in calcare-

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doi:10.1016/j.ecolind.2010.06.007

ous grasslands are characterized by low soil fertility, and nutrient transfer historically occurred through traditional grazing practices (Willems, 2001). A negative relationship between soil fertility and calcareous grasslands species richness has been demonstrated (e.g. Al-Mufti et al., 1977; Janssens et al., 1998) as well as the harmful consequences of intentional soil nutrient enrichment (Bobbink et al., 1998; Jacquemyn et al., 2003; Willems et al., 1993). On arable lands, attempts to restore soils to historically low fertility levels was shown to be the major constraint for the recovery of calcareous grassland plant communities (Hutchings and Stewart, 2002; Walker et al., 2004). However, to our knowledge, soil nutrient status has never been studied in calcareous grasslands restored from forest stands. Green (1972) stressed that natural succession should lead to global eutrophication of any habitat. Hurst and John (1999) showed nitrogen enrichment in calcareous grassland during the first step of encroachment by the native invasive grass *Brachypodium pinnatum* in England. Data from other grassland types indicate that afforestation can induce different changes in soil conditions. On one hand, it often induces a reallocation of major nutrients (N, P) from mineral soil to litter (Farley and Kelly, 2004; Ross et al., 1999), as well as changes in the form of these nutrients (Chen et al., 2008; Farley and Kelly, 2004). After clear-cutting, litter decomposition can increase the nutrient release (Ouro et al., 2001). On the other hand, shrub and tree colonization can induce modifications to the soil micro-climate, and subsequently cause changes in soil microbial activity responsible for the mineralization of soil organic matter. This can lead to modifications in soil carbon stock, acidity and C:N ratio (Thuille and Schulze, 2006). Therefore, we argue that mineralization indicators (e.g. pH, C:N ratio, and Fe), as well as fertility indicators (e.g. N, P, and K) need to be considered to assess the restoration of soil conditions. Decreasing pH and subsequent increasing Fe availability could be consequences of a lower mineralization rate (Bonneau and Souchier, 1979).

In plant community recovery efforts, species richness has been widely used as an indicator of restoration efficiency (e.g. Cristofoli et al., in press; Lindborg and Eriksson, 2004; Willems, 2001). However, it is only a crude indicator of successful restoration (Kiehl et al., 2006; Mortimer et al., 1998). An ecosystem may be species-rich, but the species may be non-representative of the native community. Therefore, restoration success should be evaluated against a reference habitat, such as a local reference site (Piqueray and Mahy, in press; Ruiz-Jaen and Aide, 2005; Society for Ecological Restoration International Science & Policy Working Group, 2004).

In Belgium, over 90% of calcareous grasslands have been lost (Adriaens et al., 2006; Bisteau and Mahy, 2005b). A large proportion was afforested with *Pinus sylvestris* and *Pinus nigra* at the end of the 19th century (Vandermotten and Decroly, 1995). Other areas experienced a natural process of succession following grazing abandonment and were progressively replaced by oak woodlands. To stop this decline, approximately 100 ha of calcareous grasslands have been restored in Belgium over the last 15 years. All restored sites derived from pre-forests or 40- to 100-year-old forest established on ancient calcareous grasslands. Restoration protocols included tree and shrub clearing followed by sheep and goat grazing (André and Vandendorpel, 2004; Graux, 2004). Restoration of species-rich grasslands from secondary forest or pre-forest ecosystems was studied in different parts of Europe (Kiefer and Poschlod, 1996; Pärtel et al., 1998; Zobel et al., 1996), but rarely in Western Europe (Hutchings and Stewart, 2002).

In this paper we combined soil condition and plant community data with the aim of assessing the success of calcareous grasslands restoration from afforested sites in Belgium. Using indicators computed from these two datasets, we compared restored sites with calcareous grassland reference sites and forest stands equivalent to pre-restoration conditions and addressed the following questions: (1) Do restoration actions lead to the reestablishment of native calcareous grassland plant communities? (2) How does soil of restored sites compare to soil of reference grasslands and pre-restoration sites?

## 2. Materials and methods

### 2.1. Study sites

The study area was located in two Belgian regions: the Viroin Valley, and the Lesse and Lomme Valleys (Table 1), both located in Calestienne, a narrow Devonian limestone strip running southwest to northeast. Both regions support large areas of calcareous grasslands, and are considered the core areas for calcareous grassland conservation in Belgium. Although several grassland communities occurred within the study area (see Butaye et al. (2005) and Piqueray et al. (2007) for communities description), we focused on the most widespread community: *Mesobromion* calcareous grasslands. A total of 12 sites (six per region) where grassland restoration had occurred were selected for the study (Table 1). Selected sites were restored half from pine stands and half from oak coppices. Pine stands were up to 100-year-old *P. nigra* or *P. sylvestris* plantations. Dense shrub oak coppices were mainly formed with *Prunus spinosa*, *Crataegus monogyna* and *Corylus avellana*, with intermingled scarce trees of *Quercus robur*. Historical maps, aerial pictures and field surveys were used to delimit three parcel types: (1) *Reference grasslands*, i.e. calcareous grasslands known to have existed for more than two centuries. They harbour the typical local calcareous grassland vegetation and are considered as the reference ecosystem for restoration. (2) *Restored parcels*, i.e. former grasslands that were afforested and were then subject to forest clearings with subsequent management (mainly grazing) with the aim of restoring grasslands. Trees and shrubs were exported from the parcels, but tree stumps remained. (3) *Pre-restoration forest stands*, i.e. forests established on former calcareous grasslands. Both reference grasslands and pre-restoration forest stands were adjacent to restored parcels, on similar topographic situations. The time passed since restoration (in years) was known for each restored parcel. Restored parcels were chosen to equally cover three age classes since restoration: 2–4 years, 5–8 years, and 10–15 years. These classes were mainly defined due to field constraints, e.g. first year was omitted as many uncertainties remained on the location of last clearcuts location at the beginning of our project. Each site comprised at least one parcel of each type. In the "Tienne des Vignes" and "Montagne au Buis" sites, two restored parcels originated from the same forest stand but were restored at different times, these restored parcels had thus the same reference forest stands and reference grasslands. In addition, at "Les Pairées" and "Abannets" sites, two restored parcels were of the same age but originated from two different forest stands (Pine and Oak). In summary, we sampled 8 pre-restoration forests parcels, 12 restored parcels (four per age class) and 8 reference grassland parcels (Table 1).

### 2.2. Soil analysis

Five soil samples were collected in each parcel, i.e. pre-restoration forests, restored parcels, and reference grasslands. Each sample consisted of a bulk soil sample collected systematically with a 2 cm diameter auger within a 1 $m^2$ quadrat. The minimum total soil volume collected was 100 $cm^3$ per quadrat. The soil was thin at all study sites (ca. 10 cm); therefore the entire soil layer, from ground surface to bedrock, was collected. Soil depth was measured at the four corners of the quadrat. Mean soil depth was estimated for each soil sample. In forests and reference grasslands, quadrats were randomly localized. In restored grasslands, samples were collected nearby randomly selected tree stumps. Positioning quadrats