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Long-term experimental restoration in a calcareous grassland: Identifying the most effective restoration strategies

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ABSTRACT

Calcareous grasslands are among the most diverse habitats, supporting species-rich vegetation. Propagule limitation and availability of microsites for germination represent major constraints to the successful restoration of these grasslands. To date, little information is available on the effectiveness of seed addition and soil disturbance on the restoration success of encroached semi-natural calcareous grasslands. Here, we conducted a *1 year before – 9 year after* control-impact (BACI) study aimed at testing the effect of the addition of seeds of native species and livestock grazing on calcareous grasslands. Each restoration measure and their combination differed in their impact on these communities and varied over time. Grazing had a significant, beneficial, impact on these communities, although the impact was species-specific. On average, grazed plots were characterized by a higher number of species and a lower vegetation cover. Nine years after treatment application, grazed site were dominated by *Trifolium incarnatum* subsp. *molinerii*, *Xeranthemum cylindraceum*, *Orlaya grandiflora*, *Teucrium chamaedrys* and *Bromus erectus* while ungrazed sites were dominated by *B. erectus*, *X. cylindraceum*, *O. grandiflora* and *Prunus spinosa*. Only 8 out of 34 species responded significantly to disturbance or/and disturbance and seed addition while 22 species were significantly affected by the sampling year and 18 by a blocking factor. The low recruitment from added seeds and the fact that seed addition is a time-and labor-consuming activity suggests that an adequate level of disturbance and natural regeneration represent the most cost-effective approach to the restoration of these calcareous grasslands.

1. Introduction

Changes in land use have resulted in a substantial decline in the extent and ecological quality of semi-natural grassland communities over the past two decades across Europe (van Dijk, 1991; Bakker and Berendse, 1999; Critchley et al., 2004). The conservation of calcareous grassland communities is strongly advocated due to their capacity to support a large number of species as well as rare and/or endangered species (Willems, 2001), and are particularly important for the diversity of vascular plants at a small scale (<10 m^2) (Kull and Zobel, 1991; Butaye et al., 2005). A number of programmes have been developed to restore these diverse habitat (see for example: Bobbink and Willems, 1993; Muller et al., 1998; Ormerod, 2003; Ruiz-Jaen and Aide, 2005; Edwards et al., 2007; Maccherini et al., 2007; Fagan et al., 2008; Török et al., 2010), although the effectiveness of such measures has varied substantially. Some general trends have, however, been identified, including an increasing similarity to reference sites with increases in time since restoration and the need for long-term monitoring programmes to properly evaluate the impact of different restoration measures (Dobson et al., 1997; Pykälä, 2003; Alard et al., 2005; Fagan et al., 2008).

Possible constraints to the restoration of calcareous grassland are a high soil fertility, propagule limitation, the absence of keystone species and inappropriate mowing or grazing regimes (Bakker and Berendse, 1999; Zobel et al., 2000; Walker et al., 2004).

The availability of seeds and local disturbance creating suitable microsites for germination and seedling establishment, as well as a reduced cover or vigor of competitive species, are generally considered primary determinants of species richness in calcareous grasslands (Mortimer et al., 1998; Pärtel et al., 1998; Poschlod et al., 1998; Kupferschmid et al., 2000; Zobel et al., 2000; Barbaro et al., 2001).

The effect of seed addition, soil disturbance, and their interaction on calcareous grassland restoration in semi-natural sites are not well documented and the majority of studies the results of restoration programmes have been monitored for only up to 7 years (Pärtel et al., 1998; Kupferschmid et al., 2000; Zobel et al., 2000).

On the calcareous massifs of southern Tuscany, xeric semi-natural grasslands dominated by *Bromus erectus* are disappearing

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due to a reduced grazing pressure, changes in management practices and reforestation with fast-growing alien species (Rocchini et al., 2006). These grasslands support a large number of species over a small spatial scale, with 32 vascular plant species have been reported over areas as small as 0.25 m^2 (Maccherini, 2006a, 2006b). They also support a large number of species belonging to the Orchidaceae (Landi et al., 2009) as well as a high number of Red-list butterflies (Maccherini et al., 2009). Thus, these habitats are classified as habitats of community importance in Annex I of the Habitats Directive (92/43/ECC; arid semi-natural grassland on calcareous substrates; Romão, 1996). Previous investigations on these grasslands have shown that shrub removal, in a lightly grazed site, only partially restored these communities. In particular, Maccherini et al. (2007) showed that the composition of restored grassland communities, 3 years after shrub removal, differed substantially from that of the reference community, that which characterized by a lower percentage cover of *B. erectus* and *Trifolium incarnatum* subsp. *molinerii*, by a lower number of weedy species as well as by a higher percentage cover of grassland species and species of high conservation value.

Despite the importance of undertaking long-term vegetation studies, in improving our understanding of the factors that affect the dynamics of these communities, has been long highlighted (Rosén, 1995; Bakker et al., 1996; Hobbs et al., 2007), long-term data on the effectiveness of restoration practices are scarce (Prach and Walker, 2011). Here, we present the results of a 10-year study

Table 1
List of plants species considered in the analysis and/or species present into seed mix. Life form was classified as follows: annual forb (AF); annual grass (AG); perennial forb (PF); perennial grass (PG); annual legume (AL); chamaephyte (Ch); Phanerophyte (P). Habitat type was classified as follows: grassland, pasture, rocky slope, rock (1); grassland and other habitat, pasture and other habitat (2); shrubland and woodland (3); waste (4); arable and urban areas (5). Dispersal mode was classified as follows: Anemochory (AC); Autochory (AUC); Zoochory (ZC); Diplochory (DC).

Species	Sowing density (g m^2)	Life form	Habitat	Present in persistent seed-bank	Dispersal mode
Acinos arvensis	–	AF	1		AC
Allium sphaerocephalon	0.03	PF	1		AC
Alyssum alyssoides	0.01	AF	1	*	AC
Anthemis tinctoria	0.02	PF	1		AC
Anthoxanthum odoratum	0.05	PG	1	*	AC
Anthyllis vulneraria subsp. *praepropera*	0.20	PF	1	*	AC
Arabis hirsuta	0.02	PF	2	*	AC
Armeria saviana	0.03	PF	1		AC
Avena barbata	0.03	AG	2		AUC
Bromus erectus	0.60	PG	1	*	AC
Bromus sterilis	–	AG	4		AC
Bupleurum baldense	0.08	AF	1	*	AC
Carduus nutans	–	PF	2		AC
Carlina corymbosa	0.02	PF	1		AC
Carthamus lanatus	–	AF	2	*	AC
Centaurea deusta subsp. *splendens*	0.14	PF	2		DC
Centaurea solstitialis	–	PF	2		DC
Cerastium arvense subsp. *arvense* var. *etruscum*	–	PF	2		AC
Convolvulus arvensis	–	PF	5		AC
Cynosurus echinatus	0.08	AG	2		AC
Dactylis glomerata subsp. *hispanica*	0.16	PG	3	*	AC
Dasypyrum villosum	0.07	AG	2		AC
Dianthus sylvestris	0.02	PF	1		AC
Echinops ritro subsp. *siculus*	–	PF	3		AC
Erysimum pseudoerhaeticum	0.04	PF	1	*	AC
Festuca stricta subsp. *trachyphylla*	0.39	PG	1		AC
Galium corrudifolium	0.10	PF	3	*	AC
Geranium columbinum	0.02	AF	2	*	AUC
Hypochoeris achyrophorus	0.03	AF	1	*	AC
Inula montana	0.05	PF	1		AC
Knautia purpurea	0.16	PF	1	*	ZC
Marrubium incanum	0.08	PF	2	*	AC
Medicago minima	0.03	AL	1	*	AC
Melica ciliata	0.01	PG	1		AC
Myosotis decumbens subsp. *florentina*	–	PF	3		AC
Oralya grandiflora	–	AF	4	*	ZC
Petrorhagia prolifera	0.03	AF	2	*	AC
Phleum hirsutum subsp. *ambiguum*	0.18	PG	1	*	AC
Phleum pratense	–	PG	1	*	AC
Prunus spinosa	–	P	3		ZC
Rhinanthus alectorolophus	0.08	AF	1		–
Rubus ulmifolius	–	P	3		ZC
Sanguisorba minor	0.18	PF	1	*	AC
Sedum acre	0.12	CH	5	*	AC
Sedum album	0.08	CH	1	*	AC
Silene italica	0.004	PF	3	*	AC
Stachys heraclea	–	PF	1		AC
Teucrium chamaedrys	–	CH	2	*	AC
Thymus longicaulis	0.28	CH	1		AC
Tordylium maximum	0.04	AF	2		AC
Trifolium incarnatum subsp. *molinerii*	0.44	AL	4	*	AC
Trifolium scabrum	0.04	AL	4	*	AC
Vulpia myuros	0.06	AG	1		AC
Xeranthemum cylindraceum	–	AF	2	*	AC