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ORIGINAL PAPER

Populations of a shrub-feeding butterfly thrive after introduction of restorative shrub cutting on formerly abandoned calcareous grassland

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Abstract Calcareous grasslands are one of the most species-rich semi-natural habitat types. However, area and species richness have considerably decreased, particularly due to the cessation of grazing or mowing. Accordingly, habitat restoration has become an important issue in the conservation of these grasslands. The aim of this study was to analyse the role of shrub cutting as a measure to restore habitats of the target butterfly *Satyrium spini* (Denis and Schiffermüller 1775) on formerly abandoned calcareous grasslands. We compared host plant density and occupancy, as well as egg batch density and size between cut, regularly managed and fallow patches. In total, we counted 3372 *Rhamnus cathartica* host plants on 17 calcareous grassland patches. On 309 (9 %) of these plants, we found a total of 490 batches containing 1168 eggs. Both *R. cathartica* and *S. spini* responded rapidly to restoration: Shrub cutting promoted the rejuvenation of the host plant, resulting in a strong population increase of the butterfly species four years after shrub cutting. The density of the preferred small host plants (growth height < 130 cm), their occupancy, as well as the density and size of the batches on these plants, clearly exceeded those of small plants on fallow and even on traditionally managed calcareous grasslands. Based on this study, we recommend shrub cutting on calcareous grasslands as both a restorative and regular management measure for *S. spini* habitats. Due to the increasing demand for fuel wood, shrub cutting in overgrown grasslands might even no longer be constrained by economic reasons.

Keywords Grazing · Habitat restoration · Invertebrate · Land-use type · Mulching · Patch connectivity

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Introduction

Grasslands are one of the prevailing habitat types throughout Europe, accounting for almost one quarter of the total EU-25 land surface (EEA 2005). Semi-natural grasslands in particular, harbour a high diversity of plant and invertebrate species and therefore, have a high nature conservation value (Veen et al. 2009). However, the area and species richness of these grasslands have considerably decreased across Europe during recent decades (Watt et al. 2007; Stoate et al. 2009). Agricultural intensification and abandonment have been identified as the main reasons for the strong loss since the 1950s (van Dijk 1991; Stoate et al. 2009). For calcareous grasslands, one of the most species-rich grassland types throughout Europe (Willems 1990; van Swaay 2002), the cessation of grazing or mowing has been the major driver (Poschlod and WallisDeVries 2002; WallisDeVries et al. 2002). Due to their role as biodiversity hotspots, and the multiple threats they face, calcareous grasslands are priority habitats of the EU Habitats Directive (EC 2007).

As a result of the large-scale destruction of calcareous grasslands, habitat restoration has recently become an important issue in the conservation of these grasslands (Bakker and Berendse 1999; Kiehl 2009; Kiehl et al. 2010). In the majority of restoration projects, only plants or plant communities have been used to evaluate the success of restoration (Mortimer et al. 1998; Littlewood et al. 2012). This arises from the assumption that a recovery in the fauna will follow that of the flora. However, the few studies that have tackled this issue have produced contrasting results (Carleton and Schultz 2013; Schultz et al. 2013; Baur 2014). In particular, dispersal-limited animal species are often not able to respond to restoration measures.

Butterflies are charismatic animals that that often exhibit a high host-plant specificity (Munguira et al. 2009) and narrow niches of the immature stages (García-Barros and Fartmann 2009; Dennis 2010). Moreover, most species form metapopulations depending on a network of suitable habitats (Dennis and Eales 1997; Thomas et al. 2001; Anthes et al. 2003; Eichel and Fartmann 2008). Due to these complex requirements, the decrease in butterflies exceeds that of many other taxonomic groups (Thomas et al. 2004; Thomas 2005). Thus, they are an important model group in ecology and conservation (Watt and Boggs 2003; Ehrlich and Hanski 2004; Merckx et al. 2013) and function as sensitive bioindicators for environmental change (Thomas and Clarke 2004; Thomas et al. 2004; Thomas 2005).

The Blue-spot Hairstreak, *Satyrium spini* (Denis and Schiffermüller 1775), is a target species for the conservation of calcareous grasslands (Koschuh et al. 2005). Due to habitat loss and fragmentation, the thermophilous lycaenid butterfly has strongly declined (Hermann 2007, Löffler et al. 2013) and is considered threatened in Germany (Reinhardt and Bolz 2012). By far the most important host plant in Central Europe (Hermann 2007; Kolbeck 2013) and the only one in the study area, the Diemel Valley, is the Common Buckthorn (*Rhamnus cathartica*) (Fartmann 2004). Detailed studies that focus on the oviposition habitat requirements of *S. spini* indicate a preference for small host plants growing under sunny and warm microclimatic conditions (Stuhldreher et al. 2012; Löffler et al. 2013). As a consequence, Löffler et al. (2013) recommended shrub cutting as one possibility to promote *S. spini* populations. However, empirical data examining the effects of shrub cutting on the species are lacking (Beneš et al. 2002).

The aim of this study was to analyse the effect of shrub cutting as a measure to restore *S. spini* habitats on formerly abandoned calcareous grasslands in a Central European landscape with a dense network of patches. Therefore, in a multi-site study, we compared host plant density and occupancy as well as egg batch density and batch size between cut, regularly managed (grazed and mulched) and fallow patches. In particular, we addressed the following hypotheses:

(i) Both the host plant and the butterfly respond rapidly to restoration measures.

(ii) Restored patches where shrubs have been cut have higher batch densities of *S. spini* than those of the two other land-use types.

(iii) Shrub cutting is a suitable tool for the restoration of *S. spini* habitats.

Materials and methods

Study species

The Blue-spot Hairstreak, *Satyrium spini* (Denis and Schiffermüller 1775) is a lycaenid butterfly distributed from the western part of the Iberian Peninsula and Central Europe to Western Asia (Kudrna 2002; Kolbeck 2013). In Central Europe, it is restricted to regions with warm summers (Ebert and Rennwald 1991; Beneš et al. 2002), where it occurs in shrubby calcareous grasslands and sunny woodland clearings (Fartmann 2004; Koschuh et al. 2005; Hermann 2007; Kolbeck 2013). Within the study area, the Diemel Valley, *S. spini* reaches its north-western range limit (Fartmann 2004). *Satyrium spini* is a univoltine species with a flight period ranging from the end of June to the beginning of August (Fartmann 2004; Kolbeck 2013). In contrast to most other Central European hairstreaks, *S. spini* lays its eggs in small batches (Fartmann and Hermann 2006) and it hibernates as an egg on the host plant.

Study area

The study area is about 250 km^2 large and comprises the middle and lower part of the Diemel Valley. It is located in central Germany along the border between the federal states of North Rhine-Westphalia and Hesse (51°29′N/9°15′E and 51°36′N/9°22′E) at an elevation of 160–280 m a.s.l. The climate is suboceanic (Müller-Wille 1981) with a mean annual temperature of 7.5–9.0 °C and a mean annual precipitation of 600–800 mm (MURL NRW 1989). The Diemel Valley contains the largest area of well-connected semi-dry calcareous grasslands in the northern half of Germany (Fartmann 2004). Because of its Europe-wide relevance, the study area has the status of a 'Prime Butterfly Area' (van Swaay and Warren 2003) and most of the calcareous grasslands are protected as Natura 2000 sites (Nitsche and Nitsche 2003). A large part (approx. 55 %) of the calcareous grasslands is still actively managed by grazing and sometimes additional mulching (Fartmann 2004; own observation). The remaining calcareous grasslands lie fallow. For a detailed characterisation of the Diemel Valley, see Fartmann (2004).

Sampling design and data analysis

Sampling took place on 17 calcareous grassland patches exhibiting south- or west-facing slopes, which is the preferred aspect of *S. spini* in the study area (Löffler et al. 2013), with shallow soils and where the occurrence of the species was proven (own unpublished data). Each patch was separated from the next calcareous grassland by more than 50 m of improved grassland, arable fields or forest (Fartmann 2006). The three following land-use types were analysed: (i) formerly abandoned shrubby calcareous grasslands where shrubs had been cut four years before the study and which were characterised by a high density of small *R. cathartica* individuals (CUT, $N = 5$), (ii) regularly grazed calcareous grasslands with irregular mulching of parts of the patches, which were covered with some small and some large host plant individuals (GRAZEMULCH, $N = 7$) and (iii) fallow calcareous grasslands with a dense shrub layer (FALLOW, $N = 5$). All patches had a long continuity of the specific land use type. On GRAZEMULCH and FALLOW, land use has not changed during at least 20 years. CUT had not been managed for at least 15 years before shrub cutting. To avoid possible effects of patch size and connectivity on *S. spini* populations, both parameters were kept constant. The mean size (± SE) of the patches was 0.9 ± 0.2 ha and did not differ among the treatments (ANOVA, $F = 2.28$, $df = 2$, $P = 0.14$). The mean patch connectivity (edge to edge distance to the next patch with occurrence of *S. spini*) was 230 ± 62 m and did also not differ among the three groups (Kruskal–Wallis *H* test, $H = 0.73$, $df = 2$, $P = 0.70$). For CUT the mean distance to the next occupied patch was 212 ± 77 m (range 50–495 m).

In March 2013, we systematically searched for egg batches of *S. spini* on all *R. cathartica* plants growing on each patch (cf. Hermann 2007). Searching at a host plant was aborted if no batch or no further batch was found within 10 min (cf. Löffler et al. 2013). A hook attached to a wooden stick helped to reach branches up to heights of about 3 m. Each *Rhamnus* plant was counted and defined as either a small (growth height: < 130 cm) or large plant (height > 130 cm), as *S. spini* is known to prefer small host plants for oviposition (Löffler et al. 2013). We recorded the number of batches per host plant, the number of eggs per batch and the shrub cover per patch (%).

Differences among the three land-use types (CUT, GRAZEMULCH, FALLOW) were compared using Kruskal–Wallis *H* tests followed by Dunn's tests, as data were not normally distributed (Shapiro–Wilk test) or variances were not homogenous (Levene test). Differences in absolute frequencies of batch occupancy and batch numbers, respectively, on small and large host plants were tested using the χ^2 test. All tests were conducted using SigmaPlot 12.5.

Results

In total, we counted 3372 *R. cathartica* plants, 2446 (73 %) small and 926 (27 %) large plants, on the 17 patches. On 309 (9 %) of these plants, we found a total of 490 batches, containing 1168 eggs. Small plants were disproportionally often used for oviposition: 80 % of the occupied plants were small ($N = 246$) and contained 81 % of all detected batches ($N = 396$) (occupied plants: $\chi^2 = 6.85$, $df = 1$, $P < 0.01$; egg batches: $\chi^2 = 4.66$, $df = 1$, $P < 0.001$). The mean batch densities (± SE) were 5.7 ± 2.4 batches per 1000 m^2 (range 0.1–36.0) and 1.6 ± 0.1 batches per occupied host plant (range 1–8).

Land use clearly affected shrub cover, host plant density and occupancy as well as batch density and size (Figs. 1, 2). In contrast to all other variables, shrub cover was the only one having highest values on FALLOW, and significantly differed from the two other land-use types (Fig. 1). The effects of land use on small *R. cathartica* (Fig. 2a) plants were totally different from those observed for shrubs in general. The density of small *Rhamnus* plants was extraordinarily high (45.5 ± 17.8 plants/1000 m^2) on CUT, followed by GRAZEMULCH and then by FALLOW. FALLOW significantly differed from the two other land-use types. In contrast, the density of large *Rhamnus* plants was generally low and had significantly higher values on GRAZEMULCH than on CUT; FALLOW had an intermediate position.

For small *Rhamnus* plants, host-plant occupancy, batch density and batch size were significantly influenced by land use (Fig. 2b–e). In contrast, for large host plants where the absolute number of occupied *Rhamnus* plants was low

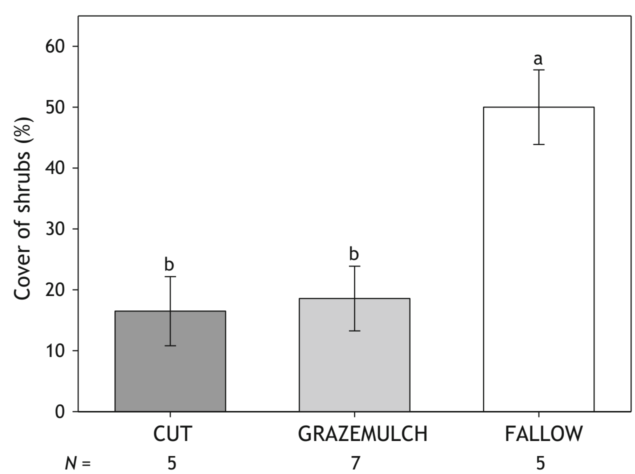

Fig. 1 Mean values (± SE) of shrub cover for CUT, GRAZEMULCH and FALLOW. Differences between land-use types were tested using the Kruskal–Wallis *H* test: H = 8.497, $df = 2$, $P < 0.05$. *Different letters* indicate significant differences of pairwise comparisons (Dunn's test; $P < 0.05$)

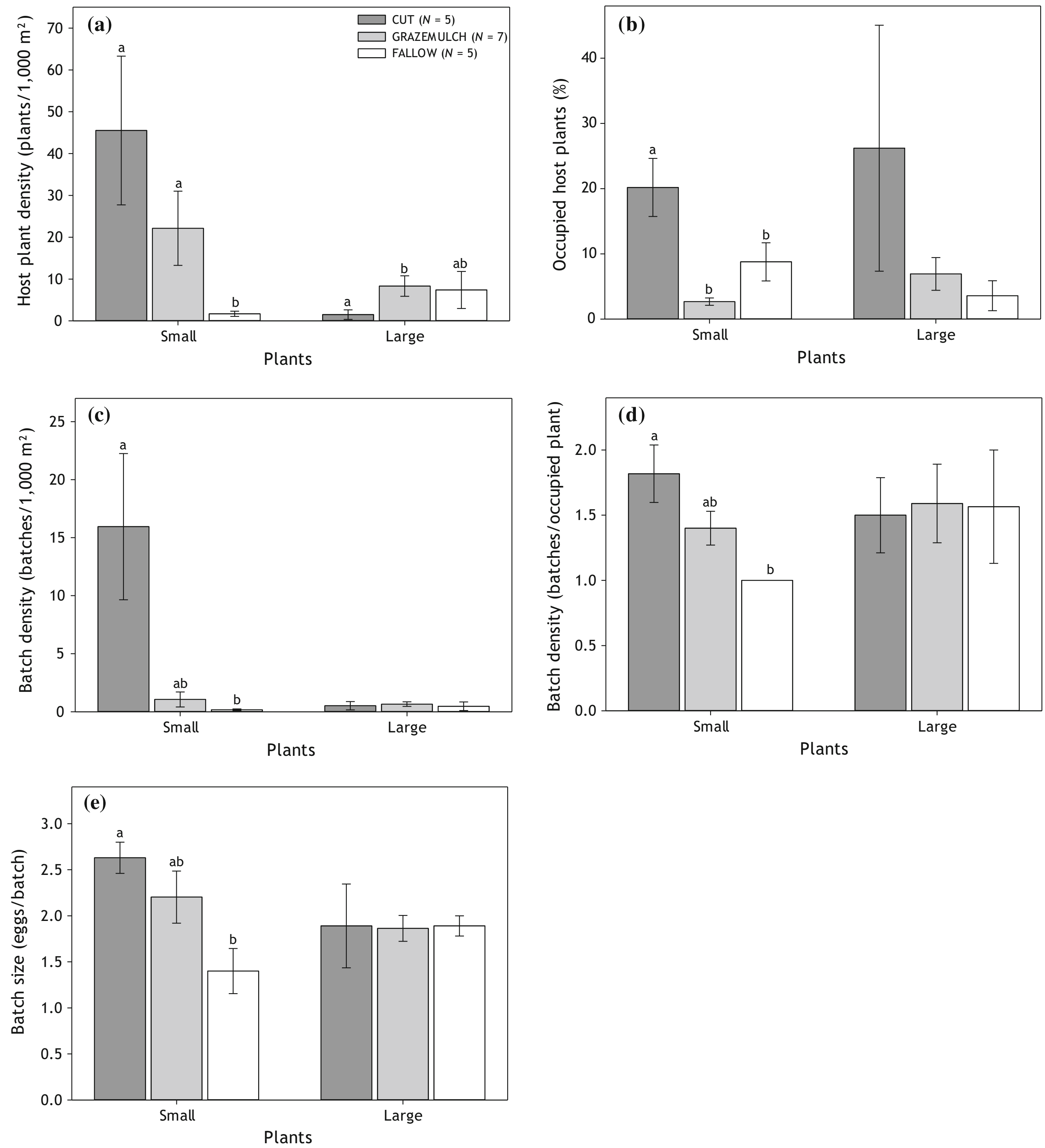

Fig. 2 Mean values (±SE) of host-plant density (**a**), occupied host plants (**b**), batch density (per 1000 m^2 [**c**] and per host plant [**d**]) and batch size (**e**) for CUT, GRAZEMULCH and FALLOW. Differences between land-use types were tested for small and large plants separately using the Kruskal–Wallis H test ($P < 0.05$). *Different letters* indicate significant differences of pairwise comparisons (Dunn's test; $P < 0.05$)

($N = 63$ plants, see above), no significant differences were detected. On CUT, about 20 % of the small *Rhamnus* plants were occupied by at least one batch (Fig. 2b). In contrast, on GRAZEMULCH and FALLOW, mean occupancy values were clearly lower, with only 3 % and 9 %, respectively, of the host plants being occupied. The values of CUT significantly differed from those of the two other land-use types. The patterns of batch density (per

1000 m^2 and occupied plant) and batch size on small *Rhamnus* plants were similar (Fig. 2c–e): Values decreased from CUT over GRAZEMULCH to FALLOW, with CUT significantly differing from FALLOW; GRAZEMULCH had an intermediate position. Most striking were the effects of land use on the density of egg batches per 1000 m^2. Although the density of small host plants on CUT was only two times higher than on GRAZEMULCH and 27 times higher than on FALLOW (Fig. 2a), batch density was 15 times higher on GRAZEMULCH and 80 times higher than on FALLOW (Fig. 2c).

Discussion

Our study showed that both *R. cathartica* and *S. spini* responded rapidly to the restoration measures: Shrub cutting on well-connected and formerly abandoned calcareous grasslands (CUT) promoted the rejuvenation of the host plant and resulted in a strong population increase of the target butterfly species four years after shrub cutting. Host plant density and occupancy as well as batch density and size clearly exceeded those of fallow (FALLOW) and even traditionally managed calcareous grasslands (GRAZEMULCH).

On CUT, overall shrub cover was clearly reduced by cutting. *Rhamnus cathartica*, however, benefited from cutting most likely for two reasons: (i) for germination and sapling establishment, the species depends on sunlit bare soil (Hegi 1975; Kurylo et al. 2007). Such microsites were largely available after shrub cutting on the patches (own observation). (ii) In contrast to some other common shrubs growing in calcareous grasslands (e.g. *Crataegus* spp.), *R. cathartica* responds vigorously to cutting by producing suckers from the stump (own observation).

In northern and central Europe, many butterfly species reach their northern range margin and frequently depend on unusual warm microhabitats (Thomas 1993; Thomas et al. 1999; Bourn and Thomas 2002). Moreover, *Satyrium* butterfly species are generally known to prefer warm microhabitats for oviposition (Stuhldreher et al. 2012; Maes et al. 2014; Power et al. 2014). In line with this, Löffler et al. (2013) demonstrated that *S. spini* females select the warmest available microsites for egg-laying in the study area, which is the northern range margin in Central Europe. CUT appeared to provide very good microclimatic conditions for *S. spini* because the patches offered high numbers of the preferred small and sun-exposed *R. cathartica* plants (46 ± 18 plants per 1000 m^2) (Stuhldreher et al. 2012; Löffler et al. 2013; this study) that allow an oviposition near the local radiation surface, the ground. As a result, on average every fifth small host plant was occupied and batch densities per area observed on CUT were by far the highest values that have ever been described for *S. spini*. Löffler et al. (2013) found a maximum of 1.7 and on average 1.0 ± 0.3 batches per 1000 m^2. In contrast, the mean batch density on small host plants on CUT in this study was 16.0 ± 6.3 batches per 1000 m^2. The mean number of batches per occupied small host plant (1.8 ± 0.2) and mean batch size on small host plants (2.6 ± 0.2 eggs/batch) were also high, a finding that confirms the high suitability of occupied small host plants on CUT for *S. spini* (cf. Stuhldreher et al. 2012; Löffler et al. 2013).

Despite the general preference for small *R. cathartica* plants growing under sunlit and warm conditions, large host plants were sometimes also used for oviposition. This can be the case if they receive much solar radiation and local conditions favour heat accumulation (e.g. host plants growing in front of a sheltered and sunny woodland edge; cf. Löffler et al. 2013). However, the number of large host plants occupied by egg batches ($N = 63$) was too low to detect effects of land-use type on host-plant occupancy, batch density and batch size on large host plants. Under such conditions, even a few occupied plants can cause considerable statistical noise.

Restoration projects often fail as the target species are not able to reach the restored sites (Baur 2014). If *S. spini* was already present on CUT before shrub cutting, it is very likely that the species has become extinct on all CUT patches due to the restoration measures as all shrubs were cut close to the ground and removed from the patches (own observation). That would mean that *S. spini* has recolonized all CUT patches within four years, even the most distant one being 495 m away from the next occupied patch. Observations of in each case a single egg batch of *S. spini* on three previously unoccupied patches in a distance of 670 to 700 m from the next occupied patch in the Diemel Valley (own observation) underline the assumption that the butterfly species is able to bridge distances of 500 m or more within the matrix. Comparable data are available based on mark-recapture studies for two other *Satyrium* species. According to Power et al. (2014) *S. jebelia* is able to disperse reasonable distances with an observed maximum of 940 m within one day. Maes et al. (2014) detected for *S. ilicis* migration distances of more than 600 m.

To conclude, cutting of formerly abandoned shrub-rich calcareous grasslands is a valuable tool for the restoration of *S. spini* habitats if suitable source populations exist in the vicinity. Under such conditions, the species responds rapidly to restoration measures. In the first years after cutting, the restored sites might even become optimal habitats for *S. spini* because they exhibit very high numbers of small *Rhamnus* plants growing under warm microclimatic conditions. The conditions at this time are even better for *S. spini* than on managed calcareous grasslands, as no batches are destroyed by grazing or mulching (cf. Löffler et al. 2013).

Implications for conservation

Based on our study, we recommend shrub cutting on calcareous grasslands as both a restorative and regular management measure for the target species *S. spini*. To date, cutting of abandoned shrubby grasslands has been unattractive because of its associated high costs (Kotowski et al. 2013). Due to the increasing demand for fuel wood, however, shrub cutting in overgrown grasslands might no longer be constrained by economic reasons (cf. Beneš et al. 2006; Freese et al. 2006; Fartmann, et al. 2013). In this restoration project, removed shrubs were converted to wood pellets for bioenergy production. For most patches, the sale of the pellets covered the costs incurred by shrub cutting and pellet production (Vollmer R., pers. comm.). The only exceptions were the steepest slopes, where the amount of work was higher.

For how long such restoration sites provide sufficient suitable microhabitats for *S. spini* strongly depends on site productivity and the disturbance regime. Rocky sites with shallow soils slow down the speed of succession. Roe deer browsing can partly also delay the height growth of *Rhamnus* plants (own observation). A way to secure suitable conditions for *S. spini* in the long run is the re-introduction of rough grazing by sheep and goats (Löffler et al. 2013). The implementation of a low-intensity grazing regime would also be beneficial for many other plant and animal species characteristic of calcareous grasslands (Kiehl 2009; Römermann et al. 2009). However, there are often economic or logistic constraints that hamper the establishment of grazing management. In those cases, we agree with Löffler et al. (2013) and recommend rotational cutting or mulching of one quarter of the shrubs every fourth year, to favour *S. spini*. Where the succession speed is low, the intervals between each cutting might even be longer. Rotational shrub cutting is also known to be beneficial for other shrub-feeding butterfly species (*Thecla betulae*: Fartmann and Timmermann 2006; Merckx and Berwaerts 2010; *Iphiclides podalirius*: Steiner et al. 2007).

In the Diemel Valley (Fartmann 2004) and large parts of Central Europe (Güthler et al. 2005) coppice woodlands were formerly widespread. Coppice woodlands are known to be hotspots for butterfly diversity in general and refuges for many threatened species (Fartmann et al. 2013; Slamova et al. 2013). Moreover, the cessation of coppice management is considered as a main cause for the decline of *S. spini* (Beneš et al. 2002). Hence, we recommend the re-introduction of coppicing adjacent to calcareous grasslands to enlarge *S. spini* habitats. Further butterfly species occurring in the Diemel Valley and known to profit from coppicing are *Hamearis lucina* (Fartmann 2006; Anthes et al. 2008) and *Pyrgus malvae* (Krämer et al. 2012).

When restoring *S. spini* habitats, we necessarily also have to consider the landscape level perspective (cf. Littlewood et al. 2012; Woodcock et al. 2012). It is necessary that source populations exist in close proximity to the restored patches (<500 m); colonisation can then rapidly occur and populations already thrive a few years after shrub cutting.

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