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Successful restoration of moth abundance and species-richness in grassland created under agri-environment schemes

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ABSTRACT

Restoring intensive agricultural fields to species-rich semi-natural grassland could have profound effects on biodiversity and ecosystem services. However, only a minority of European agri-environment scheme funding is currently devoted to such measures (< 1% in the UK) and too few studies compare biodiversity on restored habitats with that on appropriate control and reference sites. As a result, there is a lack of advice for land managers on how to implement habitat restoration to maximise conservation outcomes, especially for insects. We present a landscape-scale field study in which we tested whether the abundance and species-occurrence of moths (Lepidoptera) differed between arable fields, fields restored to species-rich grassland, and semi-natural calcareous grassland (CG). We also tested whether moths were affected by the frequency of CG indicator wildflowers, age of restoration and habitat connectivity of restored grassland. We found that the abundance of CG-associated moths on restored grassland was almost eight times that on arable fields, and abundance and species-occurrence did not differ significantly from that on semi-natural CG. The only group of moths that was more abundant on CG than restored grassland was associated with late successional stage habitats (e.g. woodland), which shows that trees and shrubs are key features maintaining insect biodiversity on CG. CG moths were more abundant on restored grassland sites where CG indicator wildflowers had established, suggesting that active enhancement of the plant community can increase the abundance of target insect groups. Restoring arable fields to species-rich grassland benefits moths over short timescales (as little as 3 years) and at great distances from semi-natural CG (up to 7 km). It should play a pivotal role in future agri-environment schemes aiming to increase insect biodiversity.

1. Introduction

Agricultural intensification has been a major driver of biodiversity declines in landscapes worldwide (Balmford et al. 2012) and has been linked to a decline in ecosystem services such as pest control and crop pollination (Landis et al. 2000; Kremen et al. 2002). Areas that are rich in wildlife can provide ecosystem services on surrounding farmland (Albrecht et al. 2007), so protecting those areas is part of the solution. Studies in the UK show that 55% of species of conservation concern are largely restricted to protected areas (Jackson & Gaston 2008), while insect species are more abundant in protected areas than elsewhere (Gillingham et al. 2014). However, in many regions preservation alone will not be sufficient to meet international targets on biodiversity (James et al. 1999). For instance, parties to the Convention on Biological Biodiversity have committed to restoring at least 15% of degraded ecosystems before 2020 (Conference of the Parties, 1992), and this implies large-scale habitat restoration.

Habitat creation and habitat restoration have been key drivers of biodiversity increase in the UK and elsewhere (Albrecht et al. 2010; Hayhow et al. 2016). Benefits to wildlife can be variable depending on local and landscape factors (Woodcock et al. 2015), but an understanding of this variation can be used to maximise biodiversity increases from habitat restoration in future. For example, during the restoration of species-rich grassland, target assemblages of phytophagous beetles are more likely to be achieved if target plant communities are also present (Woodcock et al. 2010). This suggests that both plants and invertebrates can benefit from practical measures that enhance the floral community, such as spreading green hay as a seed source from

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Abbreviations: AES, agri-environment scheme; CG, calcareous grassland
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nearby semi-natural grassland. Similarly, Alison et al. (2016) found that creating grass margins on arable fields only increases calcareous grassland moth abundance when there is a core patch of calcareous grassland habitat nearby. This reveals that spatial targeting has potential to increase the benefits provided by grass margins.

Habitat restoration across Europe largely depends on public investment through agri-environment scheme (AES) payments. For example, between 1998 and 2008 land managers in England were compensated £280 (approx. €330/$360) per hectare per year to restore 2373 ha of arable land to species-rich grassland (< 1% of AES funds paid to farmers over that period, Natural England, 2009, Natural England, 2013). To justify such costs and inform the allocation of AES funds in future, biodiversity on restored sites must be compared with that on (1) sites before habitat restoration (control sites, e.g. conventional farms in studies of AES interventions; Kleijn et al. 2006) and (2) sites that represent benchmarks for biodiversity (reference sites, e.g. existing semi-natural calcareous grassland; Woodcock et al. 2010). While previous studies have measured restoration success based on compositional similarity between communities on restored habitats and reference sites (Mitchell et al. 1999; Fagan et al. 2008; Woodcock et al. 2010, 2015), it is also important to consider the outcome where biodiversity is higher on restored habitats than on reference sites.

We present the first study to assess how restoring arable fields to grassland affects the abundance and species-occurrence (i.e. species-richness) of moths (Lepidoptera) against the benchmark of existing semi-natural grassland. Moths are an appropriate study taxon because they are highly diverse, have known habitat associations and have experienced declines in the UK (Fox et al. 2014). These declines have been linked to agricultural expansion and intensification, for example Merckx et al. (2012) found a lower abundance of nationally declining macro-moth species where there was higher arable land cover within a 0.8 km radius. Though the ecosystem services provided by moths are poorly understood, there is growing evidence that they are major nocturnal pollinators: a recent study found that 23% of sampled moths carried pollen (Macgregor et al. 2017). Defoliation by caterpillars can profoundly affect nutrient cycling, increasing the proportion of nitrogen retained in soil organic matter (Lovett et al. 2002). Furthermore, moths and caterpillars are a critical food resource sustaining populations of various insectivorous animals of cultural or economic value (e.g. great tits *Parus major*, Perrins 1991).

We survey both macro-moth and micro-moth species in three distinct habitat specialism groups (calcareous grassland moths, grassland generalist moths and other moths) on arable fields (control), former arable fields that have been restored to species-rich grassland (treatment), and semi-natural calcareous grassland (reference sites). Calcareous grassland (CG) is recognised as a priority habitat across much of Europe (Council of the European Union, 1992). While it supports very high biodiversity of plants and insects, the number and size of CG patches has declined over the last century due to agricultural intensification and abandonment (Poschlod & WallisDeVries 2002). We test for effects of the extent of CG habitat in the surrounding landscape on moths throughout our investigation, and collect data on both the age and CG plant community of restored grassland.

Our study is designed to address two key questions: (1) How do moth abundance and species-occurrence on restored grassland compare with that on arable fields and semi-natural CG? We predict that abundance and species-occurrence of CG moths will generally be lowest on arable fields, intermediate on restored grassland and highest on CG. (2) Among restored grassland sites, how are moth abundance and species-occurrence affected by the frequency of CG indicator wildflower species, age of restoration and the extent of CG habitat in the surrounding landscape? We predict that CG moth abundance and species-occurrence on restored grassland will increase with the age of restoration, connectivity to CG and frequency of CG indicator wildflowers. Our predictions primarily apply to the CG-associated moth species group, but we anticipate that grassland generalist and other moths will show weaker effects in the same direction. In answering the key questions outlined above, we aim to produce advice for land managers to optimise the benefits of AES habitat restoration in terms of both ecosystem services and the conservation of priority insect groups.

2. Methods

2.1. Geographic datasets and habitat connectivity

Four polygon layers were used to shortlist study sites in ArcMap 10.1 (ESRI, Redlands, California): (1) restored grassland managed under the "Higher Level Stewardship" (HLS) agri-environment scheme as the option "restoration/creation of species-rich, semi-natural grassland" (Natural England, 2013, Natural England, 2014), (2) cover of CG habitat according to local data centres (Hampshire Biodiversity Information Centre, 2014; Thames Valley Environmental Records Centre, 2015; Wiltshire and Swindon Biological Records Centre, 2015), (3) cover of protected areas in the form of Sites of Special Scientific Interest (Natural England, 2014) and (4) underlying chalk (soft calcareous rock) geology in Hampshire, Wiltshire, Berkshire and the surrounding area (British Geological Survey, 2013).

Polygons of CG habitat were used to derive a continuous surface of "connectivity" to CG across Hampshire, Wiltshire and Berkshire at 100 m resolution. First, polygons were converted to a 100 × 100 m raster, with the value of each cell corresponding to the % cover of CG within it. For each cell we calculated a connectivity metric that combined information on the distances to all other cells and the area of CG within them. Specifically, we followed Hanski (1994) and used a negative exponential kernel, with a mean distance of 1 km, weighted by habitat area (see Appendix A1 for more details). This particular connectivity metric was chosen as it outperforms simpler metrics when predicting colonisation events in fragmented landscapes (Moilanen & Nieminen 2002) and has been an informative variable in previous studies of Lepidoptera in farmed landscapes (Alison et al. 2016).

2.2. Site selection

We selected 32 former arable fields deliberately restored to species-rich grassland across 22 farms in southern England. Sites were selected through GIS shortlisting as well as recommendations from farmers and farm advisers. The aim was to select grassland fields that had been restored more than three years ago, were on underlying chalk and represented a wide range of connectivity to existing high-quality CG habitat. We recorded the start year and method of establishment of each restored grassland field during scoping interviews with land managers. At the time of study restored grassland fields were all managed under HLS. However, restoration had commenced within the last 20 years under a variety of initiatives, including both AESs and set-aside. Restored grassland fields had been established using a variety of methods, such as natural regeneration or sowing of wildflowers (see Table A1 for individual site characteristics). All were cut or grazed at least once per year (Natural England, 2013).

Each restored grassland (treatment site) was paired to a similarly-sized arable field nearby (control site). Treatment sites ranged from 2.6–37.5 ha (mean 14.7) while control sites ranged from 2.2–49.3 ha (mean 16.3). The mean distance between sites in a pair was 423 m, and both sites were on the same farm in 28 of 32 pairs. For eight field pairs we also identified a reference semi-natural CG site nearby (mean 837 m away from closest treatment/control field). Semi-natural CG sites were widely distributed across the study area (see Fig. A1 for a map of study sites).

2.3. Moth and plant surveys

Surveys of both macro-moths and micro-moths (detailed in