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SHORT COMMUNICATION

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The effect of agri-environment schemes on *Bombus terrestris* colony success

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Abstract

1. As with other species linked to agricultural environments, many bumblebee species are exhibiting significant population declines.
2. This study assesses the success of colonies of *Bombus terrestris audax* on farms differing in conservation inputs via agri-environment schemes (AES).
3. *B. terrestris audax* colonies were placed on farms of three treatments: Conventionally managed, AES Entry-Level Stewardship (ELS), or AES Higher-Level Stewardship.
4. Colonies on AES-compliant farms gained significantly more mass than those on conventional farms, which decreased in mass.
5. Nests on conventional farms were also more likely to become infested by the wax moth *Aphomia sociella*, followed by ELS-compliant farms.
6. The results suggest that adopting an AES can increase bumblebee colony success through the production of larger colonies and with greater ability to combat parasite infestations.

KEYWORDS
agri-environment scheme, *Aphomia sociella*, *Bombus terrestris audax*, bumblebees, colony success, wax moths

INTRODUCTION

Bumblebees (*Bombus* spp.) are known as important pollinators for agricultural crops and wild plants, an essential ecosystem service (Breeze et al., 2014; Carvell et al., 2007). Despite this ecological importance, bee species have suffered through agricultural intensification, with modern practices having a detrimental effect on population abundance (Carvell et al., 2006; Goulson et al., 2002). While some species remain overall stable, many bumblebee populations are under pressure as a result of reductions in local floral diversity (Carvell et al., 2011; Timberlake et al., 2019), loss and fragmentation of semi-natural habitats (Fijen et al., 2019; Hardman et al., 2016), and application of agrochemicals (Milano et al., 2019; Rundlof et al., 2008).

Agri-environment schemes (AES) have been implemented in the UK to provide funding to farmers who contribute to the support and enhancement of biodiversity and ecosystem services, and also make improvements to landscapes, particularly through enhancing air, water, and soil quality (Carvell et al., 2007). In terms of pollinators, the schemes increase the extent and diversity of semi-natural habitats for resource provisioning (Crowther & Gilbert, 2020). Floristically enhanced field margins are commonly implemented, using mixes developed to include a diversity of nectar- and pollen-rich flowering plants to provide foraging resources and tussock grasses for nesting (Pywell et al., 2006; Wood et al., 2015). The Entry-Level Stewardship (ELS) scheme is the basic AES that aims to improve widespread environmental conditions and maintain landscapes. The Higher-Level Stewardship (HLS) aims to promote significant environmental improvements to priority areas.

Existing research highlights the detrimental effects of parasite pressure on bumblebee colony success, with a link to land management methods and pest presence. As with many bee genera, bumblebees have associated brood parasites and cuckoo bees of the subgenus *Psithyrus* (Erler & Lattorff., 2010). The parasitic wax moth, *Aphomia sociella* (Lepidoptera: Pyralidae) is a small moth that seeks out bumblebee nests in which to reproduce (Goulson et al., 2018), and whose larvae develop within the nest, damaging the wax comb (Westphal et al., 2009). Although evidence suggests that the presence of wax moths does not prevent reproduction altogether, it is likely to limit success (Goulson et al., 2018).

This study compares the ability of ELS and HLS agri-environmental schemes to support successful *Bombus terrestris audax* colonies when compared to conventionally managed farms. The success of each colony's foraging efforts was measured by the seasonal changes in colony weight. Additionally, the presence or absence of pest species within the nest boxes was used as an indicator of the general health and robustness of the colonies through maintaining resistance to pest colonisation.

METHODOLOGY

Fourteen farms were selected across Shropshire, UK. Farms were selected for their compliance with one of three treatment groups: Conventionally managed farms, ELS or HLS. The study sites included a variety of different farm types (arable, livestock-based, livestock-arable, and dairy), selected to be representative of the local agricultural landscape.

B. terrestris audax colonies were purchased from Agralan Ltd, Wiltshire UK, in June 2018. *B. terrestris audax* was selected because it is a sub-species native to the study area. *B. terrestris audax* is adaptable and will support a reproductively successful colony in artificial nest boxes (Westphal et al., 2009). The colonies supplied were of similar sizes, made up of a founding queen and approximately 80 worker bees, and expected to last approximately eight weeks. The nest boxes were made up of an interior ventilated plastic box for the colony nest, and a 'nectar' source contained, which remained throughout the study, within a cardboard exterior. Each box was then placed inside a plywood outer case with a roofing-felt cover, positioned on top of two bricks, to limit the effect of moisture on total mass measurement. Boxes were positioned under a hedgerow to mimic the natural nest sites of *B. terrestris* (Schweiger et al., 2022). Bumblebees were able to enter and exit the nest box through a small valve that could be opened and closed manually. To limit colony foraging to within the boundary of each farm, nest boxes were situated as close to the central point of the farm as possible.

Before the experiment began, all boxes were weighed. The mass included the internal and exterior boxes, nectar solution, wax comb, and its content, and the bees. Boxes were randomly assigned to study sites. The boxes were weighed at 5, 8 and 10 weeks after the beginning of the experiment, in situ during the daytime (due to safety and accessibility to working farms and limited manpower); thus, the measured weights may be slight underestimates, due to the absence of foraging workers.

On the eighth and tenth week, all nests were examined for the presence of the wax moth, which was recorded as present or absent. The wax moth presence was identified through identification of the conspicuous larvae themselves, the white silk and frass within the internal box, and damage to the nest, that is, tunnelling and crumbled wax (Williams, 1997).

Data analysis

The nest box masses were analysed using a generalised linear mixed model with three predictors: AES (with three levels: conventional, ELS, HLS), farm (the repeated-measure random factor), and the week surveyed (a random factor). Two a priori directional assumptions were used, with the prediction that conventional farms will produce smaller/lighter colonies when compared to AES-compliant locations ($C < ELS + HLS$) and ELS farms will produce smaller/lighter colonies than HLS ($ELS < HLS$). The occurrences of wax moths inside bumblebee nests were analysed using Fisher's exact test to compare conventional against AES-compliant, due to the small sample size.

RESULTS AND DISCUSSION

At the beginning of the experiment, the average total mass of nest boxes and all internal biomass was 5980 ± 110 g (mean $\pm$ SE). The overall mass of nests on both ELS and HLS farms increased rapidly in the first five weeks. Boxes on both the ELS- and HLS-compliant farms showed a similar continuous mass gain, slowing after weeks five and eight respectively. In contrast, nests on the conventional farms showed a steady decrease in mass throughout the experiment (see Figure 1). The greater mass loss of nest boxes situated on conventional farms probably indicates a decline in the production of worker

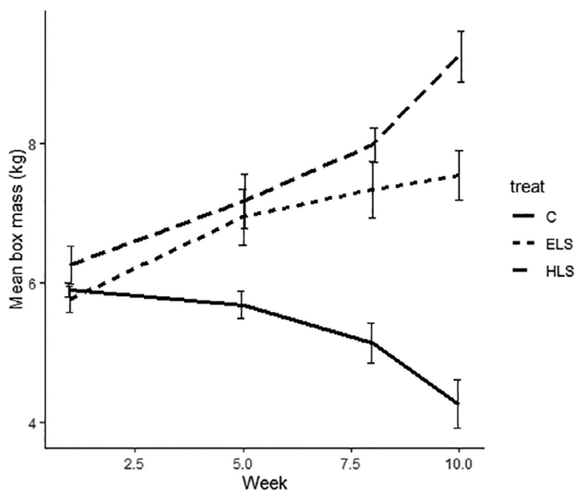

FIGURE 1 Average total weight of nest boxes of each treatment group in grams. Error bars represent standard error. Farm treatment groupings; C, conventional, ELS, Entry-Level Stewardship, HLS, Higher-Level Stewardship

bees and a lack of reproductive success since smaller colonies have lower production of sexuals (Goulson et al., 2002; Westphal et al., 2009). Colonies on conventional farms could also have exhibited a lower mass due to depletion of the original 'nectar' store (part of the weighed mass), which might possibly have been caused by a larger colony with a correspondingly higher nectar demand, or by a deficit in feeding on external floral resources.

With little to no actions taken to conserve or promote local biodiversity and long-term ecosystem health, conventional farms appear to be unable to support colonies of a greater mass. Management under AES was positively associated with the success of *B. terrestris audax*, shown through colony growth. Although we are unable solely to attribute this difference to AES, numerous studies highlight that AES provides greater landscape and resource heterogeneity, which is commonly cited as beneficial to invertebrate reproductive success (Carvell et al., 2008; Goulson et al., 2002; Schweiger et al., 2022).

There were seven cases of wax moth infestation in week eight: four on conventional and three on ELS farms (see Figure 2). In week 10, all five conventional nests were infested: three nest boxes on ELS-compliant farms remained infested, and two boxes on HLS-compliant farms. The analysis found a significant ($p = 0.04$) association between moth presence and AES-compliance, with parasitism decreasing with a higher level of compliance (Figure 2). In support of our findings, Schweiger et al. (2022) found that a lower macroparasite infestation rate was associated with greater pollen diversity, which in turn has been linked with AES compliance (Carvell et al., 2007).

A comparison of the masses alongside infestation rates suggests that smaller/lighter colonies may have reduced health and pest resistance. However, more data would be required to be sure if the infestation was a contributory factor to this difference in mass as the presence of moth larvae is likely to have an influence on colony mass.

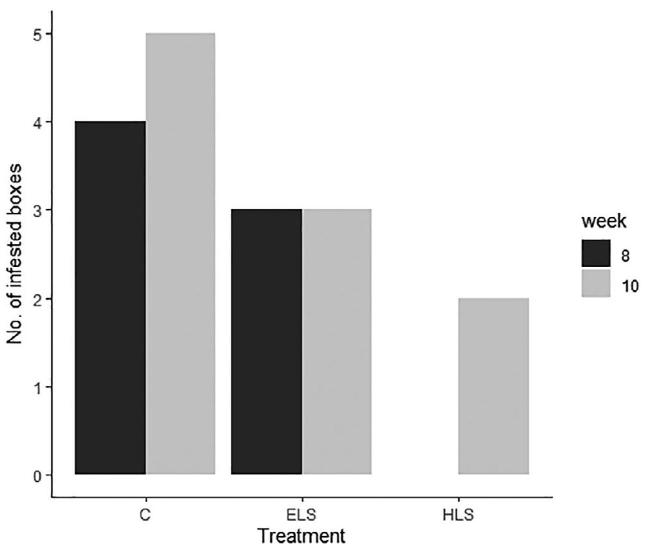

FIGURE 2 Number of nest boxes infested with *Aphomia sociella* during weeks eight and ten of the experiment. Treatment grouping; conventional (C) $n = 5$, Entry-Level Stewardship (ELS) $n = 5$, Higher-Level Stewardship (HLS) $n = 4$

In a previous study, Goulson et al. (2002) found a greater rate of infestation with more wax moths present in suburban landscapes, ascribing this to greater floral diversity. However, our results are not consistent with this conclusion since AES-compliant farms are expected to provide greater floral resources than conventional farms. Instead, our findings suggest that these heavier, and so larger colonies are better able to combat infestations, potentially due to experiencing fewer stressors, resulting in a lower proportion of nests on AES-compliant farms being infested (Goulson et al., 2015; Schweiger et al., 2022).

Analysis of the bumblebee nest-box changes in mass over the survey period highlighted the significant influence that AES compliance had on colony success (see Table S2). Of the two a priori contrasts, only C < (ELS + HLS) was significant ($p << 0.001$). While AES-compliant farms, in general, have higher floral diversity, conventional farms generally lack floral resources, and our evidence suggests an increased chance of parasite infestations: recent research suggests that both may be a consequence of agrochemical application (Goulson et al., 2015; Marja et al., 2018). Management under AES does not eliminate the use of agrochemicals, but it does change the type of chemical used, and the set-aside field margins also act as buffers to agrochemicals sprayed on crops (Carvell et al., 2007; Hanely & Wilkins, 2014).

Although simple, the techniques used in this study identify a consistent pattern in bumblebee colony success (measures through total mass) and parasite infestation. Further development of this method, weighting of individual nest components at the end of the study, would allow for greater clarification.

Thus, we conclude that there is a possible association between AES-compliance, bumblebee *B. terrestris audax* colony growth, and the parasite resistance of colonies. The HLS-compliant farms supported bumblebee colonies of the greatest overall mass while AES-compliance as whole significantly benefitted bumblebee colonies over conventional farming.

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CONFLICT OF INTEREST

The authors have no conflict of interest to declare, no gain, financial or otherwise, will be obtained through publication.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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SUPPORTING INFORMATION

Additional supporting information may be found in the online version of the article at the publisher's website.

Table S1 Key land management activities and agrochemical applications over the previous year on the study farms. Treatment groupings; conventional (C), Entry-level stewardship (ELS), higher-level stewardship (HLS). Farm type groupings; Dairy (D), Livestock based (L), Livestock-arable mix (LA), Arable (A).

Table S2. Results of generalised linear mixed models with normal errors describing the effect of agri-environment scheme (AES), farm type (type), and the AES x type interaction the mass of bumble bee nest boxes. Farm identity and survey day were treated as random factors. Two a priori contrasts were tested among the AES of Conventional (C), Entry-level (ELS) and Higher-level (HLS) schemes. n. s = non-significant. Deviances are distributed as χ^2. The 'null model' contains the random factors of farm identity and survey day.

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