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# Optimizing field margins for biocontrol services: The relative role of aphid abundance, annual floral resources, and overwinter habitat in enhancing aphid natural enemies

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ABSTRACT

Insect predators and parasitoids act as biological pest control agents in agro-ecosystems, and thus provide valuable ecosystem services. These natural enemies of pest species often need a greater diversity of resources than the crops themselves provide. In intensive farm management the numbers of these beneficial arthropod species may be constrained by a lack of additional prey, floral resources or suitable overwintering sites. While previous studies have indicated that targeted field margin management can positively influence the population dynamics of beneficial insects, the relative contribution of the various resources provided by these targeted margins remains unclear.

To help optimise field margins for conservation biological control, this study assessed the relative contribution of three key resources; aphid prey, floral resources, and grass overwintering sites, in supporting natural enemies of cereal aphids within an agricultural landscape. Trial plots were managed adjacent to wheat fields within agro-ecosystems in the UK to assess the relative importance of these three resources in isolation and in combination. The abundance of aphidophagous natural enemies was monitored with respect to these resources during two periods; prior to cereal aphid infestation in the crop, and during the infestation period. In addition, the abundance of cereal aphids and natural enemies was monitored in the crop next to the trial plots during the infestation period. The results show that resource needs of natural enemies vary both over time and between natural enemy groups. Some predators benefited from higher aphid abundance, particularly in combination with the availability of floral resources. Floral resources had the greatest individual effect in increasing natural enemy abundance, both prior to and during periods of aphid infestation. Grassy overwintering habitat provided little overall benefit during the two study periods.

In the UK, most non-crop habitat in agro-ecosystems is grass dominated winter habitat. Few Stewardship scheme initiatives are designed to provide suitable floral resources targeting natural enemies of crop pests, or to provide suitable additional prey. Given the importance of floral resources to the majority of natural enemies, providing suitable nectar and pollen sources represents the greatest opportunity for enhancing naturally occurring predators and parasitoids in agro-ecosystems.



## 1. Introduction

Agricultural pests such as cereal aphids need to be managed to reduce the risk of significant yield losses. Integrated pest management (IPM) combines crop rotation (Casida and Quistad, 1998), development of pest resistant crop varieties (Migui and Lamb, 2003), and the contribution of predators and parasitoids (Fiedler et al., 2008) to control crop pests and minimise the application of insecticides (Niehoff and Poehling, 1995). Naturally occurring enemies already make a significant contribution to IPM (Schmidt, 2003; Holland et al., 2013; Losey and Vaughan, 2006), but there is great potential to enhance their impact through targeted habitat management in so-called conservation biological control (Bugg et al., 1990; Olson and Wäckers, 2006; Jonsson et al., 2008). Most of these natural enemies require key resources beyond those provided by the crops themselves. These include additional prey, adult food resources (specifically nectar and pollen), and overwintering habitat (Landis et al., 2000; Wäckers,

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2004; Griffiths et al., 2008; Wäckers and van Rijn, 2012). In this study we focus on the flight-capable natural enemies of cereal aphids, which constitute the main invertebrate pest of cereals, and their key naturally occuring predators and parasitoids.

Availability of suitable prey is a major factor in determining the size of natural enemy populations. During periods of low pest aphid abundance the presence of plants supporting non-pest prey (banker plants) could help sustain higher natural enemy populations, enabling them to respond more rapidly to pest outbreaks (Landis et al., 2000; Evans, 2008). Commercially produced banker plants are commonly used in protected crops (Frank, 2010; Huang et al., 2011), but the concept has seen limited use in open field crops with only a few isolated successes (Salveter 1998; Pickett et al., 2004; Levie et al., 2005; Frere et al., 2007).

Flowering plants provide vital floral food resources for natural enemies. Even though most pest natural enemies are largely carnivorous in their larval stages, the majority of adults rely at least in part, on sugars and pollen for sustenance and reproduction (Wäckers 2005; Wäckers and van Rijn, 2012). While most species can acquire sugars from honeydew (Hogervorst et al., 2007), floral and extra-floral nectar tends to be of higher nutritional quality (Wäckers, 2000; Limburg and Rosenheim, 2001; Lee et al., 2004; van Rijn et al., 2006; Wäckers et al., 2008; Wyckhuys et al., 2008). Nectar varies between plants in quality, quantity, and accessibility, while floral attractiveness and resource competition may further determine flower exploitation by natural enemies (Wäckers, 2004, 2005; Begum et al., 2006; Vattala et al., 2006; Hogg et al., 2011; Lauberie et al., 2012). Many natural enemies require pollen in their diet in order to reproduce, the quality and quantity of which can also vary between plants (Wäckers, 2004; van Rijn et al., 2006; Lundgren, 2009; Wäckers and van Rijn, 2012). Provision of floral resource has had mixed effects in the field (Andow, 1991). Part of this variation is probably attributable to the fact that earlier studies often chose flowers without sufficient knowledge of their suitability for natural enemies. The success rate of stewardship schemes in terms of enhancing biological pest control services can be improved by a more informed selection of flowering species (Wäckers, 2004; Lavendero et al., 2006). Floral resources may be especially important during periods of low aphid abundance; sustaining natural enemies until prey abundance picks up again (Araj et al., 2011).

Winter habitat is an important and possibly undervalued resource for biological control agents in agro-ecosystems, providing a potential source of refuge and food for overwintering populations (Geiger et al., 2005, 2009; Pywell et al., 2005; Holland et al., 2006). These winter habitats can serve as a source of natural enemies in spring, facilitating the colonisation of fields at the start of the cropping season. Provision of additional undisturbed grass habitat for epigeal (ground dwelling) predators is now common in agro-ecosystems in the form of beetle banks, but relatively little is known about their benefits to flight capable species (Collins et al., 2003).

These three key resources are generally absent within cereal crops, and several studies have investigated the benefits of providing additional resources to agro-ecosystems. Field margins or set-asides are however, often only designed with the focus on a single resource (Olson and Wäckers, 2006; Campbell et al., 2012) and there are no quantitative studies comparing the relative impact of alternative prey, floral resources and overwinter habitat.

By addressing the abundance of natural enemies in relation to the availability of these three key resources individually and in combination, this study was set up to identify their relative importance in conservation biological control. Prior to the aphid peak, natural enemies can be especially vulnerable to a lack of additional resources. As such, the importance of each resource was assessed during two distinct periods: prior to and during the peak cereal aphid abundance period. In this way, we intended to disentangle the relative impact of different resources on natural enemies of cereal aphids during the crucial spring period. The objectives were: (1) to compare the abundance of aphidophagous natural enemies in field margin plots with relatively high or low availability of the three key resources, (2) to investigate any impact these plots had on cereal aphid/natural enemy populations in the wheat crop adjacent to the plots, and (3) to provide quantitative evidence for further optimization of targeted management schemes in terms of conservation biological control.

## 2. Materials and methods

### 2.1. Study sites and experimental design

The experiments were conducted in winter wheat fields and adjacent margins on three arable farms in the UK during 2011. Two of the farms were in Berkshire; Stern Farm (51°12′45″N, 0°56′14″W) and Manor Farm (51°12′29″N, 1°3′15″W), and a third was in Essex; Fingrith Hall Farm (51°42′28″N, 0°19′39″E). At each farm, winter wheat fields larger than 1000 $m^2$ were identified from which three were selected at random, giving nine fields in total. In each field, 300 m of 6 m wide field margin were cleared, on which five pairs of plots were installed with at least 20 m left bare between each pair. Each pair consisted of two 10 m × 6 m plots; one of which was randomly assigned as a control plot, and the other as a resource plot. These control plots were managed to provide a low abundance of all resources for aphidophagous natural enemies (aphid prey/hosts, targeted floral habitat and winter habitat) throughout the study, and provided a paired control for each resource plot. In addition, one resource plot in each field was assigned as a 'field control', again managed to minimise resource availability. Field controls improved the robustness of the statistical analysis when accounting for variation between fields. The resource plots were managed to promote the specific key resources for natural enemies within the field margin.

On each field margin, resource plots were randomly designated one of five habitats: (1) natural regeneration (to support additional aphid prey), (2) targeted floral habitat (to provide floral resources), (3) undisturbed grass habitat (to provide winter habitat), (4) a combination of these three habitats together, and (5) a field control. All of the field margins were prepared by cultivating and rolling the soil in August 2010, after which a general herbicide (glyphosate) was applied to remove all plant growth. The undisturbed grass plots and the grass portion of the combination plots were sown in August 2010, and all the other plots were left bare over the winter. Glyphosate was used to standardise the start point of vegetative growth in the natural regenerations plots, and to clear floral plots prior to sowing after the winter. It was also used to remove vegetation between plots and in control plots over the course of the study (see Supplementary Table 1 for management timings).

Plots containing natural regeneration provided habitat for alternative aphid prey without providing undisturbed winter habitat or floral resources during the spring. The herbaceous plant species used in the targeted floral mix were selected to provide accessible floral or extra-floral nectar as well as pollen for a range of aphidophagous natural enemies, without being highly susceptible to aphid infestations. The undisturbed grass habitat provided overwintering habitat, but was low in suitable floral resources. The control plots were kept free of vegetation and thus provided none of the above mentioned resources. All the plots were monitored for the abundance of the three key resources during the study period and based on these data plots were re-allocated to the three key resources for analysis, rather than their original designated habitat