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Spill-over of pest control and pollination services into arable crops

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ABSTRACT

In order to make agriculture more sustainable it is important to enhance the natural processes supporting crop production, including pollination and pest control. The distance over which these services are delivered into the crop (referred to as spill-over) sets limitations on biodiversity mediated agriculture sustainability. We assess how pest control of aphids on wheat (*Rhopalosiphum padi*) and pollinator linked yield gain in oilseed rape decline with distance from the crop edge. For natural pest control we also assess how field margin floristic diversity (simple grass *vs.* species-rich wildflower) affects pest control. We do not consider the impact of field margins on oilseed rape pollination as perennial dominated field margins are not in flower at the time of oilseed rape seed set and so do not act to attract pollinators. Aphid colonies exposed to invertebrate natural enemies went extinct at a faster rate than colonies where they were excluded. The rate of decline in per capita growth rates of aphid colonies was greatest when exposed to natural predators, with this effect being detected up to 50 m into the crop where species-rich field margins were present. While oilseed rape yield gains were correlated with pollinator (bees and flies) visitation rates, there was no evidence that yield gain declined with distance from the crop edge. Possibly this was due to honeybees showing no evidence of declining visitation rates with distance into the crop (over 200 m). This contrast with bumblebees, solitary bees and flies which showed evidence of declining visitation rates with distance from the crop edge. Our results suggests that for a typical arable field (c. 12 ha) surrounded by species rich field margins, 50% of the total area could benefit from enhanced pest control services. Increased yields of oilseed rape due to insect pollinators of c. 0.4 t ha^{-1} were identified, but there was no evidence that field size would limit the spatial distribution of yields. Our results have implications for integrated crop management world-wide through the use of variable dose rate applications technologies that could be used to target pesticides to field centres and so help support biodiversity mediated ecosystem services.

1. Introduction

By 2050 the world population is expected to rise by 46% placing increasing demands on agricultural production (FAO, 2006). To support greater yields, advances in crop breeding and application technologies have been advocated, along with more conventional forms of agricultural intensification, such as agro-chemical development and conversion of land to cropping systems (e.g. Bruce, 2010; Godfray et al., 2010; Temple et al., 2011). Unfortunately, intensification of agricultural management is widely linked to negative impacts on the provisions of ecosystem services that also play important roles in supporting crop production. In particular, the loss of semi-natural habitat and pesticide exposure have negatively impacted on invertebrate communities that support crop pollination and natural pest control (Godfray et al., 2010; Potts et al., 2010; Oliver et al., 2015). Crop pollination is worth over €153 billion p.a. worldwide and is vital for a wide range of foods including oilseeds, nuts and fruits (Gallai et al., 2009). Similarly, natural pest control by wild predatory and parasitic invertebrates is valued in the USA alone at $4.5 billion *p.a.* (Losey and Vaughan, 2006). An increased reliance on natural pest control can benefit agro-ecosystems by reducing dependence on chemical control methods and so constraining the development of pesticide resistance (Bruce, 2010). The enhancement of both of these ecosystem services in agricultural ecosystems is also likely to play an important role in the resilience of crop production to future

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environmental change (Godfray et al., 2010; Woodcock et al., 2014; Oliver et al., 2015).

The development of management approaches to support pollination and natural pest control requires an evidence base that quantifies not only the impact on beneficial invertebrate populations, but also the spatial distribution of service delivery across cropped land. This is important as the annual harvesting of arable crops effectively destroys this habitat. Beneficial invertebrates must either forage or disperse into the crops from surrounding semi-natural vegetation as the crops are re-established each year. We refer to this process of re-colonisation from the field edge as 'spill-over'. The extent to which species spill-over into crops will have fundamental consequences for the provision of biodiversity mediated ecosystem services (e.g. Saunders and Luck, 2014). This is likely to become increasingly true in the future where precision farming allows the possibility for spatial complementarity between conventional and nature conservation based strategies (Stafford, 2000). However, the quantification of spill-over for both pest control and pollination providing taxa and the ecosystem services they support remains poorly defined (but see Bailey et al., 2014; Morandin et al., 2014; Saunders and Luck, 2014).

In this paper we test the extent to which invertebrate taxa that support pollination and pest control are able to disperse into crops from boundary vegetation. We then quantify directly the extent to which this promotes increased delivery of their respective ecosystem services in economically significant crops. We focus on oilseed rape as the most important insect-pollinated crop in the UK (2.5 million tonnes annually) while wheat is the most widely sown and economically significant crop overall (10 million tonnes annually) (Defra, 2014). Both crops are economically important worldwide (http://faostat.fao.org). For predatory invertebrates we assess how the floristic diversity of field margins could also act to promote spill-over of invertebrate populations by supporting higher populations through improved foraging resources (not just invertebrate prey, but also plant based resources like pollen) and structural refuges (Haaland et al., 2011; Wäckers et al., 2013). In the UK perennial field margins do not flower concurrent with winter oilseed rape at it typically flowers early in the season. Field margins not in flower would not act as an attractant to insect pollinators and so are not considered in this study. Finally we consider interactions between different hunting guilds of predators described by their mode of activity (surface active or canopy active). This has been demonstrate to have important consequences for the delivery of pest control services (Sih et al., 1998; Vance-Chalcraft and Soluk, 2005; Woodcock and Heard, 2011). For example, when aphid pests encounter canopy active predators a common avoidance behaviour is to drop from the plants, an action that makes them more accessible to predators active on the soil surface (Losey and Denno, 1998).

We hypothesised that: (1) the exclusion of beneficial invertebrates from crops will have a negative effect on the delivery of predation or pollination services; (2) the spill-over of these invertebrates and the services they provide (natural pest control or pollination) will decline with distance into the crops; and (3) floristically diverse field margins will support a greater density of beneficial predatory invertebrates and so contribute to improved natural pest control within the crop.

2. Methods

2.1. Pest control services

Spill-over of natural pest control was assessed in Southern England during 2014 in winter wheat fields at the Earth Trust farm (Long.: 51.633256, Lat. −1.1860291), Hillesden Estate (Long.: 51.952950, Lat. −1.0040400) and Waddesdon Estate (Lat.: 51.842705, Long.: −0.93724447). Conventional inputs of fertiliser were applied to the crop, although pesticides were not applied directly to the experimental manipulations described in the following. Pairs of separate non-adjoining fields (referred to as a blocks) were chosen with field margins composed of either grass only or floristically diverse vegetation (referred to as the MARGIN treatment). These pairs of fields within a block were typically separated by less than 300 m. Fields varied in size from 10 to 16 ha and were surrounded by hedgerows of *Crataegus monogyna* Jacq. (Rosaceae) and *Prunus spinose* L. (Rosaceae). The grass only field margins supported no flowering resources and were architecturally simple compared to the floristically diverse margin (see Supplementary material Appendix A for the species composition of the floristically diverse field margins). Diverse field margins provided nectar and pollen utilised by predatory and parasitic invertebrates (Wäckers et al., 2013). All field margins were established three years before the start of monitoring. This allowed all margins to be fully established in terms of their floral composition. Reflecting availability of suitable field margins, two, three and four blocks of paired fields were chosen respectively at the Earth Trust, Hillesden Estate and Waddesdon Estate.

In each fields a single 50 m transects in from, and perpendicular to, the field edge was established. Within each transect the natural pest control of the aphid *Rhopalosiphum padi* was assessed. This aphid is a major pest of wheat in Northern Europe and its control has relevance to other aphid species on cereals worldwide (Hill, 1987). Short transects were used to assess the spill-over of natural pest control as typically many predators have relatively low mobility, for example the ground beetle *Harpalus rufipies* typically moves *c.* 12 m a day in cereal fields (Zhang et al., 1997). We quantified (i) the overall contribution of wild invertebrates to natural pest control and (ii) whether synergistic interactions occurred between predator guilds that hunt on the soil surface and those within the crop canopy. This was done by establishing three aphid colonies at each of two distances (10 m and 50 m) along the transects (DIST treatment). In each case individual colonies were established by placing five apterous adult aphids onto individual wheat tillers at the early booting growth stage (BHCC decimal code 40–45). At each distance the three colonies were separated by 1.5 m. Colonies were covered with protective clip cage for a 48 h establishment period after which this protection was removed.

Each of the three aphid colonies (at each distance along the transect) was randomly allocated to one of the following predator exclusion treatments (EXCL): (1) Aphid colonies exposed to all predators; (2) Aphid colonies exposed to canopy active predators only, achieved by excluding predators active at the soil surface by surrounding the base of the wheat tillers with a 20 cm diameter plastic tube protruding from the soil to a height of 15 cm; (3) Protected from all predators, achieved by covering the wheat tillers with a fine net bag (0.2 mm diameter holes). The three levels of the EXCL treatment allowed us to identify the overall contribution to pest control provided by wild invertebrates and identifying that supported by predominantly canopy active predators. Colonies were established on 30/5/2014 (Waddesdon), 1/6/2014 (Hillesden), and 13/6/2015 (Earth Trust).

Natural pest control was assessed by counting adult aphids in each colony every 5–7 days over an approximately 40 day period for each site (Hillesden = 7 observations over 40 days; Waddesdon = 6 observations over 41 days; Earth Trust 6 observations over 38 days). All monitoring of the aphid colonies was completed by 14/7/2014. For each colony we defined the number of days aphid colonies survived, measured from the day of aphid establishment until the wheat crop went into senescence. The number of days individual colonies survived is a measure of the temporal duration of their impact on the wheat crops and has direct relevance for applied pest management. We also analysed demographic trends