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Landscapes, orchards, pesticides–Abundance of beetles (Coleoptera) in apple orchards along pesticide toxicity and landscape complexity gradients

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ABSTRACT

Landscape composition may influence biodiversity and ecosystem services in agricultural fields. Hitherto, most studies have focused on annual crops and the available information on the impacts of landscape structure in orchards is sparse. In this study, we evaluated the effects of pesticide use as cumulative toxicity on pest and predatory beetle (Coleoptera) assemblages in the canopy of apple orchards surrounded by different proportion of semi-natural vegetation, crop fields and settlements in Hungary. Laboratory data suggest that increasing pesticide toxicity negatively affects predators (coccinellids), but we did not find such a pattern. Supposedly, the effect of pesticides was masked by the continuous recolonisation of orchards from the surrounding landscape. On the contrary, for the less mobile pest species [*Anthonomus pomorum*, *Phyllobius oblongus* (Curculionidae)] we did find a decline in abundance along the gradient of increasing pesticide toxicity. Landscape composition around the orchards significantly influenced the abundance of predatory, fungivorous and tourist species, but had no effect on pests. Contrary to expectations, however, semi-natural habitats had a minor effect compared to arable fields, orchards and settlements which habitat types had various effects on the abundance of different coleopteran groups and species. For example, *Harmonia axyridis* (Coccinellidae) abundance was positively affected by its overwintering sites, i.e. human settlements in spring, semi-natural forests in summer, and arable fields in autumn. The mass immigration of other predatory, fungivorous and tourist species from the surrounding arable fields into the orchards started from July with senescence and harvesting of arable crops. These results suggest that arable fields, other orchards and settlements might be more important sources of colonisation for natural enemies in orchards than certain semi-natural habitats.

1. Introduction

Apple is by far the most widely grown fruit crop in the temperate zone and following banana ranks the second in world fruit production (FAOSTAT, 2016). It accounts for 35% of the total European orchard area (1.3 million ha) with 10–14 million t of apple production per year (Eurostat, 2015). Pests cause substantial losses in apple production, which could reach up to 80–90% in some years without adequate pest control (Cross et al., 2015; Sutton et al., 2014). Naturally occurring predators and parasitoids, however, can substantially contribute to the biological control of apple pests and thus bring economic benefits to growers (Cross et al., 2015). Although numerous studies have focused on the effects of landscape composition on pests and natural enemies in annual cropping systems, considerably less attention has been paid to perennial crops such as apple (e.g. Herrmann et al., 2012; Herrmann et al., 2012; Inclán et al., 2015; Maalouly et al., 2013).

Landscape composition plays a key role in determining insect dispersal in agricultural landscapes (Bianchi et al., 2006; Chaplin-Kramer et al., 2011; Thies and Tscharntke, 1999; Veres et al., 2013). Semi-natural habitats provide shelter, reproduction and overwintering sites for agricultural insects, thus serve as sources of cyclic recolonisation of agricultural fields after soil cultivation, pesticide applications or harvest (Holland et al., 2016; Miliczky and Horton, 2005; Wissinger, 1997). Conversely, pests and their natural enemies reaching high abundances in agricultural fields can also disperse in opposite direction into semi-natural habitats (Tscharntke et al., 2012). These patterns of dispersal

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Table 1
Landscape characteristics (%) around twelve apple orchards in a 1-km radius circle.

Orchards	Arable fields	Forest plantations	Settlements	Grasslands	Orchards	Semi-natural forests
Győrtelek	67	0	1	4	21	5
Kocsord	62	2	22	4	4	5
Demecser	62	8	7	12	5	3
Gelénes	46	1	2	14	19	13
Gulács	46	9	5	6	22	11
Zsurk	45	1	10	23	7	13
Nagydobos	30	59	1	2	7	1
Eperjeske	26	38	18	10	5	3
Mándok	21	19	41	10	7	2
Rohod	18	33	14	20	11	4
Csaroda	15	0	25	26	7	27
Nyírmada	14	71	0	4	8	0

might show similarities but also considerable differences in perennial and annual systems. Perennial crop systems like apple orchards persist for multiple growing seasons and might offer more stable, abundant and diverse resources for insects dispersing from semi-natural habitats than arable fields. Moreover, the landscape-moderated concentration and dilution hypothesis suggests that spatial and temporal changes in habitat availability in the landscape drives the local arthropod abundances, and hence predicts that arthropods emigrating from arable fields after harvest will also concentrate in orchards (Schellhorn et al., 2015; Tscharntke et al., 2012). Thus, we presume that both natural and anthropogenic habitats can support orchard insect assemblages, with a greater contribution of undisturbed habitats. Furthermore, in general, orchards are exposed to high level of pesticides compared to arable fields (Eurostat, 2007; Roßberg, 2013), and they might be exposed to a wide range of pesticide regimes with organic and intensively managed orchards at the two endpoints (Simon et al., 2011; Dib et al., 2016). In spite of the importance of pesticides in regulating arthropod populations, most landscape-scale studies have not covered their impact or it was taken into account by using cumulative management indices, which incorporate, along with the number of pesticide treatments, the intensity of soil preparation, weed control, grazing, pruning, and harvesting (e.g. Bailey et al., 2010; Grez et al., 2013, but see Monteiro et al., 2013).

Different arthropod species and guilds respond differently to pesticide use and landscape composition. Pesticide applications may have a greater impact on natural enemies than on pests, because natural enemies have a lower level of pesticide resistance and any decline in their prey and hosts may also influence their abundance negatively (Biddinger et al., 2009; Jonsson et al., 2012; Krauss et al., 2011; Lövei et al., 1991; Markó et al., 2009; Whalon et al., 2016). On the other hand, species at higher trophic levels, such as predators and parasitoids, could be more vulnerable to habitat loss, fragmentation and isolation than those at lower levels and are therefore less able to colonise the orchards from semi-natural habitat islands and recover less rapidly after pesticide applications (Bailey et al., 2010; Herrmann et al., 2012; Holt, 1996; Tscharntke et al., 2012). Thus species traits, pesticide applications and landscape composition may interact in shaping the arthropod communities in apple orchards. Increasing pesticide pressure and landscape degradation might shift the insect communities toward pests. Conversely, with decreasing pesticide pressure and increasing amount of semi-natural habitats in the landscape insect assemblages might shift toward natural enemies.

The availability of resources necessary for pests and natural enemies vary spatially and temporally in the landscape. Resource requirements of insects (e.g. for feeding, reproduction and overwintering) and their dispersal ability (e.g. only adults can disperse over long distances) may also change during the season. Thus the temporally overlapping resources can form species-specific resource chains (Schellhorn et al., 2015). Different insect species might disperse along different resource chains, i.e. they might show species- and season-specific responses to landscape composition (Raymond et al., 2015; Schellhorn et al., 2014, 2015). Identification of these habitat use patterns is essential for understanding how different landscape elements influence natural enemies and pests, and for gaining knowledge about how to manage landscapes and agricultural fields to maximise biocontrol services (Schellhorn et al., 2015).

Apple orchards harbour species rich and abundant beetle assemblages with several pest and predatory species (Markó et al., 1995; Sutton et al., 2014). Pests might cause damage to roots, trunk, branches, leaves, buds, flowers and fruits of apple trees, while predatory beetles, mainly coccinellids, are important contributors to the control of spider mites, aphids, psyllids and scale insects (Biddinger et al., 2009; Cross et al., 2015; Sutton et al., 2014). In this study, we tested how different landscape elements (proportion of arable fields, orchards, grasslands, human settlements, forest plantations, and semi-natural forests) and management profiles (pesticide use, weed control) can influence the abundance of coleopteran species in apple orchards throughout the growing season. We hypothesized that (i) pesticide use in apple orchards has higher impact on the abundance of predatory beetles than that of pests, (ii) semi-natural habitats in the landscape faciliate colonisation of apple orchards by predatory beetles better than agricultural fields, and (iii) beetle species show different responses to landscape composition during different periods of the season.

2. Material and methods

2.1. Sampling area

Twelve apple orchards with contrasting landscape context were selected as sampling sites in Szabolcs-Szatmár-Bereg County, Hungary (Supplementary Fig. 1, Table 1). In all orchards, trees were 10-years old and the main cultivar was 'Relinda' followed by the cv. 'Rewena' in some. Orchard size varied between 3.9 and 6.9 ha (mean ± S.D., 4.8 ± 0.9 ha).

Landscape composition around each orchard was estimated in a 1 km-radius circle based on CORINE land cover maps and aerial photographs using ArcGIS 10.2 (ESRI, 2013). The 1 km buffer distance is within the spatial range where the relative proportion of habitat types is known to be stable (Marini et al., 2012).

We used the following habitat types, which covered 95–100% (on average 98.7%) of the total study area: arable fields (mostly corn, wheat and sunflower), deciduous forest plantations [mostly black locust (*Robinia pseudoacacia*) and poplar (*Populus x euramericana*)], semi-natural grasslands (meadows and pastures), human settlements (houses, gardens and streets), orchards (almost exclusively apple orchards, but also some sour cherry and walnut orchards) and semi-natural forests (mostly native riverine willow-poplar forests dominated by *Salix alba*, *S. fragilis*, *Populus alba* and *P. nigra*, hedgerows and tree lanes) (Table 1, Supplementary Fig. 2). Proportions of all these habitat types were uncorrelated with each other, except for the significant negative