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Earwigs and woolly apple aphids in integrated and organic apple orchards: responses of a generalist predator and a pest prey to local and landscape factors

Anne-Kathrin Happe[a,*], Laura Roquer-Beni[b], Jordi Bosch[b], Georgina Alins[c], Karsten Mody[a,*]

[a] Ecological Networks, Technische Universität Darmstadt, Schnittspahnstr. 3, 64287, Darmstadt, Germany
[b] CREAF, Autonomous University of Barcelona, Cerdanyola del Vallès, 08193, Barcelona, Spain
[c] Institut de Recerca i Tecnologia Agroalimentàries, IRTA-Fruit Production, PCiTAL, Parc de Gardeny, edifici Fruitcentre, 25003, Lleida, Spain

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ABSTRACT

Organic management, connective woody habitats, and landscape complexity are supposed to enhance beneficial arthropods and biological pest control in agro-ecosystems. We studied earwigs (Dermaptera: Forficulidae) as generalist predators and aphids (Hemiptera: Aphididae) as key pests serving as earwig prey in a total of 58 commercial apple orchards differing in management (integrated production (IP) *versus* organic) in Germany and Spain. We focused on the effects of local agri-environmental structures, orchard management, and composition of the surrounding landscape on earwig populations and on tree infestation by the woolly apple aphid (WAA), *Eriosoma lanigerum*. Surprisingly, the common earwig, *Forficula auricularia,* did not benefit from organic management in either country, and we found even slightly higher earwig abundances in IP than in organic orchards in Germany. In Spain, we found a negative impact of IP compared to organic management on abundance of the earwig *Forficula pubescens*, whereas orchard management did not affect the abundance of *F. auricularia*. The presence of woody habitats adjacent to the orchard reduced the abundance of *F. auricularia* in IP but not in organic orchards in Germany. We did not study the effects of woody habitats in Spain, where these structures were very scarce. There was no effect of high plant species richness at the orchard boundary or compositional landscape heterogeneity on earwig abundance in either country. In Germany, WAA infestation was very low and driven by landscape characteristics rather than orchard management. In Spain, WAA infestation differed strongly between management types (higher in organic orchards). There were no strong, consistent correlations between earwig abundance and WAA infestation in either country. Our study shows that adjacent woody structures and orchard management may affect earwigs in perennial cropping systems. The consequences of orchard management, however, seem to strongly depend on earwig species. Our study suggests that woody elements may serve as sink habitats – potentially attracting earwigs by providing alternative prey and shelter – in IP (but not in organic) orchards.

1. Introduction

Agricultural intensification affects biodiversity and biological pest control at various scales (Geiger et al., 2010; Jonsson et al., 2012; Rundlöf et al., 2007). Increased landscape complexity, local agri-environmental structures and organic management have been promoted as potential ways to mitigate biodiversity loss and associated ecosystem services in agricultural areas (Batáry et al., 2015; Chaplin-Kramer et al., 2011; Rusch et al., 2016). Increased landscape complexity (low proportion of crop cover; Jonsson et al., 2012) affects species in agricultural landscapes differently, and its effectiveness in promoting specific taxa depends on farmland type (Concepción et al., 2012). Large-scale studies of local and landscape effects on biodiversity and biological pest control have so far focused on annual cropping systems (Bianchi et al., 2006; Dainese et al., 2016; Tschumi et al., 2016). In contrast, little is known about how the interacting effects of landscape complexity, agri-environmental structures and management in perennial cropping systems, including orchards, affect generalist predators (Lefebvre et al., 2016; Malagnoux et al., 2015b; Marliac et al., 2016) such as chrysopids, coccinellids, anthocorids and earwigs.

* Corresponding authors.
E-mail addresses: ahappe@posteo.net (A.-K. Happe), mody@bio.tu-darmstadt.de (K. Mody).

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1.1. Earwigs as generalist predators in apple orchards

The common European earwig, *Forficula auricularia* L. (Dermaptera: Forficulidae), is an omnivorous predator. Although it is sometimes considered a pest of stone and soft fruits (Saladini et al., 2016), farmers, consultants and scientists generally agree that the common earwig contributes to biological pest control by maintaining populations of several fruit tree herbivores below economic threshold levels (Cross et al., 2015; Dib et al., 2017; Logan et al., 2017). In apple cultivation, in particular, negative effects such as fruit damage and frass accumulation at harvest (Alford, 2014) seem to be negligible compared to the biological control benefits (Solomon et al., 2000).

Aphids (Hemiptera: Aphididae) are major pests in apple orchards (Blommers, 1994; Rousselin et al., 2017; Solomon et al., 2000). Different aphid species, including the rosy apple aphid, *Dysaphis plantaginea* Passerini (Dib et al., 2011; Miñarro et al., 2005), the green apple aphid, *Aphis pomi* De Geer (Carroll and Hoyt, 1984; Stoeckli et al., 2008), and the woolly apple aphid, *Eriosoma lanigerum* Hausmann (Lordan et al., 2015a; Mueller et al., 1988; Nicholas et al., 2005), are amongst the main prey of earwigs in orchard environments (Dib et al., 2017). Other pests of fruit trees, including scale insects (Logan et al., 2017), psyllids (Sauphanor et al., 1993) and lepidopteran larvae and eggs (Unruh et al., 2016), may serve as supplementary food sources. Common earwigs mate in late autumn and overwinter as adults in underground shelters. In these shelters, females lay a first batch of eggs in late winter and a second one in May or June and nymphs hatch in early spring and late June. The highest numbers of adult earwigs can be found in mid-July and September (Alford, 2014; Solomon et al., 2000). An earlier peak of earwig numbers between May and July has been reported from Mediterranean orchards (Lordan et al., 2015b). Earwigs release a volatile aggregation pheromone, which enables conspecifics to detect and colonize previously occupied hideouts (Lordan et al., 2014). Thus, their populations can easily be surveyed and augmented using artificial shelters, which serve as daytime refuges (Burnip et al., 2002; Dib et al., 2017; Suckling et al., 2006). Their nocturnal activity leads to a higher effectiveness in regulating fruit pests at night than during the day (Logan et al., 2017). Earwigs' overall contribution to biological pest control in orchards has been estimated to reduce insecticide sprayings in orchards by up to three applications per year (Cross et al., 2015). Earwigs are especially important in the control of woolly apple aphids (Stap et al., 1987). In combination with the parasitoid *Aphelinus mali* Haldeman (Hymenoptera: Aphelinidae), earwigs can keep infestations of this pest below the economic threshold level (Nicholas et al., 2005).

1.2. Local management and surrounding landscape

High quality local habitats, including woodland edges and permanent grasslands, as well as agri-environmental structures, including field margins, flower strips and hedgerows, provide increased plant richness, alternative prey, overwintering sites and refuge for natural enemies (Rusch et al., 2016; Simon et al., 2010; Tscharntke et al., 2007). At the landscape level, semi-natural habitats and a high proportion of uncultivated land-cover (Bianchi et al., 2006) are usually assumed to enhance predator communities and biological control. However, in some instances, forest cover has also been associated with reduced numbers of natural enemies (Sarthou et al., 2014). As far as earwigs are concerned, the presence of woody habitats and hedgerows in the orchard surroundings has been reported to enhance their abundance (Debras et al., 2007), but the amount (cover) of woody elements appears to be less important (Stutz and Entling, 2011). Earwigs' sensitivity to habitat isolation can be explained by their dispersal mode and habitat preference. Earwigs are mostly walking dispersers inhabiting semi-open habitats and forests (Bucher et al., 2010). The benefits of woody structures and hedgerows on earwigs may be overridden by intensive orchard management and associated pesticide applications (Malagnoux et al., 2015b).

Commercial apple orchards in Europe are usually managed either under integrated production (IP) or under organic management. The differences between these two types of management are mainly based on pesticide and fertilizer use as well as weed control (mostly soil tillage in organic orchards as opposed to herbicide use in IP orchards; see European Council Regulation (EC) No 834/2007). Malagnoux et al. (2015b) reported higher insecticide (but not fungicide) application frequency in IP compared to organic orchards. Some insecticides have been shown to have non-target effects on earwigs (Beers et al., 2016, 2007; Gontijo et al., 2015; Sauphanor et al., 1993). Various laboratory and field tests revealed that non-target effects strongly depend on pesticide concentration and timing of application in relation to the earwigs' life cycle (Fountain and Harris, 2015; Gobin et al., 2008; Moerkens et al., 2009).

Landscape composition may constrain the effectiveness of agri-environmental structures and organic farming (Concepción et al., 2012; Holzschuh et al., 2008). Landscape effects on population dynamics of natural enemies and crop pests have often been analyzed within a 1 km radius, which proved to be a relevant scale to understand trophic interactions of different organisms and biological control agents (Rusch et al., 2016; Thies and Tscharntke, 1999). Compared to annual cropping systems, orchards are considered more stable habitats for natural enemies because perennial cultivation reduces disturbances such as crop rotation and plowing (Stutz and Entling, 2011). Although natural enemies in tree crops are assumed to be less dependent on landscape effects, non-crop habitat cover in the surrounding landscape has been shown to enhance biological control in these perennial systems (Eilers and Klein, 2009).

In this study, we test for the first time how local factors (plant species richness and woody habitats) and landscape composition (proportion of orchard cover within a 1-km-radius) interact with management (IP *vs.* organic) to affect earwig populations and their aphid prey in commercial apple orchards in two European countries. We expected higher earwig abundance in organic orchards due to lower management intensity and higher prey availability. We also expected increased earwig abundance in complex landscapes with a reduced proportion of crop cover and additional connective woody elements providing quality habitats.

2. Material and methods

2.1. Study sites and study design

Our study was conducted in 58 commercial apple orchards in SW Germany (lake Constance region, Baden-Württemberg; 47°43′N, 9°23′E; 15 IP and 15 organic) and NE Spain (Lleida province, 41°37′N, 0°38′E; 8 IP and 9 organic; Girona province, 41°59′N, 2°49′E; 6 IP and 5 organic). Surveys were conducted in 2015 (both countries) and in 2016 (Germany only; the same orchards as in 2015 with the exception of one IP orchard). Annual mean temperature and annual precipitation in the study areas were 11.1 °C and 736 mm (Constance 2015), 10.7 °C and 977.8 mm (Constance 2016) (DWD, 2017); 14.4 °C and 199.7 mm (Lleida 2015) and 14.9 °C and 541 mm (Girona 2015) (IDESCAT, 2017).

Orchards were planted with trees grafted onto dwarfing rootstocks (M9; 2.0–3.5 m height; 6–18 years old, Table 1). Trees were grown in rows at different spacing (minimum 3 × 1 m, maximum 4 × 5 m). Orchard size ranged from 0.7 to 4 ha. Surveys were conducted along a 40-m-long row transect per orchard. To avoid dilution effects, transect rows were at least two rows away from pollinizer cultivars and orchard edges.

In Germany, all orchards were covered with hail nets from the time of flowering (May) until harvest (September-October). The studied cultivar was Braeburn. Minimum distance between orchards of different management type was 2 km. In Spain, only three orchards had hail nets. The main cultivars in Spain were Golden and Gala. Minimum distance between orchards of different management type was 1 km.