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Landscape-scale forest cover increases the abundance of *Drosophila suzukii* and parasitoid wasps

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Abstract

Agricultural landscapes rich in natural and semi-natural habitats promote biodiversity and important ecosystem services for crops such as pest control. However, semi-natural habitats may fail to deliver these services if agricultural pests are disconnected from the available pool of natural enemies, as may be the case with invasive species. This study aimed to provide insights into the relationship between landscape complexity and the abundance of the recently established invasive pest species *Drosophila suzukii* and a group of natural enemies (parasitoid wasps), which contain species that parasitize *D. suzukii* in native and invaded ecosystems. The importance of landscape complexity was examined at two spatial scales. At the field scale, the response to introduction of wildflower strips was analysed, while the relationship with forest cover was assessed at the landscape scale. Half of the surveys were done next to blueberry crops (*Vaccinium corymbosum*), the other half was done in landscapes without fruit crops to examine effects of *D. suzukii* host presence. As expected, the number of observed parasitoid wasps increased with amount of forest surrounding the blueberry fields, but the number of *D. suzukii* individuals likewise increased with forest cover. Establishment of wildflower strips did not significantly affect the abundance of *D. suzukii* or parasitoid wasps and insect phenology was similar in landscapes with and without blueberry crops. This suggests that *D. suzukii* is enhanced by landscape complexity and is largely unlinked from the species group that, in its native range, hosts key natural enemies. Although management practices that rely on enhancing natural enemies through habitat manipulations can contribute to the long-term stability of agroecosystems and to control agricultural pests, other control measures may still be necessary in the short term to counteract the benefits obtained by *D. suzukii* from natural habitats.

Keywords: Agroecosystems; Landscape complexity; Conservation biological control; *Drosophila suzukii*; Natural enemies; Semi-natural habitat; Ecosystem services; Invasive species; Parasitoid wasp; Agri-environmental schemes

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Introduction

Pre-industrial agricultural landscapes were characterized by a diverse mixture of crop and non-crop habitats (Matthews 1983; Goldewijk 2004), in which the latter provided farms with valuable ecosystem services such as biological pest control and pollination (Altieri 1999). However, the need for increased agricultural production to meet increasing demand for food under human population growth has resulted in the conversion of non-crop habitat into productive agricultural fields (Richards 1993; FAO 2010; FAO & JRC 2012; United Nations Development Programme 2017), with negative consequences for the delivery of ecosystem services provided by species relying on these non-crop habitats (Bommarco, Kleijn, & Potts 2013). These services have been partially replaced by intensive use of agrochemicals, but the heavy reliance on pesticides by modern agriculture is increasingly being criticized as being unsustainable because of the development of pesticide-resistant weeds, pests and diseases and adverse effects on the environment and human health (Matson, Parton, Power, & Swift 1997; Stoate et al. 2001, 2009). As a consequence, alternative approaches have been developed that target ecological principles to develop productive farming systems that can do with fewer or no pesticides. For example, promoting the conservation, restoration and creation of semi-natural habitats at the local and landscape level can enhance biological control and increase the sustainability and resilience of agricultural production (Tscharntke et al. 2007).

Semi-natural habitats have been shown to enhance pest control by supporting more abundant and diverse natural enemy communities, which may colonize nearby crop fields and directly control insect pests by either predation or parasitism (Bianchi, Booij, & Tscharntke 2006; Tscharntke et al. 2007). One particularly effective practice is the creation of semi-natural habitats at the farm level such as wildflower strips designed for enhancing specific natural enemy species (Landis, Wratten, & Gurr 2000; Fiedler, Landis, & Wratten 2008). Such wildflower strips have been shown to reduce pest infestations and crop damage in the neighbouring crop field (Tschumi, Albrecht, Entling, & Jacot 2015; Tschumi et al. 2016) because floral resources in the wildflower strips enhance the abundance, diversity and longevity of natural enemies such as parasitoid wasps, hoverflies and lacewings (Walton & Isaacs 2011; Blaauw & Isaacs 2012, 2015).

Another landscape characteristic that may influence pest pressure is the proportion of host crops in the landscape. On the one hand, the resource concentration hypothesis suggests that the presence of large patches of host plants increases detectability by pests, and therefore pest incidence is expected to be higher under these conditions (Root 1973). At a small spatial scale, this has indeed been found, for example, for the tarnished plant bug on strawberry plants (Rhainds & English-Loeb 2003). However, several studies have on the other hand suggested that this mechanism may work in the oppofarm direction at large landscape scales for certain pests and natural enemies. Our colleagues (Schneider, Krauss, Riedinger, Holzschuh, & Steffan-Dewenter 2015) observed decreasing abundance of the pollen beetles *Brassicogethes* spp. and pollen beetle parasitism with increasing proportion of the host plant oil seed rape *Brassica napus* in a 1 km radius. A similar result was obtained with respect to the relation between Andean potato weevil and the amount of potatoes in the landscape (Parsa, Ccanto, & Rosenheim 2011). Negative relationships between host crop area and pest abundance may be due to a combination of aggregation effects in landscapes with low proportion of host patches (individuals aggregate at the few available host patches, thus increasing pest densities) and dilution effects in landscapes with large amounts of cultivated hosts (Schneider et al. 2015).

Effective biological control approaches based on ecological intensification require a landscape-level understanding of the population dynamics of insect pests and their natural enemies. Control of pest species by management of the habitats sustaining their natural enemies may work for native pest species that are generally part of intricate food webs. However, it is unknown whether this also applies to species that have been introduced from other areas and, in their new distribution range, have been released from their natural enemies. Existing or newly created semi-natural habitats may then provide pest species with the benefits of shelter, alternative food sources and overwintering farms, without them having to suffer the costs of being exposed to higher numbers and diversity of natural enemies. So far, little is known about the relationship between semi-natural habitats, invasive pests and potential natural enemies.

Drosophila suzukii (Drosophilidae: Matsumura) is an insect pest species originating from South-eastern Asia that has recently become invasive in Europe and North America (Hauser 2011). It was first detected in 2008 in Europe and North America (Walsh et al. 2011; Calabria, Máca, Bächli, Serra, & Pascual 2012), in 2012 in the Netherlands (NVWA 2012), and since then it has rapidly expanded at a rate of 1000–1400 km per year (Calabria et al. 2012). The lack of natural enemies that effectively interact with this pest in the newly invaded areas may be one of the main reasons behind its success (Keane & Crawley 2002). *D. suzukii* is now considered one of the most important pests of soft and stone fruits (Asplen et al. 2015). It is generating large economic costs for soft fruit farmers, who may be confronted with 50% of yield losses if no control measures are applied (Goodhue, Bolda, Farnsworth, Williams, & Zalom 2011). Currently, the most extensively used method to cope with *D. suzukii* is the use of insecticides, although the potential of classical biological control is being explored as well (Cini, Ioriatti, & Anfora 2012). Parasitoid wasps are thought to be one of the natural enemy groups that potentially can control *D. suzukii* populations (Walsh et al. 2011), since they are amongst the primary mortality factors of *Drosophila* spp. (Fleury et al. 2004; Fleury, Gibert, Ris, & Allemand 2009, chp 1). Many studies explore the effects of using natural ene-