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Immature hoverflies overwinter in cultivated fields and may significantly control aphid populations in autumn

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ABSTRACT

This study was based on broad monitoring of spring emergence of hoverflies and of aphid populations in two French agro-ecosystems. Its aim was to determine whether hoverflies overwinter in agricultural fields and/or in field margins at immature stages and to what extent local and large-scale landscape features influence the abundance of immature overwintering individuals and the associated biological control. Our results show that the influence of the landscape on the abundance of immature overwintering hoverflies varies among trophic groups. Non-aphidophagous species plus some aphidophagous species, which occasionally feed on crop aphids, preferentially overwinter in field margins near wooded land. Conversely, aphidophagous species, which mainly feed on crop aphids, preferentially overwinter within the fields and are less influenced by semi-natural features. This work also shows a strong negative correlation between the abundance of hoverflies that overwinter at immature stages within the fields and the abundance of aphids in the spring, which suggests a biological control by the hoverflies in autumn. Because they may provide a significant service of biological control, the hoverflies that overwinter within agricultural fields should be taken in consideration in the management of croplands, through agricultural practices for example. The landscape configuration also should be considered in order to maximize the hoverflies community in agricultural landscapes, and to maximize the ecosystem services it provides.

This study provides valuable insights on overwintering of hoverflies at pre-imaginal stages in agricultural landscapes and on the role of this overwintering strategy in the biological control of aphid populations. It shows that a landscape mostly composed of cultivated land can provide significant service of biological control if semi-natural features are arranged in a convenient way for natural enemies.

1. Introduction

In autumn-sown crops, pest predation in autumn may reduce the initial level of pest population in the following spring, as well as reduce the transmission of autumn occurring viruses such as Barley Yellow Dwarf Virus (Kendall et al., 1991). Winter survival of beneficial insects may determine their potential for biological control in the spring by conditioning the population levels at the end of the winter. The ecology of pests and of beneficial insects in the cold months is nevertheless largely under-considered in the current literature (Eitzinger and Traugott, 2011). In the case of aphids which are major crop pests (Dedryver et al., 2010), the impact of biological control by natural enemies in autumn is poorly documented.

Insects which overwinter without migrating often require special habitats to survive unfavorable winter conditions (Bale, 1993). Semi-natural landscape features such as field margins, woodlands, or hedges are known to be favorable winter habitats for many beneficial insects as they provide alternative prey and hosts, floral resources, and protection against inhospitable climatic conditions (Landis et al., 2000; Gurr et al., 2004). However, cultivated fields may also provide suitable conditions for overwintering, and may be sources of some ecosystem-service providers throughout the year (Sotherton, 1984; Eitzinger and Traugott, 2011). For example, in some predatory beetles such as carabids and cantharids, active

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larvae which overwinter within crop fields are major contributors to adult spring populations (Fadl et al., 1996; Noordhuis et al., 2001). The quality of cultivated lands as overwintering sites and their functionality for conservation biological control may vary with the type of crop, crop phenology, and land use intensity (Herzog et al., 2006). Veres et al. (2013) point to the need for better consideration of the functionality of cultivated lands when assessing the influence of the landscape on pest regulation. The spatial arrangement of cultivated fields, with respect to each other, and with respect to semi-natural features, influences the abundance, distribution, and persistence of organisms in the landscape, and consequently the production of various ecosystem services in the agro-ecosystem (Fahrig et al., 2011). Under certain management conditions, the cultivated fields themselves may benefit ecosystem-services providers. In this way, they may enhance agricultural ecosystem services without necessarily requiring the addition of semi-natural features in the agricultural landscapes.

The family of Diptera Syrphidae, also called hoverflies, consists in more than 6000 species belonging to 200 genera distributed all over the world. Apart from extremely rare exceptions, all hoverflies are pollinators at the adult stage as they feed on flowers. Larval ecology is more diverse and varies with the genera and species. Some species, called aphidophagous, have predatory larvae, which are predators of a wide range of crop aphid species (Chambers and Adams, 1986; Tenhumberg and Poehling, 1995). Hoverflies have developed different strategies to survive winter conditions. They can migrate southwards to warmer climes (Aubert and Goeldlin, 1981; Gatter and Schmid, 1990), or they can remain in the summer sites and overwinter as adults (Schneider, 1948; Sarthou et al., 2005), or as diapausing larvae or pupae (Dusek and Laska, 1974; Sarthou et al., 2005). In some species including *Episyrphus balteatus*, several strategies may be used simultaneously in proportions which remain unclear and which probably vary over time and with the region (Hart et al., 1997; Hondelmann and Poehling, 2007; Raymond et al., 2013). In the case of aphidophagous species, the dynamics of each overwintering strategy determines the active period of the predatory larvae responsible for biological control. Locally overwintering adults are known to be more precocious in the spring than immigrants which arrive later from the south (Pollard, 1971; Tenhumberg and Poehling, 1995). Little is known about individuals that spend the winter at immature stages except that they overwinter in the soil (Sarthou et al., 2005; Bokina, 2012) and that they enter in diapause at the beginning of the winter and emerge in the spring (Dusek and Laska, 1974; Hart et al., 1997). Knowledge about the suitable habitats for these overwintering individuals, their distribution and their dynamics is lacking. The precise periods of emergence of adults from the overwintering larvae and pupae remain poorly known and the potential of cultivated fields to host pre-imaginal overwintering hoverflies has never been investigated.

The aim of this work was thus to determine (i) what hoverfly species overwinter at pre-imaginal stages in French agro-ecosystems, (ii) what is the influence of the landscape at large and local spatial scales on the abundance of hoverflies overwintering at pre-imaginal stages, (iii) what is the contribution of pre-imaginal overwintering hoverflies to biological control of aphids. The study was based on the monitoring of hoverflies emerging in spring associated with the abundance of aphids in crop fields, in two French agro-ecosystems with different landscapes and climates.

2. Material and method

Post overwintering emerging hoverflies were collected in spring at two French sites located more than 400 km apart. The study site "Vallées et Coteaux de Gascogne" (VCG) is a 220 km^2 hilly area located in south-western France (43°17′ N, 0°54′ E). The study site "Plaine et Val de Sèvre" (PVS) is located in central western France (46°23′ N, 0°41′ W). It is a flat farmland area of 450 km^2 where mainly cereal crops are grown. The VCG study site is part of the Long Term Ecological Research network (LTER_EU_FR_003), and the PVS study site of the Zone Atelier network (ZAPVS).

2.1. Field sampling

Adults emerging from the pre-imaginal overwintering hoverflies were caught using emergence traps in 2011 and 2012 from the end of the winter to the beginning of the summer, covering most of the adult emergence period (Dusek and Laska, 1974). The operating principle of emergence traps is to seal hermetically a soil area and to collect all the insects that emerge within this area. Traps were placed in agricultural fields (within the fields and/or in the adjacent field margins) selected according to a gradient of density of the surrounding woodland (0–50% within a 500-m radius from the sampling location). In each sampling field, the positions of the traps in the field margin and inside the field were randomly chosen. Traps were set up during the second half of March and were collected every fortnight from the 15th of April until the first week in July.

In 2011, hoverfly emergences were only monitored in the VCG study site. Twenty large traps (surface area 1.8 m^2, a modified Malaise trap to the design of M.C.D. Speight; B&S Entomological Services, Co. Armagh, N. Ireland, UK) were set up in the margins of five oilseed rape fields and five winter wheat fields. In 2012, emergences were monitored in both study sites, both inside the fields and in the field margins, in 49 fields in the PVS site and in 35 fields in the VCG site. In each field, one trap was placed in the field itself, and one in the field margin. Crops in the fields were winter cereals (N = 52), oilseed rape (N = 18) or alfalfa (N = 14). The traps used in 2012 were small (surface area: 0.36 m^2, Soil Emergence trap 96 × 26 mesh, Black, MegaView Science Co., Ltd., Taichung, Taiwan). Collection bottles in all the traps were filled two thirds full with 70° ethanol and were replaced every fortnight. The use of different size emergence traps was due to the availability of the material.

Hoverflies were manually sorted, determined at the species level, and classified in three groups on the basis of larval diet. The species whose larvae are poly-aphidophagous and common predators of aphids in crops with known effective activity of biological control were classified "major aphidophagous species". The species whose larvae are oligo-aphidophagous with unknown efficiency in biological control of crop aphids were classified "minor aphidophagous species". The species whose larvae are not aphid predators were classified "non-aphidophagous species" (S1, supporting information). This classification was based on the databases Syrph the net (Speight et al., 2010) and SirfiGest (Rojo et al., 2003).

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In 2012, the abundance of aphids and hoverflies (eggs, larvae and pupae) was recorded in the fields in which the emergence traps had been placed. From the second week in April to the first week in July, they were counted every 15 days on 50 wheat stalks, 10 rape plants or 50 alfalfa plants randomly chosen in an area of 1 m^2 located near the emergence traps in the field. For each field, we determined (i) the "initial abundance of aphids in spring" (sum of the aphids counted in the recording area in the second week of April), (ii) the "total abundance of aphids in spring" (sum of all the aphids counted in the recording area in spring), (iii) the "total abundance of hoverflies in spring" (sum of all the eggs, larvae and pupae of hoverflies counted in the recording area in spring).