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Effects of local and landscape factors on spiders and olive fruit flies

Malayka S. Picchi[a,*], Gionata Bocci[a], Ruggero Petacchi[a], Martin H. Entling[b]

[a] Scuola Superiore Sant'Anna, Institute of Life Sciences, Piazza Martiri Della Libertà 33, 56127 Pisa, Italy
[b] Institute for Environmental Sciences-Universität Koblenz-Landau, Fortstrasse 7, 76828 Landau, Germany

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ABSTRACT

Conservation biological control uses naturally occurring enemies to limit pest populations and to increase agricultural sustainability. The olive is an important perennial crop in Mediterranean countries and there is a high demand for alternative solutions to pesticide applications. As spiders are the most abundant predators in olive trees, they could be effective against the olive fruit fly, *Bactrocera oleae* (Rossi) (Diptera: Tephritidae), the main pest of this crop. In order to optimise the effectiveness of spiders, it is essential to understand their relationship with environmental factors at both the local and landscape scales. We studied spiders and their potential prey in the canopies of 18 olive orchards in different landscapes of the Monte Pisano (central Italy). The abundance and species richness of spiders as well as the abundance of sheet web spiders were lower in conventional orchards than in organic orchards. The composition of spider communities was affected by the amount of Mediterranean garigue in the surrounding landscape, and the abundance of flies increased with increasing percentage of wood in the landscape. Olive fruit fly densities were negatively correlated with cursorial and sheet web spiders' abundance, suggesting that spiders may be involved in pest suppression. As the response of spiders to local and landscape factors was family and guild specific, tailored management for biological control requires further clarification of the individual and interactive effects of the different spider families and guilds on *B. oleae*.

1. Introduction

The suppression of insect pests is an economically important ecosystem service provided by predators and parasitoids (Ekschmitt et al., 1997; Harwood et al., 2001). Conservation biological control manipulates the environment of natural enemies in order to enhance their performance, by maximising their presence in the field and this can result in an enhanced effectiveness against a multitude of pests (Pickett and Bugg, 1998).

The biological control of pests can prevent crop loss by maintaining pests below the economic threshold, reducing the need for pesticide applications (Pickett and Bugg, 1998). Decreasing pesticide use contributes to the sustainability of agricultural practices: the natural control of pests can enhance and stabilize yields and resilience in the crop production system (Bommarco et al., 2013). Optimising pest control through naturally present enemies requires an understanding of how they function against pests and of their dependence on environmental factors both at the local and at landscape scales.

The olive is an important perennial crop in many Mediterranean countries (European Commission, 2012), and extra-European areas like Africa and America (Daane and Johnson, 2010). In the Mediterranean basin, the olive fruit fly, *Bactrocera oleae* (Rossi) (Diptera: Tephritidae) is the key pest in olive production (Boccaccio and Petacchi, 2009; Castrignanò et al., 2012). Larvae develop within the fruits and reduce both the amount and quality of the yield (Tremblay, 1994). Olive fly females are long-living, mobile and, thus, exposed to naturally-occurring canopy predators. In olive canopies, the most abundant predators are spiders (Cárdenas et al., 2015; Morris et al., 1999) but, to date, their contribution to the suppression of olive fly has been largely neglected.

Spiders are dominant invertebrate predators in many terrestrial ecosystems (Nyffeler and Sunderland, 2003). The majority of spiders are polyphagous (Bristowe, 1941) and many accept other spiders as prey. Thus, intra-guild predation could limit the role of spiders in controlling pests (Denno et al., 2004; Straub et al., 2008). However, spiders contribute to the reduction of herbivores in agriculture (Hodge, 1999). Their ability to suppress pests has

* Corresponding author.
E-mail address: m.picchi@sssup.it (M.S. Picchi).

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been investigated mostly in annual crops (Maloney et al., 2003), though some case studies have been carried out on perennials crops, such as apple orchards, vineyards and cherry trees. In apple orchards, Isaia et al. (2008) found a reduced damage by *Cydia* sp. in trees where the spider abundance had been artificially improved.

To our knowledge, information on olive canopy spiders and their potential role in controlling olive fly is limited, especially considering the different ecological traits of the spider assemblage. Spider communities can be divided into guilds based on their hunting strategies. In accordance with Birkhofer et al. (2008) we divided the spider population into two functional guilds: web-building spiders and cursorial spiders. They can both contribute to the reduction of pests in fields (Birkhofer et al., 2008). Given that web-building and cursorial spiders hunt in different ways, their role in pest suppression could be complementary (Takada et al., 2013). In winter wheat, Birkhofer et al. (2008) tested the effectiveness of these two functional groups, singly and in combination, and found that cursorial spiders delayed the outbreak of aphids when the pest density was low.

Spider abundance in crop fields is influenced by many factors at different scales (Batáry et al., 2008; Clough et al., 2005; Horváth et al., 2015) and generally they are reduced by intensive management (Bengtsson et al., 2005). Given their high mobility, spiders are influenced by landscape composition and configuration (Clough et al., 2005; Duelli and Obrist, 2003; Horváth et al., 2015; Schmidt et al., 2008) and by habitats directly adjacent to crop fields (Horváth et al., 2002; Pfister et al., 2015). The movement between crop and non-crop areas is called "functional spillover"(Blitzer et al., 2012; Hochman Adler et al., 2014). Spillover can be a response to anthropogenic disturbance (Entling et al., 2011), or to seasonal needs such as reproduction or overwintering (Geiger et al., 2009; Pfiffner and Luka, 2000). Another critical factor for spiders is the availability of prey. Populations interact mainly through their feeding relationships (Horváth et al., 2005) and spiders usually respond to fluctuations in prey populations. In the case of increasing prey populations, spiders can increase their individual consumption rates or their own density by generating a higher numbers of successful offspring or by greater immigration from surrounding habitats (Marc et al., 1999).

Landscape effects on natural enemies have mainly been studied in annual crops, i.e. dynamic and ephemeral habitats (Chaplin-Kramer et al., 2011; Gardiner et al., 2009) that undergo frequent and diverse types of human impacts. However, only a few studies have focused on more stable agroecosystems such as cherry trees (Stutz and Entling, 2011), vineyards (Alberto et al., 2012) or olive orchards (Ortega and Pascual, 2014). Differences in crop structure and in management practices between arable crops and orchards influenced spider density and mobility (Entling et al., 2011; Nyffeler and Sunderland, 2003) and hence their response to local and landscape factors (Birkhofer et al., 2013).

In this work, we studied the effects of local and landscape factors on spiders in olive groves. We considered as local factors the distance from the field edge, the type of field management, the adjoining semi-natural habitat types (SNH) and the abundance of prey, including *B. oleae*. Landscape factors were the percentage area of olive groves, woody areas and Mediterranean garigue in a circular buffer of 1 km radius around the sampled field.

Our aims were (I) improve knowledge on the composition of spider species in olive groves; (II) study the relative importance of environmental variables that could influence spiders in olive canopies; and (III) investigate the possible role of spiders, considering families and hunting guilds, in limiting pest populations.

2. Materials and methods

2.1. Study area

The study area is located in Italy between the cities of Pisa and Lucca in an area called the Monte Pisano. This is a mountain formation covering 16000 ha (Bertacchi et al., 2004), set in the centre-north of Tuscany (43°45′02.92″N10°33′18.61″E). The area is especially suited to terraces for olive oil production. Mean annual temperature is about 14 °C, with dry and hot summers ("Csa" type according to the Köppen–Geiger classification (Peel et al., 2007)). Olives in the area are rain fed, with an annual precipitation of around 1107 mm, of which 200 mm fall in autumn (Niccolai and Marchi, 2005). The upper altitudinal limit for olive production is 350 m.a.s.l. The majority of olive groves are managed and structured according to the traditional local olive cropping system. This is characterised by a low management intensity (Beaufoy et al., 1994), with old trees grown at a low density (100 trees/ha) producing small yields and receiving low inputs of labour and materials (Duarte et al., 2008). "Leccino" and "Frantoio" are the most widespread cultivars in this area.

2.2. Selection of focal fields

The study area is dominated by olive groves and two main semi-natural habitat types (SNH): wood and Mediterranean garigue. Garigue is a xerothermic habitat characterised by low, open vegetation mainly composed of shrubs and herbs, typical in dry soils in the Mediterranean area (Polunin and Walters, 1985). We were interested in assessing the influence of these habitat types both at the local and landscape scale, also including the type of management of the field. Thus, the choice of the 18 focal fields was based on three criteria: the adjacent semi-natural habitat (SNH), the type of management and the composition of the surrounding landscape (i.e. the proportion of surrounding area covered by each SNH).

The selection was based on interviews and questionnaires with individual farmers and farmer associations. Conventional farmers usually spray chemical insecticides (Supplementary material Table A.1). The selected conventional farmers used the organophosphate insecticide dimethoate. In organic fields, this substance is not allowed and a variety of compounds or traps certified for organic farming are used instead (regulated by CE 834/2007 and subsequent updates, (Supplementary material Table A.1). Half of the selected fields were under organic management, while the other half was conventionally managed. With respect to SNH, six of the chosen fields shared a common border either with wood, garigue or with olive grove, respectively. The two above mentioned factors were crossed, resulting in $n = 3$ fields for each combination of SNH and management type. In addition, the focal fields formed a gradient of increasing amount of SNH in the surrounding landscape (garigue or woods). In order to prevent problems due to the lack of statistical independence (Steffan-Dewenter, 2002), the landscape buffers around the focal field were not allowed to overlap by more than 10% of the total buffer area. Detailed land use maps were created considering a landscape radius of 1 km since spiders can easily balloon this distance (Horváth et al., 2013), and because the relationship between spiders and landscape composition tends to be strongest at this scale (Schmidt et al., 2008). We analysed 1 km-buffers digitizing aerial orthophotos provided by the regional government of Tuscany in a GIS environment (GRASS GIS, 2012): the land use maps were later validated through field surveys. The characteristics of the selected olive orchards are summarized in Supplementary material Table A.1.