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Community of Syrphids (Diptera: Syrphidae) in Mediterranean perennial crops

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Aos meus pais

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Abstract

Syrphids are holometabolic insects that provide several ecosystem services. In Mediterranean perennial crops, these insects play a fundamental role in the biological control of pests, in the pollination of agricultural crops and adjacent vegetation , and in the decomposition of organic matter, while the inter-rows provide shelter for other natural enemies, thus favouring predation and parasitism of crop pests. However, the ecosystem services provided by these insects or other arthropods have been compromised due to the simplification of the landscape, reduction of seminatural habitats, and increase in urbanization and agriculture. Therefore, understanding how the surrounding landscape of the crops and ground cover vegetation composition affects the syrphids is essential to implementing strategies to promote the presence of the Syrphids in the Mediterranean perennial crops and busting its ecosystem services. For that, this work was divided into two parts. In the first (Chapter 3), the Syrphidae community in Portuguese vineyards was described, and the response of the most abundant species, *Sphaerophoria scripta* Linnaeus, 1758, and *Melanostoma mellinum* Linnaeus, 1758, to the landscape composition and configuration within a gradient of distances (500, 1000, and 2000 m) from the sampled vineyards was studied. And in the second (Chapter 4), the flowering plants present in olive groves' vegetation cover were described, and these plant families' effect on the abundance of *S. scripta* was studied. Our results in vineyards showed that the presence of seminatural habitats and other crops in the surrounding landscape increased the abundance of *S. scripta* and *M. mellinum,* at the largest distance. In contrast, the artificial territory, olive orchards, and vineyards reduced *M. mellinum* at some of the buffers. In olive groves, 90 plant species belonging to 20 families were identified in the ground cover vegetation of olive groves. Asteraceae was the dominant flowering family, followed by Poaceae. The flowering plants of the families Campanulaceae, Asteraceae, Orobanchaceae, and Plantaginaceae in the ground cover vegetation promoted the abundance of *S. scripta* in the olive grove. On the other hand, flowering plants of the families Poaceae and Polygonaceae negatively affect the abundance of this syrphid. Increasing seminatural habitats in the surrounding landscape and the percentage of plant families more attractive in the adjacent vegetation and/or inter-rows in the Mediterranean perennial crops may favour syrphid abundance.

Keywords: agricultural landscape; flowering plants; *Vitis vinifera*; *Sphaerophoria scripta*; *Olea europaea.*

Resumo

Os sirfídeos, são insetos holometabólicos que fornecem diversos serviços ecossistémicos. Nas culturas perenes mediterrânicas, estes insetos desempenham um papel fundamental no controlo biológico das pragas, na polinização das culturas agrícolas e vegetação adjacente, e na decomposição da matéria orgânica, enquanto as entrelinhas providenciam abrigo a outros inimigos naturais, favorecendo a predação e parasitismo das pragas agrícolas. No entanto, os serviços ecossistémicos prestados por estes insetos ou outros artrópodes tem sido comprometidos devido à simplificação da paisagem, redução de habitats seminaturais e aumento da urbanização e da agricultura. Portanto, entender como a paisagem circundante das culturas agrícolas e a composição da vegetação do coberto do solo afeta os sirfídeos é essencial para implementar estratégias para promover a presença dos sirfídeos nas culturas perenes do Mediterrâneo e fomentar os seus serviços ecossistémicos. Para tal, este trabalho foi dividido em duas partes. Na primeira (Capítulo 3) foi descrita a comunidade Syrphidae em vinhas portuguesas e a resposta das espécies mais abundantes, *Sphaerophoria scripta* Linnaeus, 1758, e *Melanostoma mellinum* Linnaeus, 1758, à composição e configuração da paisagem num gradiente de distâncias (500, 1000 e 2000 m) nas vinhas amostradas. E na segunda (Capítulo 4) foram descritas as plantas em floração presentes no coberto vegetal de olivais e foi estudado o efeito destas famílias de plantas na abundância de *S. scripta*. Os resultados nas vinhas demostram que a presença de habitats seminaturais e outras culturas na paisagem circundante aumentou a abundância de *S. scripta* e *M. mellinum*, na maior distância. Em contraste, o território artificial, olivais e vinhas reduziram *M. mellinum* em alguns dos buffers. Nos olivais, foram identificadas 90 espécies de plantas pertencentes a 20 famílias no coberto vegetal dos olivais. Asteraceae foi a família em floração dominante, seguida pela Poaceae. As plantas com flores das famílias Campanulaceae, Asteraceae, Orobanchaceae e Plantaginaceae na vegetação do coberto do solo promoveram a abundância de *S. scripta* no olival. Por outro lado, plantas em floração das famílias Poaceae e Polygonaceae afetaram negativamente a abundância deste sirfídeo. Aumentar os habitats seminaturais na paisagem circundante e a percentagem de famílias de plantas mais atrativas na vegetação adjacente e/ou entrelinhas, nas culturas perenes Mediterrânicas pode favorecer a abundância de sirfídeos.

Palavras-chave: *Olea europaea*; paisagem agrícola; plantas floridas; *Sphaerophoria scripta*; *Vitis vinifera.*

CHAPTER 1

General Introduction and Objectives

Syrphids (Diptera: Syrphidae), considered the second largest group of pollinating insects, belong to the order Diptera and are divided into the subfamilies Syrphinae, Eristalinae, Microdontinae, and Pipizinae (Ball & Morris, 2015; Petanidou *et al.,* 2011). Their body is divided into the head, thorax, and abdomen and has two main colors, black and yellow, which vary in pattern according to the species (Ball & Morris, 2015; Gilbert, 1986).

They are vital insects for agriculture, acting as pollinators, predators, and decomposers of organic matter (Blaauw & Isaacs, 2015; Bugg *et al*., 2008). Adults feed on pollen and nectar on plant flowers (Dunn *et al.,* 2020; Rodríguez-Gasol *et al*., 2020). Larvae follow different diets; they can feed on aphids and other arthropods (aphidophagous), as well as on fungi (mycetophagous), plants (phytophageous), and dead or decaying animal or plant matter (saprophagous) (Ball & Morris, 2015). They are important in the biological control of the olive tree – they prey on the olive moth, on the Jamin moth, and on the olive psyllid – and on the vineyards – they prey on the grape moth (Pinheiro *et al*., 2013; Yilmaz & Genç, 2012; Belcari & Raspi, 1986).

Global diversity is in decline (Raven & Wagner, 2021), affecting ecosystem services' stability (Barbir *et al*., 2015; Wratten *et al*., 2012). The intensification of land use for agriculture is also a practice that generates environmental problems, causing loss of floristic resources and reduction of seminatural habitats in traditional agriculture (Eeraerts *et al*., 2019; Hoffmann *et al*., 2021). Syrphids find shelter and floral resources vital for their growth, development, reproduction, and survival in spontaneous herbaceous vegetation (Bartual *et al*., 2019; Albrecht *et al*., 2021). Therefore, the landscape is crucial for the diversity and abundance of these insects (Thomson & Hoffmann, 2009).

Given the above, this work aims to identify the abundance and diversity of syrphids in Mediterranean perennial crops and understand how the floristic composition of the vegetation cover and the surrounding landscape of agroecosystems shape the syrphid community. This work was divided into two parts, the first (Chapter 3) was carried out in Portuguese vineyards, and the second (Chapter 4) was developed in olive groves. In vineyards, (i) the Syrphid community was described, and, (ii) the response of the most abundant species to the landscape structure within a gradient of distances from the vineyards was analyzed. In olive groves (i) the families of flowering plants present in the vegetal cover were identified and the Syrphid community was described, and (ii) the determination of how the percentage of the flowering plant families in vegetation cover shapes the abundance of *S. scripta* was studied.

CHAPTER 2

Literature Review

2.1. Syrphids (Diptera: Syrphidae)

Syrphids (Diptera: Syrphidae), commonly known as hoverflies or flower flies, are black and yellow flies (Figure 2.1) that resemble Hymenoptera and can mimic bees, bumblebees, and hornets (Ball & Morris, 2015). Syrphids belong to the order Diptera, suborder Brachycera, and are traditionally divided into three sub-families: Syrphinae, Eristalinae, and Microdontinae (ITIS, 2022). Recently, the sub-family Pipizinae has been added to this order (Miranda & Rotheray, 2018). These Dipteras are dispersed over all continents except Antarctica (Rodríguez-Gasol *et al.*, 2020). Currently, in Europe, 970 species of Syrphids are described (Gaytán *et al.*, 2020), of which 195 are present in mainland Portugal (Van Eck, 2016).

Syrphids are between 4-35 mm long and are excellent flying insects with a remarkable ability to hover and fly for long distances (Sommagio, 1999). They have black bodies, with yellow to orange spots on the abdomen, they also may have other color combinations, but it is rarely observed (Thompson & Rotheray, 1998). They are active from April to September, presenting several generations in this period (Félix & Cavaco, 2019).

They are sensitive indicators of the environment's health and are recognized as essential pollinators and predators in natural and agricultural systems (Ball & Morris, 2015; Dunn *et al.*, 2020).

Figure 2.1. Example of a Syrphid specimen. Specie *Eristalinus taeniops* (Wiedemann, 1818).

2.2. Morphology

Syrphids are formed by six legs, and the body is divided into three distinct parts: head, thorax, and abdomen (Gilbert, 1986; Pinheiro *et al.*, 2013).

The head is dominated by two large compound eyes, and the distance between them is an important feature. In males, the eyes are joined together (Figure 2.2B), while in females, they are separated (Figure 2.2A) (Ball & Morris, 2015). Between these compound eyes at the top is the ocellar triangle, which comprises three ocelli, and below this, one can see the frons, a par of antennae, and the face (Ball & Morris, 2015). The mouth armor is of the licking or biting-sucking type and is located below the stylet-shaped head, forming the proboscis (Félix & Cavaco, 2019; Serra & Oliveira, 2008). The probosci's size is related to the type of pollen and nectar each species feeds on (Serra & Oliveira, 2008).

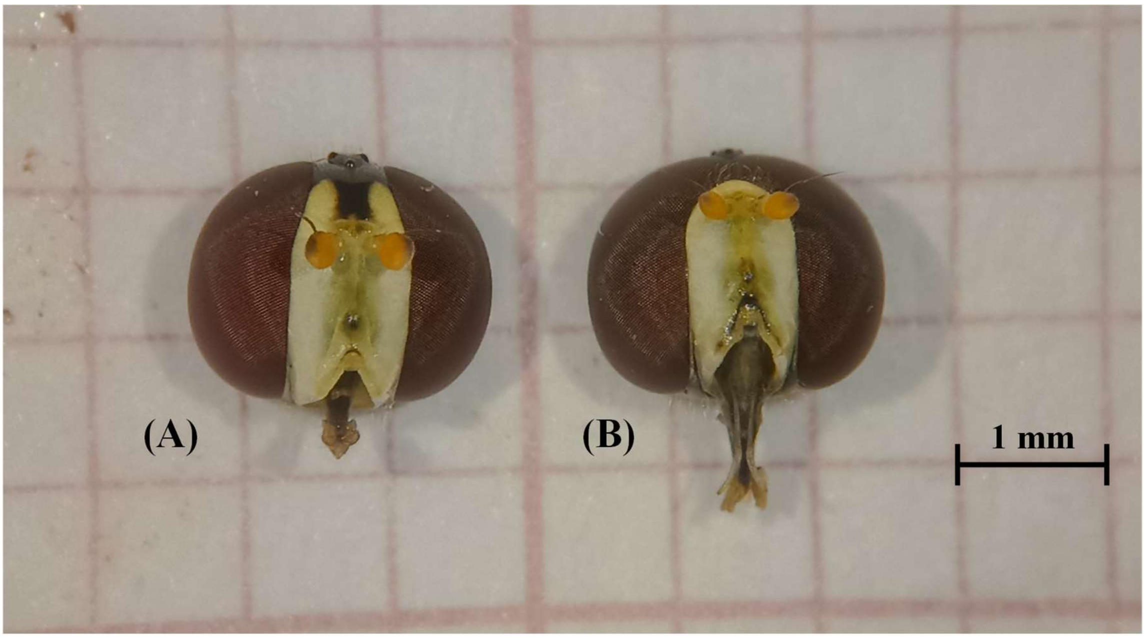


Figure 2.2. Example of *Sphaerophoria scripta* (A) adult female eyes, and (B) adult male eyes.

In the thorax are inserted three pairs of legs, a couple of wings constituted by a transparent membrane that works for flight, and the second pair of wings, called dumbbells, that function as a balance organ (Ball & Morris, 2015; Gilbert, 1986). The transparent pair of wings are composed of a network of veins (Figure 2.3), in which the radial-medial vein (R-M) intersects with the vena spuria is an identifying feature that is always present in syrphids (Gilbert, 1986).

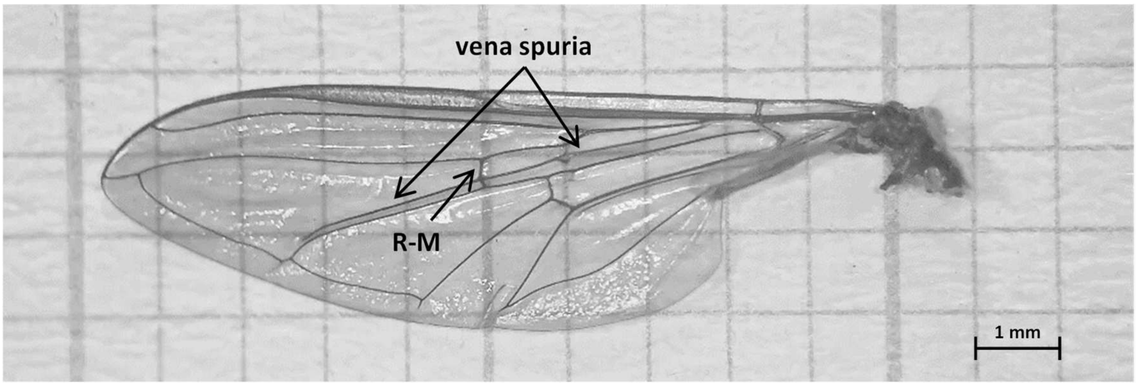


Figure 2.3. Example of a syrphid wing venation (*Episyrphus balteatus* De Geer, 1776). R-M: radial-medial vein.

The abdomen is composed of a series of segments (or tergites) that vary in number between males and females (Pinheiro *et al*., 2013). The different shapes, colors, and positions of the abdominal markings of tergites (Figure 2.4) are characteristics that help to identify syrphid species (Ball & Morris, 2015).

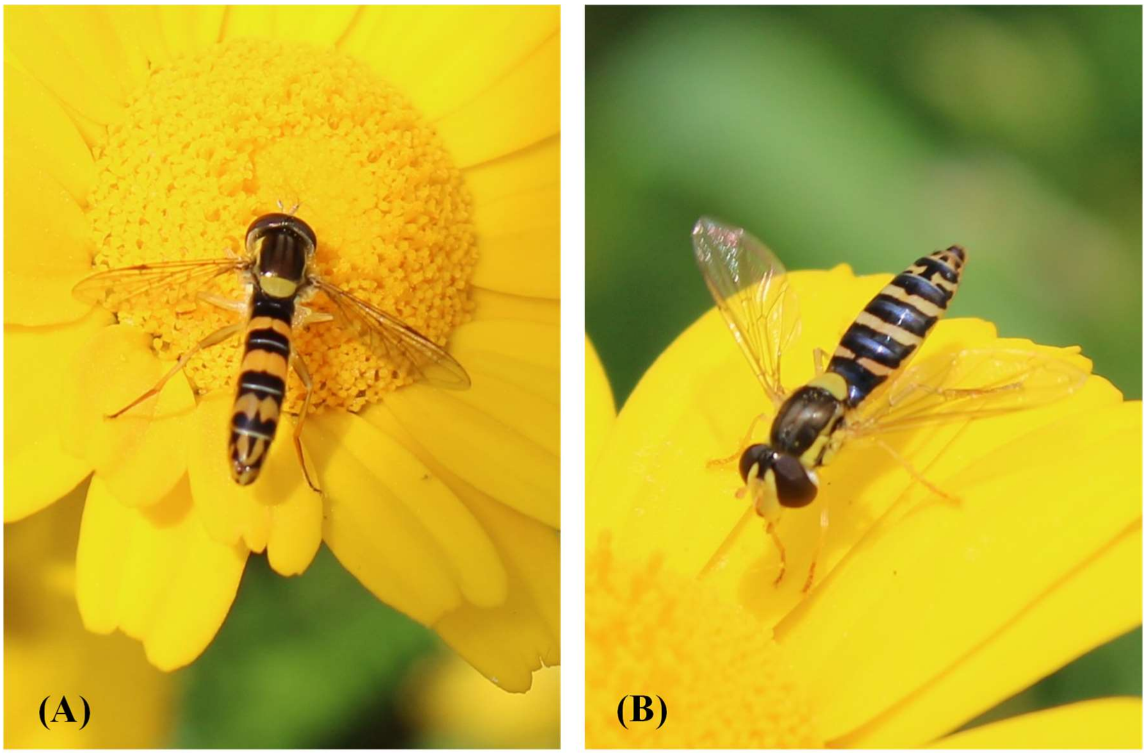


Figure 2.4. Example of *Sphaerophoria scripta* (A) male, and (B) female.

2.3. Biological cycle

Syrphids undergo complete metamorphosis, passing through the egg, three larval stages, puparium, and adult (Figure 2.5) (Bugg *et al*., 2008). The time between egg and adult varies from less than two weeks, in some species, to possibly five years in other ones (Gilbert, 1986).

Females can lay between 500 and 1000 eggs during their lifetime (Coutinho, 2007). Eggs are laid isolated or in group up to several hundred, and are related to the larval feeding habit (Gilbert, 1986). For example, larvae of species with aphid-feeding are laid together with aphid colonies (Coutinho, 2007; Gilbert, 1986). This stage of development in the most common species typically lasts less than five days, depending on temperature and humidity conditions (Gilbert, 1986).

The larvae are apodous, acephalous, and move with difficulty. They can be found immobilized and settle in lower pages of leaves, flower bases, or soil, posteriorly giving rise to pupae (Coutinho, 2007; Gilbert, 1986). The pupae are oval or pear-shaped (Pinheiro *et al*., 2013), like a drop of water.

Adult syrphids feed on pollen and nectar but can also feed on aphids and mealybugs honeydew (Doyle *et al*., 2020; Dunn *et al*., 2020; Félix & Cavaco, 2019; Pinheiro *et al*., 2013; Rodríguez-Gasol *et al*., 2020; Rotheray & Gilbert, 2011; Villa *et al*., 2021), to obtain energy for flight, ovary maturation, and egg production (Vialatte *et al*., 2017). Nectar provides the energy needed to survive, while pollen allows sexual maturation and gametogenesis, so eating habits differ between sex and physiological condition (Pinheiro *et al*., 2013; Rodríguez-Gasol *et al*., 2020; Villa *et al*., 2021). Females need to consume larger amounts of pollen for ovary development and continued egg production (Rodríguez-Gasol *et al*., 2020; Villa *et al*., 2021). On the contrary, males consume more nectar to find mates, perform tissue maintenance, and ensure spermatogenesis (Villa *et al*., 2021). These emerge before females allow their sexual maturation (Gilbert, 1986). In winter, these insects hibernate as larvae, pupae, or adults (i.e., females fertilized in reproductive diapause) (Coutinho, 2007; Rodríguez-Gasol *et al*., 2020).

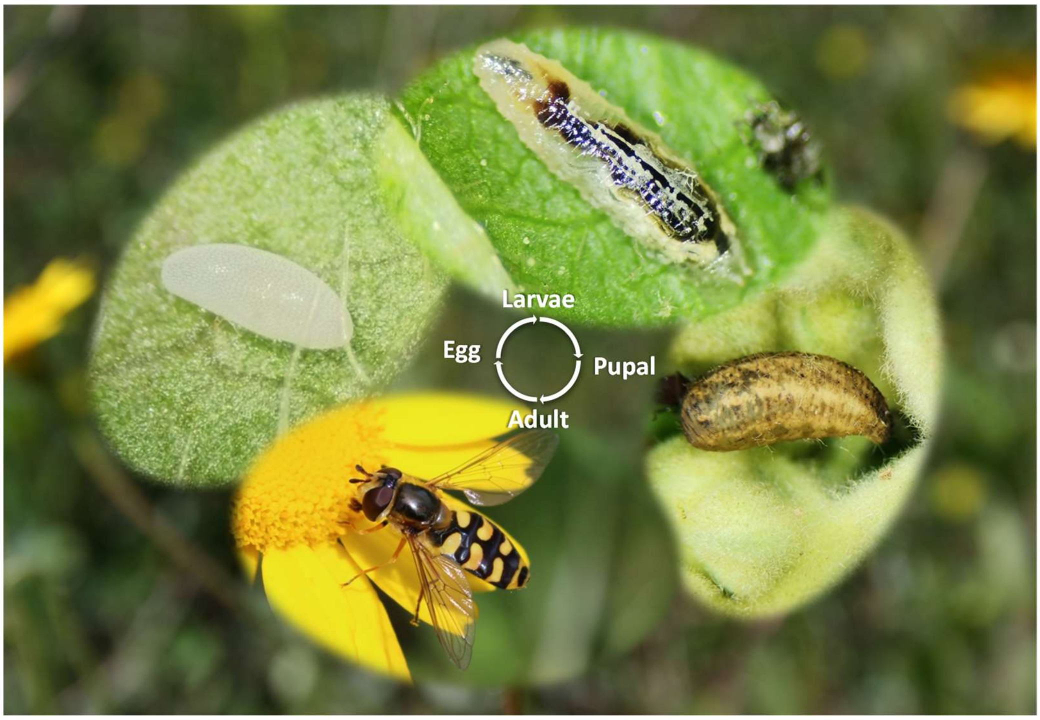


Figure 2.5. The life cycle of syrphids is egg, larvae, pupal, and adult.

2.4. Agroecosystems services provided

Syrphids provide several ecosystem services, such as biological control, pollination, and decomposition of organic matter (Blaauw & Isaacs, 2015). The ecosystem services provided are vital to agricultural production and the wild plant community (Wurz *et al*., 2021).

2.4.1. Biological control

Biological control is defined as the use of living organisms (predators, parasitoid wasps, or microorganisms) to suppress pest populations (pests, pathogens, or weeds) (Costanza *et al.*, 1997). Some Syrphidae larvae (Table 2.1) are predators, mainly of aphids (Figure 2.6A), which makes them especially precious in ecosystems (Rojo *et al*., 2003; Wojciechowicz-Żytko & Jankowska, 2017). For example, according to Tenhumberg & Poehling (1995), one larva of *Episyrphus balteatus* De Geer, 1776, the most abundant aphid predator in Europe, can consume between 400 and 1000 aphids during its larval development, which can last about one week in optimal conditions. Besides aphids, also they can feed on other soft-bodied prey, such as thrips, psyllids, whiteflies, mealybugs, springtails, and lepidopteran larvae (Rodríguez-Gasol *et al.*, 2020).

In olive groves, syrphids can feed on different important pests like the olive moth, *Prays oleae* (Bernard, 1788) - one of the main pests in Mediterranean olive-growing areas -, the Jasmin moth, *Margaronia unionalis* (Hübner), and olive psyllid, *Euphyllura olivina* (Costa, 1839) - two secondary pests of the olive-growing areas (Ksantini *et al.*, 2002; Morris *et al.*, 1999; Pinheiro *et al.*, 2013; Yilmaz & Genç, 2012). In vineyards, there are reports of syrphids, preying on *Lobesia botrana* (Denis & Schiffermüller, 1775) larvae considered one of the main pests of the vineyards in the Mediterranean region (Belcari & Raspi, 1986; Martín-Vertedor *et al.*, 2010).

Nevertheless, at the commercial level for using syrphids as biocontrol agents, farmers have only a few numbers of species available, like the species *Episyrphus balteatus* De Geer, 1776*, Sphaerophoria rueppellii* Wiedemann, 1830, to control of aphids (Amorós-Jiménez *et al.*, 2012; Koppert, 2021).

2.4.2. Pollination

Pollination is widely recognized as an essential ecosystem service since it is vital to agricultural production and other flowering plants by ensuring reproduction, fruiting development, and dispersal (Aizen *et al.*, 2009; Gallai *et al.*, 2009; Klein *et al.*, 2007; Ollerton *et al.*, 2011). In fact, approximately 80% of all flowering plant species are specialized for pollination by animals, mainly insects (Ollerton *et al.*, 2011).

Although the role of syrphids as pollinators has been underestimated compared to bees, syrphids are essential pollinators in the natural, and agricultural plant communities, contribute to the quality and quantity of crops, and influence plant reproduction and community assembly (Klecka *et al.*, 2018; Saunders, 2018). In fact, some studies demonstrated that several crops' fruit set increases with non-bee insect visits (Klein *et al.*, 2012; Rader *et al.*, 2016).

Adults syrphids are generalists in choosing the flowers to feed (Figure 2.6B), not showing specificity to any plant species. However, Fründ *et al.* (2010), Goulson & Wright (1998), and Inouye *et al.* (2015) described that they prefer to visit specific flower species, ignoring other potentially attractive ones available for short periods. The flower choice on which they feed is mainly based on the yellow and white colors, the corolla's length, and the pollen's nutritional value (Campbell *et al.*, 2012; Dunn *et al.*, 2020; Laubertie *et al.*, 2012). In the Mediterranean region, most flowering plants bloom in spring, which coincides with the phase in which syrphids are most active (Alomar *et al.*, 2018; Villa *et* *al.*, 2016). Floral resources are essential for these dipterans to grow, develop, survive, and reproduce (Vialatte *et al.*, 2017; Wojciechowicz-Żytko & Jankowska, 2017).

Although crops such as vines and olive trees do not require entomophilous pollination, syrphids can play an essential role in wildflower pollination of the adjacent vegetation and inter-rows (Doyle *et al.*, 2020). In addition, this vegetation may provide resources for other natural enemies and favor predation and parasitism of the crop pests (e.g., Rusch *et al.*, 2017; Thomson & Hoffmann, 2009, 2013).

2.4.3. Decomposition of organic matter

Decomposition plays a vital role in ecosystem functioning and is a source of nutrients for primary production (Martínez-Falcón *et al.*, 2012). The larvae of some species of syrphids are saprophagous (Figure 2.6C) (Table 2.1) (Speight, 2017). They affect the decomposition process by consuming large amounts of dead material, helping break up the organic residues by opening tunnels and making it available to bacteria and fungi (Martínez-Falcón *et al.*, 2012).

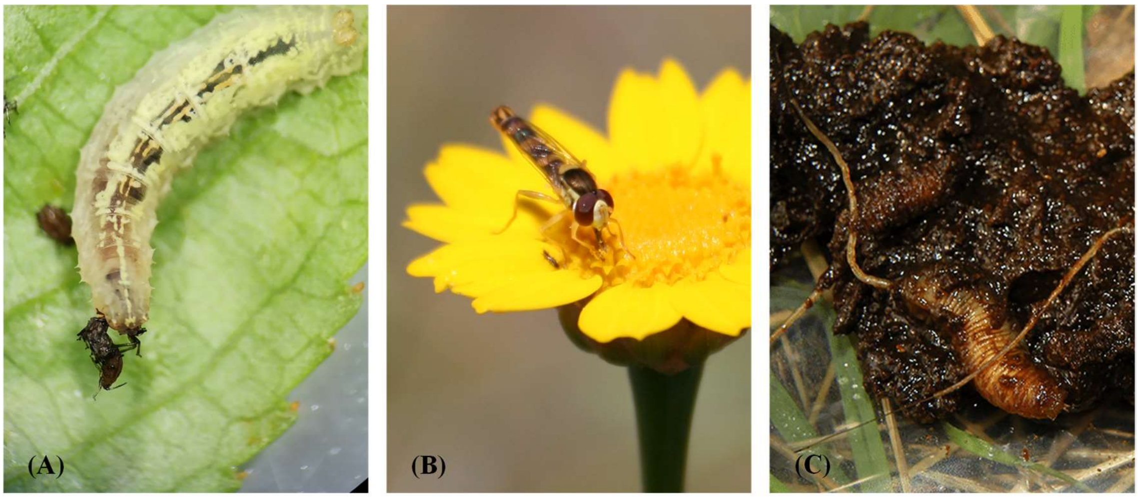


Figure 2.6. Ecosystems services provide by syrphids, (A) Aphidophagous larvae of Syrphidae feeding on aphids, (B) *Sphaerophoria scripta* feeding on pollen, and (C) Saprophagous larvae of Syrphidae decomposing organic matter (Photo: Sánchez-Galván *et al.*, 2016).

Table 2.1. Distribution of syrphid species according to their microhabitats as they have different feeding habits and some examples species found in Portugal.

Microhabitats	**Eating Habits**	**Exemple Species**	**References**
Mycetophagous	Fungi	*Cheilosia scutellata* (Fallén, 1817)	Ball & Morris, 2015; Rojo *et al.*, 2003; Scudder & Cannings, 2006; Speight, 2017
Phytophagous	Plants	*Cheilosia albitarsis* (Meigen, 1822) *Eumerus barbarus* (Coquebert, 1804) *Merodon equestris* (Fabricius, 1794)	Ball & Morris, 2015; Rojo *et al.*, 2003; Speight, 2017
Saprophagous	Dead or decaying animal or vegetable matter	*Brachypalpoides lentus* (Meigen, 1822) *Eristalinus megacephalus* (Rossi, 1794) *Eristalis arbustorum* (Linnaeus, 1758) *Eristalis tenax* Linnaeus, 1758	Ball & Morris, 2015; Rojo *et al.*, 2003; Scudder & Cannings, 2006; Souba-Dols *et al.*, 2020; Speight, 2017
Aphidophagous	Aphids and other arthropods	*Sphaerophoria scripta* Linnaeus, 1758 *Melanostoma mellinum* Linnaeus, 1758 *Episyrphus balteatus* De Geer, 1776 *Eupeodes corollae* Fabricius, 1794	Ball & Morris, 2015; Scudder & Cannings, 2006; Speight, 2017

2.5. What affects syrphids agrosystems?

In the last years, global biodiversity has declined at an alarming rate (Karp *et al.*, 2012; Raven & Wagner, 2021; Stoate *et al.*, 2009), consequently affecting the performance of ecosystems since it threatens the ecosystem services' stability (Barbir *et al.*, 2015; Dobson *et al.*, 2006; Wratten *et al.*, 2012). Insects and more specifically the syrphids are no exception, and some studies have linked the decline of these insects with the decrease in predation of agricultural pests (Fréchette *et al.*, 2007; Grass *et al.*, 2017; Hindayana *et al.*, 2001; Rotheray, 1993; Rotheray & Gilbert, 2011), climate change (Milić *et al.*, 2019; Miličić *et al.*, 2018; Radenković *et al.*, 2017), landscape composition, reduction and fragmentation of habitats (Judt *et al.*, 2019; Power *et al.*, 2016; Santos *et al.*, 2018; Sjödin *et al.*, 2008), expansion of intensive agriculture (Jovičić *et al.*, 2017; Mueller & Dauber, 2016; Schweiger *et al.*, 2007), cultural practices, and high inputs of pesticides (Kleijn & Van Langevelde, 2016; Moens *et al.*, 2011; Mueller & Dauber, 2016; Power *et al.*, 2016).

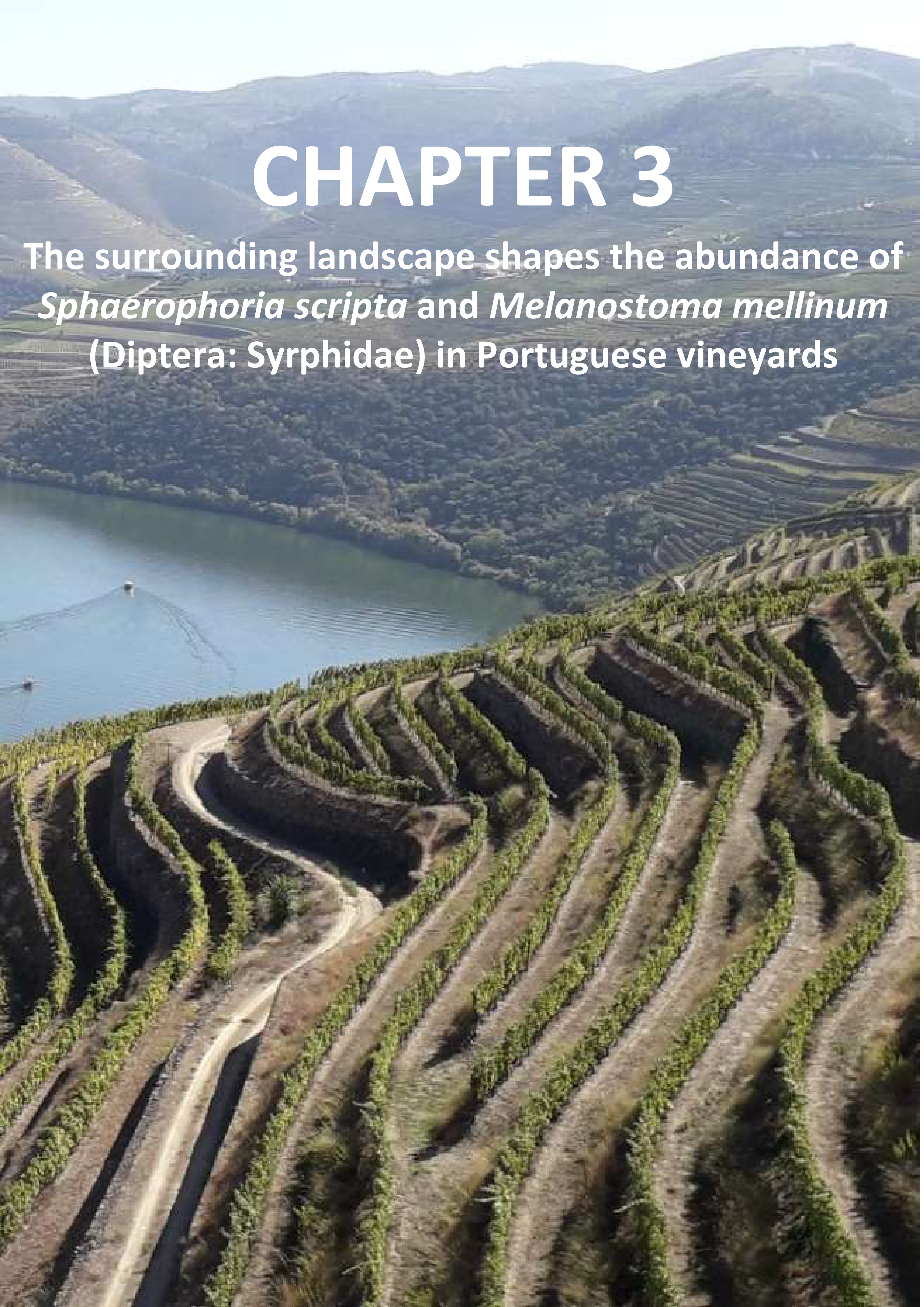
Although adult syrphids exhibit Batesian mimicry, i.e., they have morphological similarities with bees or wasps to intimidate potential predators, and larvae present colors and patterns that facilitate camouflage among vegetation, they are prey for birds, reptiles, spiders, and other predators (Rotheray & Gilbert, 2011). Also, parasitism can reduce the syrphid's population. Different parasitoid species belonging to the families of Ichneumonidae and Pteromalidae, Encyrtidae, Figitidae, and Megaspilidae can mainly attack syrphids larvae (Rotheray, 1984; Rotheray & Gilbert, 2011). Therefore, high syrphids' predation and parasitism rates can affect the biological control outcome (Rodríguez-Gasol *et al.*, 2020).

Global climate change is considered a major threat and is not only a conservation problem for the future but has also been found to impact the distribution range, abundance, phenology, voltinism, physiology and behaviour, and community structure of the syrphids (Banda *et al.*, 2021; Milić *et al.*, 2019; Miličić *et al.*, 2018; Minachilis *et al.*, 2021; Radenković *et al.*, 2017). If the syrphids cannot adapt to the changes in the ecosystems, species can either remain in rare and isolated unchanged environments or become extinct (Miličić *et al.*, 2018; Minachilis *et al.*, 2021).

Landscape composition (i.e., amount of seminatural habitat or other habitats that provide shelter), diversity, and configuration, also affect the diversity and abundance of natural enemies and pollinating insects (Bianchi *et al.*, 2006). Several studies have associated the syrphids community structure with the composition of the landscape, the amount of natural and seminatural habitats, and the diversity of the landscape (Judt *et al.*, 2019; Power *et al.*, 2016; Santos *et al.*, 2018; Sjödin *et al.*, 2008). However, how the landscape structure and composition affect syrphid species depends on their ecological characteristics (Meyer *et al.*, 2009; Moquet *et al.*, 2018; Schweiger *et al.*, 2007). For example, some species might require specific habitats and resources and therefore need to move frequently between habitats to acquire resources, which is largely affected by the composition and availability of seminatural habitats in the landscape (Rodríguez-Gasol *et al.*, 2020). Conversely, more generalist species, usually aphidophagous, appear to be less vulnerable to landscape simplification and to loss of natural and seminatural habitats (Raymond *et al.*, 2014; Schirmel *et al.*, 2018; Schweiger *et al.*, 2007). In addition to the species' different ecological characteristics, syrphids require various resources at the larval and adult stages. So, the availability of resources for both developmental stages in the landscape also plays an important role in shaping the syrphids' community (Meyer *et al.*, 2009; Moquet *et al.*, 2018). Regarding the response of syrphids to the spatial scales, Haenke *et al.* (2009), Power *et al.* (2016), and Werling *et al.* (2011), reported that syrphids can respond to the landscape up to 4 km; however, most syrphids species only respond to habitats up to 1 km away from the main habitat (Haenke *et al.*, 2009; Kleijn & Van Langevelde, 2006; Pfister *et al.*, 2017). The fragmentation of habitats influences the dispersal of the syrphids from the main crop into surroundings crops or seminatural habitats, as they are less likely to cross areas such as dirt and asphalt roads, tilled fields, or creek/hedge combinations (Harwood *et al.*, 1994).

Intensive agriculture generates environmental problems, depletes natural resources, and declines functional biodiversity compared to traditional agriculture (Bakış *et al.*, 2021). Modern agricultural landscapes of intensive agriculture associated with vegetation deprivations cause loss of floristic resources and reductions of seminatural habitats (Eeraerts *et al.*, 2019, 2021; Hoffmann *et al.*, 2021). Cultural practices in perennial crops, such as mobilization, burning of crop residues on land, and the intensive use of plant protection products, also harm the soil and functional biodiversity (Maiato, 2016; Pinheiro *et al.*, 2013). These practices negatively affect the composition of the landscape. Additionally, the use of pesticides for pest and disease control can potentially affect non-target organisms (Aktar *et al.*, 2009; Gill & Garg, 2014; Ware, 1980).

Spontaneous herbaceous vegetation and seeded plant species present in perennial crops provide food resources, shelter, and habitat for the hibernation of beneficial insects (Bartual *et al.*, 2019; Pinheiro *et al.*, 2013). Introducing spontaneous or sown vegetation cover and eliminating harmful cultural practices allows important environmental benefits in terms of erosion reduction, soil fertility, functional biodiversity, tree productivity, and the nutritional status and physiological performance of plants (Maiato, 2016; Rodrigues *et al.*, 2017). Seminatural habitats are effective alternatives that provide regulatory ecosystem services that are important in the functioning of agricultural landscapes, as they sustain plant and animal populations (Bartual *et al.*, 2019).



CHAPTER 3

The surrounding landscape shapes the abundance of *Sphaerophoria scripta* and *Melanostoma mellinum* (Diptera: Syrphidae) in Portuguese vineyards

The surrounding landscape shapes the abundance of *Sphaerophoria scripta* and *Melanostoma mellinum* (Diptera: Syrphidae) in Portuguese vineyards

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Abstract

The intensification of urban and agricultural use in the landscape is the major driver of biodiversity loss and the consequent decrease of ecosystem services provided by insects. Syrphids are important ecosystem services providers, including pest regulation, pollination, and matter decomposition. Understanding how the surrounding landscape to crops affects syrphids is essential to implementing strategies to reverse the negative effects of the agricultural landscape's simplification. This study describes the Syrphidae community in Portuguese vineyards and the response of the most abundant species, *Sphaerophoria scripta* Linnaeus, 1758, and *Melanostoma mellinum* Linnaeus, 1758, to the landscape composition and configuration within a gradient of distances (500, 1000, and 2000 m) from the sampled vineyards. The presence of seminatural habitats (SNH) and other crops in the surrounding landscape increased both species at the largest distance, while the presence of artificial territory, olive orchards, and vineyards reduce *M. mellinum* at some of the buffers. Increasing SNH in the vineyards surrounding landscape (2000 m) and, potentially, introducing nature-friendly practices in the principal crops around vineyards may favour syrphid abundance.

Keywords: agricultural landscapes, *Melanostoma mellinum*, seminatural habitats, *Sphaerophoria scripta*, *Vitis vinifera*

3.1. Introduction

The landscape is crucial to insects' diversity and abundance by providing shelter, food, and overwintering places. Specific landscape structures may drive an increase in the activity of ecosystem services provided by insects. In turn, it may reduce the damage caused by agricultural pests and, consequently, a reduction of phytosanitary treatments carried out on crops (Bartual *et al.,* 2019; Thomson & Hoffmann, 2009).

Syrphids (Diptera: Syrphidae) are providers of multiple ecosystem services. The larvae of some species are voracious predators of insects and agricultural pests (Belcari & Raspi, 1989; Bellefeuille *et al.,* 2019; Dunn *et al.,* 2020; Hopper *et al.,* 2011; Sacchetti, 1990), while others are decomposers (Martínez-Falcón *et al.,* 2012; Speight, 2017). The adults feed on nectar and pollen in flower plants (Rotheray & Gilbert, 2011; Villa *et al.,* 2021), acting as pollinators (Doyle *et al.,* 2020; Klecka *et al.,* 2018; Raguso, 2020; Saunders, 2018). In adiction, syrphids can also play an important role as bioindicators have been proven useful in evaluating environmental health (Sommaggio & Burgio, 2014; Souza *et al.,* 2014; Velli *et al.,* 2010).

Syrphidae is one of the largest families of Diptera, with more than 6000 species described worldwide (Brown, 2009), of which 970 are described in Europe (Gaytán *et al.,* 2020). However, the ecological characterization of Mediterranean syrphids communities is scarce, with few studies focussing on the effect of landscape variables on the abundance and richness (e.g., Herrault *et al.,* 2016; Jovičić *et al.,* 2017; Santos *et al.,* 2018). The Mediterranean can feature a great diversity of syrphids because it has a wide range of habitats for the development of the larvae and floristic resources for adults (Gaytán *et al.,* 2020).

Vineyards are among the oldest and most emblematic crops in the Mediterranean landscapes (Fraga *et al.,* 2017). In this crop, syrphids prey on aphids, mealybugs, and other soft-bodied insects (Rodríguez-Gasol *et al.,* 2020). Moreover, there are reports of syrphids, namely *Xanthandrus comtus* (Harris, 1780), preying on *Lobesia botrana* (Denis & Schiffermüller, 1775) larvae, which is considered one of the main pests of the vineyards in the Mediterranean region (Belcari & Raspi, 1989; Martín-Vertedor *et al.,* 2010). Furthermore, syrphids can play an essential role in wildflower pollination of the adjacent vegetation and inter-rows of the vineyards (Doyle *et al.,* 2020). This vegetation may provide resources for other natural enemies and favour predation and parasitism on vineyard's pests (e.g., Rusch *et al.,* 2017; Thomson & Hoffmann, 2009, 2013).

In the last years, global biodiversity has declined at an alarming rate, frequently associated with human activity (Karp *et al.,* 2012; Raven & Wagner, 2021; Stoate *et al.,* 2009). Besides abiotic and biotic parameters, human activity is a determining factor in shaping the landscape (Jovičić *et al.,* 2017), which often results in the intensification of agricultural and urban land use and the consequent fragmentation of seminatural habitats (hereafter SNH). Such fragmentation has been reported as the main element for declining natural enemies and pollinators (Aronson *et al.,* 2017; Bianchi *et al.,* 2006; Emmerson *et al.,* 2016; Gardiner *et al.,* 2009; Persson *et al.,* 2020). Vineyards, as a monoculture, could represent a potential threat to regional biodiversity due to the constant expansion, replacement of native habitats, and simplification of the surrounding landscape (Underwood *et al.,* 2009).

According to Jauker *et al.* (2009), syrphids are not particularly susceptible to agricultural intensification. However, they can still benefit from a lower management intensity at the landscape scale (Kleijn & Van Langevelde, 2006; Meyer *et al.,* 2009; Schirmel *et al.,* 2018). The diversity of habitats, complex shapes of land patches, and landscape composition are the main factors responsible for increasing the diversity and abundance of pollinators and natural enemies (Judt *et al.,* 2019; Santos *et al.,* 2018). For some syrphids, such diverse habitats are essential to switch between foraging, mating, overwintering, and larval habitats. In addition, due to larvae' highly differentiated feeding habits, syrphids depend on specific habitats that can be scarce in agricultural landscapes (Moquet *et al.,* 2018).

In terms of spatial scales, insect species richness response to their landscape context depends on the analysed scale (Stoms, 1994). For example, Haenke *et al.* (2009) and Power *et al.* (2016) reported that adults of syrphids could respond to the landscape up to 4 km. Kleijn & Van Langevelde (2006) and Meyer *et al.* (2009) stated that syrphids are optimally related to landscape composition at spatial scales between 500 and 1500 m. Some syrphids are very mobile, making them sensitive to large spatial scales conditions (Smith *et al.,* 2007), while other syrphids species are considered nonmigrants (Speight, 2008). Migrant syrphids can disperse up to 400 m in one day, whereas nonmigrants rarely disperse more than 50 m (Wratten *et al.,* 2003).

Therefore, understanding how the configuration and composition of the landscape, within a gradient of distances, shapes the richness and abundance of syrphids in the Portuguese vineyards is extremely important to implement strategies to enhance these insects within the agricultural landscape. Strategies such as enhancing crop diversity and increasing SNH in the landscape for more food resources and habitats for nesting and dispersal might support the syrphids community (Fahrig *et al.,* 2011; Raderschall *et al.,* 2021).

This work aimed to describe the Syrphidae community in Portuguese vineyards and determine the effect of the landscape context on the most abundant species. For that, (i) the Syrphid community was described; and (ii) the response of the most abundant species to the landscape structure within a gradient of distances from the vineyards was analysed.

3.2. Material and methods

3.2.1. Study Area

For this study, 35 vineyards distributed in mainland Portugal (Figure 3.1) were selected. From that, 21 were sampled in 2018 and 35 in 2019.

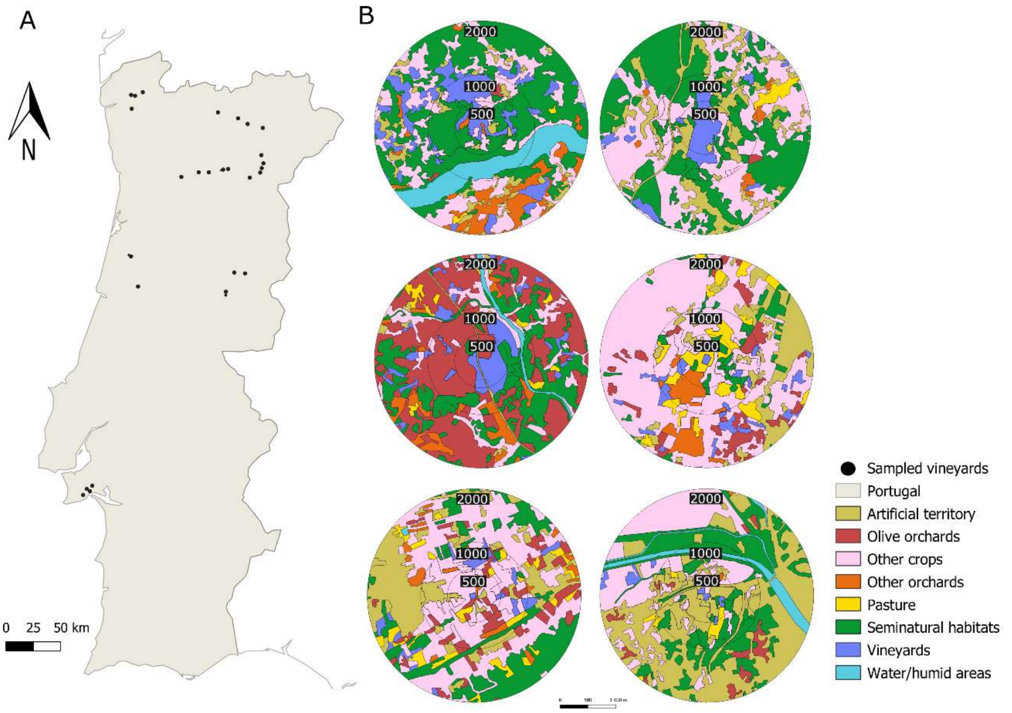

Figure 3.1. (A) Location of the sampled vineyards in Portugal. (B) Examples of land cover categories with different spatial scales (500, 1000, and 2000 m). Maps projected in ETRS89/PT-TM06.

All vineyards were under sustainable producing systems (integrated or organic), and the vegetation ground cover was maintained in the inter-rows during the sampling periods. The information regarding each vineyard is available in the supporting information - Table S3.1.

3.2.2. Sampling methods

The sampling occurs in three periods, early summer, summer, and autumn (supporting information Table S3.1). In each vineyard, in an area of 1 ha, twenty samples, ten for the canopy and ten for the vegetation ground cover, were taken, using a standard entomological sweep at three different sample dates in two consecutive years. Each sample consisted of 50 sweeps of the canopy and ten sweeps of the herbaceous vegetation ground cover. The net contents were transferred into a plastic bag, and diethyl ether (PanReac AppliChem ITW Reagents, USA) was added to kill the arthropods. All samples were frozen at -20°C. Syrphids were separated under a stereomicroscope and conserved in ethanol 96% for further identification. The adults were identified up to the species level using entomological keys (Gilbert, 1986; Speight, 2020; Thompson & Rotheray, 1998).

3.2.3. Landscape variables

The response of the abundance of *Sphaerophoria scripta* Linnaeus, 1758 and *Melanostoma mellinum* Linnaeus, 1758 (please, see Results: Syrphids), the most abundant species, to the landscape structure within a gradient of distances (500, 1000, and 2000 m radii, hereinafter referred to as buffers) from the vineyards were analysed (Figure S3.1).

For that, landscape configuration and composition metrics were calculated within each buffer constructed around each vineyard. Overlapping vineyards were excluded to avoid spatial autocorrelation. Thus, 16, 15, and 13 vineyards in 2018 and 20, 20 and 17 vineyards in 2019 were selected respectively for 500, 1000 and 2000 m buffers. The map "Carta de Uso e Ocupação do Solo de Portugal Continental para 2018″ (COS 2018) (DGT, 2018) was used to obtain the land uses and respective areas within each buffer. Buffers were constructed using the spatial scale, intersect and aggregate functions from the "raster" package (Hijmans, 2021) and the msexplode function from "rmapshaper" package (Teucher & Russell, 2021). To obtain more accurate landscape variables, the small polygons (< 25 m^2 because the resolution of orthophotos for COS 2018 is 25 m^2) generated in the spatial scale edges during the intersection process were merged to a larger adjacent polygon using ArcGIS, version 10.3.1 (ESRI, Redlands, California). Then, landscape variables were calculated using the software Patch Analyst for ArcGIS.

The land-use classes considered to calculate the landscape metrics were: vineyards, SNH (i.e., forest – mainly *Quercus* sp., *Pinus* sp., and *Castanea sativa* Mill. and Mediterranean scrublands) (DGT, 2018), olive orchards, other crops (i.e., herbaceous crops), other orchards (i.e., woody crops, excluding vineyards and olive orchards), pasture, bared areas (i.e., with low or no vegetation), artificial territory (i.e., urban territory or buildings) and water/humid areas.

The landscape-level metrics calculated for further analysis were the Simpson's diversity index (SEI) to quantify the landscape composition, which represents the probability that any land types selected at random would be different types, and the mean patch fractal dimension (MPFD) to quantify the degree of configuration complexity of the landscape. This metric measures the complexity of a polygon by relating perimeter and area (McGarigal & Marks, 1995). At the class level, the considered landscape metrics were: the areas of artificial territories, olive orchards, vineyards, other crops, and SNH because of their variability across regions (in the case of artificial territories, olive orchards, vineyards, other crops) or because of their potential importance for syrphids (in the case of SNH).

3.2.4. Response to landscape variables

The response of *S. scripta* and *M. mellinum* abundance to landscape variables at the different buffers were analyzed using a series of separated generalized mixed models (GLMMs) (one model for each buffer – 500, 1000, and 2000 m). Elevation was included as an explanatory variable because it can determine the Syrphids community (Haslett *et al.,* 1997). Thus, the following explanatory variables were considered for the model's construction: the coordinates of the sampling sites (longitude and latitude), SEI, MPFD, areas of artificial territories, olive orchards, vineyards, other crops, and SNH, the elevation, the year (two levels: 2018 and 2019), the strata (two levels: vegetal ground cover and canopy). Only samples from the early summer period were considered due to the small numbers of syrphids in the other sampling dates. Before running the models, the standardized continuous explanatory variables were selected for each spatial scale to avoid multicollinearity. For that: (i) three principal component analyses (PCAs) were constructed with the correlation matrix of the landscape metrics, one for each spatial scale (Figure S3.1). The PCA function from the "FactoMineR" package (Lê *et al.,* 2008) was used to visualize the contribution to the variance of the explanatory variables and their relations. The correlation biplot of the two first PCs was drawn using the fviz_pca_biplot function from the "factoextra" package (Kassambara & Mundt, 2020). (ii) The Pearson correlations were calculated using the function cor from base R (Figure S3.2). Pearson correlations were lower than 0.7 in all cases. (iii) A higher variance inflation factor (VIF) than three was not allowed, minimizing potential model misspecifications (Dormann *et al.,* 2013). When multicollinearity among explanatory variables was found, the variables with more potential biological meaning for syrphids were maintained in the models.

Poisson (for count data), negative binomial-linear (nbinom1), or quadratic (nbinom2) parameterization - to account for overdispersion or zero-inflated (Poisson or nbinom1) to account with zero inflation distributions (Bolker, 2021) were used for the models. The distribution used for each model is indicated in the results section. The backward selection was performed until all explanatory variables were significant or the model validation failed. The most explanatory model (keeping a higher number of explanatory variables) within < 2 ΔAIC (Akaike Information Criterion) was selected (Burnham & Anderson, 2004). The function glmmTMB from the "glmmTMB" package was used for fitting the models (Brooks *et al.,* 2017). Models were validated using the simulateResiduals function from "DHARMa" package (Hartig, 2021).

3.3. Results

3.3.1. Syrphids

In the sampled vineyards, 549 syrphids (Syrphidae: Diptera) were recovered in 2018 and 2019. Early summer was the period with a higher abundance of syrphids (251 in 2018 and 242 in 2019) (Table 3.1). Whereas in summer (24 in 2018 and two in 2019) and autumn (25 in 2018 and five in 2019), the abundance was lower. Seven syrphid species were identified in the early summer period (Table 3.1).

Table 3.1. Abundance of Syrphidae species found in the canopy (C) and herbaceous vegetation cover (H) in the sampled vines in early summer of 2018 and 2019. The functional group (FG) is indicated (Sp: Saprophytic larva; P: Pollinator adult; Pr: Predatory larva). The number of females and males is shown between brackets: (number of females/number of males).

Syrphid species	FG	Early summer 2018			Early summer 2019			Total
		C	H	Total	C	H	Total	
Eristalis tenax Linnaeus, 1758	Sp / P		1 (1/0)	1 (1/0)				1 (1/0)
Eupeodes corollae Fabricius, 1794	Pr / P	1 (0/1)		1 (0/1)				1 (0/1)
Melanostoma mellinum Linnaeus, 1758	Pr / P	50 (25/25)	34 (19/15)	84 (44/40)	8 (3/5)	12 (7/5)	20 (10/10)	104 (54/50)
Paragus quadrifasciatus Meigen, 1822	Pr / P	4 (1/3)	4 (3/1)	8 (4/4)				8 (4/4)
Sphaerophoria rueppelli Wiedemann, 1830	Pr / P		1(1/0)	1 (1/0)		3 (0/3)	3 (0/3)	4 (1/3)
Sphaerophoria scripta Linnaeus, 1758	Pr / P	74 (42/32)	81 (48/33)	155 (90/65)	37 (22/15)	182 (91/91)	219 (113/106)	374 (203/171)
Syrphus vitripennis Meigen, 1822	Pr / P	1 (1/0)		1 (1/0)				1 (1/0)
Total		130 (69/61)	121 (72/49)	251 (141/110)	45 (25/20)	197 (98/99)	242 (123/119)	493 (264/229)

The most abundant were *S. scripta* (Figure 3.2A) followed by *M. mellinum* (Figure 3.2B), dominating the specimens recovered in early summer. In the summer sampling, the species *S. scripta* (13 in 2018 and one in 2019), *M. mellinum* (11 in 2018), and *Episyrphus balteatus* De Geer, 1776 (one in 2019) were captured. In the autumn, the species *S. scripta* (two in 2018 and one in 2019), *M. mellinum* (11 in 2018 and two in 2019), *E. balteatus* (one in 2018), *Paragus quadrifasciatus* (Meigen, 1822) (one in 2019), and *Platycheirus albimanus* (Fabricius, 1781) (one in 2019) were collected.

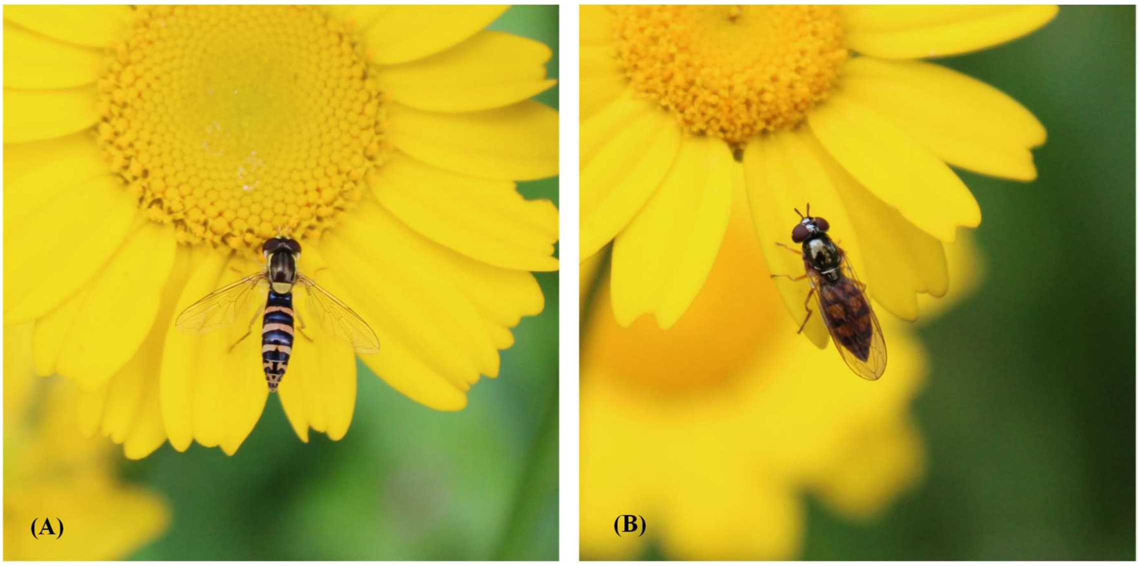

Figure 3.2. Example of (A) *Sphaerophoria scripta*, and (B) *Melanostoma mellinum*.

3.3.2. Explanatory variables selection

Regarding the 500, and 1000 m buffers, the final models included: latitude, SEI, artificial territories, olive orchards, vineyards, SNH, elevation, year, and strata. MPDF, other crops, and longitude were excluded from the models because SNH was negatively correlated with MPFD and other crops and because longitude was negatively correlated with elevation (Figure S3.1.A and S3.1.B). The maximum VIF among the continuous variables was 2.82, and 1.84 for 1000, and 500 m buffers, respectively.

The final model for the 2000 m buffer included latitude, olive orchards, other crops, vineyards, SNH, elevation, year, and strata. Longitude, SEI, MPFD, and artificial territories were excluded from the model because longitude was negatively correlated with artificial territories, other crops, and SEI and positively correlated with elevation and olive orchards. Moreover, MPFD was positively correlated with vineyards (Figure S3.1.C). The maximum VIF among the continuous variables was 2.26.

3.3.3. Syrphid response to landscape structure

Generally, the abundance of the most representative species, *S. scripta* and *M. mellinum* of syrphids increased in the north of the country and showed higher values in 2018 than in 2019.

Table 3.2. GLMMs outputs testing the response of *Sphaerophoria scripta* abundance, to landscape composition and configuration variables at three spatial scales (500, 1000, and 2000 m).

Spatial scale	Distribution	Variables	Landscape structure			
			Estimate	SE	*z*	*p*
500	nbinom2	(Intercept)	-0.1943	0.4476	-0.434	0.664
		Latitude	0.6395	0.3745	1.707	0.088
		SEI	**0.9014**	**0.5126**	**1.759**	**0.079**
		Olive orchards	-0.4142	0.3201	-1.294	0.196
		SNH	0.2857	0.3721	0.768	0.443
		Year 2019 (vs 2018)	-2.2506	0.7162	-3.142	0.002
1000	nbinom2	(Intercept)	-0.5534	0.4636	-1.194	0.233
		Latitude	0.7634	0.3731	2.046	0.041
		SEI	-0.4877	0.3557	-1.371	0.170
		Year 2019 (vs 2018)	-1.7297	0.7073	-2.446	0.014
2000	nbinom2	(Intercept)	-0.3748	0.4404	-0.851	0.395
		Latitude	0.6730	0.3438	1.957	0.050
		Other crops	**1.5407**	**0.5502**	**2.800**	**0.005**
		SNH	**1.3008**	**0.5366**	**2.424**	**0.015**
		Year 2019 (vs 2018)	-2.4011	0.7602	-3.159	0.002

SEI - Simpson diversity index; SNH – Seminatural habitats; Year – 2018 and 2019.

Table 3.3. GLMMs outputs testing the response of *Melanostoma mellinum* abundance, to landscape composition and configuration variables at three spatial scales (500, 1000, and 2000 m).

Spatial scale	Distribution	Variables	Landscape structure			
			Estimate	SE	*z*	*p*
500	nbinom2	(Intercept)	-1.2554	0.3994	-3.14	0.002
		Latitude	0.2019	0.2778	0.73	0.467
		SEI	0.3839	0.2858	1.34	0.179
		Artificial territory	-0.3438	0.3476	-0.99	0.323
		Olive orchards	**-0.6277**	**0.3800**	**-1.65**	**0.099**
		Year 2019 (vs 2018)	-1.3379	0.5182	-2.58	0.010
1000	nbinom1	(Intercept)	0.8252	0.4112	2.01	0.045
		Latitude	1.2940	0.3458	3.74	<0.001
		Artificial territories	**-1.1167**	**0.4579**	**-2.44**	**0.015**
		Olive orchards	-0.6232	0.4029	-1.55	0.122
		Vineyards	**-1.8051**	**0.6446**	**-2.80**	**0.005**
		Year 2019 (vs 2018)	-2.7430	0.7132	-3.85	<0.001
		Strata ground cover (vs canopy)	-0.7471	0.4434	-1.69	0.092
2000	nbinom1	(Intercept)	-1.9254	0.6000	-3.21	0.001
		Latitude	1.0089	0.5250	1.92	0.055
		Olive orchards	1.2270	0.7807	1.57	0.116
		Other crops	**3.1514**	**1.2557**	**2.51**	**0.012**
		SNH	**2.7043**	**1.0262**	**2.64**	**0.008**
		Elevation	-1.3055	0.8545	-1.53	0.127
		Year 2019 (vs 2018)	-2.9215	1.1342	-2.58	0.010

SEI - Simpson diversity index; SNH – Seminatural habitats; Year – 2018 and 2019; Strata - vegetal ground cover and canopy.

The presence of SNH and other crops increased both species at 2000 m buffer (Figure 3.3, Table 3.2 and 3.3). Though not significant, there was a positive trend on *S. scripta* by SEI at 500 m. The presence of artificial territory and vineyards (at 1000 m), and olive orchards (at 500 m), showed a general tendency to reduce *M. mellinum* (Table 3.3).

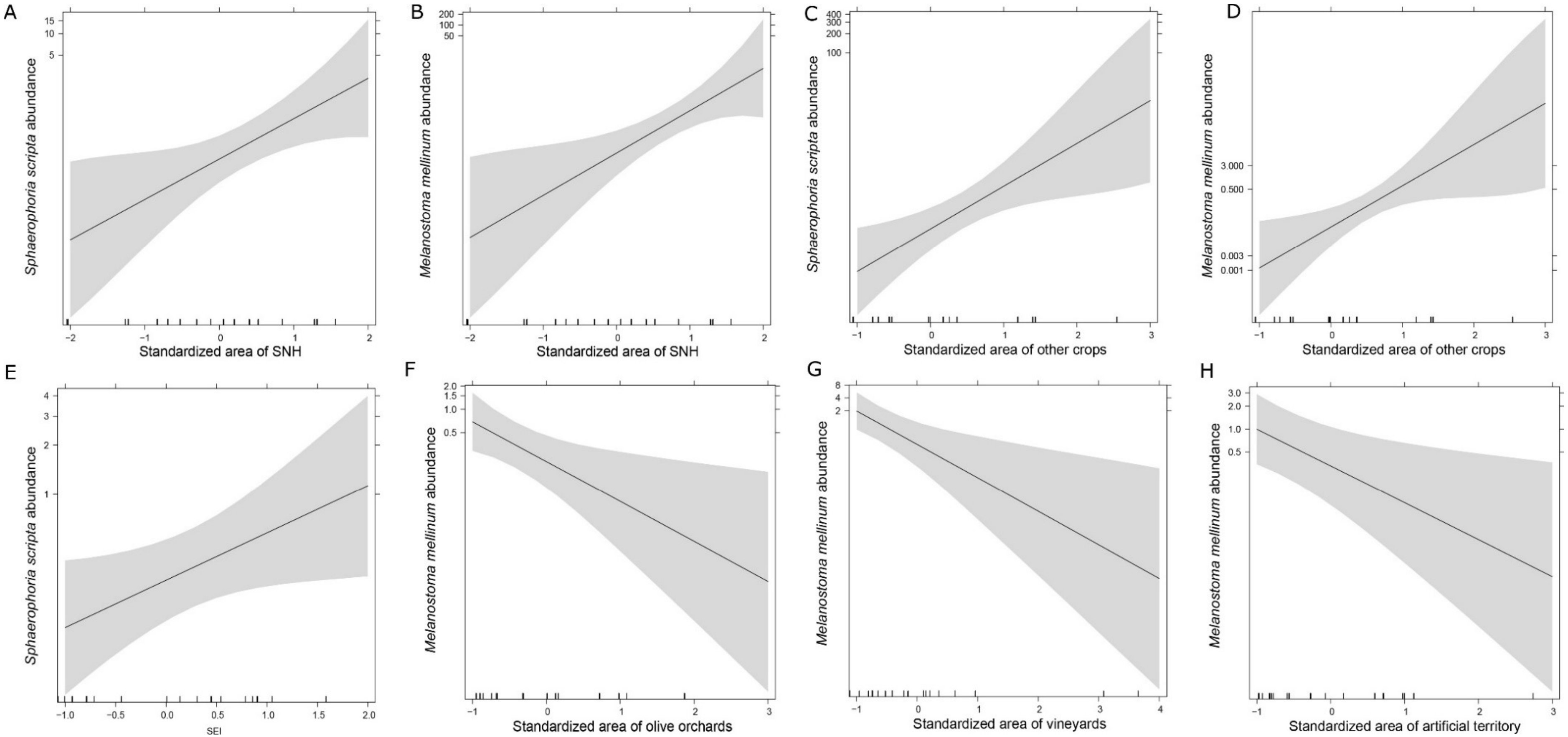

Figure 3.3. Response of *Sphaerophoria scripta* to SNH (A), other crops (C) at the 2000 m buffer and SEI (E) at the 500 m buffer; and response of *Melanostoma mellinum* to SNH (B), other crops (D) at the 2000 m buffer, to olive orchards (F) at 500 m and to artificial territory (H) and vineyards (G) at the 100 m buffer.

3.4. Discussion

Previous studies revealed the importance of the landscape structure on insect species abundance, diversity, and composition (e.g., Adams *et al.,* 2020; Medeiros *et al.,* 2019; Steffan-Dewenter *et al.,* 2002; Toivonen *et al.,* 2022; Warzecha *et al.,* 2021). Here, we investigated how the landscape structure affects the abundance of the most representative species in Portuguese vineyards. We found several landscape features to drive the abundance and the richness of syrphids mainly at large scales (2000 m).

Our results indicated that syrphids were more abundant and richer in early July, most likely because the majority of plants bloom in spring, whereas in summer and autumn, syrphids would remain in diapause, concurring with Salveter (1998), Speight (2014), and Villa *et al.* (2021). However, a relatively low number of species were identified compared with other studies in the vineyard (e.g., Gonçalves *et al.,* 2015; Pétremand *et al.,* 2017; Sommaggio & Burgio, 2014). This low richness may be related to the sampling dates (early summer and autumn, instead of early spring). *Sphaerophoria scripta* and *M. mellinum* were the most abundant syrphids, in agreement with previous studies carried out in the Mediterranean region (Ricarte *et al.,* 2011; Sabater & García, 2008; Villa *et al.,* 2021). Larvae of both species are aphidophagous while adults feed on pollen and are active from the beginning of the spring to the middle of the autumn (Speight, 2017).

Our results suggest that high proportions of SNH in the landscape significantly increase the abundance of *S. scripta* and *M. mellinum* in the vineyards, particularly when the SNH are at the lagest scale (2000 m). SNH can provide important resources to syrphids, such as alternative hosts or prey, pollen, or nectar (Landis *et al.,* 2000). They may also be overwintering habitats and refuges from disturbance (Pfiffner & Luka, 2000). In accordance with the present results, Jauker *et al.* (2009) described that the abundance of syrphids increased with the distance to the SNH. Whereas several studies have only reported the positive effect of SNH on syrphids abundance and richness on lower distances to the main crop (e.g., Beduschi *et al.,* 2018; Kleijn & Van Langevelde, 2006; Krimmer *et al.,* 2019; Moquet *et al.,* 2018). Our results could be related to the quality and type of the SNH in close proximity to the sampled vineyards. SNH in this study were mainly composed of forests of *Quercus* sp., *Pinus* sp., and *C. sativa* Mill., and Mediterranean scrublands (DGT, 2018). These habitats contain plants that bloom in July such as the trees *C. sativa* and *Sambucus nigra* L. or the scrubs *Daphne gnidium* L., *Cytisus* sp., *Genista* sp., *Rubus* sp. and *Erica* sp., all of them well-known food resources for syrphids (e.g., Villa *et al.,* 2021; Wojciechowicz-Żytko & Jankowska, 2016). Accordingly, to Kleijn & Van Langevelde (2006), Meyer *et al.* (2009), and Schirmel *et al.* (2018), syrphids depend on floral resources for adults, such as the quantity and quality of pollen and nectar, as well as the type of the SNH (woody or herbaceous) and on the presence of requirements for larval development. Additionally, the main sampled syrphids are aphidophagous, and such individuals exhibit long-distance dispersal behavior and movements associated with life-cycle stages and seasonality (Arrignon *et al.,* 2007; Meyer *et al.,* 2009), justifying the higher effect of large scales.

The high presence of other crops (e.g., field crops, outdoor horticultural crops, and outdoor flower crops) (DGT, 2018) in the landscape also positively influenced the abundance and richness of syrphids and the most representative species in the 2000 m buffer. Aphids are a common pest in horticultural crops (Van Emden & Harrington, 2017). Because the most abundant species are aphidophagous, syrphids could recourse to these cultures for food. Moreover, outdoor flower crops may also provide pollen and nectar to the adult's syrphids.

Artificial territory, vineyards (at 1000 m buffer), and olive orchards (at 500 m buffer) in the landscape negatively affected the abundance of *M. mellinum*. The artificial territory is one of the significant drivers of biodiversity loss, given the destruction and fragmentation of the habitats (Aronson *et al.,* 2017; Persson *et al.,* 2020). Although urban areas may provide beneficial habitats to flower-visiting insects (e.g., parks, gardens, SNH fragments, and brownfields) (Aronson *et al.,* 2017; Baldock *et al.,* 2019; Hall *et al.,* 2017; Persson *et al.,* 2020), the buildings and roads that shape the artificial territory function as barriers that fragment the foraging landscapes of pollinators (Buchholz *et al.,* 2020; Jha, 2015; Johansson *et al.,* 2018).

Within the study area, vineyards are typically intensively managed agricultural systems. The inter-row herbaceous vegetation is controlled by pre- or post-weed emergence herbicides or mechanical methods (soil tillage). Additionally, vineyards are also subjected to a series of phytosanitary treatments. Such cultural practices are well known to negatively affect biodiversity at multiple trophic levels (Peris-Felipo *et al.,* 2021; Pétremand *et al.,* 2017).

Regarding the olive groves, contrary to what was previously reported by Villa *et al.* (2021), our results indicate that the presence of this crop in the landscape had a weak negative effect on the abundance of *M. mellinum*. In the study conducted by Villa *et al.* (2021), all the olive groves sampled had spontaneous ground cover vegetation. The vegetation cover in the agrosystems provides shelter and vital floral resources for the syrphids. Such resources can contribute to syrphids' growth, development, reproduction, and survival (Albrecht *et al.,* 2021). However, in Portugal, the olive orchards are mainly under rainfed conditions (Fraga *et al.,* 2021) and intensely subjected to soil and ground cover vegetation management to minimize competition for water and nutrients (Zipori *et al.,* 2020), which may have triggered our results.

Diverse landscapes can facilitate the movement of syrphids between optimal habitats and provide several suitable sites for adults and larvae to grow, contributing to a more diverse community of syrphids (Burgio & Sommaggio, 2007; Hendrickx *et al.,* 2007; Kleijn & Van Langevelde, 2006; Schirmel *et al.,* 2018). Our results suggest that landscape diversity may positively influence *S. scripta* at 500 m, although with a weak significance. Similarly, Meyer *et al.* (2009) and Wratten *et al.* (2003) only reported a positive correlation between landscape diversity and syrphid abundance at smaller buffers (200 and 250 m, respectively).

Lefebvre *et al.* (2018) reported that elevation is an important factor shaping the syrphid community; however, our results indicated that altitude does not influence *S. scripta* and *M. mellinum*. Furthermore, in our work, vineyards have a lower elevation than Lefebvre *et al.* (2018), so the effect may not be noticeable.

3.5. Conclusion

Despite the growing knowledge of the effect of the landscape structure in the arthropod community, we described for the first time the influence of the landscape context on two abundant species of syrphids, *S. scripta* and *M. mellinum*, in Portuguese vineyards.

First, our results suggest that the landscape composition, through the presence of SNH and other crops around vineyards, contributes to the abundance of the studied species at the larger buffer (2000 m), and those increasing areas of SNH at the largest buffer may enhance the syrphid community within this agroecosystem. Second, our results suggest that land use, like the increase of urban areas and the intensification of agriculture in the landscape (although not consistently across buffers) may contribute to reducing syrphids within vineyards. In this context, further studies should address if the application of sustainable management practices on the main perennial crops (such as vineyards and olive groves) in the landscape enhance syrphids and consequently, benefit the ecological services they provide.

CHAPTER 4

Ground cover vegetation composition shapes the abundance of *Sphaerophoria scripta* (Diptera: Syrphidae) in Mediterranean olive groves

Ground cover vegetation composition shapes the abundance of *Sphaerophoria scripta* (Diptera: Syrphidae) in Mediterranean olive groves

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Submited

Abstract

The ground cover vegetation, commonly found in olive groves, provides shelter and vital floral resources for syrphids. Such resources can contribute to syrphids' growth, development, reproduction, and survival, allowing them to maximize their function as natural pest enemies, pollinators, and decomposers of organic matter. Therefore, identifying the flowering plant families driving the abundance of *Sphaerophoria scripta* Linnaeus, 1758, one of the most abundant syrphid on the Mediterranean olive groves, is essential to promote its presence and abundance. Here, we described the flowering plants present in the vegetation cover of olive groves and studied how these flowering plant families shape the abundance of *S. scripta*. A total of 90 plant species belonging to 20 families were identified. Asteraceae was the dominant flowering family, followed by Poaceae. The presence of flowering plants of the families Campanulaceae, Asteraceae, Orobanchaceae, and Plantaginaceae in the ground cover vegetation promotes the abundance of *S. scripta* in olive groves. Conversely, flowering plants of the families Poaceae and Polygonaceae negatively affect the abundance of this syrphid species. Our results suggest that increasing particular plant families and decreasing others in the ground cover vegetation may favour *S. scripta* abundance in the Mediterranean olive groves.

Keywords: Asteraceae; flowering plants; *Olea europaea*; Poaceae; Syrphids

4.1. Introduction

Olea europaea L. (Oleaceae) is an evergreen tree emblematic in the agricultural landscapes of the Mediterranean basin since ancient times for producing fruits for olive oil extraction and table olives preparation (Canale & Loni, 2010; Loumou & Giourga, 2003). Olive groves are one of the most traditional agricultural activities and are of great socioeconomic importance for these areas, as they are the world's leading producers of olive oil (FAO, 2020).

The olive tree can be attacked by insect pests that cause important damage and production loss (Torres, 2017). The most dangerous and considered the key-pests in Portugal are the olive fly, *Bactrocera oleae* (Rossi, 1790) (Diptera: Tephritidae), and the olive moth, *Prays oleae* (Bernard, 1788) (Lepidoptera: Praydidae) (Torres, 2017). Nevertheless, other minor pests can attack the olive tree depending on the region, season, and years (Torres, 2017). The regulation of these and other pests can be carried out naturally by beneficial insects that provide this and other important ecosystem services (Ricarte *et al.*, 2011; União Europeia, 2010; Villa *et al.*, 2021).

Syrphids (Diptera: Syrphidae) are beneficial insects that are present in olive groves (Torres, 2017), contributing as pollinators, decomposers, and predators of pest enemies present in crops (Villa *et al.*, 2021). Adults visit floral species present in the vegetation cover of the olive grove or in the surrounding area, where they feed on nectar and pollen (Ambrosino *et al.*, 2006; Ricarte *et al.*, 2011). In addition, there are reports of larvae of some species of syrphids preying on olive tree pests, such as *Euphyllura olivina* (Costa, 1839) (Hemiptera: Liviidae), *Euphyllura straminea* Loginova, 1973 (Hemiptera: Liviidae), *P. oleae*, and *Palpita vitrealis* (Rossi, 1794) (Lepidoptera: Crambidae) (Gonçalves *et al.*, 2021; Pineda & Marcos-García, 2008; Pinheiro *et al.*, 2013; Villa *et al.*, 2021).

Sphaerophoria scripta Linnaeus, 1758, is a widespread and abundant syrphid in a wide range of crops and habitats (e.g., Naderloo & Pashaei Rad, 2014; Ricarte *et al.*, 2011; Villa *et al.*, 2021; Wojciechowicz-Żytko & Jankowska, 2017). Furthermore, *S. scripta* was reported as one of the most abundant syrphids on the Mediterranean olive groves (Villa *et al.*, 2021). This Diptera visits flowers between April and November in open terrain and settles in the ground cover vegetation (Speight, 2017).

Ground cover vegetation in perennial crops increases the diversity and abundance of natural enemies (Silva *et al.*, 2010), which contributes to the biological control of crop pests (Wojciechowicz-Żytko & Jankowska, 2017). This soil manipulation technique, in contrast to soil mobilization, offers natural enemies food resources - pollen, nectar, honeydew, and prey - altered microclimate, habitat, and shelter for estivation (Silva *et al.*, 2010). Syrphids, as natural enemies, need plant cover rich in floral resources so they can grow, develop, survive, and reproduce (Wojciechowicz-Żytko & Jankowska, 2017).

Diverse and large floral resources increase the number of syrphids, but if the opposite occurs, these dipterans are negatively affected (Naderloo & Pashaei Rad, 2014). Syrphids are considered generalists regarding flower visits (Branquart & Hemptinne, 2000; Lucas *et al.*, 2018). However, despite being generalists, several studies have reported that they tend to prefer certain plant species (e.g., Branquart & Hemptinne, 2000; Colley & Luna, 2000; Klecka *et al.*, 2018). This preference mainly depends on flower availability and phenology (Colley & Luna, 2000; Cowgill *et al.*, 1993; Klecka *et al.*, 2018). Moreover, flowers attract pollinators through distinct stimuli, such as colour, shape, size, and scent (Fenster *et al.*, 2004). Understanding how the vegetation cover influences the abundance of syrphids is essential to implement measures that promote them in agrosystems and consequently maximize their ecosystem services. We describe the Syrphidae community in Mediterranean olive groves, and determine how the percentage of ground cover of flowering plant families shapes the abundance of the most abundant species.

4.2. Material and methods

4.2.1. Study Area

The study was carried out in two olive groves (41°29′15.77″N, 7°07′52.11″W; 41°29′217.88″N, 7°07′35.21″W) located in Cedães (Mirandela, Northeast of Portugal), with a typical Mediterranean landscape who olive trees dominate. The olive groves were non-irrigated, conducted under the integrated production management guidelines, the distance between plants varies between 7 and 9 meters, and the age of the trees also varies between 18 and 80 years.

4.2.2. Sampling methods

From May to August 1st, 2018, weekly, the flowering plant family/specie of the spontaneous herbaceous ground cover were identified, and the adult syrphids were recovered. For plant family/species identification, thirty rectangular sampling units (100 × 25 cm) were randomly distributed along a 100 m diagonal transect covering approximately 1 ha. In each rectangular sampling unit, the vegetative stage of the plants and the percentage that each plant family occupied in the vegetation cover were recorded. The collection of syrphids was carried out randomly over 1 ha with a standard entomological sweep net. Ten sweeps of the vegetation cover of each olive grove were sampled, and the contents of each sweep were transferred to a plastic bag. Diethyl ether (0.3 mL) was introduced into each plastic bag to kill the arthropods. Subsequently, in the laboratory, the samples were frozen at -20 ºC. Using a stereomicroscope, syrphids were separated and identified using entomological keys (Gilbert, 1986; Speight, 2020; Thompson & Rotheray, 1998) and preserved in 96% ethanol.

4.2.3. Response of S. scripta to flowering plant families

The response of the most abundant species, *S. scripta*, to the percentage of flowering plant families in the ground cover vegetation was assessed with a generalized linear mixed model (GLMM). The plant families were used as explanatory variables, and the olive groves were considered a random factor. The families: Apiaceae, Hypericaceae, Lamiaceae, Solanaceae, and Violaceae, were not included in the model because they presented a percentage lower than 1%.

Before running the model, the plant families were checked for multicollinearity. Principal component analyses (PCA) and Pearson correlations were calculated for that. The PCA function from the "FactoMineR" package (Lê *et al.*, 2008) was used to visualize the contribution to the variance of the plant families and their relations (Figure S4.1), and the Pearson correlations were calculated using the function cor from base R (Figure S4.2). To further assess multicollinearity, the variance inflation factor (VIF) was also calculated: the highest VIF scores were below four (the common threshold for VIF is usually > 10; Dormann *et al.*, 2013). The model was selected by comparing the Akaike information criterion (Akaike, 2011). Thus, the final model comprises the families Campanulaceae, Asteraceae, Orobanchaceae, Plantaginaceae, Poaceae, and Polygonaceae. The model was checked for overdispersion and residual distribution using the "DHARMa" package (Hartig, 2021).

4.3. Results

4.3.1. Syrphids

In total, 212 syrphids adults (Syrphidae: Diptera) were recovered (Table 4.1). The most abundant species were *S. scripta* (198 specimens) followed by *Melanostoma mellinum* Linnaeus, 1578 (7 specimens).

Table 4.1. Abundance of Syrphidae in herbaceous vegetation cover in the sampled olive grooves from May to August of 2018. The functional group (FG) is indicated (P: Pollinator adult; Pr: Predatory larva; NA: Not identified). The number of females and males is shown between brackets: (number of females/number of males).

Syrphid species	FG	May	June	July	August	Total
Eupeodes corollae Fabricius, 1794	Pr/P		1 (0/1)			1 (0/1)
Melanostoma mellinum Linnaeus, 1758	Pr/P			7 (6/1)		7 (6/1)
Melanostoma scalare (Fabricius, 1794)	Pr/P		1 (0/1)			1 (0/1)
Sphaerophoria rueppelli Wiedemann, 1830	Pr/P	1 (0/1)	1 (1/0)			2 (1/1)
Sphaerophoria scripta Linnaeus, 1758	Pr/P	11 (4/7)	112 (60/52)	70 (36/34)	5 (2/3)	198 (102/96)
Syrphidae spp.	NA/P		1	2		3
Total		12 (4/8)	116 (61/54)	79 (42/35)	5 (2/3)	212 (109/100)

Sphaerophoria scripta, showed a peak of abundance in June (112), followed by July (70). In the first three weeks of sampling and the last two, the number of *S. scripta* individuals was almost zero (Figure 4.1).

Figure 4.1. Heatmap plot showing 2018 data: percentage of the 20 families of flowering plants (dark purple to yellow) and *Sphaerophoria scripta* (ME+ES) by date.

4.3.2. Plants

In total, 90 plant species belonging to 20 families were identified (Table 4.2). During the sampled period, Asteraceae was the dominant flowering family with 50.90%, followed by the families Poaceae (12.81%), Fabaceae (12.71%), and Caryophyllaceae (7.04%). Asteraceae, on June 27th, reached maximum flowering with a coverage of 21.63% (Figure 4.1).

Table 4.2. Family and species nomenclature of identified flowering plant with the percentage of ground cover from May to August weekly.

Family	Species Nomenclature	04/may	10/may	24/may	29/may	04/jun	12/jun	21/jun	27/jun	03/jul	10/jul	20/jul	25/jul	01/aug
Apiaceae	*Eryngium campestre* L.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.00	0.00	0.00	0.00
Asteraceae	*Andryala integrifolia* L.	0.00	0.00	0.00	2.00	0.00	1.75	3.25	3.67	5.13	5.38	3.43	3.58	2.47
	Andryala sp.	0.00	0.00	0.00	0.00	0.00	0.00	3.00	0.00	0.00	0.00	0.00	0.00	0.00
	Asteraceae	0.00	5.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.00	0.00	0.00	0.00
	Calendula arvensis L.	1.67	10.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Chamaemelum mixtum (L.) All.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.94	4.14	2.20	2.36	3.33	0.00
	Chondrilla juncea L.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.50	10.00	2.00	1.20	2.15
	Chrysanthemum segetum L.	1.33	0.00	1.83	3.55	2.14	2.10	3.86	1.20	0.00	0.00	0.00	0.00	0.00
	Cnicus benedictus L.	0.00	15.00	0.00	2.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Coleostephus myconis (L.) Rchb.f.	15.00	10.63	8.18	5.32	6.69	3.95	2.32	3.65	5.13	1.33	1.00	1.33	0.00
	Crepis capillaris (L.) Wallr.	0.00	2.00	0.00	2.25	3.80	3.29	4.13	3.63	3.43	2.50	2.62	2.38	0.00
	Filago vulgaris Lam.	0.00	0.00	0.00	0.00	0.00	6.67	0.00	10.00	3.00	0.00	5.00	0.00	0.00
	Hedypnois cretica (L.) Dum.-Courset	2.80	4.00	0.00	0.00	0.00	0.00	0.00	0.00	1.50	0.00	0.00	0.00	0.00
	Hypochaeris glabra L.	0.00	1.00	1.29	2.13	1.88	1.00	2.00	1.00	0.00	0.00	0.00	0.00	0.00
	Hypochaeris radicata L.	0.00	1.86	1.00	1.75	1.00	0.00	0.00	0.00	2.00	0.00	0.00	0.00	0.00
	Hypochaeris sp.	4.57	4.33	1.00	0.00	0.00	1.00	0.00	0.00	1.75	0.00	0.00	0.00	0.00
	Leontodon sp.	0.00	0.00	2.50	1.93	2.14	1.52	2.00	1.14	2.27	1.17	1.50	0.00	0.00
	Leontodon taraxacoides (Vill.) Mérat	3.50	6.50	3.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Logfia gallica (L.) Coss. & Germ.	0.00	5.00	0.00	0.00	0.00	2.00	15.00	3.38	6.12	4.88	10.00	0.00	0.00
	Senecio vulgaris L.	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sonchus tenerrimus L.	5.30	8.78	0.00	0.00	1.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Tolpis barbata (L.) Gaertn.	0.00	2.00	1.43	2.00	2.28	3.20	4.69	7.27	7.50	7.82	5.42	3.24	2.75
Boraginaceae	*Echium plantagineum* L.	0.00	8.00	2.38	3.14	1.89	1.25	2.17	2.63	2.25	1.50	1.00	1.33	2.00

	Myosotis discolor Pers.	3.14	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Brassicaceae	*Brassica barrelieri* (L.) Janka	1.33	1.00	1.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Cardamine hirsuta L.	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Raphanus raphanistrum subsp. *raphanistrum* L.	2.50	4.50	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Campanulaceae	*Jasione montana* L.	0.00	0.00	2.00	1.50	2.00	1.50	2.13	3.65	4.56	6.45	2.35	2.00	5.00
Caryophyllaceae	*Cerastium brachypetalum* subsp. *brachypetalum* Desp. ex Pers.	10.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Petrorhagia nanteuilii (Burnat) P.W.Ball & Heywood	0.00	0.00	1.35	1.58	1.73	1.41	1.64	1.40	1.35	1.25	1.27	2.00	1.50
	Scleranthus annuus L.	1.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Silene gallica L.	3.40	4.61	3.00	6.33	5.40	4.29	6.72	3.29	3.88	4.00	2.00	2.00	0.00
	Spergula arvensis L.	2.90	2.00	0.00	1.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Spergularia purpurea (Pers.) G.Don	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.50	2.00	1.00	0.00	0.00	0.00
Convolvulaceae	*Convolvulus arvensis* L.	0.00	0.00	3.00	4.33	5.80	5.00	6.29	5.00	8.75	8.00	10.50	5.20	3.71
Euphorbiaceae	*Euphorbia* sp.	7.00	17.50	12.00	8.38	4.50	7.29	6.25	2.00	2.00	4.00	0.00	2.33	5.00
Fabaceae	*Astragalus pelecinus* subsp. *pelecinus* (L.) Barneby	2.79	3.09	0.00	0.00	0.00	10.00	1.00	0.00	7.50	3.00	1.00	0.00	0.00
	Hymenocarpos lotoides (L.) Vis.	4.17	4.20	2.00	3.33	1.00	0.00	1.00	1.33	1.25	1.00	1.00	0.00	0.00
	Lathyrus angulatus L.	1.25	3.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Lupinus sp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00
	Medicago arabica (L.) Huds.	5.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Medicago rigidula (L.) All.	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Medicago sp.	1.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Ornithopus compressus L.	4.43	5.47	5.00	11.21	15.14	11.44	11.25	6.75	3.00	4.50	0.00	0.00	0.00
	Trifolium angustifolium L.	0.00	0.00	0.00	0.00	0.00	0.00	2.67	0.00	0.00	0.00	0.00	0.00	0.00
	Trifolium arvense L.	0.00	0.00	1.91	1.88	4.00	4.25	0.00	2.71	5.55	6.17	5.00	0.00	0.00
	Trifolium campestre Schreb.	0.00	2.00	0.00	1.33	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

	Trifolium cernuum Brot.	2.67	3.57	0.00	3.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Trifolium glomeratum L.	0.00	3.00	2.00	1.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Trifolium micranthum Viv.	3.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Trifolium repens L.	0.00	1.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Trifolium sp.	5.00	5.33	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Trifolium subterraneum L.	5.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Trifolium tomentosum L.	5.00	2.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Vicia lathyroides L.	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Vicia lutea subsp. *lutea* L.	1.00	4.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Vicia sp.	1.13	6.27	1.67	1.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Vicia villosa Roth	0.00	0.00	5.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Geraniaceae	*Erodium cicutarium* (L.) L'Hér.	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	1.50	0.00	0.00	0.00	0.00
	Geranium molle L.	3.64	4.25	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hypericaceae	*Hypericum perforatum* L.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00
Lamiaceae	*Lavandula pedunculata* subsp. *pedunculata* (Mill.) Cav.	0.00	0.00	2.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Stachys arvensis (L.) L.	3.20	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Orobanchaceae	*Bartsia trixago* L.	0.00	0.00	1.92	1.75	2.10	2.33	1.25	0.00	0.00	0.00	0.00	1.00	0.00
	Orobanche ramosa L.	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Orobanche sp.	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Parentucellia latifolia (L.) Caruel	1.63	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Plantaginaceae	*Linaria spartea* (L.) Chaz.	0.00	0.00	0.00	0.00	1.00	2.00	3.25	5.00	0.00	2.00	10.67	1.80	3.50
	Misopates orontium (L.) Raf.	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Plantago lanceolata L.	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Veronica arvensis L.	3.60	2.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Poaceae	*Avena barbata* Link	6.00	2.70	1.60	1.75	1.67	0.00	0.00	1.50	1.00	2.00	0.00	0.00	0.00
	Briza maxima L.	0.00	2.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Bromus diandrus Roth	0.00	12.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

	Bromus hordeaceus L.	1.00	1.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Bromus madritensis L.	0.00	8.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Bromus tectorum L.	3.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Cynodon dactylon (L.) Pers.	0.00	0.00	0.00	0.00	0.00	9.75	0.00	13.75	20.00	17.22	20.00	20.77	23.50
	Hordeum murinum L.	20.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Lolium rigidum subsp. *rigidum* Gaudin	0.00	0.00	1.33	2.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Molineriella laevis (Brot.) Rouy	5.91	4.56	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Vulpia ciliata subsp. *ciliata* Dumort.	9.27	11.46	5.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Polygonaceae	*Rumex bucephalophorus* L.	2.92	7.43	6.75	6.67	8.00	10.67	0.00	20.00	5.00	0.00	0.00	0.00	0.00
	Rumex induratus Boiss. & Reut.	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rosaceae	*Sanguisorba verrucosa* (Link ex G.Don) Ces.	1.00	5.50	3.00	3.25	0.00	2.00	0.00	2.67	0.00	1.00	0.00	0.00	0.00
Rubiaceae	*Cruciata pedemontana* (Bellardi) Ehrend.	2.62	3.73	1.00	0.00	2.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Galium parisiense L.	1.75	3.50	1.73	3.58	3.17	4.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sherardia arvensis L.	2.50	3.22	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Solanaceae	*Solanum nigrum* L.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00
Violaceae	*Viola kitaibeliana* Schult.	2.80	2.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

4.3.3. *Response of S. scripta to flowering plant families*

According to the model, increasing the ground coverage percentage of the olive grove with plants of the families Campanulaceae, Asteraceae, Orobanchaceae, and Plantaginaceae promotes the abundance of *S. scripta* (Figure 4.2). On the opposite side, increasing the ground coverage percentage with plants of the families Poaceae and Polygonaceae negatively affects the abundance of *S. scripta*.

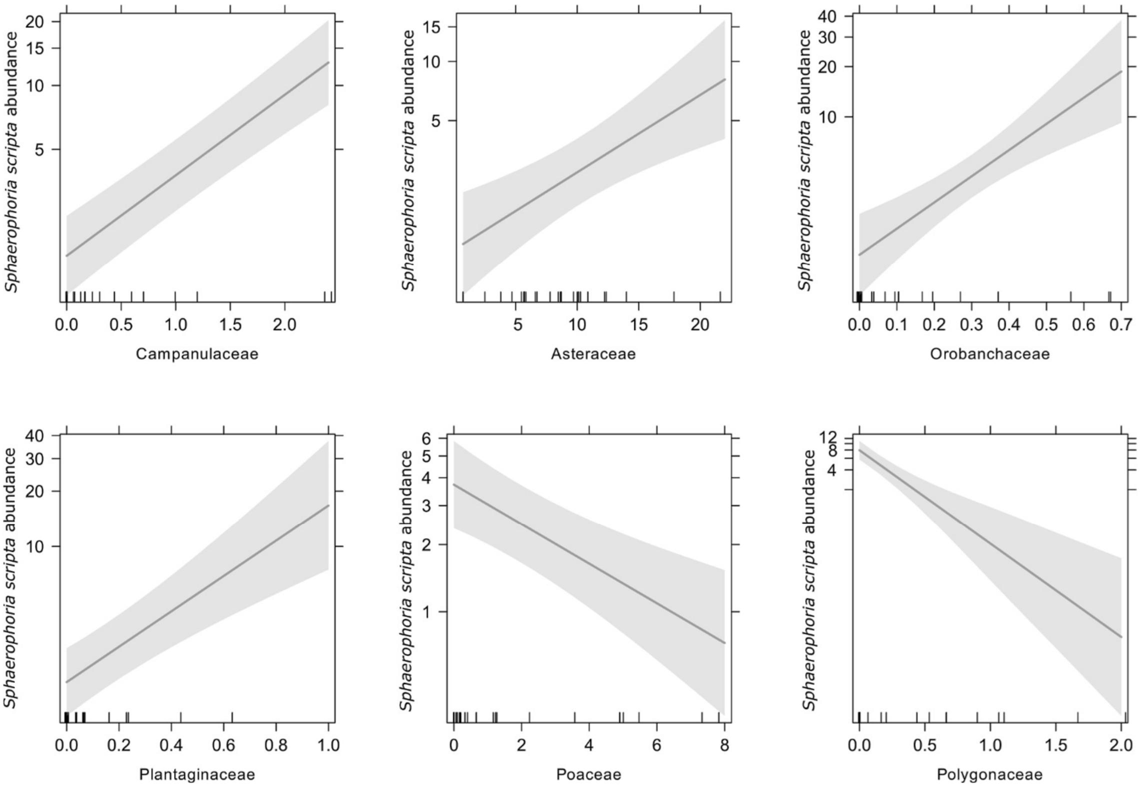

Figure 4.2. Response of S*phaerophoria scripta* abundance to the coverage of Campanulaceae, Asteraceae, Orobanchaceae, Plantaginaceae, Poaceae, and Polygonaceae. Plots include model estimate (green line) and 95% confidence interval (green shading) of the GLM (response variable – *Sphaerophoria scripta* abundance; explanatory variable – plant family abundance; data distribution – Poisson).

In the six families that affect the abundance of *S. scripta*, a total of 43 species were identified. Asteraceae, with 21 species of flowering plants, was the family with the highest number of identified plant species with 15.00%, in which the species *Cnicus benedictus* L., *Coleostephus myconis* (L.) Rchb.f. and *Logfia gallica* (L.) Coss. & Germ. Also, the plant species *Cynodon dactylon* (L.) Pers. and *Hordeum murinum* subsp. *leporinum* (Link) Arcang. from Poaceae and *Rumex bucephalophorus* L. from

Polygonaceae, were the plants that covered the landscape with percentages greater than 15.00% on certain dates. Contrary, *Rumex induratus* Boiss. & Reut., *Plantago lanceolata* L., *Misopates orontium* (L.) Raf., *Orobanche* sp., *Orobanche ramosa* L., *Senecio vulgaris* L. were the species of plant identified with less importance (1.0%).

4.4. Discussion

We describe the Syrphidae community and the flowering plants present in the vegetation ground cover of Mediterranean olive groves and how these plants influence the abundance of *S. scripta*. Identifying correlations between plants and *S. scripta*, the main syrphid associated with the Mediterranean olive grove, can be helpful information to farmers for good management of the olive groves to promote the abundance of this syrphid in the olive groves since these individuals are essential pollination agents (wildflowers and economically important crops) and biological pest control.

The species of Syrphidae recovered in the olive groves are in agreement with previous studies carried out in the Mediterranean region (Canale & Loni, 2010; Villa *et al.*, 2021; Pinheiro *et al.*, 2013; Madureira *et al.*, 2022). Previously, Villa *et al.* (2021) described that *S. scripta* was the most abundant syrphid in the Mediterranean olive groves' vegetation cover, which is in line with our results.

Typically, *S. scripta* begins its flight period in April (Speight, 2017). However, our results showed that the peak abundance of this syrphid occurs in June, starting to decrease in summer, which agrees with what was previously reported by Djellab *et al.* (2019), Rossi *et al.* (2006), Salveter (1998), and Villa *et al.* (2021). In fact, the peak abundance of this syrphid corresponds with the two generations of olive moths and the olive psyllid's main generation, in the sampled olive grooves (visual observation by Madureira).

Portugal has mostly a temperate continental climate with dry summers, so the plants flower throughout the year, with the flowering peak between April and June (IPMA, 2022; Flora-On, 2022). However, the sampling site was in the north of Portugal, characterized by colder temperatures (IPMA, 2022; Coelho *et al.*, 2020), which can delay the development of the plants, causing them to enter the flowering state later (Balasubramanian *et al.*, 2006; Seo *et al.*, 2009). Gaião *et al.* (2017), and Nave *et al.* (2021) identified in olive grooves *C. myconis*, *L. gallica*, *C. dactylon*, *H. murinum*, and

R. bucephalophorus, the most abundant flowering plant species in this study, as well as other species.

The abundance and diversity of natural enemies, such as syrphids, are affected by the diverse composition of the agricultural landscape (Bianchi *et al.*, 2006). And the herbaceous vegetation present in the perennial crops represents an essential source of pollen, nectar, and refuge for the syrphids (Bianchi *et al.*, 2006). Therefore, the abundance of syrphids in an agrosystem will depend on the landscape composition and configuration and the plants' preferences (Bianchi *et al.*, 2006; Judt *et al.*, 2019; Santos *et al.*, 2018). The preference for plants may vary depending on several factors like the nutritional value of pollen, color (Laubertie *et al.*, 2012), local availability of flowers, and plant phenology (Klecka *et al.*, 2018). Additionally, accessibility to pollen and nectar depth of the corolla tube also proved to be an important aspect in the choice of plants (Dunn *et al.*, 2020; Laubertie *et al.*, 2012). *Sphaerophoria scripta* has a compressed proboscis, so they can feed on flowers with deep and short corollas (Branquart & Hemptinne, 2000; Klecka *et al.*, 2018).

Our results showed that the abundance of *S. scripta* was positively influenced by plants from the families Asteraceae, Campanulaceae, Orobanchaceae, and Plantaginaceae (Figure 4.2).

In a study conducted by Villa *et al.* (2021), where pollen consumption by abundant syrphids across different land uses and seasons was analysed and identified through gut dissection, it showed that the most consumed pollen by *S. scripta* belonged to the Asteraceae family. Moreover, Gibson *et al.* (2006), and Klecka *et al.* (2018) also reported that *S. scripta* frequently visits plants of the Asteraceae family. Additionally, it should be noted that the yellow and white colors dominate in the plants identified in the Asteraceae family. Several studies reported that yellow and white flowers have been shown to elicit feeding in syrphids (e.g., Amy *et al.*, 2018; Cowgill, 1989; Lunau & Wacht, 1994; Speight, 2017).

Plants of the family Campanulaceae were described as a common food resource for *S. scripta* (Speight, 2017; Villa *et al.*, 2021). In this family, only *Jasione montana* L. was identified in the olive groves under study. Villa *et al.* (2021) also reported *Jasione* type pollen in the gut of *S. scripta*, however, in a very small percentage compared to other families' plants. Mendes *et al.* (2022), reported that the other plant of the same genera, *Jasione maritima* var. *sabularia* (Cout.) Sales & Hedge, is frequently visited by insects of the order Diptera, namely syrphids. In fact, these plant species are self incompatible and extremely dependent on the pollinator population (Mendes *et al.*, 2022). Moreover, the flowers of *J. montana* have shades of blue and lilac. *Sphaerophoria scripta* was previously reported to be attracted to some plants in the blue-violet-purple shade group (de Buck, 1990).

Although *S. scripta* and other syrphids have already been reported in plants of the Orobanchaceae family (de Buck, 1990; Piwowarczyk & Mielczarek, 2018), to our knowledge, they were not reported in the plants identified in our study. *Bartsia trixago* L. was the plant of this family whose flowering corresponds to the highest abundance peak of *S. scripta* (Figure 4.2), indicating that this flowering plant may be of great importance to *S. scripta*. Further studies on direct observation of *S. scripta* in this plant or feeding preference trials will be necessary to validate our results.

Regarding the Plantaginaceae family, there are several reports of *S. scripta* feeding on these plants (de Buck, 1990; Klecka *et al.*, 2018; Rossi *et al.*, 2006; Villa *et al.*, 2021). Additionally, *Melanostoma mellinum* Linnaeus, 1758, another very abundant syrphid in Mediterranean olive groves, has been described to feed on plants of this family frequently (Villa *et al.*, 2021).

Controversially, the families Poaceae and Polygonaceae showed to have a negative effect on the abundance of *S. scripta*. These anemophilous plants tended to flower earlier than animal pollinated species (Saunders, 2018), which agrees with our results (Figure 4.2).

Although the flowering time of these plants does not coincide with the peak abundance of *S. scripta*, according to Villa *et al.* (2021). *Sphaerophoria scripta* males present pollen of Poaceae and Polygonaceae in the gut. However, males complete their development slightly faster than females to reach sexual maturation when the females appear (Gilbert, 1986).

The remaining families of flowering plants identified in this study showed no effect on the abundance of *S. scripta*, although there are reports of this syrphid visiting or feeding on some of these family's plants (e.g., Apiaceae, Euphorbiaceae, Lamiaceae, Rosaceae; Speight, 2017). We hypothesized that this may be related to the availability of pollen or nectar of this family's plants at the peak of the abundance of *S. scripta* or related to plant fitness.

4.5. Conclusion

The vegetation cover rich in floristic species in the Mediterranean olive grove increases the abundance of *S. scripta*. Asteraceae is the identified family that dominates the vegetation cover of this essay. It is a huge family composed of mostly yellow and white flowers, the most appreciated by this dipteran. In June, *S. scripta* is most abundant throughout its flight period. The abundance of *S. scripta* accompanies the flowering peak of the Asteraceae family's plant species and the other identified families.

This model proves the influence that the different flowering plant families have on the abundance of *S. scripta*. With this knowledge, we can adopt more sustainable management measures, and practices, such as the implementation of plant covers rich in the most appreciated floristic species by *S. scripta* from the Asteraceae, Campanulaceae, Orobanchaceae, and Plantaginaceae families. This measure can enhance *S. scripta* and other species of syrphids, thus influencing greater biological control of pests *E. olivina*, *E. straminea*, *P. oleae*, and *P. vitrealis*, present in Mediterranean olive groves.

CHAPTER 5

General Conclusions and Future Perspectives

The results obtained in this work contribute to a better understanding of how the main species of syrphids present in Mediterranean vineyards and olive groves can be affected by the surrounding landscape and the floristic composition of the vegetation cover.

Our results suggest that the presence of seminatural habitats and other crops around the vineyards increases the abundance of the species studied in the 2000 m buffer. And that the increase in urban areas and the intensification of agriculture contribute to the reduction of syrphids in the vineyards.

Flowering plants of the Asteraceae family predominate in the vegetation cover of the Mediterranean olive groves. And our results suggested that different families of flowering plants have different effects on the abundance of *S. scripta*. The increase of Campanulaceae, Asteraceae, Orobanchaceae, and Plantaginaceae family plants promotes the abundance of *S. scripta* in the olive grove.

The obtained knowledge gives drivers for adopting more sustainable management measures and practices, such as increasing seminatural habitats around the main crop and designing ground cover vegetations with syrphids' most appreciated floristic plant species.

Future studies that include visual observations in the field and, particularly, the observation of plant-syrphid interactions will be necessary to better interpret our results and understand the factor that influences the abundance of these individuals in the Mediterranean perennial crops and the ecosystem services provided. In addition, expanding the studies carried out in this work to other species of syrphids and other crops will also be valuable to better understanding what affects the syrphid community.

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APPENDIX

CHAPTER 3 - SUPPLEMENTARY INFORMATION

The surrounding landscape shapes the abundance of *Sphaerophoria scripta* and *Melanostoma mellinum* (Diptera: Syrphidae) in Portuguese vineyards

Table S3.1. Vineyards' information: sampling dates (2018 and 2019), metric characteristics, and management data.

Vineyards	**2018 Sampling dates**			**2019 Sampling dates**			**Y**	**X**	**Elevation (m)**	**Spacing (m)**	**Variety**	**Training System**	**Insecticide**	**Herbicide**	**Fungicide**	**Production mode**	**Soil management**
	LS	**S**	**A**	**LS**	**S**	**A**											
V1	27/jun	30/aug	19/oct	16/jul	-	21/oct	40.213508	-8.455542	24.219	2.10 x 0.90	Marselan	Cordon de Royat (unilateral)	Lambda-Cyhalothrin - July/ August	Glyphosate + Oxifluorfen - February	Mancozeb + Metalaxyl M - March/ April; Mancozeb - April; Wettable sulfur - April/ May; Cymoxanil + Folpet-April; Folpet + Fosetil al. + Iprovalicarb - May; Metirame + Piraclostrobin - May/ June; Kresoxim-methyl + diphenoconazole - June; Copper Oxychloride - June; Penconazole - July/ August; Pirimetanil - July/ August	Integrated Production	Tillage between vines
V2	27/jun	30/aug	19/oct	16/jul	-	21/oct	40.207294	-8.451814	43.258	2.30 x 1	Castelão; Baga, Bical, Arinto	Cordon de Royat (bilateral)	Lambda-Cyhalothrin - July/ August	Glyphosate + Oxifluorfen - February	Mancozeb + Metalaxyl M - March/ April; Mancozeb - April; Wettable sulfur - April/ May; Cymoxanil + Folpet-April; Folpet + Fosetil al. + Iprovalicarb - May; Metirame + Piraclostrobin - May/ June; Kresoxim-methyl + diphenoconazole - June; Copper Oxychloride - June; Penconazole - July/ August; Pirimetanil - July/ August	Integrated Production	Tillage between vines
V3	27/jun	30/aug	19/oct	16/jul	24/sep	21/oct	40.472186	-8.55042	46.770	2.5 x 1	Typical varieties of the region	Unilateral Cordon	Lambda-Cyhalothrin - July/ August	Glyphosate + Oxifluorfen - February	Mancozeb + Metalaxyl M - March/ April; Mancozeb - April; Wettable sulfur - April/ May; Cymoxanil + Folpet-	Integrated Production	No

															April; Folpet + Fosetil al. + Iprovalicarb - May; Metirame + Piraclostrobin - May/ June; Kresoxim-methyl + diphenoconazole - June; Copper Oxychloride - June; Penconazole - July/ August; Pirimetanil - July/ August		
V4	27/jun	30/aug	19/oct	16/jul	24/sep	21/oct	40.472386	-8.555479	59.408	2.5 x 2	Typical varieties of the region	Unilateral Cordon	Lambda-Cyhalothrin - July/ August	Glyphosate + Oxifluorfen - February	Mancozeb + Metalaxyl M - March/ April; Mancozeb - April; Wettable sulfur - April/ May; Cymoxanil + Folpet- April; Folpet + Fosetil al. + Iprovalicarb - May; Metirame + Piraclostrobin - May/ June; Kresoxim-methyl + diphenoconazole - June; Copper Oxychloride - June; Penconazole - July/ August; Pirimetanil - July/ August	Integrated Production	No
V5	27/jun	30/aug	19/oct	16/jul	24/sep	21/oct	40.461199	-8.531627	54.375	2.30 x 1	Typical varieties of the region	Unilateral Cordon	Lambda-Cyhalothrin - July/ August	Glyphosate + Oxifluorfen - February	Mancozeb + Metalaxyl M - March/ April; Mancozeb - April; Wettable sulfur - April/ May; Cymoxanil + Folpet- April; Folpet + Fosetil al. + Iprovalicarb - May; Metirame + Piraclostrobin - May/ June; Kresoxim-methyl + diphenoconazole - June; Copper Oxychloride - June; Penconazole - July/ August; Pirimetanil - July/ August	Integrated Production	No
V6	27/jun	30/aug	19/oct	16/jul	-	21/oct	40.212725	-8.454453	27.714	2.30 x 0.90	Touriga Nacional; Tinta Roriz; Alfrocheiro	Cordon de Royat (unilateral)	Lambda-Cyhalothrin - July/ August	Glyphosate + Oxifluorfen - February	Mancozeb + Metalaxyl M - March/ April; Mancozeb - April; Wettable sulfur - April/ May; Cymoxanil + Folpet- April; Folpet + Fosetil al. + Iprovalicarb - May; Metirame + Piraclostrobin - May/ June; Kresoxim-methyl + diphenoconazole - June; Copper Oxychloride - June; Penconazole - July/ August; Pirimetanil - July/ August	Integrated Production	Between vines

V7	-	-	-	19/jun	23/sep	21/oct	40.140458	-7.512300	473.104	3 x 1.50	Touriga Nacional; Trincadeira, Syrah	Bilateral Cordon	-	Glyphosate - March	Mancozeb + cymoxanil - May; Wettable sulfur- June; Fluopyram + tebuconazole - July	Integrated Production	Vegetation cover mowing - June and August
V8	-	-	-	19/jun	23/sep	21/oct	40.164472	-7.520331	439.722	3 x 1	Touriga Nacional, Jaen	Bilateral Cordon	-	-	Wettable sulfur - April	Integrated Production	Vegetation cover mowing - March and June
V9	-	-	-	19/jun	23/sep	21/oct	40.168936	-7.510456	409.972	3 x 1	Jaen, Rufette, Syrah	Bilateral Cordon	-	-	Wettable sulfur - April	Integrated Production	Vegetation cover mowing - April and June
V10	-	-	-	19/jun	23/sep	21/oct	40.326719	-7.418683	459.561	3 x 1	Jaen, Moscatel, Maroco	Bilateral Cordon	-	Glyphosate - April;	Azoxystrobin + Folpet - May; Mancozeb + metalaxyl-M - June; Tetraconazole - June; Fenebuconazole - July	Integrated Production	Vegetation cover mowing - April and June
V11	-	-	-	19/jun	23/sep	21/oct	40.317892	-7.302781	484.359	3 x 2	Touriga Nacional	Unilateral Cordon	-	Glyphosate - April;	Wettable sulfur - April; Dimethomorph + Dithianon - April/June; Penconazole - June	Integrated Production	Vegetation cover mowing - April and June
V12	-	-	-	27/jul	26/sep	25/oct	41.1485948	-7.1271711	151.303	2.20 x 1	Sousão	Cordon de Royat (bilateral)	-	-	Wettable sulfur + Fosetyl aluminium - March; Cymoxanil + Folpet + Fosetyl aluminium + Spiroxamine - April; Kresoxim-methyl and Penconazole -June; Boscalid + Kresoxim-methyl - July	Integrated Production	Vegetation cover mowing - March, April and May
V13	4/jul	29/aug	16/oct	27/jul	26/sep	25/oct	41.184728	-7.109831	133.797	2 x 10	Tinta Cão	Unilateral Cordon	-	-	Wettable sulfur + Fosetyl aluminium - March; Mancozeb -May/ June	Integrated Production	No
V14	11/jul	29/aug	16/oct	27/jul	26/sep	22/oct	41.224727	-7.091073	125.710	2.20 x 0.95	Tourina Nacional	Cordon	-	-	Wettable sulfur + Fosetyl aluminium - March; Mancozeb -May	Integrated Production	No
V15	-	-	-	27/jul	26/sep	24/oct	41.1169499	-7.9869087	211.473	2 x 1.2	Viognier	Cordon de Royat (unilateral)	-	-	Sulfur - April/ May/ June; Copper - April/ May/ June	Organic	Vegetation cover mowing - in March and April
V16	-	-	-	27/jul	26/sep	24/oct	41.1550118	-7.7978446	77.685	2 x 1	Touriga Nacional, Tinta Roriz, Touriga Franca, Tinta Barroca	Cordon de Royat (unilateral)	-	Glyphosate - March;	Sulfur - May; Mandipropamid + zoxamid - May	Integrated Production	No
V17	-	-	-	27/jul	26/sep	24/oct	41.154265	-7.687574	176.179	4.5 x 0.90	Touriga Franca	Cordon de Royat (unilateral)	-	-	Sulfur - April/ May/ June; Copper - April/ May/ June	Organic	Vegetation cover mowing - February and June
V18	-	-	-	27/jul	26/sep	24/oct	41.171111	-7.556944	289.758	2.30 x 0.80	Touriga Nacional	Cordon de Royat (unilateral)	-	Glyphosate - March;	Sulfur - May; Mandipropamid + zoxamid - May	Integrated Production	No

V19	-	-	-	27/jul	26/sep	24/oct	41.175709	-7.530771	267.565	2.5 x 1	Tinta Francista, Touriga Nacional, Vinhas Velhas	Cordon de Royat (unilateral)	-	Glyphosate - March;	Folpet + Metalaxyl - April/ May; Sulfur and Penconazole - April; Fluopyram + tebuconazole - June; Copper sulfate - July; Boscalid + Kresoxim-methyl - July	Integrated Production	No
V20	-	-	-	27/jul	26/sep	24/oct	41.180833	-7.476667	285.160	2.20 x 1	Touriga Nacional, Touriga Franca, Tinta Roriz, Tinto Cão	Cordon de Royat (unilateral)	-	Glyphosate - March;	Folpet + Metalaxyl - April/ May; Sulfur and Penconazole - April; Fluopyram + tebuconazole - June; Copper sulfate - July; Boscalid + Kresoxim-methyl - July	Integrated Production	No
V21	-	-	-	27/jul	26/sep	24/oct	41.108056	-7.241389	300.447	2 x 1	Touriga Franca	Cordon de Royat (bilateral)	-	-	Folpet + Metalaxyl - April/ May; Sulfur and Penconazole - April; Fluopyram + tebuconazole - June; Copper sulfate - July; Boscalid + Kresoxim-methyl - July	Integrated Production	No
V22	26/jun	11/sep	19/oct	15/jul	23/sep	21/oct	38.522541	-8.953211	50.382	3 x 1	Tinta Roriz, Touriga Nacional, Tinta Amarela	Unilateral Cordon	-	-	Mancozeb + cymoxanil - May; Wettable sulfur- June; Fluopyram + tebuconazole - July	Integrated Production	No
V23	26/jun	11/sep	19/oct	15/jul	23/sep	21/oct	38.567994	-8.928173	99.902	3 x 1	Moscatel Roxo, Touriga Nacional	Unilateral Cordon	-	-	Mancozeb + cymoxanil - May; Wettable sulfur- June; Fluopyram + tebuconazole - July	Integrated Production	No
V24	26/jun	11/sep	19/oct	15/jul	-	-	38.490498	-9.022675	108.713	3 x 1	Fernão Pires, Moscatel de Setúbal	Unilateral Cordon	-	-	Mancozeb + cymoxanil - May; Wettable sulfur- June; Fluopyram + tebuconazole - July	Integrated Production	No
V25	26/jun	11/sep	19/oct	15/jul	23/sep	21/oct	38.540465	-8.985373	96.520	3 x 1	Castelão, Trincadeira e Touriga Nacional	Unilateral Cordon	-	-	Mancozeb + cymoxanil - May; Wettable sulfur- June; Fluopyram + tebuconazole - July	Integrated Production	No
V26	11/jul	29/aug	16/oct	15/jul	17/sep	22/oct	41.5162149	-7.092967	344.346	2 x 1	Touriga-Franca; Sousão	Unilateral Cordon	-	-	Sulfur and Copper - June/ July	Organic	Vegetation cover mowing - June
V27	-	-	-	25/jun	25/sep	22/oct	41.550195	-7.259052	260.920	2 x 1	Touriga Franca, Touriga Nacional, Bastardo,	Unilateral Cordon	-	-	Wettable sulfur - May/ June/ July	Integrated Production	Vegetation cover mowing - March and June
V28	-	-	-	25/jun	25/sep	22/oct	41.59775	-7.363637	510.649	2 x 2	Viosinho, Códega do Larinho,	Unilateral Cordon	-	-	Wettable sulfur - May/ June/ July	Integrated Production	Vegetation cover mowing - March and June

											Malvasia Fina,						
V29	11/jul	29/aug	19/oct	26/jun	25/sep	22/oct	41.6473833	-7.5843222	385.721	2 x 1	Alvarinho	Unilateral Cordon	-	-	Malcozeb + cymoxanil - May; Wettable sulfur- June; Fluopyram + tebuconazole - July;	Integrated Production	Vegetation cover mowing - June
V30	11/jul	29/aug	16/oct	26/jun	1/oct	22/oct	41.292179	-7.112580	393.805	2 x 0.90	Touriga-Franca, Touriga Nacional, Rabigato,	Cordon	-	-	Wettable sulfur + Fosetyl aluminium - March; Mancozeb -May;	Integrated Production	No
V31	22/jun	28/aug	26/oct	8/jul	25/sep	21/oct	41.680022	-8.53092	168.628	3 x 1	Espadeiro, Borraçal, Alvarinho	Unilateral Cordon	Deltamethrin - June/July	-	Folpet + Metalaxyl - April/ May; Mancozeb + cymoxanil - May; Wettable sulfur- June; Fluopyram + tebuconazole - July;	Integrated Production	No
V32	22/jun	28/aug	26/oct	8/jul	24/sep	21/oct	41.678658	-8.531356	165.049	3 x 1	Alvarinho	Unilateral Cordon	Deltamethrin - June/July	-	Folpet + Metalaxyl - April/ May; Mancozeb + cymoxanil - May; Wettable sulfur- June; Fluopyram + tebuconazole - July;	Integrated Production	No
V33	22/jun	28/aug	26/oct	8/jul	25/sep	21/oct	41.785855	-8.494984	68.918	3 x 1	Alvarelhão, Borraçal, Pedral	Unilateral Cordon	Deltamethrin - June/July	-	Folpet + Metalaxyl - April/ May; Mancozeb + cymoxanil - May; Wettable sulfur- June; Fluopyram + tebuconazole - July;	Integrated Production	No
V34	22/jun	28/aug	26/oct	8/jul	25/sep	21/oct	41.815375	-8.410264	57.641	3 x 1	Amaral, Rabo de Anho, Vinhão	Unilateral Cordon	Deltamethrin - June/July	-	Folpet + Metalaxyl - April/ May; Mancozeb + cymoxanil - May; Wettable sulfur- June; Fluopyram + tebuconazole - July;	Integrated Production	No
V35	22/jun	28/aug	26/oct	8/jul	25/sep	21/oct	41.792375	-8.538943	39.478	3 x 1	Vinhão, Espadeiro	Unilateral Cordon	Deltamethrin - June/July	-	Folpet + Metalaxyl - April/ May; Mancozeb + cymoxanil - May; Wettable sulfur- June; Fluopyram + tebuconazole - July;	Integrated Production	No

LS – Late spring; S – Summer; A – Autumn; Y – Latitude; X – Longitude.

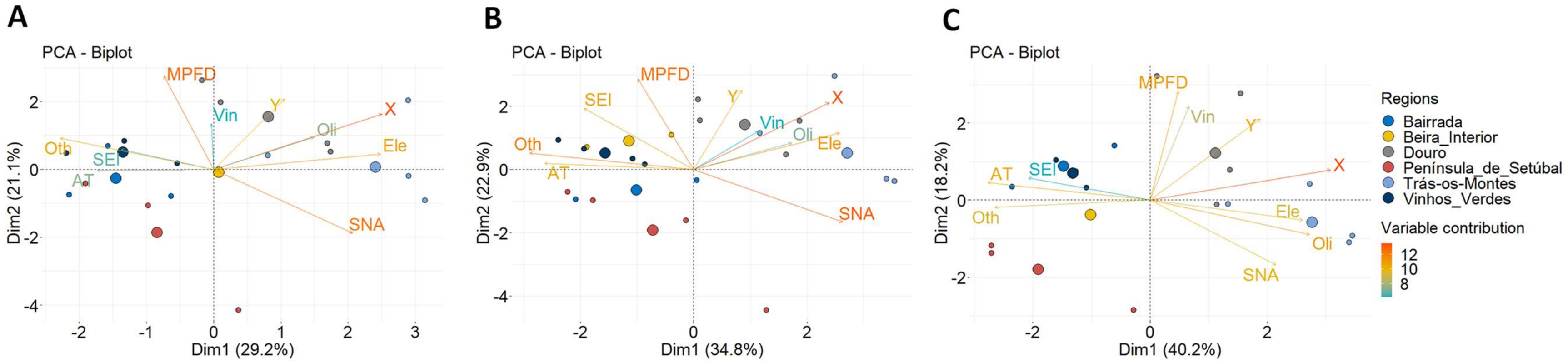


Figure S3.1. PCA biplot for the landscape metrics at 500 (A), 1000 (B), 2000 (C), m spatial scales. SEI – Simpson diversity index; MPFD - mean patch fractal dimension; AT – artificial territory; Oth - Other crops; Oli – Olive crops; Vin – Vineyards; SNH - seminatural habitats; Ele – elevation; Y – Latitude; X – Longitude.

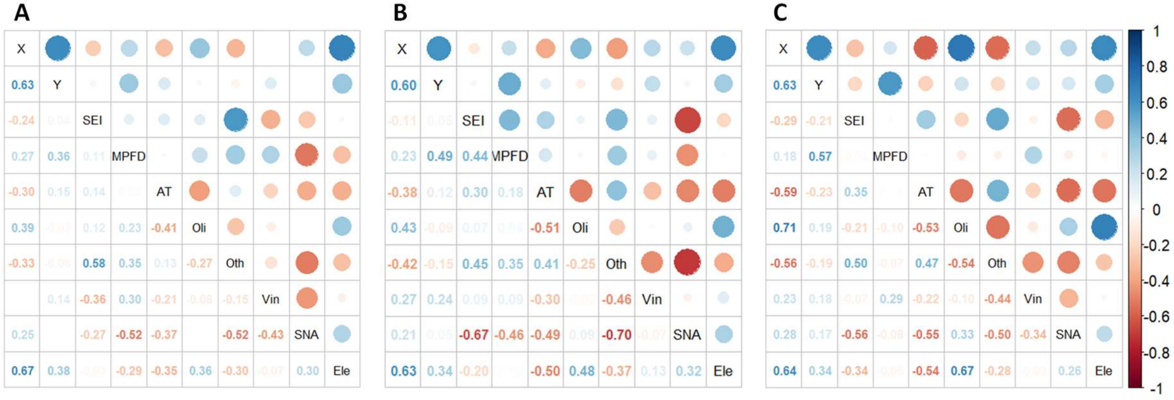


Figure S3.2. Pearson correlations among landscape variables at 500 (A), 1000 (B), 2000 (C) m spatial scales. SEI – Simpson diversity index; MPFD - mean patch fractal dimension; AT – artificial territory; Oth - Other crops; Oli – Olive orchards; Vin – Vineyards; SNH - seminatural habitats; Ele – elevation; Y – Latitude; X – Longitude.

CHAPTER 4 - SUPPLEMENTARY INFORMATION

The surrounding landscape shapes the abundance of *Sphaerophoria scripta* and *Melanostoma mellinum* (Diptera: Syrphidae) in Portuguese vineyards

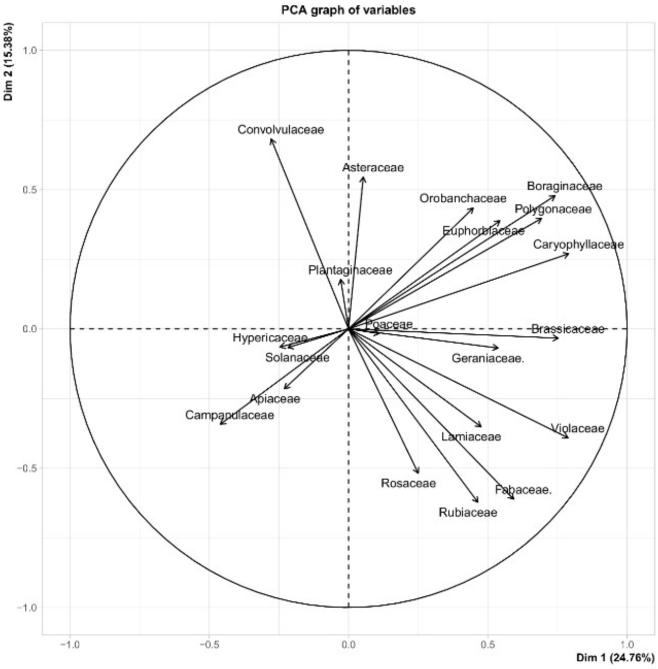
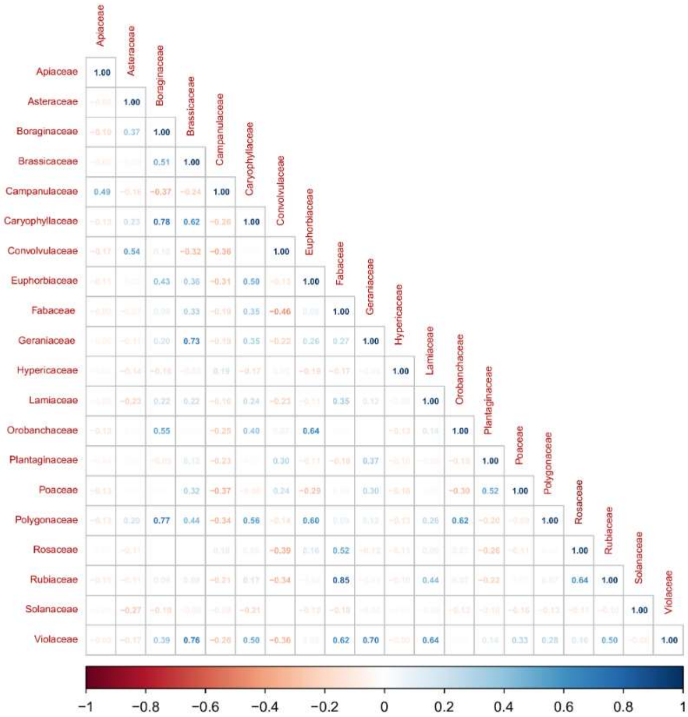


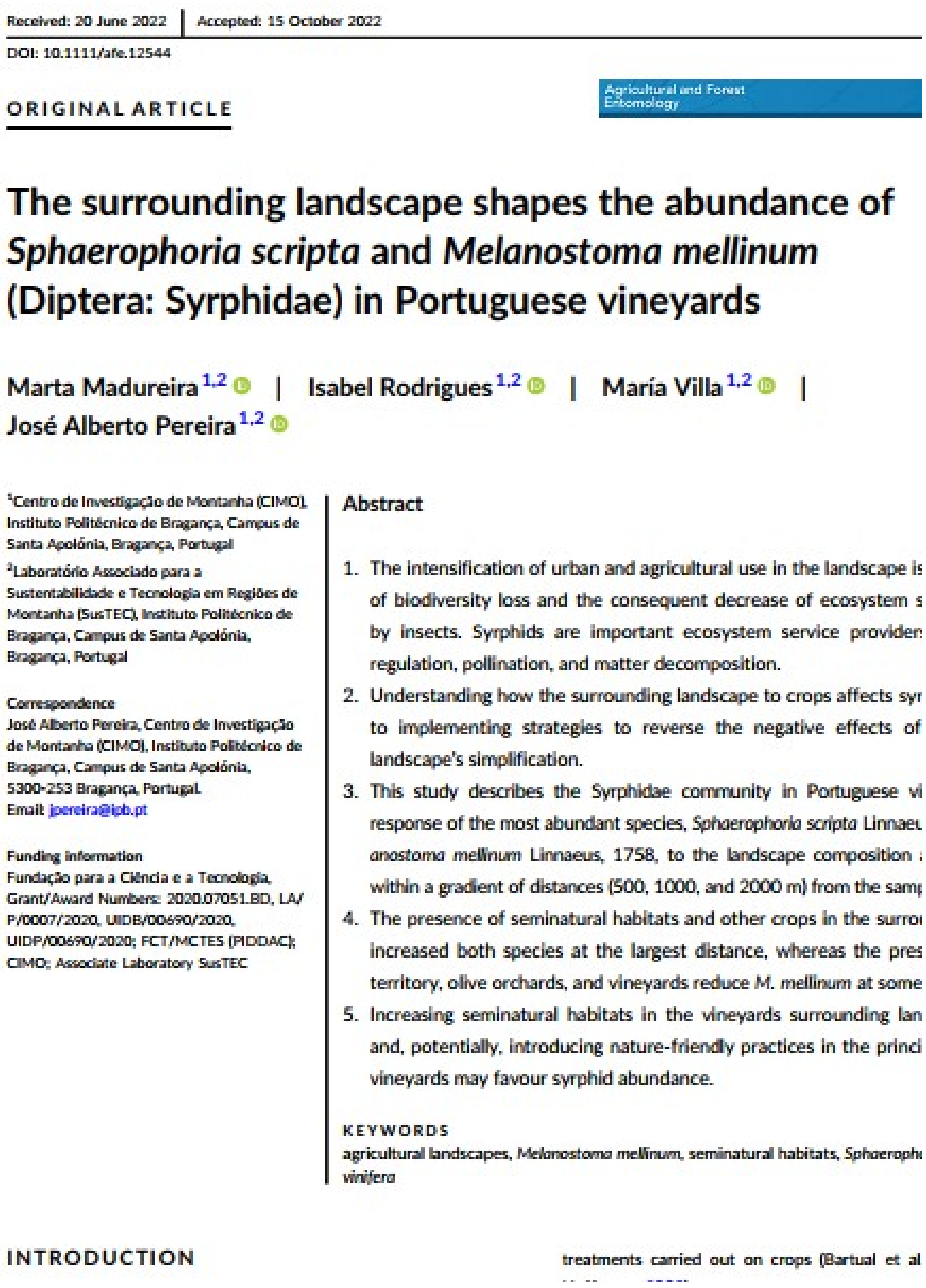
Figure S4.1. PCA graph of variables for families of flowering plant species identified.



	Apiaceae	Asteraceae	Boraginaceae	Brassicaceae	Campanulaceae	Caryophyllaceae	Convolvulaceae	Euphorbiaceae	Fabaceae	Geraniaceae	Hypericaceae	Lamiaceae	Orobanchaceae	Plantaginaceae	Poaceae	Polygonaceae	Rosaceae	Rubiaceae	Solanaceae	Violaceae
Apiaceae	1.00																			
Asteraceae	[illegible]	1.00																		
Boraginaceae	−0.10	0.37	1.00																	
Brassicaceae	[illegible]	[illegible]	0.51	1.00																
Campanulaceae	0.49	−0.16	−0.37	−0.24	1.00															
Caryophyllaceae	−0.13	0.23	0.78	0.62	−0.26	1.00														
Convolvulaceae	−0.17	0.54	0.10	−0.32	−0.36	[illegible]	1.00													
Euphorbiaceae	−0.11	[illegible]	0.43	0.36	−0.31	0.50	−0.13	1.00												
Fabaceae	[illegible]	[illegible]	[illegible]	0.33	−0.19	0.35	−0.46	[illegible]	1.00											
Geraniaceae	[illegible]	−0.11	0.20	0.73	−0.19	0.35	−0.22	0.26	0.27	1.00										
Hypericaceae	[illegible]	−0.14	−0.16	[illegible]	0.19	−0.17	[illegible]	−0.19	−0.17	[illegible]	1.00									
Lamiaceae	[illegible]	−0.23	0.22	0.22	−0.16	0.24	−0.23	−0.11	0.35	0.12	[illegible]	1.00								
Orobanchaceae	−0.13	[illegible]	0.55	[illegible]	−0.25	0.40	[illegible]	0.64	[illegible]		−0.13	0.14	1.00							
Plantaginaceae	[illegible]	[illegible]	[illegible]	0.12	−0.23	[illegible]	0.30	−0.11	−0.18	0.37	−0.10	[illegible]	−0.15	1.00						
Poaceae	−0.13	[illegible]	[illegible]	0.32	−0.37	[illegible]	0.24	−0.29	[illegible]	0.30	−0.18	[illegible]	−0.30	0.52	1.00					
Polygonaceae	−0.13	0.20	0.77	0.44	−0.34	0.56	−0.14	0.60	[illegible]	0.12	−0.13	0.26	0.62	−0.20	[illegible]	1.00				
Rosaceae	[illegible]	−0.11			[illegible]	[illegible]	−0.39	0.16	0.52	−0.12	−0.11	[illegible]	[illegible]	−0.26	−0.11	[illegible]	1.00			
Rubiaceae	−0.11	−0.11	[illegible]	[illegible]	−0.21	0.17	−0.34	[illegible]	0.85	[illegible]	−0.10	0.44	[illegible]	−0.22	[illegible]	[illegible]	0.64	1.00		
Solanaceae	[illegible]	−0.27	−0.18	[illegible]	[illegible]	−0.21		−0.12	−0.18	[illegible]	[illegible]	[illegible]	−0.12	−0.10	−0.16	−0.13	−0.11	[illegible]	1.00	
Violaceae	[illegible]	−0.17	0.39	0.76	−0.26	0.50	−0.36	[illegible]	0.62	0.70	[illegible]	0.64	[illegible]	0.14	0.33	0.28	0.16	0.50	[illegible]	1.00

Figure S4.2. Pearson correlations for families of flowering plant species identified.

CHAPTER 3 - PUBLISHED



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ORIGINAL ARTICLE

Agricultural and Forest Entomology

The surrounding landscape shapes the abundance of *Sphaerophoria scripta* and *Melanostoma mellinum* (Diptera: Syrphidae) in Portuguese vineyards

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Abstract

1. The intensification of urban and agricultural use in the landscape is
of biodiversity loss and the consequent decrease of ecosystem s
by insects. Syrphids are important ecosystem service provider
regulation, pollination, and matter decomposition.
2. Understanding how the surrounding landscape to crops affects syr
to implementing strategies to reverse the negative effects of
landscape's simplification.
3. This study describes the Syrphidae community in Portuguese vi
response of the most abundant species, *Sphaerophoria scripta* Linnaeu
anostoma mellinum Linnaeus, 1758, to the landscape composition
within a gradient of distances (500, 1000, and 2000 m) from the samp
4. The presence of seminatural habitats and other crops in the surro
increased both species at the largest distance, whereas the pres
territory, olive orchards, and vineyards reduce *M. mellinum* at some
5. Increasing seminatural habitats in the vineyards surrounding lan
and, potentially, introducing nature-friendly practices in the princi
vineyards may favour syrphid abundance.

KEYWORDS
agricultural landscapes, *Melanostoma mellinum*, seminatural habitats, *Sphaeroph*
vinifera

INTRODUCTION

treatments carried out on crops (Bartual et al