

A complex landscape favours the abundance and species richness of syrphids (Diptera: Syrphidae) in olive groves

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Abstract

1. Sustainability of agroecosystems depends on the ecosystem services, provided by beneficial organisms, such as the syrphids (Diptera: Syrphidae) acting as other-insect predators and pollinators in different crops. In the case of olive groves, syrphids are predators of important pests and are endangered by the continuous intensification of agriculture, including landscape simplification. In this work, the effect of landscape structure on the abundance and species richness of syrphids in the olive agroecosystem of central Spain is assessed.
2. Adult syrphids were sampled in 2015 and 2016 in the centre of circular areas of 15 olive grove landscapes (from 250 to 1500 m radius) representing a gradient of landscape complexity, in the province of Madrid, central Spain.
3. The syrphid assemblage was made up of 57 species, although *Eupeodes corollae*, *Eristalis tenax*, *Eristalis similis* and *Chrysotoxum intermedium* made up 76% of the captures.
4. Syrphid abundance and species richness were favoured in complex landscapes, with low olive grove area (CAO). Other landscape indices showed also this trend although their effect was not as strong and consistent as that of CAO. The area of scrublands (CAS) favoured syrphids in spring, but was unfavourable in autumn. The effect of Shannon's Evenness Index (SHEI) and mean shape index (MSI) was less consistent. The effect of CAO increased with increasing buffers radii, while the effect of CAS, SHEI and MSI was detected in general at smaller radii, indicating these indices affect different processes.
5. Redundancy analysis (RDA) detected some differences between species regarding their abundance in spring *versus* autumn, and their relationship with landscape indices.
6. This work provides new evidence that maintenance of complex landscapes is essential for maintaining functional biodiversity in the olive agroecosystem.

KEYWORDS

ecosystem service, landscape diversity, landscape structure, syrphid populations

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INTRODUCTION

Maintenance of ecosystem services of pollination and biological control provided by syrphids is essential for sustainable agricultural systems. Syrphid adults are pollinators (Doyle et al., 2020) and the larvae of many species are predators of pests (Rotheray & Gilbert, 2011). Among the non-bee pollinators of crops, taxa within the dipteran families Syrphidae and Calliphoridae are the most common visitors to many crops (Rader, Cunningham, Howlett, & Inouye, 2020). The larvae of the subfamilies Syrphinae and Pipizinae are important predators of aphids (Aphidoidea), and other soft-bodied arthropods including thrips (Thysanoptera) and caterpillars (Lepidoptera) (Dunn, Lequerica, Reid, & Latty, 2020) and are used in integrated control of aphids in greenhouse crops (Marcos-García & Galante, 2021). Syrphids are also indicators of ecosystem quality (Burgio & Sommaggio, 2007).

Specific landscape structures may increase the ecosystem services provided by insects (Tscharntke, Klein, Kruess, Steffan-Dewenter, & Thies, 2005). This may reduce the damage caused by agricultural pests and, consequently, reduce phytosanitary treatments carried out on crops (Bartual et al., 2019; Thomson & Hoffmann, 2009). Maintaining an adequate level of landscape complexity around agricultural plots, that is, landscape heterogeneity, is essential for sustainable agricultural systems. In complex landscapes, natural and semi-natural habitats favour overwintering syrphids and provide floral food sources and alternative prey. Thus, increased landscape heterogeneity is relevant to the maintenance of syrphid populations. The vegetation type of the sites affects syrphid diversity in Mediterranean ecosystems (Ricarte, Marcos-García, & Moreno, 2011). Although, evidences on the effects of landscape change on syrphid populations in agricultural systems is limited (Rodríguez-Gasol, Alins, Veronesi, & Wratten, 2020), some research indicates that different management efforts, focused on land-use intensity (grazing) or connectivity, seem to be appropriate to syrphids conservation (Burgio et al., 2015; Jovičić et al., 2017).

In the olive agroecosystem, syrphid larvae are predators of the olive psyllids, *Euphyllura olivina* (Costa, 1839) and *Euphyllura straminea* Loginova, 1973 (Hemiptera), the green moth, *Palpita vitrealis* (Rossi, 1794) and the olive moth, *Prays oleae* (Bernard, 1788) (Lepidoptera) (Rojo, Gilbert, Marcos-García, Nieto, & Mier, 2003), contributing to biological control of these insect pests. The study of the effect of landscape structure on different trophic guilds and processes in the olive agroecosystem has received attention in the last 20 years, showing in general a beneficial effect of complex landscapes (Alves, Mendes, Alves da Silva, Sousa, & Paredes, 2021; Boccaccio & Petacchi, 2009; Costa et al., 2020; Lantero et al., 2019; Martínez-Núñez et al., 2020; Ortega, Moreno, Fernández, & Pascual, 2022; Ortega, Sanchez-Ramos, González-Núñez, & Pascual, 2018; Paredes et al., 2022; Pascual, 2022; Picchi, Bocci, Petacchi, & Ending, 2016; Scalercio, Brandmayr, Iannotta, Petacchi, & Boccaccio, 2012; Villa, Santos, Pascual, & Pereira, 2021). We hypothesize that landscape complexity favours syrphid community in the olive agroecosystem. In this study, we aimed to add new evidence of this beneficial effect in the olive grove landscapes of central Spain.

MATERIALS AND METHODS

Study area

Sampling of adult syrphids was carried out in an area covering approximately 750 km² in the south eastern part of Madrid province, Central Spain. The dominant natural habitat in southeastern Madrid is a Mediterranean scrubland with plant species adapted to drought and gypsiferous soils, and the main crops are olives, vineyards, and cereals. Gypsophilic plants are *Thymus zygis* Loefl. ex L., *Reseda suffruticosa* Loefl., or *Stipa tenacissima* L., with *Lygos sphaerocarpa* (L.) Boiss., *Teucrium pseudochamaepitys* L., *Thymus vulgaris* L., and some interspersed oak (*Quercus ilex*) trees. The climate is continental Mediterranean, with long, cold winters and long, hot summers. Fifteen olive groves separated at least 4 km were selected to do the samplings. Size of olive groves ranged between 1 and 11 ha, slopes between 1 and 10% and heights between (570 and 700 m asl). Trees were planted in a 10 × 10 framework. These olive groves are usually ploughed one or more times per year and maintain an integrated management with phytosanitary treatments only in cases of pest alert.

Adult syrphids were sampled in the centre of circular areas of 15 olive grove landscapes from 250 to 1500 m radio (Figure 1). While syrphids are capable of flying long distances, most syrphid species are known as non-migrants (Schweiger et al., 2007; Speight, 2003) for this reason small scales were used. The olive grove landscapes were representative of a landscape gradient according to the percentage of natural habitat, the percentage of olive groves and the landscape diversity assessed by the Shannon landscape diversity index (González-Núñez, Sánchez-Ramos, Ortega, Rescia, & Pascual, 2017). A 2 × 2 km grid was used to characterize the olive growing area in Southeastern Madrid. Values of Shannon landscape diversity index, percentage of olive groves and percentage semi-wild area were calculated for each square in the grid using the land cover maps provided by SIOSE (Sistema de Información sobre Ocupación del Suelo de España; SIOSE, 2005).

Syrphid sampling and determination

In each olive grove, four yellow sticky traps (20 × 25 cm; Econex[®] Sanidad Agrícola, S.L) were placed in the south facing part of the canopy of four consecutive trees, separated from the field edge about 30–40 m. This type of traps have also been used for syrphids because they mimic the colour of flowers (Burgio & Sommaggio, 2007; Hickman, Wratten, Jepson, & Frampton, 2001). Traps were attached to two twigs in the canopy using wires, and they were placed in the field for seven days for each sampling. Samplings were carried out in 2015 and 2016, along two sampling periods: “spring” and “autumn”. The “spring” period comprised between 20th March and 8th July in 2015 and between 10th March and 30th June in 2016. In this “spring” period six samplings were carried out, and the dates starting each sampling are showed in Table 1.

After the seven days in the field, traps were taken to the laboratory, where syrphid specimens were counted and determined at the

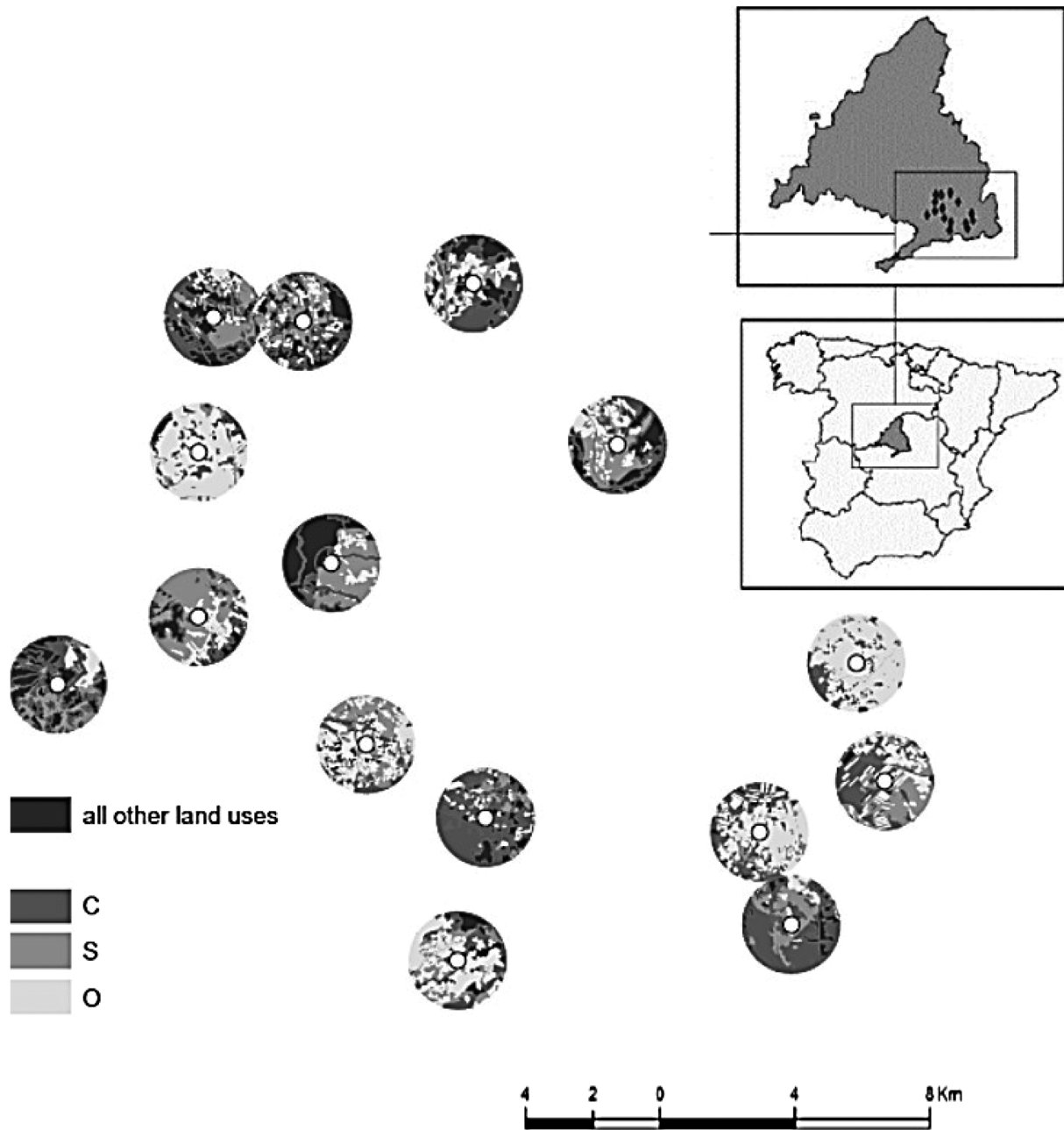


FIGURE 1 Spatial representation of the 15 analysed plots showing the areas of the three main land uses. The circles have a radius of 1500 m and within them are circles of 250 m radius. Both circles were centred on the sampling points. The used acronyms are: olive grove (O), field crop (C), scrubland (S).

species level, using the keys and information provided in Speight (2017), Speight (2020), Speight and Sarthou (2017), Van Veen (2004) and other specialised literature. When determination was not feasible observing the specimen on the trap with naked eye or under a binocular microscope, the part of the trap containing the specimen was cut using a scalpel, placed in a glass Petri dish and covered with baby oil (Johnson & Johnson®) until the specimen was detached to be able to observe morphologic characters that could be found on the side sticking to the trap. Oil had to be washed off from some specimens. Washing was done with 5% Tween 20, and then specimens were kept in 70% ethanol. All the examined material is deposited at the INIA collection.

Landscape analysis

Landscape structure was assessed in circular areas of 250, 500, 750, 1000 and 1500 m radii around the 15 olive groves selected. Data taken from the Spanish Land Use and Land Cover Information System (SIOSE, 2005) map were used to calculate landscape structure indices. Verification and updating of land uses were done with the aid of aerial photographs taken in 2015 (provided by National Aerial Orthophotography Plan; <https://pnoa.ign.es/>) and information provided by SIGPAC (2004). Patches were reclassified to give a final number of 13 land use classes. The software

TABLE 1 Dates of sampling in olive groves.

Sampling	2015	2016	Julian day
1	20th March	10th March	79 and 69
2	8th April	3st April	98 and 93
3	30th April	21th April	120 and 111
4	20th May	12th May	140 and 132
5	10th June	2nd June	161 and 153
6	1st July	23th June	182 and 174
7	27th August	24th August	239 and 236
8	17th September	14th September	260 and 257
9	8th October	6th October	281 and 279
10	27th October	27th October	300

Patch Analyst for ArcGIS® 10.1 (ESRI, Redlands, CA, USA) was used to calculate the following landscape indices: Total area of olive groves (CAO), Total area of scrublands (CAS), Mean shape index (MSI), Number of patches (NP), Patch richness (PR), Shannon landscape diversity index (SDI), Shannon's Evenness Index (SHEI) and Total edges (TE).

Data analysis

The effects of landscape structure on syrphid abundance and species richness were assessed by fitting generalized linear mixed models (GLMMs) separately for each buffer radius and sampling period. The specimens captured during each sampling period were pooled for analysis. The explanatory variables (landscape indices) were previously selected, allowing a minimum collinearity using the variance inflation factor (VIF) criteria ($VIF < 3$) (Zuur, Ieno, & Elphick, 2010), and the stepwise backward model selection based in hypothesis testing, i.e. dropping the less significant term of the model and refitting it until p -value for all terms was < 0.1 , was applied (Zuur, Ieno, Walker, Saveliev, & Smith, 2009). Olive grove was a random factor in the models. A negative binomial family was considered to account for over-dispersion, and the link function was log.

The composition of the syrphid community was related to the sampling periods and the CAO, CAS, SIEI and MSI landscape indices using a constrained ordination by redundancy analysis (RDA). Only species with a minimum of 10 individuals were included in this analysis. The Hellinger transformation was applied to species abundance data (Legendre & Gallagher, 2001).

All statistical analyses were performed using R, version 4.0.3. The `glmmTMB` function from the "glmmTMB" package version 1.1.2.3. was used for model building (Brooks et al., 2017). The models were validated by plotting residuals versus fitted values and covariates using the package DHARMA version 0.4.4. (Hartig, 2021). The `vegan` package version 2.5-6 (Oksanen et al., 2019), was used for RDA. Bonferroni correction on the significance value was applied because

five models (five buffers) were fitted on the same data for each response variable. Therefore, p -value = 0.01 is considered significant and p -values between 0.1 and 0.01 are considered only as weakly significant.

RESULTS

Dynamics and composition of the assemblage of syrphids in olive groves

A total of 955 adult syrphids belonging to 47 species were captured, 328 in 2015 and 627 in 2016. More individuals were captured in spring, 594; while 361 individuals were captured in autumn. Figure 2 shows the number of syrphids captured on each sampling date. The largest number of syrphids were captured in samplings one (20th March in 2015 and 10th March in 2016) and ten (27th October in 2015 and 2016).

Only 883 syrphids could be determined at the species level. Ten specimens were determined at genus level, and 62 specimens lacked essential taxonomic features for determination. Five species made up 76% of the captures. The most abundant species during almost all periods was *Eupoedes corollae*. Six species were captured in numbers ranging between 10 and 50. The rest of species were scarce, with captures between 2 and 10 individuals and singletons (Table 2). Figure 3 shows the percentages of the most abundant syrphid species captured on each sampling period.

Effect of landscape structure on syrphids abundance

The mean percentages of the different land uses in circular areas of 1500 m radius around the olive groves were as follows: 26.8% olive groves, 27.7% gypsophilic scrublands, intermingled in some cases with oak trees (*Quercus ilex* L.), 20.8% cereal crops, 5.8% watered crops, 5.2% pine forest (*Pinus pinea* L.), 4.1% oak forest (*Quercus ilex*), 3.8% woody crops (almonds and vineyards), 3.2% artificial uses, 1% pastures, 1.6% Other minor uses.

Table 3 shows all the results of fitting GLMM to abundance of syrphids. The index that more consistently affected syrphid abundance was the area of olive groves (CAO). This effect was negative in all cases it was detected. In 2015, this effect was detected only in spring, while in 2016, it was in spring and autumn, although the significance was higher in spring. In spring 2015 it was detected at all radii, with increasing significance as radius increased. In spring 2016 it was detected only at the largest radii, with maximum significance at 1000 m radius. On the other hand, in autumn 2016 significances were greatest for 500 and 750 m radius.

Other landscape indices affected also syrphid abundance, but not as strongly as the CAO. The area of scrubland (CAS) had an opposite effect depending on the sampling period. It affected positively syrphid abundance in spring 2016 at 500 and weakly at 500 m radius, while in

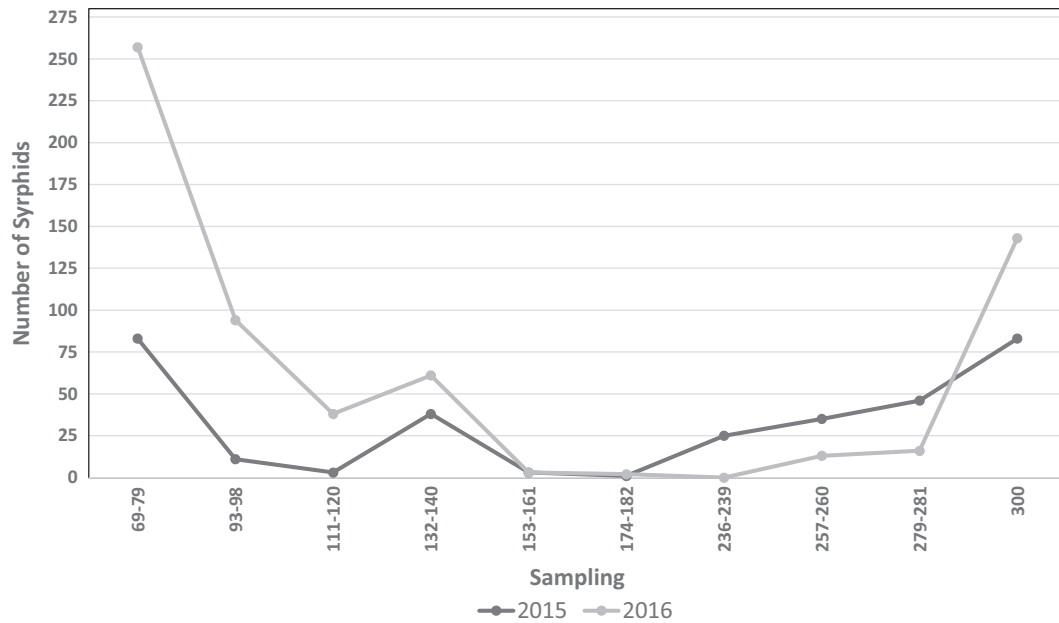


FIGURE 2 Number of syrphids captured along sampling period in the years 2015 and 2016. The samplings are indicated by Julian days. Dates of sampling in olive groves are in Table 1.

TABLE 2 Composition of the assemblage of syrphids in olive groves. The first column shows in order of frequency the five species that accounted for 76% of the captures. The second and third columns show in the same order the species found in numbers ranging between 10 and 50 and between 2 and 10. The last column shows the singleton species.

76% captures	Between 10 and 50	Between 2 and 10	Singletons
<i>Eupeodes corollae</i> (Fabricius, 1794)	<i>Sphaerophoria scripta</i> (Linnaeus, 1758)	<i>Eristalis arbustorum</i> (Linnaeus, 1758)	<i>Cheiliosia grossa</i> (Fallén, 1817)
<i>Eristalis tenax</i> (Linnaeus, 1758)	<i>Episyrphus balteatus</i> (De Geer, 1776)	<i>Eumerus amoenus</i> (Loew, 1848)	<i>Dasysyrphus albostrigatus</i> (Fallén, 1817)
<i>Eristalis similis</i> (Fallén, 1817)	<i>Meliscaeva auricollis</i> (Meigen, 1822)	<i>Eumerus cf pulchellus</i> (Marcos-García & Láska, 1983)	<i>Epistrophe eligans</i> (Harris, 1780)
<i>Chrysotoxum intermedium</i> (Meigen, 1822)	<i>Merodon albifrons</i> (Meigen, 1822)	<i>Eumerus cf strigatus</i> (Marcos-García & Láska, 1983)	<i>Eumerus gibbosus</i> (van Steenis, Hauser & van Zuijlen, 2017)
	<i>Eristalinus taeniops</i> (Wiedemann, 1818)	<i>Eupeodes lucasi</i> (Marcos-García & Láska, 1983)	<i>Eumerus subornatus</i> (Claussen, 1989)
	<i>Eristalinus aeneus</i> (Scopoli, 1763)	<i>Melanostoma mellinum</i> (Linnaeus, 1758)	<i>Melanostoma scalare</i> (Fabricius, 1794)
		<i>Merodon geniculatus</i> (Strobl, 1909)	<i>Merodon quercetorum</i> (Marcos-García, Vujić & Mengual, 2007)
		<i>Merodon ibericus</i> (Vujić 2015)	<i>Pipiza festiva</i> (Meigen, 1822)
		<i>Myathropa florea</i> (Linnaeus, 1758)	<i>Platycheirus ambiguus</i> (Fallén, 1817)
		<i>Paragus quadrifasciatus</i> (Meigen, 1822)	<i>Platynochaetus setosus</i> (Fabricius, 1794)
		<i>Scaeva pyrastris</i> (Linnaeus, 1758)	<i>Scaeva albomaculata</i> (Macquart, 1842)
		<i>Syrirta pipiens</i> (Linnaeus, 1758)	<i>Scaeva mecogramma</i> (Bigot, 1860)
		<i>Xanthandrus comtus</i> (Harris, 1776)	<i>Scaeva selenitica</i> (Meigen, 1822)
			<i>Syrphus vitripennis</i> (Meigen, 1822)
			<i>Syrirta flaviventris</i> (Macquart, 1842)
			<i>Volucella elegans</i> (Loew, 1862)

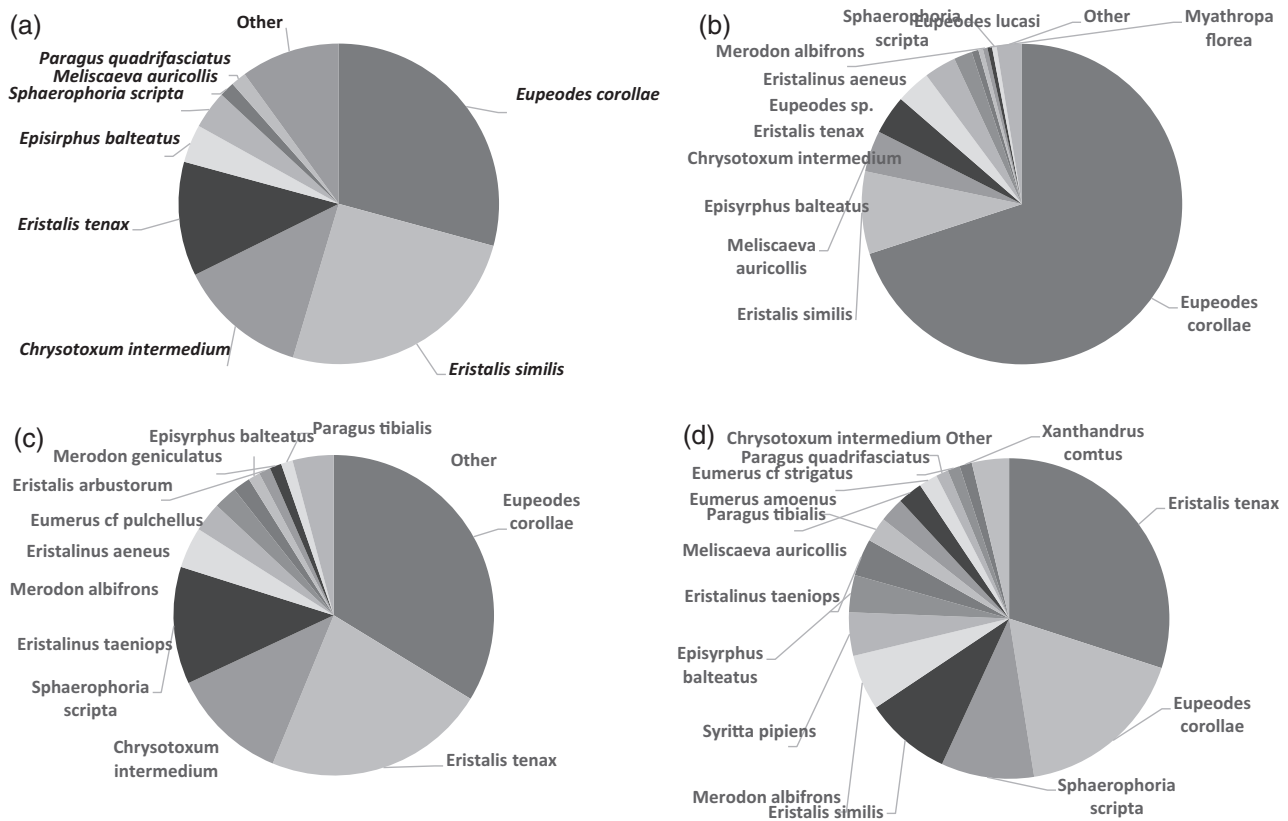


FIGURE 3 Percentages of the most abundant syrphid species captured in spring 2015 (a), spring 2016 (b), autumn 2015 (c) and autumn 2016 (d).

autumn had a weakly negative effect in 2015 and 2016 at 500 and 750 m radius. The Shannon's Evenness Index (SHEI) affected syrphid abundance only in spring, while the Mean shape index (MSI) did that only in autumn. The effect of SHEI was positive in spring 2016 at 500 m radius. The effect of MSI was positive in 2015, at 500 and 750 m, Figure 4 shows the trend plots for the most significant landscape indices calculated at 500 m buffer areas.

Effect of landscape structure on syrphid species richness

Landscape affected similarly species richness and abundance of syrphids. Table 4 shows all the results of fitting GLMM to species richness of syrphids. CAO was the index that most strongly affected species richness. High values of CAO were associated with low species richness in both years of study and seasons. However, this effect was more consistent in spring 2015 and autumn 2016, because it was detected at all radii studied; while in autumn 2015 it was detected only at 500 m radius with marginal significance, and in spring 2016 only at 1000 and 1500 m radius. The area of scrublands affected positively species richness in spring 2016 at 500 and 750 m radii, but negatively in autumn in 2015 at 500 m radius, and in 2016 at all radii except 1000 m. SHEI affected positively species richness, but only in spring 2016 at 250 and 500 m radii. The effect

of MSI was detected in autumn, and it was opposite in the two years studied. In 2015, species richness increased for increasing values of MSI at 500 and 750 m, while in 2016, a negative relationship between MSI and species richness was detected at 1000 m. Figure 5 shows the trend plots for the most significant landscape indices calculated at 500 m buffer areas.

Ordination of syrphid composition

The RDA model explained 31% of the total variation in the community of syrphids (R^2 adjusted = 0.196, $F = 2.802$ $p = 0.001$). The variables that significantly affected variation were Spring 2015 ($F = 2.299$ $p = 0.020$), Autumn 2015 ($F = 3.1360$ $p = 0.005$), Spring 2016 ($F = 7.9386$ $p = 0.005$), CAO ($F = 2.6964$ $p = 0.010$) and SIEI ($F = 2.1458$ $p = 0.045$). RDA1 explained 0.553% of the constrained variation ($F = 12.3985$ $p = 0.002$). This axis described a gradient between spring and autumn (Figure 6). RDA2 explained 0.220% of the constrained variation ($F = 4.935$ $p = 0.020$). This axis described a gradient in landscape complexity.

DISCUSSION

The results of this research show that the structure of the landscape affects both the abundance and the richness of syrphid species in olive

TABLE 3 Response of abundance of syrphids to landscape variables (at 250, 500, 750, 1000 and 1500 m buffers), in spring and autumn 2015 and 2016 (GLMM with negative binomial distribution, olive orchard is the random factor).

		2015					2016				
		Fixed effect	Estimate	SE	z-value	p-value	Fixed effect	Estimate	SE	z-value	p-value
SPRING	GLMM for 250 m buffers	Intercept	1.447	0.299	4.835	<0.001	Intercept	1.395	0.204	6.842	<0.001
		CAO	-0.103	0.035	-2.970	0.003	CAS	0.113	0.026	4.358	<0.001
	Dropped variables	CAS; SHEI					CAO; SHEI				
		GLMM for 500 m buffers	Intercept	1.305	0.265	4.929	<0.001	Intercept	-0.870	0.955	-0.911
	CAO		-0.026	0.009	-2.942	0.003	CAS	0.015	0.007	2.058	0.040
	Dropped variables	CAS; SHEI; MSI					CAO				
		GLMM for 750 m buffers	Intercept	1.316	0.293	4.494	<0.001	Intercept	2.528	0.230	10.979
	CAO		-0.014	0.005	-2.955	0.003	CAO	-0.0129	0.003	-3.579	<0.001
	Dropped variables	SHEI					CAS				
		GLMM for 1000 m buffers	Intercept	1.343	0.243	5.520	<0.001	Intercept	2.575	0.220	11.734
	CAO		-0.008	0.002	-3.298	<0.001	CAO	-0.008	0.002	-4.039	<0.001
	Dropped variables	CAS					CAS				
GLMM for 1500 m buffers		Intercept	3.617	1.271	2.845	0.004	Intercept	2.435	0.214	11.384	<0.001
	CAO	-0.005	0.001	-4.150	<0.001	CAO	-0.003	0.001	-2.988	0.003	
Dropped variables	SHEI					CAS; SHEI; MSI; PR					
	AUTUMN	GLMM for 250 m buffers	Intercept	1.073	0.166	6.447	<0.001	Intercept	1.377	0.224	6.155
CAO			-0.044	0.024	-1.829	0.067	CAO	-0.044	0.024	-1.829	0.067
Dropped variables	CAO; CAS; MSI					CAS; MSI; PR					
	GLMM for 500 m buffers	Intercept	-4.579	1.613	-2.839	0.005	Intercept	1.874	0.313	5.993	<0.001
CAS		-0.016	0.008	-2.132	0.033	CAO	-0.019	0.008	-2.824	0.005	
Dropped variables	MSI					CAS					
	GLMM for 750 m buffers	Intercept	3.079	0.843	3.652	<0.001	Intercept	-0.015	0.008	-1.906	0.057
CAO; SHEI		SHEI; MSI					SHEI; MSI				
Dropped variables	CAO; SHEI					SHEI; MSI					
	GLMM for 1000 m buffers	Intercept	-3.012	1.320	-2.282	0.023	Intercept	1.962	0.308	6.372	<0.001
CAS		-0.006	0.004	-1.745	0.081	CAO	-0.010	0.003	-3.129	0.002	
Dropped variables	MSI					CAS					
	GLMM for 1500 m buffers	Intercept	2.221	0.686	3.239	0.001	Intercept	-0.008	0.004	-2.166	0.030
SHEI; PR		MSI; PR					MSI; PR				
Dropped variables	SHEI; PR					MSI; PR					
	GLMM for 1500 m buffers	Intercept	1.0729	0.1664	6.447	<0.001	Intercept	4.301	1.552	2.772	0.006
CAO; CAS; MSI; PR		CAS; PR					CAS; PR				
Dropped variables	CAO; CAS; MSI; PR					CAS; PR					
	GLMM for 1500 m buffers	Intercept	1.0729	0.1664	6.447	<0.001	Intercept	1.0376	0.1423	7.292	<0.001
CAO; CAS; SHEI; MSI; PR		CAO; CAS; SHEI; MSI; PR					CAO; CAS; SHEI; MSI; PR				

Note: Bonferroni correction on the significance value was applied. Therefore, $p = 0.01$ is considered significant and p -values between 0.1 and 0.01 are considered only as weakly significant and is indicated in italic.

Abbreviations: CAO, olive grove area; CAS, scrubland area; MSI, mean shape index; PR: patch richness; SE, standard error; SHEI, Shannon's evenness index.

groves, with more complex landscapes having a positive and almost equal effect on both parameters. The negative effects of landscape simplification on ecosystem services is mostly due to richness losses of service-providing organisms, with negative consequences for crop yields (Dainese et al., 2019). However, measuring species richness is a more labour-consuming task than estimating abundance. Thus, from a

practical point of view, in the agroecosystem studied, the assessment of landscape effect on syrphid abundance would provide an estimation of the effect of landscape simplification on the ecosystem services provided by syrphids.

The main landscape effect detected in this study was a negative effect of the area of olive groves (CAO) surrounding the sampled olive

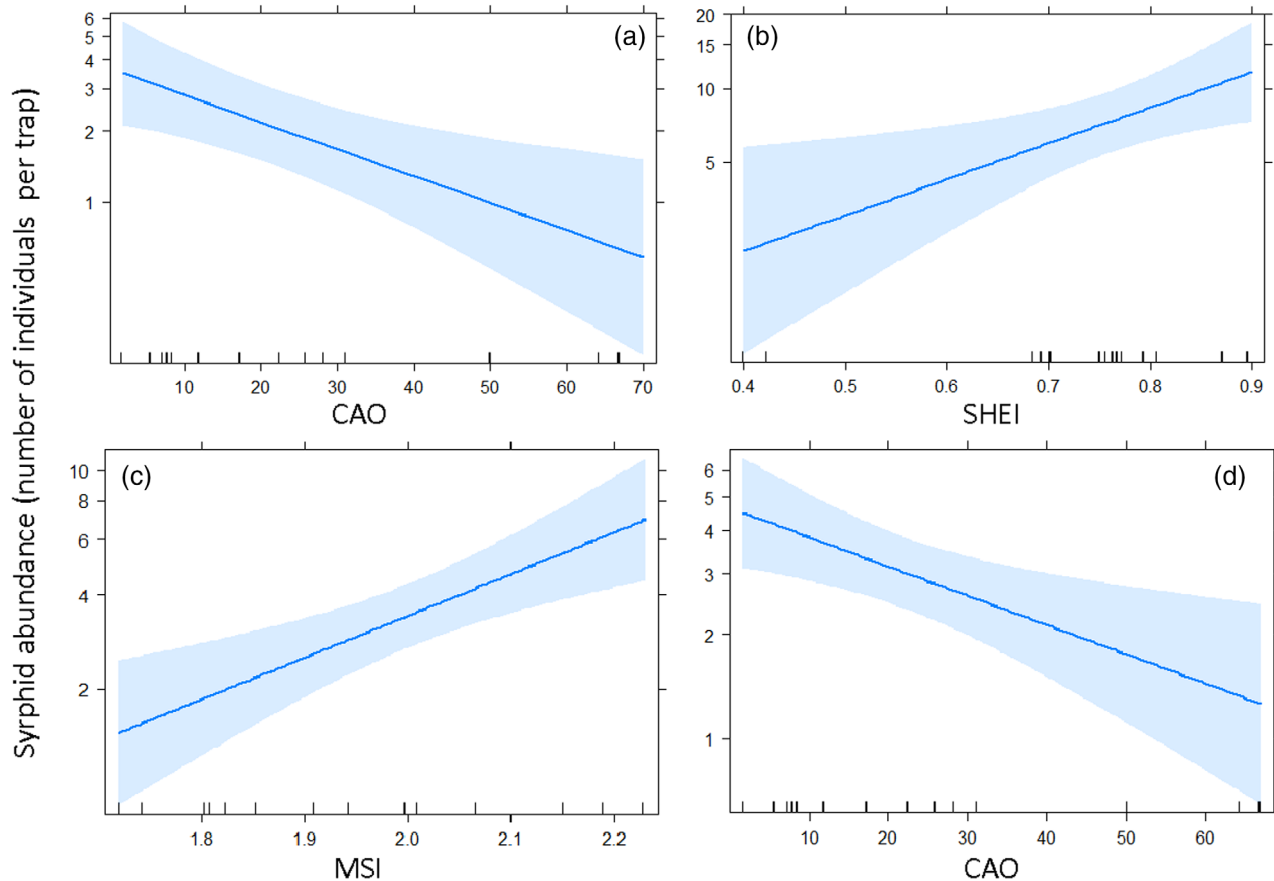


FIGURE 4 Effect of landscape structure on syrphid abundance in spring 2015 (a), spring 2016 (b), autumn 2015 (c) and autumn 2016 (d). Landscape indices were Olive grove area (CAO) and Shannon's Evenness Index (SHEI) and Mean Shape Index (MSI) calculated at 500 m buffer areas.

groves. A complex landscape with a diversity of land uses supports syrphids community better than a more homogeneous landscape dominated by olive groves, because wild land uses provide resources for syrphids. In the same study area, CAO had also a negative effect on other insects, such as bees, although the responses of the different families varied slightly (Pascual, 2022), lacewings (Neuroptera: Chrysopidae) (Pascual, Rescia, Ayca Ondul, Paul, & Ortega, 2022), or the ground beetle *Orthomus barbarus* (Dejean, 1828) (Lantero et al., 2019). On the other hand, simple landscapes, with olive grove predominance, were associated to higher richness of hymenopteran parasitoid families (Pascual, Rescia, et al., 2022) and higher abundance of the ground beetle *Pterostichus globosus* (Fabricius, 1792) (Lantero et al., 2019). The attack of *P. oleae* on olives was also positively related with the area of olive groves (Pascual, Ortega, & Villa, 2022), and in other study areas the abundance of *P. oleae* increased for higher percentages of surrounding olive groves (Alves et al., 2021). High CAO was associated also with higher abundance of the olive fruit fly, *Bactrocera oleae* (Rossi, 1790), in this (Ortega et al., 2022) and other study areas (Ortega, Pascual, & Rescia, 2016; Paredes et al., 2022). In other agroecosystems a higher crop percentage was also related to lower abundance of natural enemies or biocontrol (Gagić et al., 2011; Janković et al., 2017; Rusch et al., 2016). However, in the case of syrphids this is not always the

case, as for example it has been reported a parabolic relationship between syrphid abundance and richness and % raw crops (Mogren, Rand, Fausti, & Lundgren, 2016).

Other landscape structure indices affected also syrphids, but not as consistently and strongly as CAO. The effect of the area of scrubland (CAS) on abundance and species richness was positive in spring but negative in autumn. Scrubland is the main natural land use in the study area, and it was the parameter that most affected the abundance and richness of bee genera in the same study area, with a positive effect (Pascual, 2022). On the other hand, a negative relationship was observed with the abundance of the ground beetle *O. barbarus*, especially in autumn (Lantero et al., 2019) and also with the abundance of pirate bugs (Hemiptera: Anthocoridae) (Pascual, Ortega, & Villa, 2022). *B. oleae* abundance was also lower in complex landscapes with high CAS (Ortega et al., 2022). In other study areas, seminatural habitats surrounding olive groves affected also negatively the abundance of the olive moth, *P. oleae* (Costa et al., 2020). In other agroecosystems, landscapes with higher proportions of semi-natural areas usually have lower pest abundance and higher pest control (Rusch, Valantin-Morison, Sarthou, & Roger-Estrade, 2011; Veres, Petit, Conord, & Lavigne, 2013). Syrphid abundance increased with the proportion of natural habitat surrounding

TABLE 4 Response of syrphid species richness to landscape variables (at 250, 500, 750, 1000 and 1500 buffers), in spring and autumn 2015 and 2016 (GLMM with negative binomial distribution, olive orchard is the random factor).

		2015					2016				
		Fixed effect	Estimate	SE	z-value	p-value	Fixed effect	Estimate	SE	z-value	p-value
SPRING	GLMM for 250 m buffers	Intercept	0.927	0.263	3.527	<0.001	Intercept	-0.248	0.392	-0.633	0.527
		CAO	-0.086	0.031	-2.773	0.006	SHEI	1.694	0.464	3.651	<0.001
	Dropped variables	CAS; SHEI					CAS; CAO				
		GLMM for 500 m buffers	Intercept	0.858	0.219	3.917	<0.001	Intercept	-0.925	0.586	-1.579
	CAO		-0.024	0.008	-3.055	0.002	CAS	0.012	0.005	2.666	0.008
	Dropped variables	CAS; SHEI; MSI					CAO				
		GLMM for 750 m buffers	Intercept	0.874	0.206	4.239	<0.001	Intercept	0.650	0.153	4.261
	CAO		-0.012	0.004	-3.316	0.001	CAS	0.008	0.002	3.681	<0.001
	Dropped variables	SHEI					CAO				
		GLMM for 1000 m buffers	Intercept	0.892	0.203	4.406	<0.001	Intercept	1.439	0.127	11.336
	CAO		-0.007	0.002	-3.413	<0.001	CAO	-0.004	0.001	-3.357	<0.001
	Dropped variables	CAS					CAS				
GLMM for 1500 m buffers		Intercept	0.916	0.207	4.419	<0.001	Intercept	1.450	0.128	11.324	<0.001
	CAO	-0.004	0.001	-3.408	<0.001	CAO	-0.002	0.001	-3.399	<0.001	
Dropped variables	CAS; MSI; PR; SHEI					CAS; SHEI; MSI; PR					
	AUTUMN	GLMM for 250 m buffers	Intercept	0.647	0.149	4.337	<0.001	Intercept	1.505	0.262	5.738
CAO							CAO	-0.067	0.021	-3.118	0.002
CAS							CAS	-0.064	0.030	-2.121	0.034
Dropped variables	CAO; CAS; MSI					MSI; PR					
	GLMM for 500 m buffers	Intercept	-3.296	1.433	-2.300	0.021	Intercept	1.512	0.263	5.740	<0.001
CAO		-0.012	0.006	-1.838	0.066	CAO	-0.017	0.006	-3.072	0.002	
CAS		-0.020	0.009	-2.141	0.032	CAS	-0.017	0.007	-2.396	0.017	
MSI		2.414	0.759	3.180	0.002						
Dropped variables	SHEI					SHEI; MSI					
	GLMM for 750 m buffers	Intercept	-2.205	1.215	-1.815	0.067	Intercept	1.594	0.261	6.120	<0.001
MSI		1.4413	0.5966	2.416	0.016	CAO	-0.009	0.003	-3.324	<0.001	
CAS						CAS	-0.009	0.0039	-2.730	0.006	
Dropped variables	CAS; SHEI; PR					MSI; PR					
	GLMM for 1000 m buffers	Intercept	0.650	0.147	4.440	<0.001	Intercept	3.553	1.300	2.732	0.006
CAO						CAO	-0.002	0.001	-1.882	0.060	
MSI						MSI	-1.320	0.648	-2.038	0.042	
Dropped variables	CAO; CAS; MSI; PR					CAS; PR					
	GLMM for 1500 m buffers	Intercept	0.650	0.147	4.440	<0.001	Intercept	1.404	0.327	4.294	<0.001
CAO						CAO	-0.002	0.001	-1.978	0.048	
CAS						CAS	-0.001	0.000	-1.814	0.070	
Dropped variables	CAO; CAS; SHEI; MSI; PR					SHEI; MSI; PR					

Note: Bonferroni correction on the significance value was applied. Therefore, p -value = 0.01 is considered significant and p -values between 0.1 and 0.01 are considered only as weakly significant and is indicated in italic.

Abbreviations: CAO, olive grove area; CAS, scrubland area; MSI, mean shape index; PR, patch richness; SE, standard error; SHEI, Shannon's evenness index.

broccoli fields (Chaplin-Kramer, de Valpine, Mills, & Kremen, 2013). In neotropical agroecosystems, total syrphid abundance presented a non-clear pattern, but species richness was positively associated with the percentage of non-crop habitats (Medeiros et al., 2018).

However, lower syrphid abundance was associated with higher percentages of grass/pasture (Mogren et al., 2016).

Heterogeneous landscapes (measure through Shannon's Evenness Index - SHEI) did have a positive effect on syrphid abundance

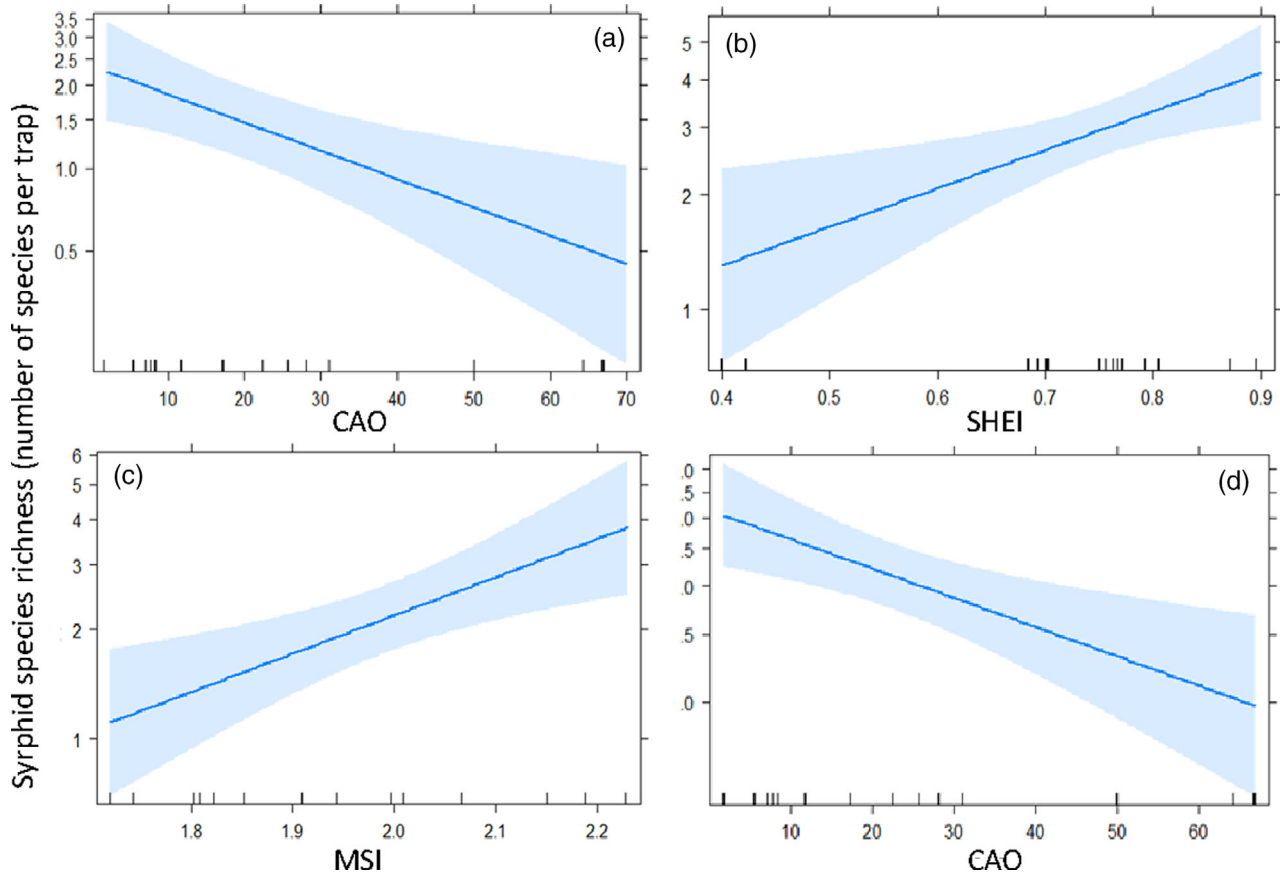


FIGURE 5 Effect of landscape structure on syrphid species richness in spring 2015 (a), spring 2016 (b), autumn 2015 (c) and autumn 2016 (d). Landscape indices were Olive grove area (CAO), Shannon's Evenness Index (SHEI) and Mean Shape Index (MSI) calculated at 500 m buffer areas.

and species richness. In this study, landscape heterogeneity was driven by the dominance of olive groves, other crops and shrublands. In the same study area, landscape diversity affected negatively richness of hymenopteran parasitoids, and abundance of the olive fruit fly, *B. oleae* (Ortega et al., 2022; Pascual, Rescia, et al., 2022). In addition, in other growing areas, diversity of land uses surrounding olive groves decreased *B. oleae* and *P. oleae* abundances (Alves et al., 2021; Ortega & Pascual, 2014; Villa et al., 2020, Villa et al., 2022). In apple orchards diversity of the surrounding landscape matrix had a marginal positive effect on the species richness of syrphids (Földesi et al., 2016) and landscape diversity had positive effects on syrphid abundance and species richness also in annual crops (Martin, Seo, Park, Reineking, & Steffan-Dewenter, 2016).

In addition to landscape composition indices (CAO, CAS, and SHEI), landscape configuration, measured using the mean shape index (MSI), affected syrphid abundance and species richness. Although this was not a consistent effect, it was more significant when high values of MSI were associated with high abundance and species richness, which is consistent with the general trend of a more complex landscape favouring syrphids in different agroecosystems (Burgio & Sommaggio, 2007; Fahrig et al., 2015; González et al., 2022; Haenke et al., 2014; Martin et al., 2016; Popov et al., 2017). In the same study

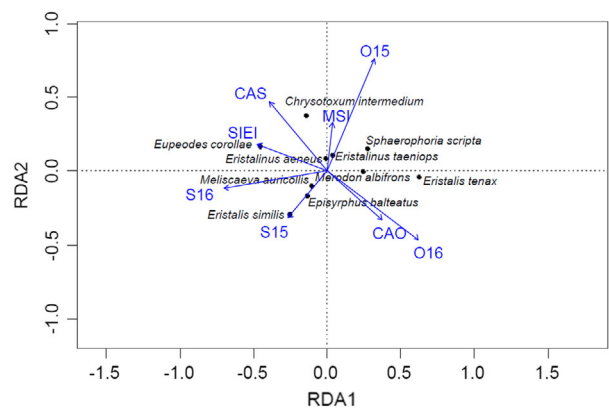


FIGURE 6 RDA plot of syrphid species by sampling period and landscape indices. Sampling periods: Spring 2015 (S15), Autumn 2015 (O15), Spring 2016 (S16), Autumn 2016 (O16). Landscape indices (calculated at 500 m buffer areas): Olive grove area (CAO), Scrubland area (CAS), Shannon's Evenness Index (SHEI) and Mean Shape Index (MSI).

area MSI affected also positively wild bees (Pascual, 2022); and negatively the olive moth, *P. oleae*, in another olive growing area (Villa et al., 2020).

Complex landscapes provide beneficial insects with food, refuge and alternative prey/host (Landis, Wratten, & Gurr, 2000) and this results in enhanced abundance and biodiversity in agroecosystems (Chaplin-Kramer, O'Rourke, Blitzer, & Kreme, 2011; Tschamtker et al., 2005). However, this general pattern varied in our study for different landscape indices, different years and seasons and different study radii. It is remarkable that the effect of CAS on syrphid abundance and species richness was positive in spring and negative in autumn, and this was especially detected in 2016. In addition, very many species of herbaceous plants are present in hedgerows, for example *Carduus bourgeanus* Boiss. & Reut., *Centaurea melitensis* L., *Sisymbrium runcinatum* DC., *Anthemis arvensis* L., *Mantisalca* sp., *Echium plantagineum* L., *Plantago lanceolata* L., *Silene vulgaris* (Moench.) Garcke, *Teucrium pseudochamaepitys* L., *Bellardia trixago* (L.) All., *Sisymbrium irio* L., *Crepis capillaris* (L.) Wallr., *Eryngium campestre* L. or *Malva sylvestris* L. In spring, these species are flowering and provide food for syrphids, boosting the growth of their populations and therefore favouring their presence in nearby olive groves. However, in autumn most of the herbaceous plants are dry, which makes the thicket an unfavourable habitat for syrphids, so their numbers in the nearby olive groves decrease. This effect is clearly noticeable in 2016, a year that according to the Spanish Agency of Meteorology (AEMET) was more humid than 2015 (http://www.aemet.es/es/serviciosclimaticos/vigilancia_clima/resumenes). In this year 2015, being drier, the positive effect of the scrublands in spring is not observed, and the negative effect in autumn is less evident than in 2016.

Regarding the different radii studied, in general, the effect of CAO is stronger at higher radii, while the effect of CAS is stronger at small-medium radii. Landscape heterogeneity has been shown to be beneficial for syrphids in the apple agroecosystem also at small radii, between 300 and 500 m (Földesi et al., 2016), and 800–900 m was the most predictive scale for measuring the effect of landscape configuration, diversity and seminatural habitat amount on syrphids in annual crops (Martin et al., 2016). We can hypothesize that the negative effect that the dominance of the olive grove has on the landscape on a large scale, can be counteracted in some way on a local scale by the plants that the scrubland provides. Linear elements (more abundant in high MSI landscapes) could also contribute to this effect, but our results are inconclusive in this regard. It would be necessary to carry out more in-depth research studying the flora of both the scrublands and the linear elements to confirm this hypothesis.

The RDA analysis allowed us to determine the extent to which the different syrphid species followed the general pattern of landscape structure. *C. intermedium* and *S. scripta* seems to be the species more associated with landscape complexity, indicated by CAS and SHEI, while *E. similis* appears more associated with simpler landscapes, indicated by CAO.

Villa et al. (2021) found that one specimen of *E. tenax* in olive groves and none in herbaceous and scrubby vegetation. However, they found *E. balteatus* preferentially in herbaceous patches, while in our case these species do not show remarkable patterns regarding the landscape. However, *S. scripta* was associated to the presence of

seminatural habitats and other crops in the surrounding vineyards landscape (Madureira, Rodrigues, Villa, & Pereira, 2022).

The RDA analysis showed also that some species were preferentially captured in spring, especially *E. corollae*, while *E. tenax*, *S. scripta* and *M. albifrons* correlated more with autumn. This does not agree with other studies reporting higher abundance of *S. scripta* in spring than in autumn (Villa, Santos, Lopez-Saez, et al., 2021), or *E. tenax* visiting olive flowers in spring (Canale & Loni, 2010). In addition, *E. corollae* and *E. balteatus* were the most abundant species collected in northeastern Portugal in olive groves and adjacent areas in autumn (Villa et al., 2016), while we found these species more associated with spring. There is evidence of high migration rates of *E. corollae* in relation to winds (Gao et al., 2020) and seasonal migrations (Wotton et al., 2019) that could explain the abundance of the species in spring. Different bioclimatic contexts probably account for these discrepancies, especially the differences in the species of plants that can provide food for syrphids, and their phenology in different areas. However, in spite of the possible different behaviour in relation to landscape and different phenology of syrphids in different olive agroecosystems, many species we found have been also found in other studies (Canale & Loni, 2010; Chafaa, Mimeche, & Chenchouni, 2019; Ricarte et al., 2011; Villa et al., 2016; Villa, Santos, Lopez-Saez, et al., 2021). In addition, many species are shared also with other Mediterranean agroecosystems (Burgio & Sommaggio, 2007).

Our study shows the importance of maintaining complex landscapes in the olive agroecosystem to favour the maintenance of syrphid populations, important providers of ecosystem services for olive cultivation but also for other crops and in general for well-balanced ecosystems.

AUTHOR CONTRIBUTIONS

M. Ortega: Conceptualization; investigation; methodology; writing – review and editing. **B. Matallanas:** Data curation. **A. Ricarte:** Data curation; conceptualization; methodology; writing – review and editing. **S. Pascual:** Conceptualization; investigation; funding acquisition; writing – original draft; methodology; validation; data curation; supervision; project administration; formal analysis.

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CONFLICT OF INTEREST STATEMENT

The authors declare that they have no conflict of interest.

DATA AVAILABILITY STATEMENT

Data available upon request to the authors.

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