Following the pest outbreak: preliminary findings on the landscape effect on *Dasineura oleae* and its parasitoids in central Italy

Malayka Samantha Picchi¹ · Elena Tondini · Nicola Albertarelli · Gaia Monteforti · Ruggero Petacchi¹

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Abstract *Dasineura oleae* (Angelini, 1831) (Diptera: Cecidomyiidae), the olive leaf gall midge, is a pest of olive crops that was not problematic in Italy until 2016 when a massive infestation of this pest was reported in a small region in central Italy. We identified infested olive orchards using farmers' reports and quantified the pest infestation level and parasitism rate in each field. We also explored the effect of the landscape on both the pest and parasitoids using the abundance of olive crops and semi-natural habitats and the Shannon index, estimated at four different scales (250 m, 500 m, 750 m and 1000 m buffers around the sampling points). The results showed

a small-scale effect on the parasitism rate and a large-scale effect on leaf infestation mediated by the Shannon Index. Moreover, some preliminary results showed that the parasitism rate was high in sites where plants associated with *D. oleae* parasitoids were present in the adjacent semi-natural habitat. Further studies are needed to validate our findings on the effect of landscape and vegetation on the natural enemies of *D. oleae* in order to develop new suppression strategies.

Keywords Olive leaf gall midge · *Platygaster demades* · Semi-natural habitat · *Erica* sp., conservation biological control

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M. S. Picchi (✉) · E. Tondini · G. Monteforti · R. Petacchi
Biolabs, Institute of Life Science, Scuola Superiore Sant'Anna, Via Alamanni 22, San Giuliano Terme, 56127 Pisa, Italy
e-mail: m.picchi@santannapisa.it

E. Tondini
e-mail: elena.tondini@live.it

G. Monteforti
e-mail: g.monteforti@santannapisa.it

R. Petacchi
e-mail: r.petacchi@santannapisa.it

N. Albertarelli
Via canaletto 16, Castelnuovo Magra, 19033, La Spezia, Italy

Introduction

Dasineura oleae (Angelini, 1831) (Diptera: Cecidomyiidae), commonly known as the olive leaf gall midge, damages to young leaves and flower buds (Barnes, 1948), however in several Mediterranean countries, it has always been considered as a minor pest of the olive tree (*Olea europaea* L.). The characteristics of this pest have thus never been extensively investigated and the literature on this topic is scarce. In Italy, this pest was not problematic until 2016, when several outbreaks were officially registered (Picchi et al., 2017).

In the following years, the infestation spread unevenly, in the southern part of Tuscany (central

Italy), particularly throughout the province of Grosseto (Petacchi et al., 2019; Picchi et al., 2017; Tondini & Petacchi, 2019).

Through field observations, farmers and technicians reported that the pest is abundant in the countryside. Outbreaks have recently become common in the Mediterranean basin, leading to an increase in olive leaf gall midge case studies (Doğanlar et al., 2011; Batta, 2019; Batta & Doganlar, 2020). However, apart from these studies, there is a little knowledge about *D. oleae* and there are no studies on the effect of this phytophagous insect on the olive yield.

On the other hand, results of Caselli et al. (2020) suggested that the pest may alter leaf morphology and influence some physiological activities of olive leaves related to photosynthesis performance. Other recent studies have explored the life cycle and the parasitoid complex of *D. oleae*.

The pest develops two generations every year: one in spring and one in autumn according to the favourable climatic conditions of coastal zones and spends the summer period as a second instar larva. During this period, some parasitoids may develop at the expense of the pest.

The natural enemies of *D. oleae* in Italy consist of four species of koinobiont endoparasitoids (Tondini & Petacchi, 2019). Two species of parasitoids belong to the family of Pteromalidae (*Mesopolobus aspilus* (Walker, 1835) and *Mesopolobus mediterraneus* (Mayr, 1903)), whereas the other two are Platygasteridae wasps (*Platygaster demades* Walker 1835 and *Platygaster oleae* Szelenyi 1940). Only *P. oleae* is a specific parasitoid of *D. oleae*. Both Pteromalidae and Platygasteridae include species that are effective control agents of many Cecidomyiidae species. (He & Wang, 2011; Roubos & Liburd, 2013; Sampson et al., 2002).

A survey of the current pest status and natural enemies may provide useful information for defining guidelines for Integrated Pest Management (IPM) (Barzman et al., 2015). In addition, pest trends and its natural enemies can provide broader information on the effect of crop-pest synchrony in the long term (Haynes et al., 2014) as well as the dispersal probability, temperature tolerance and preference of its parasitoids (Chaianunporn & Hovestadt, 2015) and the effect of the composition and configuration of the landscape. In fact, pest outbreaks and pest control by natural enemies have very strong links to landscape

patterns and are not just dependent on local conditions in the field (With et al., 2002).

The arthropods of cultivated fields are influenced by the surroundings habitats. Favorable local and landscape conditions with specific ecological traits can enhance predators and parasitoids and can lead to higher rates of pest suppression (Bengtsson et al., 2005; Bianchi et al., 2006; Haan et al., 2020; Happe et al., 2019; Tschumi et al., 2016). Usually, a high proportion of semi-natural habitats (hereafter “SNH”) benefit natural enemies (Chaplin-Kramer & Kremen, 2012 but see Tscharncke et al., 2005; Hawro et al., 2015) and an increase in the complexity of the landscape corresponds to a greater parasitism in the crop (Cronin & Reeve, 2005) however the biological control could also depend on the taxon-specific mobility and dispersal capacity of pests and natural enemies (Gallé et al., 2019; Happe et al., 2019; Schweiger et al., 2005).

Indeed, SNH provides natural enemies with resources such as alternative hosts or/and overwintering shelters. *D. oleae* parasitoids, except *P. oleae*, are oligophagous or polyphagous. It is therefore likely that vegetation adjacent to olive orchards hosts several plant species associated with alternative hosts (hereafter “associated plants”). Also, *M. mediterraneus* and *M. aspilus* are polyphagous parasitoids and hyperparasitoid that attack numerous Cecidomyiidae (Askew et al., 2001; Del Bene & Landi, 1993; Doğanlar, 2011; Graham, 1969) and several species belonging to different insect orders (Askew et al., 2013; Gomez et al., 2006; Herting & Simmonds, 1973, 1975; Öncüler, 1991; Vidal, 1997; Viggiani, 1967).

These hosts are associated with plants such as *Quercus* spp. and *Clematis vitalba* (Askew et al., 2013; Gomez et al., 2006; Xiao et al., 2016). *Platygaster demades* is an oligophagous parasitoid that attacks *D. oleae*, *Dasineura pyri* (Bouché, 1847), *Dasineura mali* (Kieffer, 1904) and *Wachtliella ericina* (Low, 1885), associated with *O. europaea*, *Malus domestica* (Suckow) Borkh (1803), *Pyrus communis* subsp. *pyraster* (L.) Ehrh. and *Erica* spp., respectively.

In this paper, we estimated the infestation level of *D. oleae* by evaluating the number of galls per infested leaf as an indicator of the intensity of the pest attack and the leaf infestation rate as the indicator of the extent of the infestation and it was used to assess the effect of the landscape. We also, we calculated the

effect of parasitoids, based on the parasitism rate. We then provided farmers with management guidelines based on the number of galls per infested leaf in combination with the parasitism rate.

We carry out a preliminary investigation of the effects of landscape characteristics on the leaf infestation rate and parasitism by measuring the landscape composition (i.e. the proportion of olive orchards and proportion of SNH) and diversity (i.e. Shannon index “SH”, richness of the different land cover classes in the landscape) at four spatial scales (250 m, 500 m, 750 m, and 1000 m radius) around the sampling sites.

Finally, we obtained preliminary data on the effect of the associated plants on the biological control of *D. oleae*.

Materials and methods

The study area

The survey was carried out in the province of Grosseto, a coastal area of southern Tuscany (central Italy). The area covers 5000 km² and 25% of its territory is defined as “Utilised Agricultural Area” (UUA) (Regione Toscana, 2012). Olive orchards occupy 14, 5% of the land, which are generally small fields (Maselli et al., 2012). The province of Grosseto produces 20% of the olive oil and hosts 19% Tuscany’s oil mills (ISMEA, 2018).

The climate is typically Mediterranean with dry and hot summers (“Csa” type according to the Köppen–Geiger classification (Peel et al., 2007)), average annual rainfall of 730 mm/year and the lowest rainfall in in July (5 mm). February is the coldest month with a mean minimum of 0° C and July is the hottest with a mean maximum of 32° C (Vallebona et al., 2015).

Grosseto is the driest and warmest area of Tuscany, with long periods of summer drought and it is therefore more suitable for olive growers rather than other crops, since olive have physiological mechanisms that confer resistance to drought stress (Sofo et al., 2008).

Monitoring of *Dasineura oleae* and its parasitoids

The sampling points were olive orchards selected from a database of local reports of *D. oleae* infested sites and considering the olive land use. Initially, we

collected information on infested fields in previous years from providers of extension services and consortiums in the province (OLMA, Terre dell’Etruria, Consorzio Agrario del Tirreno). Their data came from visual inspection of *D. oleae* infestations and they also provided GPS coordinates and an approximate estimation of the level of infestation. We, then calculated the size of the area dedicated to olive orchards using the “Utilised Agricultural Area” (UUA) value for each municipality. Finally, we drew up a list of 24 representatives for infested olive orchards for our study (Fig. 1A).

Many farmers use dimethoate against the olive fruit fly (*Bactrocera oleae*, Rossi 1970; Diptera Tephritidae) in the summer however, during the period of sampling and in previous years, no treatments were applied against the olive leaf midge.

In the proximity of the middle of each field, we performed a transect starting from the third row of the edge toward the centre of the field to minimize the edge effect and spillover from adjacent fields. We sampled six trees, choosing one tree every two, within the transect.

Four sprigs were collected from each tree, one from each cardinal direction at *circa* 1.5 m height consisting of the eight apical nodes of the branch, in order to collect the last growth of the plants and therefore, the last generation of *D. oleae*.

In the laboratory, we counted the number of leaves, the number of infested leaves and the number of galls in each sample (branch). For each olive orchards, we calculated the percentage of infested leaves (“leaf infestation rate”), the ratio between the number of galls and the number of infested leaves (“galls per infested leaf”). Then, samples of galls were dissected under the stereomicroscope (Tondini & Petacchi, 2019). The number of galls dissected per sample was randomly chosen in infested leaves and ranged from a minimum of one gall (if the number of galls did not reach 10) to a rounded figure of 10% of the galls in leaves of each sprig collected. The parasitism rate was calculated as the relative abundance of parasitoids on the number of galls inspected (Tondini & Petacchi, 2019).

Olive orchards were visited between 26 March and 3 April 2019, which was the last period available before the emergence of pest and parasitoids. During this period, *D. oleae* develops into the third instar

Fig. 1 **A** Map of the 24 olive orchards considering during the survey on *Dasineura oleae*. The olive orchards were located in the province of Grosseto (central Italy). **B** Landscape patterns

of focal fields (4, 7 18 and 24), at 250 m buffer, in which the botanical composition in the adjacent SNH was evaluated

stage and parasitisation become evident (Tondini & Petacchi, 2019).

Landscape metrics and vegetation sampling

The landscape analysis was performed using QGIS 3.8.2 Zanzibar (QGIS Development Team, 2019). We evaluated the land-use of the 24 fields in four concentric buffers with radii of 1000 m, 750 m 500 m and 250 m buffer, nested around each olive orchard. The land-use classes were obtained from the Geoscopia WebGIS Service of Tuscany region (Regione Toscana, 2020). The types of land-use belong to five classes: excluding olive orchards and SNH, construction land, annual crop and other types of orchards were considered.

The abundance of olive orchards and SNH land use were calculated for each buffer and were used as estimators of landscape composition. In addition, we evaluated the spatial diversity of each buffer through the SH index. This index considers the proportional abundance of each habitat type

with the highest value for the smallest amount of land-use dominance (McGarigal et al., 2012).

We collected preliminary data on plant assemblages in the SNH surrounding the olive orchards. To do this, we chose four fields to represent the combination of two levels of abundance of SNH in the 250 m buffer (high and low) and two levels of parasitism (high and low).

The landscape models in 250 m buffers around these fields are shown in Fig. 1B. The spontaneous vegetation in SNH was sampled with three transects of 100 m at five different distances (0 m, 25 m, 50 m, 75 m, 100 m), starting from the edge with olive orchard towards the field. In each site, the transects were perpendicular to the olive orchards and parallel between them. The abundance of both associated plants and “non-associated plants” (i.e. plant species not associated with alternative hosts of parasitoids) was evaluated by visually assessing the percentage cover of each species in a 250 m buffer around each sampling point.

Statistical analysis

All the analyses were performed with R software (R Development Core Team, 2016). First, we ensured that 1000 m buffers did not overlap more than 10% in order to guarantee statistical independence (Stefan-Dewenter, 2002). We checked the collinearity among landscape variables through the function “pair.panels” (psych package; Revelle, 2020).

The effect of landscape factors (olive orchards abundance, SNH abundance and SH index) on the leaf infestation and parasitism rate were estimated through Generalized Linear Models using a binomial distribution (Zuur et al., 2009). Since overdispersion was detected, we corrected the standard errors using a quasi-binomial model for each scale. The interaction between the abundance of olive orchards, SNH and SH index was evaluated in the models. The minimum adequate model was selected by a backward selection using the “drop” function in the package “stats” (Chambers, 1992; SM1). Significant variables according to GLMs were also tested by exploring landscape traits of sites by a K-means partitioning. Which was carried out using the values of the landscape indices described above.

The optimal number of clusters was assessed using the Elbow method based on the sum of the square for each cluster (Zhang et al., 2016) and the characteristics of each cluster were evaluated graphically (package ggraphExtra: Moon, 2018).

We estimated differences in the parasitism rate among clustered sampling sites using Generalized Linear Models. The parasitism rate was used as the response variable and landscape factors the explanatory variables. A binomial distribution of the data was assumed.

The model was tested against a null model and χ^2 and p - values were obtained by likelihood tests.

Estimated marginal means and standard errors were obtained with the function “emmeans” (emmeans package: Lenth, 2020) and post-hoc Tukey tests were performed with “multcomp” (Hothorn et al., 2008).

To visualize the association between plant species type (“associated” or “non-associated”) and sampling sites we calculated the average cover of each plant species for each sampling site (sites 4, 7, 18 and 24). Then we performed a correspondence analysis (CA) using the packages “FactoMineR”

(Lê et al., 2008) and “factoextra” (Kassambara & Mund, 2019).

In the CA, *O.europaea* was not considered because it is not attacked by other insect species that are potential hosts for parasitoids, apart from *D. oleae*.

Results

Infestation and parasitism rates

We found that the mean number of infested leaves out of the total number of leaves sampled was 23%, with the highest value being 71%. Only 3 out of the 24 olive orchards had more than 50% of leaves infested. The average number of galls per infested leaf was 1.77 and the infestation range varied from 1 to 3.24 galls per infested leaf. The average parasitism value was 15.8% with the parasitism rate ranging between 0.0% and 43.75%. Parasitoids were absent in samples from three olive orchards. The results of each olive orchard are reported in Table 1.

The landscape effect

GLMs showed significant effects at 250 m, 750 m and 1000 m buffer, as reported in Fig. 2. At the 250 m scale, the parasitism rate increased as the SH index increased (Fig. 2A). This positive effect was then explored by multivariate analysis. The cluster analysis showed four distinct clusters (Fig. 3A and B), characterized by: high landscape diversity; low landscape diversity with a high proportion of olive orchards and SNH; high olive orchard abundance and a cluster that showed both a low abundance of olive orchards and SNH, and low landscape diversity (“Mixed land-use”).

GLM underlined a significant difference between clusters ($p=0,003$). Using a post-hoc test, we then explored the differences between clusters (Fig. 3C) highlighting the positive effect of landscape diversity on the parasitism rate. No significant effect of the tested landscape variables was detected at the 500 m, 750 m and 1000 m buffers for the parasitism rate. On the other hand, the infestation rate showed a crossover interaction between the landscape variables at 250 m, and a significant increase of infestation as the diversity increased in large buffers, at 750 m and 1000 m (Fig. 2B and C), however it

Table 1 Characteristics of the sampling sites, with geographical coordinates and meters above sea level (m.a.s.l.)

ID site	Latitude	Longitude	m.a.s.l	infestation rate	Parasitism rate	Total Parasitoids	Total galls	Total dissected galls	% of dissected galls	Number of samples with one gall dissected	Mean number of dissected galls	SD	Galls/infested leaf
1	42.4303306	11.4337197	40	0.714	0.096	8	819	83	10.13	1	3.45	2.04	3.10
2	42.7885200	11.2292240	40	0.204	0.250	6	92	24	26.09	24	2.21	1.38	1.21
3	42.8928080	11.2170970	165	0.091	0.125	2	52	16	30.77	14	2.83	2.20	1.63
4	42.5661800	11.3767946	50	0.039	0.000	0	20	11	55.00	4	1.21	0.66	1.43
5	42.6452386	11.5062583	190	0.158	0.222	6	75	27	36.00	9	0.25	0.44	1.29
6	42.6576772	11.3991171	210	0.138	0.421	8	78	19	24.36	17	0.54	0.51	1.53
7	42.8503419	11.1089940	65	0.091	0.438	7	41	16	39.02	16	0.54	0.51	1.24
8	42.8032499	11.1496279	50	0.455	0.108	4	362	37	10.22	5	0.83	0.87	2.00
9	42.5564064	11.4117549	120	0.594	0.324	24	551	74	13.43	3	0.92	1.21	2.67
10	42.4368320	11.3756149	25	0.511	0.278	15	527	54	10.25	5	1.04	0.20	2.61
11	42.7606829	11.2556789	120	0.080	0.286	4	39	14	35.90	13	1.17	1.34	1.39
12	42.8033059	11.2074170	60	0.088	0.143	3	56	21	37.50	18	0.88	0.45	1.60
13	42.8301040	11.3064839	130	0.066	0.077	1	25	13	52.00	13	0.79	0.51	1.00
14	42.6393049	11.1280320	30	0.474	0.118	4	278	34	12.23	12	0.96	0.69	2.16
15	42.7939090	11.2768309	100	0.135	0.050	1	71	20	28.17	19	1.38	0.97	1.34
16	42.8276909	11.1889829	125	0.384	0.025	1	317	40	12.62	5	0.96	1	2.13
17	42.8677419	11.1483059	110	0.140	0.048	1	84	21	25.00	18	0.67	0.48	1.65
18	42.8919520	10.9283089	110	0.293	0.037	4	957	107	11.18	7	0.92	0.50	3.24
19	42.9166555	11.0178649	50	0.192	0.000	0	115	21	18.26	21	1.25	0.74	1.67
20	42.9852684	10.9389858	100	0.085	0.000	0	44	13	29.55	13	0.58	0.88	1.42
21	42.7160279	11.1733059	80	0.043	0.154	2	24	13	54.17	13	1.25	0.68	1.14
22	42.5733380	11.4680560	200	0.469	0.125	5	364	40	10.99	8	1.5	1.32	2.09
23	42.5447332	11.4365112	100	0.178	0.143	2	105	14	13.33	5	0.46	0.83	1.54
24	42.6018329	11.2507330	45	0.028	0.170	1	14	6	42.86	6	0.38	0.49	1.40

The leaf infestation rate and parasitism rate were reported for each site. Moreover, results of the samplings were reported using the number of parasitoids sampled, the total number of galls, the number and percentage of galls dissected, the number of samples (branch) with one galls dissected, the mean number of dissected galls and standard deviation (SD) and the number of galls per infested leaves

Fig. 2 Effect of Shannon landscape diversity index (SH), with confidence intervals of 95% on **A** the parasitism rate on *D. oleae* at the 250 m scale buffer ($F_1=7.65$, p value=0.011) **B** the leaf infestation rate by *D. oleae* at the 750 m scale buffer ($F_1=5.18$, p value=0.032) and **C** the leaf infestation rate by *D. oleae* at the 1000 m scale buffer ($F_1=11.93$, p value=0.002)

was not possible to explore the characteristics of the sites in more detail due to clustering problems.

There were not enough sites to divide olive fields according to the variables chosen.

The analysis of the vegetation profile

Fields were selected corresponding to four combinations of the SNH abundance and parasitism rate, respectively. Site 7 corresponds a high abundance of SNH (37.67%) and high parasitism rate (43.75%); site 18 to a high abundance of SNH (32.35%) and low rate of parasitism (5%), site 24 to low abundance of SNH (16.58%) and high rate of parasitism (16.67%) and site 4 to a low abundance of SNH (17.65%) and low rate of parasitism (0.0%).

Analyses of the vegetational composition revealed the presence of 28 plant species in the adjacent vegetation, of which seven species were associated with alternative hosts of the parasitoids complex of *D. oleae* (Table 2).

Quercus sp. was the only species found in site 18 (high SNH-low parasitism rate), while site 4 (low SNH-low parasitism rate) hosted *Quercus* sp. and also *C. vitalba*.

Regardless of the composition of the landscape, the other two fields with a high parasitism rate hosted three and five associated plant species, respectively. Besides olive and oak trees, *Erica* sp. and *P. communis* subsp. *pyraster* were in the surrounding of the two fields, which are both plants associated with alternative hosts of *P. demades*.

Considering the associated plant cover, sites with a high parasitism rate had a high cover of associated species in the adjoining vegetation, while sites with low parasitism rate had a low cover of associated plant species. Notably, site 7 had a parasitism rate of 44% and hosted in 75.3% of the *Erica* sp.

The results of the correspondence analysis (Fig. 4) show that dimensions 1 and 2 explain 85.96% of the total variance. *Rubus ulmifolius* Schott, *Erica* sp. and *Quercus* sp. contributed the most to the definition of dimensions 1 and 2. Considering the associated species, site 7 was associated with *Erica* sp. and *Quercus suber* L. The presence and abundance of *Quercus ceris* L., *Pyrus communis* subsp. *pyraster* and *Quercus* sp. were related to site 24. Site 4 was associated with *C. vitalba* L. and *Quercus* sp. and site 18 with the presence of *Quercus ilex* L. subsp. *ilex*.

Fig. 3 The cluster analysis of the parasitism rate on *D.oleae* in the 250 m scale buffer: **A** the olive fields as clustered by environmental variables; **B** the structure of each cluster using environmental variables: abundance of olive (OL) abundance

of semi-natural habitat (SNH) and Shannon landscape diversity index (SH); **C** The boxplot of the parasitism rate for each cluster, considering the average value. In addition, the Tukey post-hoc results are reported

Discussion

Dasineura oleae always used to be considered a minor pest in olive orchards. Consequently, the influence of biotic and abiotic factors on this pest and its natural enemies as well as the effects on plant physiology and yield have never been thoroughly investigated. In this study, we assessed the infestation and the parasitism rate in 24 olive orchards in an outbreak area in Italy. Our aim was to understand the significance of several environmental factors by analysing preliminary findings of the effect of landscape on both leaf infestation by the olive leaf gall midge and parasitism rate. In addition, we investigated the importance of the plant assemblages in the surroundings SNH in terms of improving the biocontrol of *D.oleae*.

The average leaf infestation rate was lower than had been estimated in 2017 in the same area (Tondini & Petacchi, 2019), although some orchards had a severe infestation with more than 50% of infested leaves. In Turkey, Doğanlar et al. (2011) reported an average leaf infestation rate of 15% and the average parasitism rate of 66.2% consisted mostly of *Eurozonus*. On the other hand in Palestine, they found an average rate of 36.4% of leaf infestation and an average parasitism rate of 35.6% with the dominance of *P.oleae* (Batta & Doganlar, 2020). These

authors suggest that differences could be linked to the elevation of the olive orchards considered in their study.

Our preliminary findings showed a landscape effect mediated by the diversity of the land cover. The parasitism rate was significantly influenced by the SH index only at the smallest scale which was confirmed by the multivariate analysis and a post-hoc approach. These findings support the hypothesis that parasitoids, with their limited body size, do not travel far (Kruess & Tschamtker, 1994, 2000; Ritchie & Olff, 1999).

In addition, we observed that the parasitism is also high in clusters characterized by a high abundance of olive orchards, where parasitoids may find the olive leaf gall midge during the season.

Landscape diversity is the main driver of the effectiveness of natural enemies because diverse habitats support different natural enemy assemblages (Bianchi et al., 2006; Redlich et al., 2018). In fact, this could lead to an increasing rate of pest suppression (Greenop et al., 2018; Griffin et al., 2013; Letourneau et al., 2009). Different habitat types provide different resources and, in the case of parasitoids with multiple hosts living on different plant species, food availability can be a key factor in the population dynamics of a parasitoid-host system (Wackers, 2002).

Table 2 List of plant species sampled in sites 4,7,18 and 24 during the survey on *Dasineura oleae*

Families	Plants	Alternative host plants species	Parasitoids						CA code
				ID 4	ID 7	ID 18	ID 24	Notes	
Anacardiaceae	<i>Pistacia lentiscus</i> L								Pi_len
Asparagaceae	<i>Asparagus acutifolius</i> L							Naturalized	As_acu
	<i>Ruscus aculeatus</i> L								Ru_acu
Cistaceae	<i>Cistus</i> sp.								Ci_sp
Ericaceae	<i>Arbutus unedo</i>								Ar_une
	<i>Erica</i> sp.	X	<i>Platygaster demades</i> (Walker, 1835)		x		x		Er_sp
Fabaceae	<i>Robinia pseudoacacia</i> L							Invasive	Ro_pse
	<i>Spartium junceum</i> L							Naturalized	Sp_jun
	<i>Cytisus spinosus</i> (L.)								Cy_spi
Fagaceae	<i>Quercus cerris</i> L	X	<i>Mesopolobus mediterraneus</i> (Mayr, 1903)				x		Qu_cer
	<i>Quercus ilex</i> L. subsp. <i>ilex</i>	X	<i>Mesopolobus mediterraneus</i> (Mayr, 1903)				x		Qu_ile
	<i>Quercus</i> sp.	X	<i>Mesopolobus mediterraneus</i> (Mayr, 1903)	x		x	x		Qu_sp
	<i>Quercus suber</i> L	X	<i>Mesopolobus mediterraneus</i> (Mayr, 1903)		x			Alien	Qu_sub
Lamiaceae	<i>Lavandula stoechas</i> L. subsp. <i>stoechas</i>								La_sto
Lauraceae	<i>Laurus nobilis</i> L							Naturalized	La_nob
Myrtaceae	<i>Myrtus communis</i> L								My_com
Oleaceae	<i>Fraxinus ornus</i> L. subsp. <i>ornus</i>								Fr_orn
	<i>Phillyrea</i> sp.								Ph_sp
Poaceae	<i>Arundo donax</i> L							Invasive	Ar_don
Ranunculaceae	<i>Clematis vitalba</i> L	X	<i>Mesopolobus mediterraneus</i> (Mayr, 1903)	x					Cl_vit
Rhamnaceae	<i>Paliurus spinachristi</i> Mill							Naturalized	Pa_spi

Table 2 (continued)

Families	Plants	Alternative host plants species	Parasitoids	CA code				
				ID 4	ID 7	ID 18	ID 24	Notes
Rosaceae	<i>Crataegus monogyna</i> Jacq							Cr_mon
	<i>Pyrus communis</i> subsp. <i>pyraster</i> (L.) Ehrh	X	<i>Platygaster demades</i> (Walker, 1835) <i>Mesopolobus mediterraneus</i> (Mayr, 1903)		x		x	Py_pyr
	<i>Rosa canina</i> L							Ro_can
	<i>Rubus ulmifolius</i> Schott							Ru_ulm
Santalaceae	<i>Osyris alba</i> L							Os_alb
Smilacaceae	<i>Smilax aspera</i> L							Sm_asp
Ulmaceae	<i>Ulmus</i> sp.							Ulm_sp
Viburnaceae	<i>Sambucus</i> sp.							Sam_sp
Total	18	30	7		2	3	1	5
% Olive orchards				19.03%	43.81%	56.31%	9.59%	
% SNH				17.65%	37.67%	32.35%	16.58%	
Parasitism Rate				0%	43.75%	5%	16.67%	
Host Plant Cover				2.3%	82.13%	22.46%	63.2%	
Cover <i>Pyrus communis</i> subsp. <i>pyraster</i>				0%	0%	0%	1%	
Cover <i>Erica</i> sp.				0%	75.3%	0%	4.6%	

Species known to be plants associated with alternative hosts of parasitoids from the literature are cross-checked. Indeed, for each sampling sites we reported plants that were sampled in the 250 m buffer. There are also notes and codes associated with the CA (Fig. 4). Below the percentage of the abundance of olive and semi-natural habitats (SNH) with the parasitism rate and the cover of associated plants are reported. The percentage cover of *Erica* sp. and *Pyrus communis* subsp. *pyraster* was indicated as they are associated with alternative hosts of *Platygaster demades*

In addition, our preliminary results on the composition of adjacent vegetation suggested that, from the parasitoid perspective, the diversity of the landscape seems more relevant than the amount of SNH. The four fields consisted of different vegetation assemblages, as shown in the CA, and where *Erica* sp. was sampled. and, to a lesser extent *P. communis* subsp. *pyraster*, the parasitism rate was found to be high, regardless of the composition of the landscape. *Erica* sp. was present in both fields with a high abundance of parasitoids and where the parasitism rate reached 44% the highest cover of *Erica* sp. was found.

These plants are both attacked by alternative hosts of *P. demades*, such as *Wachtliella ericina* (Low, 1885), a gall-inducing insect of Ericaceae (Ghahari

& Buhl, 2011; Skuhrava & Skuravy, 1994) and *Dasineura pyri* (Bouchè, 1847), the pear leaf midge.

Tondini et al. (unpublished results) used Malaise traps to evaluate the species and the abundance of parasitoids of *D. oleae* in olive orchards in the same province. These authors highlighted that *P. demades* was the most abundant olive leaf gall midge parasitoid.

Although the data refers to a simple combination of a limited number of fields, we hypothesized that the presence of *Erica* sp. in the proximity of the olive field is essential to support the population of *P. demades* hosted in *Erica* sp. in the adjoining vegetation, may quickly colonize olive orchards when the *D. oleae* population increases.

Fig. 4 Correspondence analysis of the vegetation composition of focal olive orchards. Plants associated with alternative hosts of the parasitoids of *Dasineura oleae* are showed in red. The legend can be found in Table 2 “CA code” column

Parasitoids can also be able to find chemical cues to the host location. First, they use general cues emitted by different plant species in the host habitat and then intercept specific cues to accurately locate the host (Meiners, 2015, Silva & Clarke, 2020). Different habitats with wild or cultivated species may therefore promote the abundance of parasitoids and affect their effectiveness on *D. oleae* galls.

Unexpectedly, a significant effect of the SNH abundance on the pest was not found in our study, despite it is usually being an important factor for pest control. The review made by Veres et al. (2013) highlighted that high proportions of semi-natural areas exhibited a low pest abundance in adjacent crop fields.

Usually, non-crop perennial habitats provide alternative resources that sustain the natural enemy assemblage. Further case studies would provide a more reliable conclusions regarding this issue.

At the 750 m and 1000 m buffer scale, the leaf infestation increased as the diversity of the landscape increased. We expected the leaf infestation to increase where olive orchards were most abundant since, to our knowledge, *D. oleae* has no alternative host plant and spends the entire life cycle in the crop. In addition, currently there is no specific pesticide formula against olive leaf gall midge. The relationship

between olive orchards abundance and the pest should therefore have been positive. The availability of food resources is one of the major driver of many pests (Power, 1992). However, we found that land cover diversity supported a high level of olive leaf infestation. A complex landscape may favour not only natural enemies but also the pest aphid population as found in cereal crop by Thies et al. (2005), leading to an overall neutral effect of the landscape on the biological control.

Apart from the need for further data validation, other factors may help to explain this. One hypothesis is that due to an increase of the land diversity, the natural enemy population may steer other organisms, or rather become prey or hyperparasitized, thus less effective at large scale (Rosenheim, 1998). This situation then benefits the olive leaf gall midge.

Frere et al. (2007) call this situation “apparent mutualism”: if predators become satiated by higher densities of one alternative prey species, then a second prey species may benefit from the presence of the first, and therefore the pest may benefit from the lack of spillover inside cultivated fields. Besides, by its complex structure, olive orchards may not be affected by spillover of functional diversity from the outside (Albertini et al., 2017; Picchi et al., 2016, 2019).

We do not want to rule out other factors that could mask some important environmental variables. Further analysis over time and space is thus needed to understand better how the effect of the landscape depends on other abiotic factors such as temperature, rainfall, photoperiod or other variables related to the development of the olive tree, in addition to the role of complementary local scale variables that strictly depend on the traits of pest and of the natural enemies community. In fact, some land use variables may not completely capture the specific ecological prerequisites of such organisms (Aartsma et al., 2020). We also found a small-scale crossover effects on the infestation rate but not an overall effect of single variables. The role of the landscape on the olive leaf gall midge needs more investigation. Our preliminary results suggest that both pest leaf infestation and parasitism rate are influenced by the landscape diversity and that some plant species associated with alternative hosts of *D. oleae* parasitoids are related to a high rate of parasitism.

In addition to these findings, we would like to highlight the importance of the farmers' reports in assessing the current pest trends.

The collaboration between the farmers and scientists, contributes to the establishment of a sensitive landscape management. This approach may help preserve natural enemies, improves the reliability and effectiveness of the pest suppression service in order to prevent or reduce the severity of pest outbreaks.

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Author contributions MSP and RP designed the survey. MSP, GM collect the leaves and inspected galls, NA made the vegetation samplings and landscape analysis. ET analysed data. MSP wrote the manuscript. All authors read and approved the manuscript.

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Declarations

Conflict of interest The authors have no relevant financial or non-financial interests to disclose.

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