

Article

Shedding Light on *Dasineura oleae* Parasitoids: Local and Landscape Effects

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Abstract: *Dasineura oleae* was considered a minor pest in olive orchards. However, in the last decade, outbreaks have been reported all over its distribution area. Little is known about *D. oleae* biological control strategies; therefore, investigations into the biology and ecology of *D. oleae* parasitoids are urgently needed. In this scenario, the present field study reported the flight period of *D. oleae* parasitoids, evaluating their relative abundance over other parasitoids living in olive orchards. Furthermore, it estimated the effect of local and landscape features on *D. oleae* parasitoids within the frame of the overall parasitoid community. Lastly, we aimed to provide useful insights into the effectiveness of parasitoids for *D. oleae* population management. Hymenopteran parasitoids were sampled using Malaise traps in six sampling sites in central Italy. Results showed that *Platygaster demades* was the most abundant *D. oleae* parasitoid. Its presence was associated with high rates of *D. oleae* parasitism. The abundance of this parasitoid was influenced by the abundance of seminatural habitats.

Keywords: Cecidomyiidae; conservation biological control; *Olea europaea*; *Platygaster demades*; Platygastriidae

1. Introduction

The Mediterranean region covers 93.6% of the world's olive oil production [1]. Olive crops have high economic importance in several countries due to the increasing demand for olive oil worldwide [2]. The olive leaf gall midge, *Dasineura oleae* (Angelini, 1831) (Diptera: Cecidomyiidae), attacks *Olea europaea* L. leaflets, young branches, and floral buds, inducing the formation of galls. This midge, endemic to the Mediterranean region, has been recorded in several countries in this area, including most of the largest olive producers [3]. *Dasineura oleae* was considered a sporadic pest [4] until recent reports of outbreaks [5–8]. *Dasineura oleae* adults emerge from galls in spring, live a few days, and lay their eggs on the surface of young leaves or floral buds [4]. The trophic activity of the larva induces the formation of galls a few weeks after the eggs hatch. The larva develops, overwinters, and pupates inside the gall, usually emerging the following spring [7]. In central Italy, *D. oleae* populations complete a main generation per year, emerging in late March–early April; however, part of the population may complete a second generation in autumn [8]. Among Mediterranean countries, Italy experienced severe outbreaks of this cecidomyiid pest [9], affecting, on average, 50% of the leaves, but a more severe infestation rate has also been recorded, with peaks of 95% of attacked leaves [8]. Regarding crop damage, the physiological alterations caused by *D. oleae* on *O. europaea* have been recently studied [10], but no information is available on the effects on olive yield.

Parasitoids play a crucial role in the control of several cecidomyiids of economic importance [11–13]. Recently, four parasitoid species attacking *D. oleae* have been reported in Italy [8], i.e., *Platygaster demades* Walker, 1835, *Platygaster oleae* Szelenyi, 1940 (Platygastriidae), *Mesopolobus mediterraneus* Mayr, 1903, and *Mesopolobus aspilus* Walker, 1835 (Pteromalidae). Parasitoid population dynamics can be affected by several biotic and abiotic features, both at local and landscape scales [14–17]. A number of parasitoid populations



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have been reported as host density-dependent [18–21]. However, some studies failed to find a relationship between host density and the corresponding parasitoid abundance [14,22,23]. Local features such as the plant flower characteristics [24,25], with special reference to their semiochemical profile [26–28], as well as pollen and nectar production [14], have been reported as important in affecting parasitoid abundance. On a landscape scale, parasitoid populations' abundance and diversity are influenced by landscape complexity (i.e., the number of seminatural habitats surrounding the crop) [29,30]. Indeed, seminatural vegetation adjacent to agroecosystems can provide overwintering refugia, floral food resources, and alternative hosts [9,31]. The presence of different resources may vary according to vegetational composition, shaping natural enemy communities [30,31]. Therefore, seminatural habitats may act as a reservoir of natural enemies, and they may have a role in their spillover toward the field [15,32,33]. Indeed, there is a large amount of available data about the positive effect of landscape complexity on the abundance and diversity of biocontrol agent populations [29,34,35] and, accordingly, on pest suppression [36–38], although the effect may vary according to the analyzed system [39]. Understanding the local and landscape effects on specific host–parasitoid interactions is a crucial background for conservation biocontrol attempts.

Among the parasitoid species that attack *D. oleae*, *P. demades* is known to be associated with the young stages of the few Cecidomyiidae species that infest *Malus domestica* (Borkh.) Borkh, *Malus sylvestris* (L.) Mill, *Erica* spp., *Pyrus communis* L., and its subspecies [40–42], while *P. oleae* is known as a monophagous parasitoid of *D. oleae* [43,44], but its biology is poorly known. Both *M. aspilus* and *M. mediterraneus* are generalist species [45–47]. Most of their hosts are associated with woody plant species such as *Quercus* spp., *Juniperus* spp., and *Pinus* spp. [46,48]. To the best of our knowledge, scarce information is currently available on the biology and ecology of *D. oleae* natural enemies.

In this scenario, the aim of the present field study included (i) evaluating *D. oleae* parasitoid abundance over other parasitoids in olive orchards, (ii) describing natural flight dynamics of *D. oleae* parasitoids, (iii) evaluating the potential effects of local and landscape features on *D. oleae* parasitoids, and (iv) investigating the relationship between *D. oleae* density and parasitism rate, to better understand the potential contribution of parasitoidism in *D. oleae* conservation biological control.

2. Materials and Methods

2.1. Study Area

This field study was carried out in 6 sampling sites, i.e., olive orchards located in Tuscany (Grosseto Province, Central Italy); all sites were close to the core of *D. oleae* outbreak range [49]. Questionnaires to olive growers were not able to precisely identify the year of *D. oleae* outbreak appearance in each orchard, leading to the impossibility of evaluating this issue.

Grosseto province is characterized by a mosaic of agricultural land and natural or seminatural areas: 39.6% of the province is covered with woodlands, mainly Mediterranean evergreen broadleaves and deciduous forest [50], and the agricultural surface is developed on 41.9% of the province with olive orchards as the main woody crop of the area. The climate is typically Mediterranean, with an annual mean temperature of 15.57 °C and annual average precipitation of 757.03 mm (Braccagni weather station, 42°52'22.08" N 11°04'32.57" E). Herein, 6 sampling sites were selected, each one having natural vegetation adjacent to the field margin. Olive orchards had an average size of 5 ha and lay between 46 and 150 m a.s.l. All orchards were rainfed, underwent weed mowing once a year in June and managed through organic agricultural practices. The main cultivars were Frantoio, Leccino, and Moraiolo. We conducted vegetational surveys on the adjacent vegetation nearby each olive orchard to assess the habitat type (sensu EUNIS habitat classification [51]) and to evaluate the vegetation cover of the arboreal and shrub layer using the Braun-Blanquet phytosociological scale [52] (Table 1 and Supplementary Materials Table S1).

Table 1. Locality, coordinates, type of adjacent vegetation, altitude, and size of each sampled olive orchard (A–F). The vegetation is described according to EUNIS habitat nomenclature. For more details on vegetational features, see Table S1 in the Supplementary Materials.

| Olive Orchard | Locality | Coordinates | Adjacent Vegetation | Olive Orchard Size (ha) |
|---------------|------------|--------------------|--|-------------------------|
| A | Caldana | 42.88793; 10.94198 | <i>Quercus ilex</i> woodland (EUNIS habitat type G2.12) | 8.38 |
| B | Grilli | 42.89278; 10.97986 | Western <i>Quercus pubescens</i> woods (EUNIS habitat type G1.711) with aspects of Western garrigues (EUNIS habitat type F6.1) | 7.01 |
| C | Caldana | 42.88969; 10.94707 | <i>Quercus ilex</i> woodland (EUNIS habitat type G2.12) | 5.88 |
| D | Giuncarico | 42.90452; 10.99963 | Western <i>Quercus pubescens</i> woods (EUNIS habitat type G1.711) | 2.60 |
| E | Giuncarico | 42.90870; 10.99753 | Western <i>Quercus pubescens</i> woods (EUNIS habitat type G1.711) | 1.11 |
| F | Giuncarico | 42.90768; 11.00312 | Western <i>Quercus pubescens</i> woods (EUNIS habitat type G1.711) with aspects of Western garrigues (EUNIS habitat type F6.1) | 5.57 |

2.2. Parasitoid Trapping and Identification

Hymenopteran parasitoids were sampled using malaise traps (120 cm × 150 cm × 100 cm) [53–55]. Two malaise traps were settled in each site, i.e., one in the core of the olive orchard and one nearby the edge confining natural vegetation, to test the effect of the distance from the natural vegetation (“edge effect”, hereafter). Surveys were undertaken once a month from March 2018 to April 2019, with a total of 10 samplings. January and February sampling materials were lost after severe thunderstorms. Malaise traps were supplied with a jar filled with 70% (v:v) ethanol at the top of the trap hood. Jars were replaced every 10 days on average. Samples were stored at 4 °C in the dark until specimen examination. Identification was limited to hymenopteran parasitoids (hereafter parasitoids). Parasitoids were initially identified to the family level relying on the keys by Goulet and Huber [56] and Noyes [57]. Then, Platygasteridae were identified to genus, and the number of *P. demades* and *P. oleae* were counted. Platygasteridae identification was performed under the supervision of the taxonomist Prof. Peter Neruup Buhl.

2.3. Landscape Features Assessment

We considered as landscape effects the olive orchard size, the habitat type of adjacent vegetation, and the amount of seminatural habitat (hereafter SNH). Olive orchard size was calculated using QGIS 3.8.2 (QGIS Development Team, Gossau, Swiss), and information on land use was assessed using the Regional Tuscan Database Geoscopio (Regione Toscana, Firenze, Italy) [58]. Data were imported in QGIS 3.8.2 (QGIS Development Team, Gossau, Swiss), and all patches with SNH, such as woodlands, grasslands, shrublands, rocky areas, waterways, etc., were selected. The amount of SNH in a buffer with a 250 m radius around each olive was calculated with rasterized images using Fragstats v.4.2.1 (U.S. Department of Agriculture, Portland, OR, USA). The 250 m radius buffer was used to prevent overlapping and the consequent violation of statistical independence between sampling sites.

2.4. *Dasineura oleae* Density and Parasitism Rate

Herein we considered as local factors the density of *D. oleae* and the “edge effect”. Pest density and the parasitism rate were assessed in March 2018, 2019, and 2020. Indeed, at the end of winter or the beginning of spring, *D. oleae* larvae develop into third instar larvae, and their koinobiont parasitoids pupate inside the host larvae. Parasitization became evident in this period, and it is, therefore, possible to discriminate between healthy *D. oleae* larvae and parasitized larvae [59]. This is the only time when it is possible to visually assess both the infestation and the parasitism rate. Five olive trees were selected in a transect from the core trap to the edge trap. Samples consisted of five branches of eight nodes from each tree. For each sample, we counted the total number of leaves, the number of leaves with galls, and the overall number of galls. The infestation rate (host density) was calculated as the ratio

between the number of galled leaves and the total number of leaves. The parasitism rate was assessed by the dissection of 10% of the galls [8].

2.5. Statistical Analysis

2.5.1. Difference in Parasitoid Abundance among Sampling Sites

Our analysis focused on the parasitoids of *D. oleae*, evaluating local and landscape effects on Pteromalidae and *P. demades*. *Platygaster oleae* was not included in the analysis due to the low number of trapped specimens. We used correspondence analysis (CA) to visualize and evaluate the differences in the abundance of parasitoid families among sampling sites. Parasitoid families with fewer than three individuals were excluded from the CA. For each malaise trap, we calculated the overall parasitoid abundance, the parasitoid family richness, the Shannon diversity index, as well as the abundance of *D. oleae* parasitoids (i.e., *P. demades* and *Pteromalidae* spp.). Then, four generalized linear models (GLMs) were used to evaluate differences among the orchards (explanatory variable) on the total number of parasitoid individuals, *P. demades*, *Pteromalidae* spp., and parasitoid family richness (response variables). The negative binomial distribution for overdispersed count data was used for the first three response variables and Poisson distribution for the last. The log link was used. A fifth model, linear model (LM), was fitted for analyzing the response of Shannon diversity index to the orchard. Likelihood ratio tests were conducted to assess the significance of the main factors in the LM and each of GLMs. Post hoc test was performed to evaluate differences among olive orchards with the multcomp package version 1.4-12 [60]. All analyses were conducted in R environment version 3.6.2 (Statistical Computing, Vienna, Austria) [61]. Multivariate analyses were carried out using factoextra version 1.0.6 [62], FactoMineR version 2.2 [63], and Vegan version 2.5-6 [64]. GLMs were performed using the MASS package version 7.3-51.4 [65].

2.5.2. Landscape and Local Effects

Landscape (size of the olive orchard, type of adjacent vegetation, and amount of SNH in a radius of 250 m around the orchards) factors were tested on *D. oleae* parasitoid (number of *P. demades* and *Pteromalidae* spp.) sampled with the malaise traps, using generalized linear mixed models (GLMMs) using Poisson distribution.

The effect of local factors (pest density and edge effect) was tested on Pteromalidae abundance using GLMM with Poisson distribution and on *P. demades* using a GLMM with negative binomial distribution.

The olive orchard was used as a random factor in each of the models. In the case of overdispersion, each observation was modeled as a random effect [66]. For each model, a manual backward elimination of nonsignificant variables was used until we reached the minimum adequate model. Likelihood ratio tests were conducted to assess the significance of the main factors in each GLMM. We used glmmTMB version 1.0.1 [67] and lme4 package version 1.1-21 [68] for GLMMs; post hoc analyses were conducted with the multcomp package version 1.4-12 [60].

2.5.3. Correlation between Parasitism Rate and Pest Suppression

Herein we tested the biocontrol effectiveness of *D. oleae* parasitoids through a Spearman correlation test between parasitism rate and infestation rate of the following year, obtained by the sampling of the infested olive branches.

3. Results

A total of 2073 parasitoid individuals were collected in the malaise traps during the sampling period, and 25 families were identified. Ichneumonidae, Braconidae, Diapriidae, and Platygastriidae were the most abundant, representing overall 58.4% of the trapped specimens, while Pteromalidae represented 3.7% of the parasitoid abundance (Supplementary Materials Table S2).

Platygaster demades was trapped in March and showed a peak in April (Figure 1), while Pteromalidae were trapped up to July. The presence of *P. demades* abruptly ceased in May, while Pteromalidae gradually decreased throughout the summer. Platygastriidae were represented by nine genera: *Platygaster*, *Trichacis*, *Synopeas*, *Acerotella*, *Leptacis*, *Amblyaspis*, *Allotropa*, *Inostemma*, and *Anopedias*. Notably, 55.6% of Platygastriidae abundance was constituted by the single species *P. demades*, while *P. oleae* represented just 2.2%.

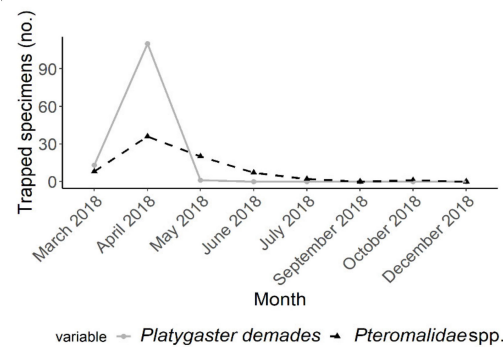


Figure 1. Number of trapped *P. demades* (Hymenoptera: Platygastriidae) and Pteromalidae grouped by sampling date.

3.1. Difference in Parasitoid Abundance among Sampling Sites

The CA (Figure 2) showed that during the 2018 sampling season, olive orchard A was associated with Pteromalidae, Platygastriidae, and Proctotrupidae, and olive orchard C was associated with Azotidae, Diapriidae, Dryinidae, and Megaspilidae. No further associations were shown. Olive orchards A, D, and C highly contributed to the definition of dimensions 1 and 2. The major contributions to the definition of dimensions 1 and 2 were given by Platygastriidae, Azotidae, Ceraphronidae, Mymaridae, Pteromalidae, and Diapriidae.

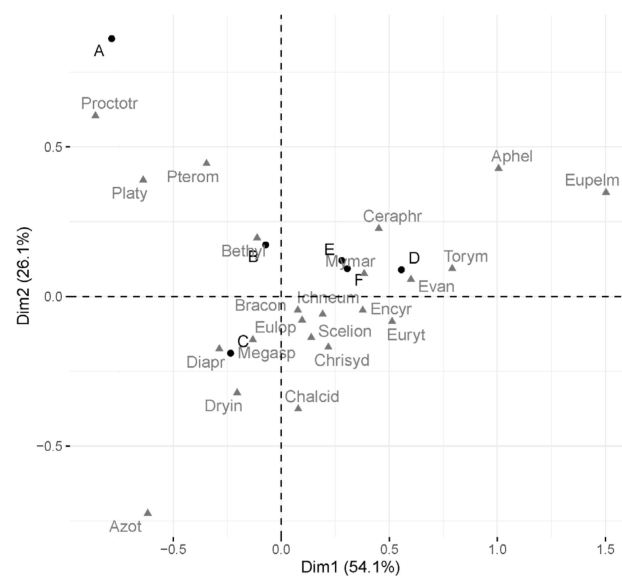


Figure 2. Correspondence analysis of 2018 field data showing the association of hymenopteran parasitoid families to each sampled olive orchard (i.e., A–F, with increasing pest density from A to F). The first dimension of CA explains 54.1% of the total variance, while dimension 2 explains 26.1%: Platy, Platygastriidae; Pterom, Pteromalidae; Encyr, Encyrtidae; Eulop, Eulophidae; Euryt, Eurytomidae; Eupelm, Eupelmidae; Aphel, Aphelinidae; Azot, Azotidae; Torym, Torymidae; Mymar, Mymaridae; Chalcid, Chalcididae; Ichneum, Ichneumonidae; Bracon, Braconidae; Proctotr, Proctotrupidae; Diapr, Diapriidae; Ceraphr, Ceraphronidae; Megasp, Megaspilidae; Bethyl, Bethylidae; Scelion, Scelionidae; Dryin, Dryinidae; Chrysid, Chrysididae; Evan, Evanioidea.

The GLMs showed that the sampling site had a significant effect on the total abundance of parasitoids (χ^2 (5, 15.09) $p = 0.009$) and *P. demades* (χ^2 (5, 11.44) $p = 0.043$) but did not affect the number of trapped Pteromalidae (Figure 3A). Olive orchard C showed a significantly higher overall parasitoid abundance compared with orchards A, B, and F ($p < 0.05$). *Platygaster demades* abundance was significantly higher in olive orchard C compared with D, E, and F. The total number of parasitoid families (χ^2 (5, 17.30) $p = 0.003$) was significantly different between sampling sites (Figure 3B), contrary to the Shannon diversity index (Figure 3C).

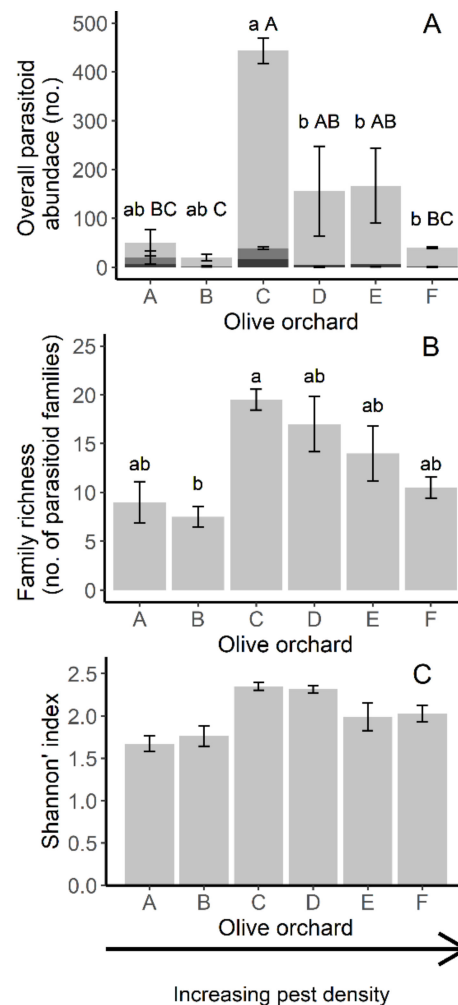


Figure 3. (A) Overall abundance (no.) of hymenopteran parasitoids (light gray), *P. demades* (gray), and Pteromalidae (dark gray) trapped in malaise traps in each olive orchard (i.e., A–F, with increasing pest density from A to F) during the entire sampling period. Different capital letters indicate a significant difference among the number of trapped parasitoids, while different lower-case letters indicate a significant difference between the number of *P. demades* ($p < 0.05$), (B) family richness, and (C) Shannon index. All values are means \pm SEs.

3.2. Local and Landscape Effects on the Olive Orchard Parasitoid Community and on *Dasineura oleae* Parasitoids

GLMMs evaluating the effect of landscape factors showed that the size of the olive orchard did not have any significant effect on the presence of *P. demades* or Pteromalidae. The GLMMs showed that the amount of SNH in the surroundings of the orchards positively affected *P. demades* (χ^2 (1, 7.73) $p = 0.005$) but did not have any effect on Pteromalidae abundance. GLMMs that evaluated the effect of local features such as pest density and edge effect showed that these predictors do not seem to influence the analyzed variables.

3.3. *Dasineura oleae* Density and Parasitism Rate

Olive orchards A, B, and C had the highest infestation rate in 2018 and quickly developed a parasitoid response that led to a steep decrease in the infestation rate (Figure 4). The parasitoid response was quicker in olive orchard A. Olive orchards D and E had an intermediate infestation of *D. oleae* in 2018, but the parasitoid response was registered with a 2-year delay in 2020. Indeed, in olive orchards D and E, we registered an increase in *D. oleae* infestation rate in 2019, followed by a slender decrease in 2020. Olive orchard F showed a linear increase in the infestation rate and a good parasitoid response in 2020.

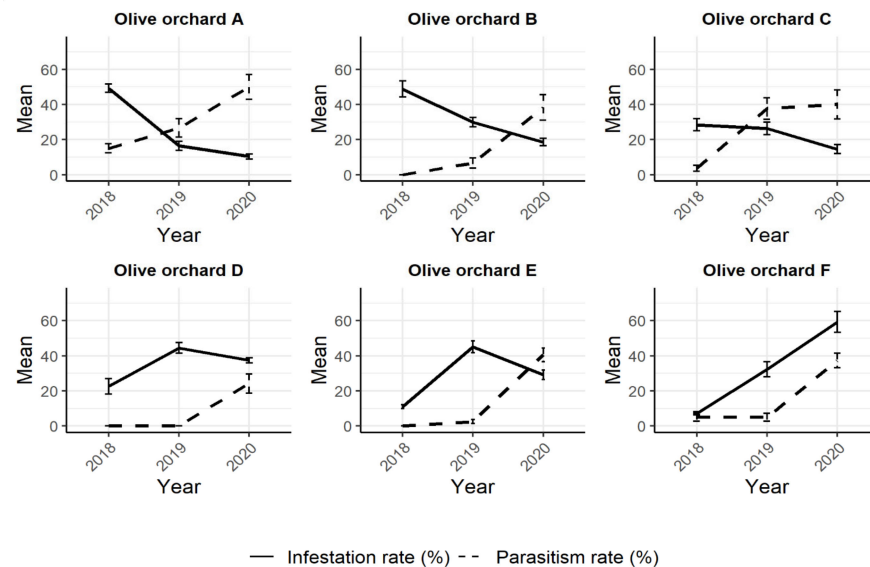


Figure 4. Parasitism rate (dashed line) and *D. oleae* infestation rate (full line) during 2018, 2019, and 2020 in each olive orchard. All values are means \pm SEs.

The correlation test revealed the effectiveness of the biological control carried out by the parasitoids, showing that a higher parasitism rate was followed by a lower infestation rate in the subsequent *D. oleae* generation ($R = -0.74$, $p = 0.0061$ (Figure 5)).

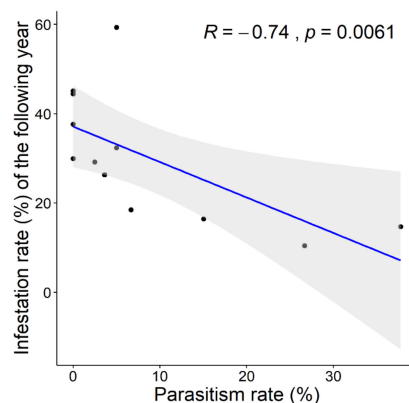


Figure 5. Correlation between parasitism rate and infestation rate of the subsequent *D. oleae* generation; the correlation test was performed using Spearman rho rank. The blue line and the 95% confidence interval (gray area) show the linear regression. Each point corresponds to the medium value of each orchard's parasitism and infestation rate.

4. Discussion

4.1. *Dasineura oleae* Parasitoids in the Olive Orchards

Results showed a high abundance of Ichneumonoidea, Proctotrupidae, and Platygasteridae. While the former is the largest superfamily of the order Hymenoptera and is

well represented in olive orchards, the latter is usually less represented [69,70]. Studies on parasitoid communities in olive orchards showed that different key pests affect the prevalence of specific parasitoid species [70,71]. In the studied olive orchards, *D. oleae* was the main pest, and our findings showed that its parasitoid *P. demades* was abundant. On the other hand, Pteromalidae, which are usually more abundant than Platygasteridae in olive orchards, represented just 3.7% of the total parasitoid abundance [70,72]. Generalist natural enemies are less likely to respond to an increase in one of their prey, whereas specific parasitoids usually display density-dependent responses [73]. This could partially explain the high catches of *P. demades*; however, the scarcity of trapped individuals of the monophagous parasitoid *P. oleae* is still difficult to interpret. The rarity of this species was also confirmed by the emergence of few individuals of *P. oleae* from laboratory-reared infested branches [74]. According to our results, the activity of *P. demades* in olive orchards is limited to March and April, simultaneous with *D. oleae* adult emergence as well as with the presence of eggs and young larvae. This suggests that the parasitoid is synchronized with the life cycle of the pest, as earlier reported by Baidaq et al. [75]. Chemical control of gall midges is usually oriented toward adults or young stages since mature larvae are protected inside galls and are hardly reached by insecticides [76,77]. Tomkins et al. [78] observed that the applications of insecticides for controlling *Dasineura mali* (Kieffer, 1904) in spring strongly affected populations of its parasitoid *P. demades*; even spray residuals may be toxic to adult parasitoids and should be avoided [79]. Similarly, one may argue that chemical control programs carried out in spring against *D. oleae* may have detrimental effects on *P. demades* populations.

4.2. Local and Landscape Features on *D. oleae* Parasitoids and on the Overall Parasitoid Community

Besides *D. oleae*, *P. demades* is known to attack *D. mali* [80], *Dasineura pyri* (Bouché, 1847) [81,82], and *Wachtliella ericina* F. Löw [40]. Therefore, *P. demades* may be associated with several arboreal or shrub plant species such as *Erica arborea* L., which was detected in the adjoining vegetation of olive orchards A, B, and C, and *P. communis* L., which was present nearby the olive orchard C. These olive orchards are the ones that showed higher numbers of trapped *P. demades* and also had the fastest increase in parasitism rates over the years. On the other hand, plant species associated with alternative hosts of *Mesopolobus* spp., such as *Quercus* spp., have been recorded in all SHN adjacent to each orchard. Indeed, the abundance of Pteromalidae was not statistically different among olive orchards. The study by Picchi et al. [9] supports our evidence, having revealed that olive orchards with higher proportions of *Erica* spp., *P. communis*, and other plant species associated with alternative hosts of *D. oleae* parasitoids in the adjacent SNH had greater parasitism rates than olive orchards with a comparable amount of SNH but lacking those plant species.

Aside from plant species composition, our results show that the abundance of *P. demades* in the olive orchards was positively influenced by the amount of SNH in a 250 m buffer around the orchards, while the habitat type of the adjoining vegetation had no effect on this species presence and there were no differences in the abundance of this parasitoid between the core and edge of the field. Olive orchards surrounded by higher proportions of SNH may have been quickly colonized by *P. demades*, influencing the parasitism pressure on *D. oleae*. Indeed, a number of studies have reported an increase in natural enemies' abundance in complex habitats and, therefore, reduced crop pest pressure [37,38,83]. However, the effect could vary at different spatial scales: positive effects have been registered at a medium distance (buffer 1–2 km), while at a lower buffer (500 m), no significant effect has been detected [84]; the study of Boccaccio and Petacchi [85] showed the positive response of *Bactrocera oleae* parasitoids at intermediate scales (750 m buffer), while Rusch et al. (2011) [86] observed a consistent effect of landscape on pollen beetle parasitism rate at a lower (250 m) and higher distance (1.5–2 km). The agroecosystems studied in the present research were small (1–8 hectares) in the whole geographical area; furthermore, Platygasteridae has shown a small dispersal rate [87,88] and are, therefore, likely to respond at low spatial scales, such as the 250 m buffer used in the present study.

Local factors such as the presence of herbaceous ground cover seem to have a significant influence on parasitoids [72,89,90]. Our results evidenced a limited effect of local factors: we evaluated pest density and distance from adjacent vegetation, while most of the literature focuses on the type of management or local plant diversity. The effect of the increasing distance from adjacent vegetation has been investigated on natural enemies, showing a significant reduction in predators in vineyards [91] and parasitoids in apple and pear orchards [92] or almond orchards [93], while nonsignificant effects were evidenced on parasitoids in olive orchards [89].

4.3. Relationship between *Dasineura oleae* Density and Its Parasitoids

Considering the influence of pest density on parasitoid abundance, Stiling [94] reported that positive density-related parasitoid responses were found in 25% of the studies, revealing that this response is less frequent than expected. Nevertheless, some features of the studied host–parasitoid complex represent a favorable condition for density dependence [94]. Density-dependent responses of *D. oleae* parasitoids, as well as the extent of the resulting biological control, may be affected by the timing of outbreak development in a specific sampling site and may, therefore, be difficult to evaluate. Despite olive orchard C having a higher abundance of trapped parasitoids, the number of trapped *P. demades* is not significantly different from orchards A and B, which have similar *D. oleae* infestation rates, showing that a high abundance of parasitoids in an orchard does not correspond to a high abundance of *P. demades* or a high parasitism rate. Correspondence analyses highlighted that Platygastriidae and Pteromalidae were associated with olive orchard A, explaining the high parasitism rate. Differences in *D. oleae* parasitoid abundances seem to be related to landscape factors such as the amount of SNH, while the results did not show any effect of density of the studied pest. Further investigations should be carried out to assess whether the presence of specific plant species, both in the adjoining vegetation and in the grass layer, could have influenced the presence of *D. oleae* parasitoids.

5. Conclusions

Nowadays, several Mediterranean countries have experienced *D. oleae* outbreaks to some extent. Our results showed that the oligophagous parasitoid *P. demades* is the most abundant enemy of *D. oleae*. We evidenced that *D. oleae* parasitoids, particularly *P. demades*, were strictly associated with the appearance of *D. oleae* adults, eggs, and young larvae. Furthermore, landscape composition has a greater effect than local predictors (i.e., pest density and distance from the edge confining with SNH) on the main natural enemy of *D. oleae*. This finding highlights the importance of maintaining an adequate proportion of SNH for natural enemies conservation, even in diverse agroecosystems such as olive orchards. Conservation biological control strategies should consider both the above-mentioned issues, boosting the presence of SNH in the surroundings of olive orchards and avoiding the contiguity of the same crop in large territories.

The scattered pattern of *D. oleae* outbreaks is still difficult to interpret, and future studies should evaluate possible drivers both in areas with a high density of *D. oleae* and pest-free orchards.

Supplementary Materials: The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/agronomy13030667/s1>, Table S1: Synoptic table of vegetation communities of study area (only trees and shrubs). Abundance/dominance index according to Braun-Blanquet phytosociological scale; Table S2: Number of individuals collected using malaise traps, and relative abundance of each parasitoid family (cumulative data from the 6 sampling sites and all sampling dates).

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