Attraction of green lacewings (Neuroptera: Chrysopidae) to native plants used as ground cover in woody Mediterranean agroecosystems

Rafael Alcalá Herrera[a,*], Francisca Ruano[b], Cándido Gálvez Ramírez[c], Stephanie Frischie[c,1], Mercedes Campos[a]

[a] Plant Protection Group, Department of Environmental Protection, Estación Experimental del Zaidín (CSIC), C/Profesor Albareda 1, 18008 Granada, Spain
[b] Department of Zoology, University of Granada, Campus de Fuentenueva s/n, 18071 Granada, Spain
[c] Semillas Silvestres S.L., C/Aulaga n° 24, 10012 Córdoba, Spain

GRAPHICAL ABSTRACT

	Biscutella auriculata	Borago officinalis	Crepis capillaris	Echium plantagineum	Nigella damascena	Papaver rhoeas	Silene colorata
Chrysopids in 2016/2017	✓/✓	✗/✓	✓/✓	✓/✓	✓/✓	✗/✓	✓/✓
Presence of adults/preimaginal	✓/✓	✓/✓	✓/✓	✓/✓	✓/✓	✓/✓	✓/✓
Type of prey — Acari	✗	✓	✓	✗	✓	✗	✓
Type of prey — Aphid	✓	✓	✓	✓	✓	✓	✓
Type of prey — Collembola	✓	✓	✓	✓	✓	✓	✓
Type of prey — Thysanoptera	✓	✓	✓	✓	✓	✓	✓
No reported harmful effects on olive crop	✓	✓	✓	✗	✓	✓	✓
Good vegetative development	✓	✓	✓	✓	✓	✓	✓

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ABSTRACT

Using native seeds to establish semi-natural habitats is a novel strategy to restore biodiversity and ecosystem services such as biological control. As green lacewings (Neuroptera: Chrysopidae) are regarded as major biological control agents in different crops, the objective of this study was to test the attractiveness of selected native plant species to lacewings. During a two-year (2016–2017) field experiment near Villarrubia (Andalusia, Spain), 42 native plant species belonging to 13 families were planted. Plant development was monitored, and arthropods were vacuumed from each plot twice during the peak May flowering period. Green lacewings were observed to use 28 of the 36 well developed species to reproduce, feed and/or rest. *Chrysoperla lucasina* was the predominant species among the captured adults. No clear pattern of attraction common to all species was observed during the two-year sampling period. In 2017, eight plant species showed above-average chrysopid abundance. In addition, Acari abundance correlated positively with chrysopid abundance. Given the attraction of chrysopids, the effect of pests and disease on olive orchards and satisfactory plant development, we consider *Biscutella auriculata*, *Borago officinalis*, *Silene colorata*, *Crepis capillaris*, *Nigella damascena* and *Papaver rhoeas* to be the native plant species best suited to host chrysopids and to restore ground cover in perennial Mediterranean crops.

* Corresponding author.
  E-mail addresses: rafa.alcala@eez.csic.es (R. Alcalá Herrera), fruano@ugr.es (F. Ruano), candido@semillassilvestres.com (C. Gálvez Ramírez), mercedes.campos@eez.csic.es (M. Campos).
  [1] Current address: The Xerces Society for Invertebrate Conservation, 628 NE Broadway Ste 200, Portland, OR 97232, USA.

1. Introduction

The expansion and intensification of agroecosystems have led to a decrease in insect population and diversity, resulting in a decline in ecosystem services such as biological pest control (Altieri and Nicholls, 2004; Penn et al., 2017). The European Union has designed and implemented agri-environmental measures within the framework of the Common Agricultural Policy to restore and maintain biodiversity in agricultural landscapes, which include programs to reduce pesticides and to enhance semi-natural wildlife habitats (European Union, 2009; Holland et al., 2017; Science for Environment Policy, 2017). There are a wide range of semi-natural habitats in the European agricultural landscape characterized by different plant compositions, structures, types (spontaneous or sown plants), as well as locations in relation to the crop, among other characteristics (Haaland Christine et al., 2011; Holland et al., 2016; Holland et al., 2017). Nevertheless the increased use of herbicides has led to depauperate seed banks (Fracchiolla et al., 2016), and ground cover vegetation needs to be established through active sowing in order to create useful habitats for beneficial insects. There is growing interest and research into suitable plant species for ecological restoration in places such as olive groves, vineyards, citrus and almond orchards, as well as in ecosystem services to prevent soil erosion and to maintain soil fertility in response to a wide range of human activities (Alcántara et al., 2017; Oldfield, 2019; Pedrini et al., 2019). The commercial seed mixtures currently available for agroecological purposes are, on the whole, temperate forage species which are less suited to Mediterranean environmental conditions than native varieties (Hernández González et al., 2015). Native species are used as a novel strategy to ensure the success of ground cover restoration for crops and can also help to establish and maintain seed banks in order to avoid re-sowing, invasion by non-native species and higher farming costs (Araj and Wratten, 2015; Siles et al., 2017).

Lacewings, which are common, active predators, occupy a prominent position among the wide variety of natural enemies of pests in agricultural areas (McEwen et al., 2001; Pappas et al., 2011; Porcel et al., 2017). In southern Europe and Mediterranean countries, *Chrysoperla carnea* (Stephens) *s.l.* complex is the most important predator in olive groves, cotton, potato and alfalfa crops (Al-Darkazly and Jabri, 1989; Campos, 2001; Duelli, 2001; Mostafa et al., 1976; Pantaleoni et al., 2001). *Chrysoperla carnea s.l.* adults consume a palyno-glycophagous diet of nectar and pollen resources (even insect honeydew) to obtain protein and carbohydrate, essential for their survival and reproduction (Canard et al., 1984; Gonzalez et al., 2016; Villa et al., 2016; Villenave et al., 2005). Larvae consume a diet principally based on small arthropods such as aphids, thrips, mites, scales, springtails and moths, which may be supplemented with non-prey food resources, such as pollen and nectar, when prey is less abundant (Canard, 2001; Patt et al., 2003; Villa et al., 2016).

Ground cover vegetation helps to support and increase chrysopid populations, even in the canopy of perennial crops such as olives and apples (Porcel et al., 2017; Wyss, 1995). Thus, landscape management strategies to promote ground cover vegetation are expected to improve the biological control provided by chrysopids (Duelli, 2001; Porcel et al., 2017; Szentkirályi, 2001b; Wyss, 1995).

The complex trophic relationship between natural enemies and plants is influenced by various factors. For example, the functional traits of flowers, as well as other factors such as the presence of prey, affect attractiveness to natural enemies (Hatt et al., 2017; Nave et al., 2016; Van Rijn and Wackers, 2016). With respect to chrysopids, flowers with well exposed nectaries are known to be a suitable food source (Van Rijn and Wackers, 2016), while the presence of available prey at the preimaginal stage could prompt the appearance of adults in plants containing these arthropods (Schultz, 1988). The fundamental aspects of this tri-trophic relationship are linked to reproduction and feeding. The habitats in which reproduction occurs can be identified by the presence of preimaginal-stage arthropods characterized by limited

mobility, while habitats which support adults are selected for feeding and/or resting purposes (Bianchi et al., 2013). Chrysopids, which use a wide range of habitats even in the absence of prey, show less discriminatory oviposition (Duelli, 1984) than other predators such as syrphids and ladybirds which only lay eggs when prey abundance exceeds a certain threshold (Bianchi et al., 2013). With regard to feeding behaviour, given their generalist and opportunistic nature, *C. carnea s.l.* adults feed on a broad variety of plant species (Villenave et al., 2006).

The objective of this study is to evaluate the attractiveness of selected native plant species to lacewings. We hypothesized that chrysopid abundance is increased by the presence of particular plants in the study area and/or by prey abundance on the plant species studied, both of which hypotheses could be important in explaining the attractiveness of lacewings to certain plants. In addition, based on previous studies by Denis and Villenave (2009) and Villenave et al. (2006), we expected to collect different *C. carnea s.l.* complex species from most of the plant species selected and from all the plant families sown given their indiscriminate chrysopid oviposition behaviour and their generalist conduct when exploiting flower resources.

2. Materials and methods

2.1. Site description

The experiment was conducted in two growing seasons from November 2015 to June 2017 at an experimental farm in the village of Villarrubia (Andalusia, Spain; 37°49′49″N, 4°54′20″W). The farm was bordered to the north by a commercial orange orchard and various irrigated crops and to the south by the River Guadalquivir with riverbank vegetation. Olive plantations are also located 1.5 km from the farm. The soil, Calcaric Fluvisol, has a neutral/basic pH (IUSS Working Group, 2015). During the two-year study, meteorological conditions varied slightly, with a mean temperature in May 2016 of 19.3 °C and in May 2017 of 21.6 °C, as well as mean rainfall in May 2016 of 3.4 mm and in May 2017 of 1.3 mm (AEMET meteorological station, 37°50′56″N, 4°50′48″W) (Supplementary Material Table A.1).

2.2. Plant species and experimental design

Sown plant species were selected according to the following criteria (Frischie, 2017): (1) native angiosperms, (2) annual plants (ptherophytes), (3) plant height of less than 1 m (Castroviejo, 1986–2012), (4) flowering season in May before olive blooming (winter annuals), (5) self-seeding (Castroviejo, 1986–2012), (6) limited water competition, especially from trees, (7) and high erosion control potential.

The experimental area was 145×23 m in 2016 (Fig. 1a) and 169×163 m in 2017 (Fig. 1b). The area was tilled in late November of 2015 and 2016, and the seeds were planted in the days that followed. Weeds were managed by manual methods three times per year, and the plots were irrigated by overhead sprinklers once during germination and several times when required during plant development.

In both years of the study, we sampled three 3×3 m squares for every plant sown. However, the plants were sown differently each year: in 2016, a total of 40 plant species from 13 botanical families (Table 1) were planted according to a fully randomized design in each of the three blocks. Each plant species was sown in three 3×3 m squares, with 1.75 m between plots in the same block and 5 m between blocks (total of 120 samples, Fig. 1a).

In 2017, based on the chrysopid abundance results for 2016, 22 plant species from nine botanical families were planted, 20 of which had been planted in 2016 and only two (*Borago officinalis* and *Papaver rhoeas)* were planted in 2017. A single randomized plot design was used for each plant species, with an area ranging from 50 m^2 to 5,640 m^2. We collected three samples located equidistantly from the centre of each plot to avoid a border effect (total of 66 samples, Fig. 1b).

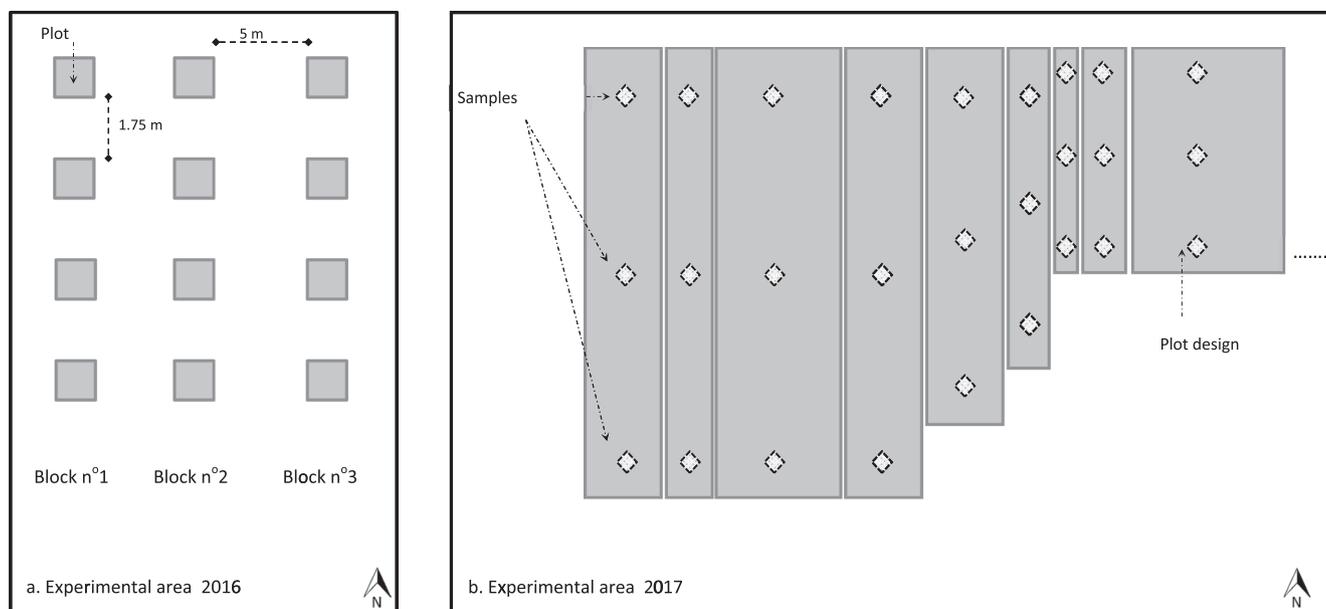The phenological stages and indices of plant cover were calculated

Fig. 1. Experimental design diagrams for 2016 (Fig. 1a) and 2017 (Fig. 1b). Each plant species plot in 2016 measured $9\,m^2$ and ranged from 50 to $5640\,m^2$ in 2017. We sampled three $3 \times 3\,m$ squares for every plant sown in each sampling date.

by visual observation for each $3 \times 3\,m$ square samples in each sampling date.

It is important to note that we carried out the study in both years on plants under similar conditions (phenology, location and sampling time).

2.3. Arthropod collection

After six months, when the plant species had reached optimal flowering, the arthropods were sampled by suction sampling of emerged and well-developed plant species (34 in 2016 and 19 in 2017) throughout the covered area (Table 1).

The three $3 \times 3\,m$ squares for each plant species were vacuumed twice for 40 s using an insect aspirator (InsectaZooka, BioQuip® Products Inc., Rancho Dominguez, CA, US) at the beginning and in the middle of May in 2016 and 2017. We then stored the samples at $-20\,°C$, which were later sorted in the laboratory. Arthropods (chrysopids and prey) were identified to the highest taxonomic level required to determine their functional group. To assess the function of each plant species at species level, we distinguished between the different development stages (preimaginal egg and larva/adult) of the chrysopids found in each plant species. Chrysopid adults were determined up to species level according to the latest Iberian chrysopids survey (Monserrat, 2016).

2.4. Statistical analysis

All statistical analyses were carried out using R software version 3.5.0 (R Development Core Team, 2017). Data analysis began with a data exploration (Zuur et al., 2010). Total chrysopid abundance per plant species was expressed as the sum of adult and preimaginal (eggs and larvae) stages in each $3 \times 3\,m$ squares.

Two experimental designs with different plant species were used in 2016 and 2017. Thus, to test differences in chrysopid abundance per year, the data for which do not follow a normal distribution, we used the Kruskal-Wallis test with Bonferroni adjustment with the aid of the "agricolae" software package (De Mendiburu, 2017).

Total chrysopid abundance per year was also separately modelled by fitting a generalized linear model (GLM) to a negative binomial distribution as a function of the abundance of the plant species Acari,

Aphididae, Collembola and Thysanoptera using the "MASS" software package (Venables and Ripley, 2002). We used only those plant species in which chrysopids were recorded (19 in 2016 and 18 in 2017). In addition, in 2017, the area sown per plant species was included in the model to offset the effects of disturbances in the model. The residuals and uniformity of the model were checked using the "DHARMa" software package (Hartig, 2018). The multiple comparisons in each model (2016 and 2017) for plant species were checked with the aid of the Tukey test using the "multcomp" software package (Hothorn et al., 2008).

3. Results

3.1. Growth of plant species

A total of 30 out of 42 plant species sown, which covered over 70% of the area sown, recorded adequate growth in both years of the study (Table 1). The other 12 plant species sown showed poor growth, while the cover was less than 70% (Table 1). In 2016, 40 plant species, belonging to 13 families, were sown, although five species, which showed unsatisfactory plant development, were not sampled: *Tuberaria guttata, Helianthemum ledifolium* (Cistaceae), *Anarrhinum bellidifolium* (Veronicaceae), *Aegilops geniculata* and *Aegilops triuncialis* (Poaceae). On the other hand, in 2017, while 22 plant species, belonging to nine families, were sown, two species of the Fabaceae family, *Medicago polymorpha* and *Medicago orbicularis,* which did not grow correctly, were omitted. Additionally, two other plant species, *Capsella bursa-pastori* in 2016 and *Vaccaria hispanica* in 2017, which failed to bloom during the sampling period, were omitted the sampling (Table 1).

3.2. Arthropods collected

A total of 42,094 arthropods were collected (21,699 in 2016 and 20,395 in 2017), of which 234 arthropods belonged to the Order Neuroptera and exclusively members of the Chrysopidae family (0.27% in 2016, 0.86% in 2017). The other natural enemies collected were parasitoids (8.57% in 2016, 5.05% in 2017), as well as predators belonging to the Suborder Heteroptera (0.69% in 2016, 1.04% in 2017), the Order Araneae (0.94% in 2016, 1.25% in 2017) and the Syrphidae family (0.07% in 2016, 0.09% in 2017). The abundance of chrysopids

Table 1
Plant species studied, area sown, presence of chrysopids and mean plant cover (%) in 2016 and 2017. Y – Yes, N – No and NA – Not applicable.

Family	Species	Plant code	Seed 2016 (m^2)	Seed 2017 (m^2)	Chrysopids collected (2016)	Chrysopids collected (2017)	Mean plant cover (%) (2016)	Mean plant cover (%) (2017)
Apiaceae	*Tordylium maximum L.*	TOMA	Y (9)	N	Y		100	
Asteraceae	*Anthemis cotula L.*	ANCO	Y (9)	Y (1467)	N	Y	95	70
Asteraceae	*Calendula arvensis M.Bieb*	CAAR	Y (9)	Y (630)	N	N	100	100
Asteraceae	*Crepis capillaris (L.) Wall.*	CRCA	Y (9)	Y (50)	Y	Y	95	95
Asteraceae	*Glebionis segetum L.*	GLSE	Y (9)	Y (978)	Y	Y	100	98.3
Asteraceae	*Tolpis barbata (L.) Gaertn.*	TOBA	Y (9)	Y (50)	N	Y	33.3	60
Boraginaceae	*Borago officinalis L.*	BOOF	N	Y (489)		Y		80
Boraginaceae	*Echium plantagineum L.*	ECPL	Y (9)	Y (2632)	Y	Y	86.7	100
Brassicaceae	*Biscutella auriculata L.*	BIAU	Y (9)	Y (214)	Y	Y	100	100
Brassicaceae	*Capsella bursa-pastoris (L.) Medik.*	CABU	Y (9)	N	NA		83.3	
Brassicaceae	*Moricandia moricandioides Boiss.*	MOMO	Y (9)	Y (978)	Y	Y	100	95
Caryophyllaceae	*Silene colorata Poir.*	SICO	Y (9)	Y (232)	Y	Y	100	100
Caryophyllaceae	*Silene gallica L.*	SIGA	Y (9)	Y (489)	N	Y	95	80
Caryophyllaceae	*Vaccaria hispanica (Mill.) Rauschert*	VAHI	Y (9)	Y (489)	Y	NA	100	80
Cistaceae	*Helianthemum ledifolium (L.) Mill.*	HELE	Y (9)	N	NA		0	
Cistaceae	*Tuberaria guttata (L.) Fourr.*	TUGU	Y (9)	N	NA		0	
Dipsacaceae	*Scabiosa atropurpurea L.*	SCAT	Y (9)	Y (489)	Y	Y	95	
Fabaceae	*Anthyllis vulneralia L.*	ANVU	Y (9)	N	N		78.3	
Fabaceae	*Medicago orbicularis (L.) Bartal.*	MEOR	Y (9)	Y (163)	Y	NA	100	0
Fabaceae	*Medicago polymorpha L.*	MEPO	Y (9)	Y (163)	N	NA	100	0
Fabaceae	*Trifolium angustifolium L.*	TRAN	Y (9)	Y (1560)	Y	Y	33.3	100
Fabaceae	*Trifolium hirtum All.*	TRHI	Y (9)	Y (163)	N	Y	81.7	80
Fabaceae	*Trifolium lappaceum L.*	TRLA	Y (9)	Y (163)	N	Y	50	70
Fabaceae	*Trifolium stellatum L.*	TRST	Y (9)	N	Y		90	
Lamiaceae	*Cleonia lusitanica L.*	CLLU	Y (9)	N	Y		86.7	
Lamiaceae	*Salvia verbenaca L.*	SAVE	Y (9)	N	N		75	
Lamiaceae	*Stachys arvensis L.*	STAR	Y (9)	Y (100)	N	Y	45	90
Papaveraceae	*Papaver dubium L.*	PADU	Y (9)	Y (489)	N	Y	58.3	100
Papaveraceae	*Papaver rhoeas L.*	PARH	N	Y (5640)		Y		100
Poaceae	*Aegilops geniculata Roth.*	AEGE	Y (9)	N	NA		0	
Poaceae	*Aegilops triuncialis L.*	AETR	Y (9)	N	NA		0	
Poaceae	*Anisantha madritensis L.*	ANMA	Y (9)	N	N		100	
Poaceae	*Anisantha rubens L.*	ANRU	Y (9)	N	N		100	
Poaceae	*Bromus hordeaceus L.*	BRHO	Y (9)	N	Y		100	
Poaceae	*Bromus scoparius L.*	BRSC	Y (9)	N	N		100	
Poaceae	*Cynosurus echinatus L.*	CYEC	Y (9)	N	Y		91.7	
Poaceae	*Hordeum murinum, subsp. leporinum L.*	HOMU	Y (9)	N	Y		95	
Poaceae	*Lolium multiflorum Lam.*	LOMU	Y (9)	N	Y		100	
Poaceae	*Trachynia distachya (L.) Beauv.*	TRDI	Y (9)	N	Y		100	
Ranunculaceae	*Nigella damascena L.*	NIDA	Y (9)	Y (978)	Y	Y	90	80
Scrophulariaceae	*Misopates orontium (L.) Raf.*	MIOR	Y (9)	N	N		41.7	
Veronicaceae	*Anarrhinum bellidifolium (L.) Willd.*	ANBE	Y (9)	N	NA		0	

collected in 2017 (1.54 ± 0.17 individuals/sample, n = 114 samples) was also significantly higher than in 2016 (0.28 ± 0.06 individuals/sample, n = 204 samples) (Kruskal-Wallis Chisq = 68.83, $p < 0.001$). Of the prey available for natural enemies, the most abundant taxa among the total number of arthropods captured were the Orders Collembola (40.47% in 2016, 31.99% in 2017) and Thysanoptera (21.28% in 2016, 29.01% in 2017) (Table 2). The irregular abundance of the Order Acari ranged from zero in many plant species to 75.5 ± 37.3 individuals/sample. Members of the Aphididae family, which were more abundant in 2017, were present in all plant species (Supplementary Material, Table A.2).

3.3. Chrysopid species

Chrysopid species diversity was low, with all 46 adults recorded in 2016 identified as belonging to the *C. lucasina* (27 females and 19 males; Table 3). Meanwhile, 95% (63) of specimens collected in 2017 were identified as *C. lucasina* (44 females and 19 males), with 5% (3) of specimens identified as *Chrysoperla pallida* Henry, Brooks, Duelli & Johnson, 2002 (Table 3).

3.4. Plants visited by chrysopid species

With regard to the 36 plant species sampled, during the two years of the study, preimaginal and/or adult chrysopid stages were found in 28 species. Of the eight plants not visited by chrysopids, seven were only sown in 2016, and only one out of eight plant species (*Calendula arvensis*) had been sown in both years of the study (Table 1). Of the 28 species visited by chrysopids, 21 were visited by *C. lucasina* adults, while *C. pallida* adults were recorded in the plant species *Echium plantagineum*, *Glebionis segetum* and *Trifolium hirtum* (Tables 3).

3.5. Experimental design in 2016

Chrysopids were collected from 19 of the 34 plant species sampled in 2016, with nine of these plants presenting abundant chrysopids (up to average chrysopid abundance for that year 2016), and the plant species with the highest mean chrysopid abundance were *Moricandia moricandioides* and *Biscutella auriculata*. On the other hand, ten plant species, from which only one chrysopid specimen was collected, showed below average chrysopid abundance in 2016 (Tables 1 and 3).

In the 2016 sampling, the results showed that chrysopid abundance depends solely on plant species and not on Acari, Aphididae, Collembola and Thysanoptera abundance (Table 4). However, pairwise

Table 2
Total abundance and frequency (%) of taxa collected in 2016 and 2017.

Taxa	2016		2017	
	No. of specimens	%	No. of specimens	%
Acari	111	0.51	2,035	9.98
Aphididae	326	1.5	1,276	6.26
Araneae	205	0.94	255	1.25
Apidae	25	0.12	63	0.31
Cicadellidae	824	3.8	159	0.78
Coleoptera	1,228	5.66	435	2.13
Collembola	8,782	40.47	6,525	31.99
Diptera	3,184	14.67	863	4.23
Embioptera	2	0.01	0	0
Formicidae	75	0.35	176	0.86
Heteroptera	345	1.59	1,190	5.83
Lepidoptera	20	0.09	73	0.36
Neuroptera	58	0.27	176	0.86
Orthoptera	2	0.01	0	0
Parasitoids	1,859	8.57	1,029	5.05
Psocoptera	19	0.09	204	1
Syrphidae	16	0.07	19	0.09
Thysanoptera	4,618	21.28	5,917	29.01
Total	**21,699**		**20,395**	

Table 4
ANOVA (type II Wald Chi-square test) results of GLM models in 2016 and 2017. Degree of freedom (d.f.), Chisq (χ^2) and *p* value. Significance codes: ***$p < 0.001$, **$p < 0.01$, *$p < 0.05$.

Year	Variable	χ^2	d.f.	*p* value	
2016	Plant species	44.02	18	< 0.001	***
	Acari	0.035	1	0.851	
	Aphididae	0.228	1	0.633	
	Collembola	1.128	1	0.288	
	Thysanoptera	1.278	1	0.258	
2017	Plant species	310.698	17	< 0.001	***
	Acari	9.620	1	< 0.01	**
	Aphididae	2.695	1	0.101	
	Collembola	0.615	1	0.433	
	Thysanoptera	1.727	1	0.189	

comparisons did not show any differences between plant species.

3.6. Experimental design in 2017

In 2017, 18 of the 19 plant species were visited by chrysopids (Tables 1 and 3), seven of which exceeded the average chrysopid
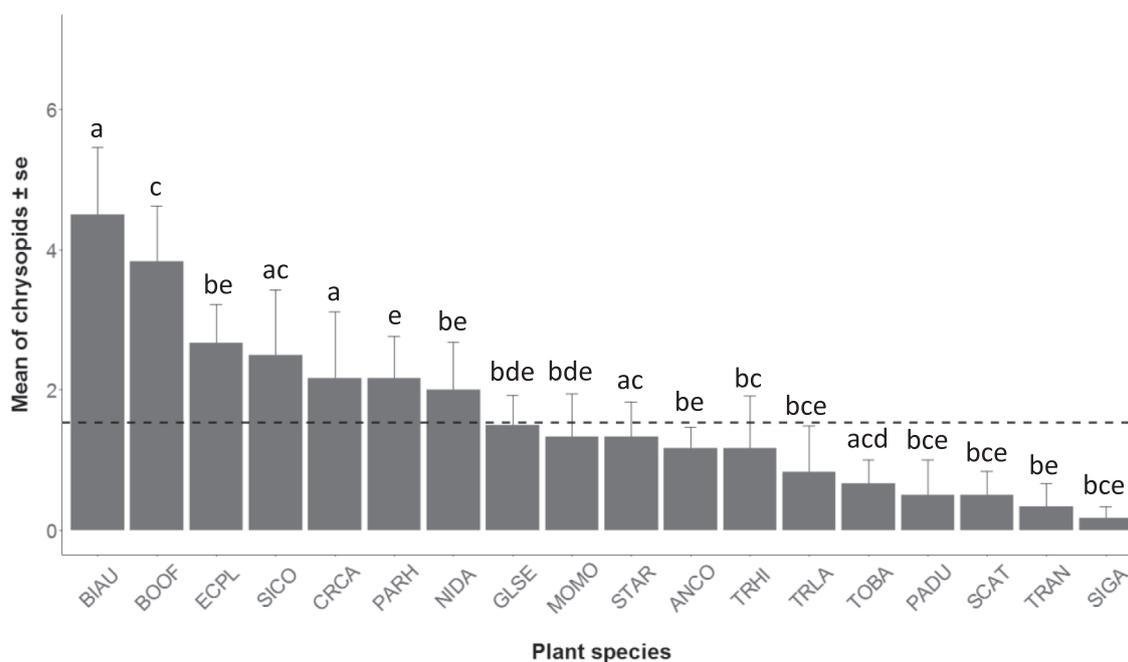
Table 3
Chrysopids collected from plant species in 2016 and 2017. Rows in bold indicate plant species with above-average chrysopid abundance in each sampling year.

Year	Family	Species	Plots with chrysopids (maximum = 6)	Total chrysopids (mean ± se)	Adults	Preimaginal stages	*C. lucasina* female	*C. lucasina* male	*C. pallida* female
2016	Apiaceae	*Tordylium maximum* L.	2	2 (0.3 ± 0.2)	1	1	1	0	0
	Asteraceae	*Crepis capillaris* (L.) Wall.	1	1 (0.2 ± 0.2)	1	0	0	1	0
	Asteraceae	*Glebionis segetum* L.	1	1 (0.2 ± 0.2)	1	0	1	0	0
	Boraginaceae	*Echium plantagineum* L.	1	1 (0.2 ± 0.2)	1	0	1	0	0
	Brassicaceae	***Biscutella auriculata* L.**	**4**	**7 (1.2 ± 0.5)**	**5**	**2**	**4**	**1**	**0**
	Brassicaceae	***Moricandia moricandioides* Boiss.**	**4**	**17 (2.8 ± 1.5)**	**16**	**1**	**5**	**11**	**0**
	Caryophyllaceae	***Silene colorata* Poir.**	**4**	**5 (0.8 ± 0.3)**	**3**	**2**	**3**	**0**	**0**
	Caryophyllaceae	***Vaccaria hispanica* (Mill.) Rauschert**	**3**	**5 (0.8 ± 0.4)**	**5**	**0**	**3**	**2**	**0**
	Fabaceae	***Medicago orbicularis* (L.) Bartal.**	**2**	**2 (0.3 ± 0.2)**	**2**	**0**	**1**	**1**	**0**
	Dipsacaceae	*Scabiosa atropurpurea* L.	1	1 (0.2 ± 0.2)	1	0	1	0	0
	Fabaceae	***Trifolium angustifolium* L.**	**1**	**2 (0.3 ± 0.3)**	**0**	**2**	**0**	**0**	**0**
	Fabaceae	*Trifolium stellatum* L.	1	1 (0.2 ± 0.2)	0	1	0	0	0
	Lamiaceae	*Cleonia lusitanica* L.	1	1 (0.2 ± 0.2)	1	0	1	0	0
	Poaceae	*Bromus hordeaceus* L.	1	1 (0.2 ± 0.2)	0	1	0	0	0
	Poaceae	*Cynosurus echinatus* L.	1	1 (0.2 ± 0.2)	1	0	1	0	0
	Poaceae	*Hordeum murinum, subsp. leporinum* L.	1	1 (0.2 ± 0.2)	0	1	0	0	0
	Poaceae	***Lolium multiflorum* Lam.**	**3**	**5 (0.8 ± 0.4)**	**5**	**0**	**3**	**2**	**0**
	Poaceae	*Trachynia distachya* (L.) Beauv.	1	1 (0.2 ± 0.2)	1	0	0	1	0
	Ranunculaceae	***Nigella damascena* L.**	**2**	**2 (0.3 ± 0.2)**	**2**	**0**	**2**	**0**	**0**
2017	Asteraceae	*Anthemis cotula* L.	5	7 (1.2 ± 0.3)	0	7	0	0	0
	Asteraceae	***Crepis capillaris* (L.) Wall.**	**4**	**13 (2.2 ± 1)**	**4**	**9**	**2**	**2**	**0**
	Asteraceae	*Glebionis segetum* L.	5	9 (1.5 ± 0.4)	3	6	2	0	1
	Asteraceae	*Tolpis barbata* (L.) Gaertn.	3	4 (0.7 ± 0.3)	0	4	0	0	0
	Boraginaceae	***Borago officinalis* L.**	**6**	**23 (3.8 ± 0.8)**	**1**	**22**	**1**	**0**	**0**
	Boraginaceae	***Echium plantagineum* L.**	**6**	**16 (2.7 ± 0.6)**	**5**	**11**	**3**	**1**	**1**
	Brassicaceae	***Biscutella auriculata* L.**	**6**	**27 (4.5 ± 1)**	**15**	**12**	**11**	**4**	**0**
	Brassicaceae	*Moricandia moricandioides* Boiss.	4	8 (1.3 ± 0.6)	3	5	2	1	0
	Caryophyllaceae	***Silene colorata* Poir.**	**4**	**15 (2.5 ± 0.9)**	**12**	**3**	**7**	**5**	**0**
	Caryophyllaceae	*Silene gallica* L.	1	1 (0.2 ± 0.2)	0	1	0	0	0
	Dipsacaceae	*Scabiosa atropurpurea* L.	2	3 (0.5 ± 0.3)	2	1	1	1	0
	Fabaceae	*Trifolium angustifolium* L.	1	2 (0.3 ± 0.3)	2	0	2	0	0
	Fabaceae	*Trifolium hirtum* All.	2	7 (1.2 ± 0.8)	1	6	0	0	1
	Fabaceae	*Trifolium lappaceum* L.	2	5 (0.8 ± 0.7)	1	4	0	1	0
	Lamiaceae	*Stachys arvensis* L.	4	8 (1.3 ± 0.5)	5	3	4	1	0
	Papaveraceae	*Papaver dubium* L.	1	3 (0.5 ± 0.3)	1	2	1	0	0
	Papaveraceae	***Papaver rhoeas* L.**	**6**	**13 (2.2 ± 0.6)**	**9**	**4**	**7**	**2**	**0**
	Ranunculaceae	***Nigella damascena* L.**	**6**	**12 (2 ± 0.7)**	**2**	**10**	**1**	**1**	**0**

Fig. 2. Chrysopid abundance (mean ± se) for each plant species studied (n = 6) in 2017. Lower case denotes significant pairwise Tukey's test differences between the plant species studied. The average annual chrysopid abundance in 2017 is indicated by a horizontal dashed line. For plant species codes, see Table 1.

abundance in that year 2017, with *B. auriculata* recording the highest mean abundance of captured chrysopids. On the other hand, 11 plant species showed a below annual average mean abundance of captured chrysopids (1 to 8 specimens).

The results demonstrated that chrysopid abundance in 2017 depended on both plant species and Acari abundance (Table 4). Pairwise comparison of plant species with above-average abundant chrysopids in 2017 (Fig. 2) showed a wide range of attractiveness, with *B. auriculata*, *B. officinalis*, *Silene colorata* and *Crepis capillaris* being especially attractive to chrysopids.

3.7. Use of plant species as habitats for reproduction, feeding and/or resting

In the 28 plant species visited by chrysopids, 23 eggs, 98 larvae of different ages and 112 adults were found. Of these plant species, 22 contained preimaginal-stage chrysopids, indicating that these plants were used for oviposition. Adults were found in 22 plant species, which were possibly used for feeding and/or rest. These activities (oviposition, feeding and/or rest) occurred in 16 of the plant species (Table 3).

4. Discussion

Plant selection was highly effective, as 36 of the 42 species sown showed satisfactory plant development, with blossoming occurring before that of olive trees.

The abundance of the Neuroptera taxa was found to be much lower than that of other predator arthropods such as spiders which is in line with the findings of other authors (Franin et al., 2016; Mignon et al., 2003; Silva et al., 2010). More specifically, various studies have found that chrysopids, among the most widespread and active predators, are the least abundant predators of aphids as compared to ladybeetles and hoverflies (Bertolaccini et al., 2011; Hatt et al., 2017). However, in our study, chrysopids were more abundant than hoverflies, while no ladybeetles were captured in either year of study.

With regard to chrysopid species richness, we examined two species, *C. lucasina* and *C. pallida*. *Chrysoperla lucasina* was the most abundant species collected, probably due to its wide holomediterranean distribution, effective adaptation to high temperatures as compared to

other species (Thierry et al., 1996) and its preference for spring-flowering herbaceous plants (Paulian, 2001; Villenave et al., 2005). On the other hand, the limited presence of *C. pallida* could be related to its preference for trees both inside and on the edge of forests despite its visits to herbaceous plants (Duelli et al., 2002; Monserrat, 2016).

Fluctuations in the abundance of chrysopid populations over the two years studied could be explained by changes in weather conditions and/or prey (Szentkirályi, 2001a) or by the possible differential attractiveness of the areas sown during the two years of the study. In the study area, the warmer and drier spring of 2017 may have favoured *C. lucasina* populations with their xerophile tendencies. In addition, the colder winter in 2015 as compared to 2016 may have raised adult chrysopid mortality, which, as in other zones, would affect the spring populations of this species (Villenave, 2006). With regard to prey, the increased presence of aphids in 2017 may have benefited *C. lucasina* populations given their marked aphidophagous nature (Canard et al., 1984).

With regard to the 36 plant species sampled under similar conditions (phenology, location and sampling) during the two-year period of the study, 28 were visited by chrysopids. Plant species availability played a major role in visits by chrysopids (Villenave et al., 2006), and we observed that plant species was an important factor affecting their presence. However we did not observe a clear pattern in plant species preference, probably due to a mix of factors related to inter-annual variations in arthropod populations. For example, in 2016, the absence of a marked preference for any of the plant species is explained by the highly variable abundance of the chrysopids captured in each sample. Nevertheless, with the large size of the areas sown and higher chrysopid abundance in 2017, the plant species *B. auriculata*, *B. officinalis*, *S. colorata* and *C. capillaris* were found to be particularly attractive to chrysopids. Although the selection of plants by *C. carnea s.l.* has not been reported due to its generalist and opportunistic behaviour (Duelli, 1987), adult lacewings would be expected to be clearly associated with or to have a preference for certain plant species when seeking pollen, nectar or prey, given that their presence and availability stimulate colonization (Canard et al., 1984; Devetak and Klokocovnik, 2016; Ruby et al., 2011). Other factors that may affect chrysopid plant visits are flower morphology and pollen production, as *C. carnea s.l.* is known to

be most attracted to umbelliferous members of the Asteraceae family and other plant species with exposed nectaries. However, the width of its head and thorax and length of its antennae may limit the number of flowers capable of providing nectar, which is extracted from extrafloral nectaries in some species (Nave et al., 2016; Van Rijn, 2012; Wäckers and Van Rijn, 2012). With its consumption apparently essential for *C. carnea s.l.* reproduction (Villa et al., 2016), the availability of pollen may explain the large number of visits to species such as *B. auriculata* and *P. rhoeas* despite their reported low nectar production (Hicks et al., 2016; Hidalgo and Cabezudo, 1995).

Though known to randomly forage on a broad range of plant species, *C. lucasina* adults only consume the pollen of certain plant species (Villenave, 2006; Villenave et al., 2006). The plant species *Calendula arvensis* was not visited by chrysopids during the two years of the study, which possibly due to the unattractiveness, or repellency of the plant, a phenomenon observed in other chrysopid species (Villa et al., 2016; Villenave, 2006). On the other hand, the preference of *C. lucasina* for low vegetation and large patches of flowering plants (Villenave, 2006) led chrysopid adults to visit 22 of the plant species sampled belonging to 11 botanical families, which could constitute an important source of food for chrysopids.

Prey residing in the plants constitutes another resource for chrysopids. Prey and/or honeydews produced by some prey, emit attractive kairomones which enable *C. carnea s.l.* adults to locate the plant and to find optimal oviposition sites (McEwen et al., 1993). Furthermore, herbivore-induced plant volatiles such as methyl salicylate that combined with acetic acid and 2-phenylethanol, have been reported to be attractive to lacewings in vineyards (Lucchi et al., 2017). Our study showed that abundant prey (Acari, Aphididae, Collembola and Thysanoptera) were available on the plant species sampled, although chrysopid abundance correlated with Acari abundance only in 2017.

The plant species most visited by chrysopids in our study belonged to four families: *B. auriculata* (Brassicaceae), *B. officinalis* (Boraginaceae), *S. colorata* (Caryophyllaceae) and *C. capillaris* (Asteraceae). This could be related to the feeding preference of *C. carnea, C. lucasina* and *Chrysoperla affinis* (Stephens, 1836) on these botanical families' previously reported by Denis and Villenave (2009). Our study shows that four species belonging to the genus *Trifolium* (Fabaceae), whose pollen, in line with the findings of Villenave et al. (2005), has been detected on the diverticulum of *C. carnea s.l.*, were visited by chrysopids as habitats both for reproduction and probably also for feeding. Moreover, certain Brassicaceae and Fabaceae species commonly used as plant cover in olive groves also prevent erosion and boost crop fertility (Gálvez et al., 2016). Thus, the selection of certain plant species could enhance ecosystem services such as biological control.

Knowledge of the function of habitats as reproduction and feeding sites is vital for improving the sustainability of ecosystem services (Bianchi et al., 2013). In our study, 22 species were used by chrysopids for oviposition in spring, with 22 species being used for feeding or rest. Chrysopids were found to perform these activities in 16 plant species; adults chrysopids, which are mostly female, usually oviposit where food is available, behaviour which has been observed in *C. carnea s.l.* (Duelli, 1984), and specifically on species such as *Trifolium pratense, Centaurea cyanus* and *P. rhoeas* (Franin et al., 2016). These findings are highly important with respect to managing the survival and maintenance of chrysopid populations in agroecosystems.

Given the practical focus of our study, it is also worth pointing out that the plants selected do not transmit diseases to crops and/or have a positive impact on their pest populations. In this study, the species *M. moricandioides* and *Hordeum murinum* were observed to be used by chrysopids to feed and/or rest and reproduce. However, they can present a certain level of susceptibility to the major olive tree-killing bacterium *Verticillium dahliae* or act as asymptomatic visitors, which favours the maintenance and multiplication of *V. dahliae* populations in olive plantations (Bejarano-Alcazar et al., 2004). Likewise, species such

as *Malva sylvestris* and *E. plantagineum* have been shown in the laboratory to positively affect the longevity and/or reproduction of *Prays oleae,* one of the principal pests in olive groves (Nave, 2016; Villa et al., 2017).

5. Conclusion

In summary, 36 out of the 42 native plant species studied showed good plant growth and ground cover. 28 native plants were used by chrysopids as habitats to reproduce, feed and/or rest, thus demonstrating that plant species plays a role in chrysopid attraction. The predominant chrysopid species collected from these plants was *C. lucasina.* Another factor of attraction was Acari abundance, which had a positive effect on chrysopid abundance in 2017. Of the 22 plant species sown in 2017, seven were particularly attractive to lacewings. Thus, given their attractiveness to chrysopids, the effect of pests and disease on olive groves, satisfactory plant growth and cover vegetation, in our view, *B. auriculata*, *B. officinalis*, *S. colorata*, *C. capillaris, N. damascena* and *P. rhoeas* are among the best species to restore ground cover for woody Mediterranean crops such as olive trees and to increase populations of these key natural enemies of olive pests

Author contribution statement

MC and FR obtained funding. MC, RAH, FR, CGR and SF conceived and designed the study. CGR and SF planted, cultivated and maintained the experimental plots. MC, RAH and FR carried out the sampling and analysed the data. RAH, MC, FR, CGR and SF wrote the manuscript. The manuscript was revised and approved by all the authors.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.biocontrol.2019.104066.

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