

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

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20 **Abstract**

21 Using native seeds to establish semi-natural habitats is a novel strategy to restore
22 biodiversity and ecosystem services such as biological control. Given that green
23 lacewings (Neuroptera: Chrysopidae) are regarded as major biological control agents in
24 different crops, the objective of this study was to test the attractiveness of selected
25 native plant species to lacewings, and to measure plant effect on chrysopid abundance
26 and/or species richness. During a two-year (2016-2017) field experiment near
27 Villarrubia (Andalusia, Spain), 42 native plant species belonging to 13 families were
28 planted in replicated plots. Plant development was monitored, and arthropods were
29 vacuumed from each plot twice during the peak flowering period of May. Of the 36
30 plant species that developed well, green lacewings were observed to use 28 of these
31 species to reproduce, feed and/or rest. The captured adults were mainly *Chrysoperla*
32 *lucasina*, with some *Chrysoperla pallida*. No clear pattern of attraction common to all
33 species was observed during the two-year sampling period. In 2017, eight plant species
34 showed above-average chrysopid abundance and four of these were the most
35 attractive to the green lacewings. In addition, Thysanoptera abundance correlated
36 positively with chrysopid abundance. Given the attraction of chrysopids, the effect of
37 pests and disease on olive orchards and satisfactory vegetative development, we
38 consider *Biscutella auriculata*, *Borago officinalis*, *Silene colorata*, *Crepis capillaris*,
39 *Nigella damascena* and *Papaver rhoeas* to be the native plant species best suited to
40 host chrysopids and to restore ground cover in perennial Mediterranean crops.

41

42 **Keywords.** Non-crop vegetation, native seeds, ecological infrastructure, ground cover,
43 chrysopids

44 **1. Introduction**

45 The general homogenisation of the agricultural landscape has led to a decrease in the
46 insect population and diversity, resulting in a decline in ecosystem services such as
47 biological pest control (Altieri and Nicholls, 2004; Penn et al., 2017). The European
48 Union (EU) has been developing policy tools such as the agri-environment scheme
49 (AES) (Science for Environment Policy, 2017) to “reduce environmental risks associated
50 with modern farming on the one hand, and preserve nature and cultivated landscapes
51 on the other hand” (European Commission, 2005), which will contribute to increasing
52 crop sustainability (Tschumi et al., 2014).

53 Spanish legislation regulating pesticides includes the use of ecological infrastructure in
54 the crops to protect and enhance natural enemy populations (RD 1311/14 September
55 2012). On-farm habitat of spontaneous or sown species is a good example of ecological
56 infrastructure. Nevertheless the increased use of herbicides has led to a depauperate
57 seed banks, and in order to create useful habitats for beneficial insects, it necessary to
58 establish an ecological infrastructure through active sowing. One specific type of on-
59 farm habitat for perennial woody crops (orchards) is the herbaceous understory
60 between trees. There is growing interest and research into suitable plant species for
61 ground cover restoration in woody Mediterranean agroecosystems such as olive,
62 vineyards, citrus and almond orchards, as well as ecosystem services to prevent soil
63 erosion and to maintain soil fertility (Alcántara et al., 2017; Gálvez et al., 2016).
64 Additionally, the EU has been promoting programs such as The NATive Seed Science,
65 TEchnology and Conservation (NASSTEC) scheme on the use of native seeds to restore
66 herbaceous communities in Europe. For agroecological applications, the seed mixes
67 that are currently available commercially are generally temperate forage species that

68 are less suited to Mediterranean soil and weather conditions than to wild, native
69 species (Hernández González et al., 2015). There is a great diversity of native plant
70 species which are adapted to the climate conditions of orchards (Castroviejo, 1986-
71 2012), and the use of native species is a novel strategy to ensure the success of ground
72 cover restoration for crops. In addition, sowing these conservation seed mixes could
73 help to establish and maintain seed banks without the need for re-sowing and defend
74 against invasion by non-native species and to reduce farming costs (Araj and Wratten,
75 2015; Siles et al., 2017). Additionally, regional native species contribute to increasing
76 local arthropod biodiversity (Ruby et al., 2011) and provide cultural ecosystem
77 services, such as wild food and medicinal plants, and to enhance landscape aesthetics
78 (Nave et al., 2017).

79 The *Chrysoperla carnea* s.l. group (Chrysopidae: Neuroptera), some of the most
80 widespread and active predators, occupy an outstanding position among the wide
81 variety of natural enemies of pests in agricultural areas (McEwen et al., 2001; Pappas
82 et al., 2011; Porcel et al., 2017). In Europe, seven species belonging to this predator
83 group have been characterized (Montserrat, 2016; Noh and Henry, 2010). *C. carnea* s.l.
84 adults have a palyno-glycophagous diet of nectar and pollen resources (even insect
85 honeydew) to obtain protein and carbohydrate, essential for their survival and
86 reproduction (Canard et al., 1984; Gonzalez et al., 2016; Villa et al., 2016; Villenave et
87 al., 2005). The larvae have a diet principally based on small arthropods such as aphids,
88 thrips, mites, scales, springtails and moths, which may be supplemented with non-prey
89 food resources, such as pollen and nectar, when prey are less abundant (Canard, 2001;
90 Patt et al., 2003; Villa et al., 2016).

91 Ground cover vegetation contributes to supporting and increasing chrysopid
92 populations, even on the canopy of perennial crops such as olives and apples. Thus,
93 landscape management strategies to promote ground cover vegetation are expected
94 to improve the biological control provided by chrysopids (Duelli, 2001; Porcel et al.,
95 2017; Szentkirályi, 2001b; Wyss, 1995). However, the enhancement of natural enemies
96 through landscape management does not necessarily lead to improved biological pest
97 control due to numerous factors such as crop type, tritrophic interactions, intraguild
98 predation, habitat, species synchrony, management regime and landscape. Because of
99 this, it is necessary to identify the conditions that provide effective biological control
100 (Bianchi et al., 2013; Rand et al., 2006; Tschardt et al., 2016).

101 The complex trophic relationship between natural enemies and plants is influenced by
102 various factors. The functional traits of flowers, as well as other factors such as the
103 presence of prey, affect the attractiveness to natural enemies (Hatt et al., 2017; Nave
104 et al., 2016; Van Rijn and Wackers, 2016). With respect to chrysopids, flowers with
105 well-exposed nectaries are known to be a suitable food source (Van Rijn and Wackers,
106 2016), and the presence of available prey at the preimaginal stage could prompt the
107 appearance of adults in plants containing these arthropods (Schultz, 1988). The
108 fundamental aspects of this tri-trophic relationship are linked to reproduction and
109 feeding. The habitats in which reproduction occurs can be identified by the presence of
110 preimaginal stage arthropods characterized by limited mobility, while habitats which
111 support adults are selected for feeding and/or resting purposes (Bianchi et al., 2013).
112 Chrysopids, which use a wide range of habitats even in absence of prey, show less
113 discriminatory oviposition (Duelli, 1984) than other predators such as syrphids and
114 ladybirds which only lay eggs when prey abundance exceeds a certain threshold

115 (Bianchi et al., 2013). With regard to feeding behaviour, given their generalist and
116 opportunistic nature, *C. carnea* s.l. complex adults feed on a broad variety of plant
117 species (Villenave et al., 2006).

118 It also needs to be taken into account that species belonging to the *C. carnea* and
119 *Pseudomallada prasinus* complex could have different feeding behaviours due to their
120 physiological and ecological differences (Denis and Villenave-Chasset, 2013; Henry and
121 Wells, 2007). Thus, the range of *C. carnea* (Stephens, 1836) visitors is more diverse
122 than that of *Chrysoperla lucasina* (Lacroix, 1912) visitors belonging to the complex
123 mentioned above (Villenave et al., 2005). It is therefore essential to determine the
124 specific requirements of each chrysopid species with respect to each plant species in
125 order to select the appropriate plants that support natural enemies with their
126 associated benefits (Chaplin-Kramer et al., 2013; Pantaleoni, 1996).

127 The objective of this study is to evaluate the attractiveness of selected native plant
128 species to lacewings, their impact on chrysopid abundance and/or species richness and
129 their correlation with potential prey abundance. We hypothesized that chrysopid
130 abundance could be increased by the presence of particular plants in the area
131 surveyed and/or depends on prey abundance. Both these hypotheses could be
132 important factors in explaining the attraction of lacewings. In addition, based on
133 previous studies by Denis and Villenave (2009) and Villenave et al. (2006), we expect to
134 collect different *C. carnea* s.l. complex species in most of the plant species and in all
135 the family plants sown given the low selectivity of their chrysopid oviposition
136 behaviour.

137 **2. Materials and Methods**

138 *2.1. Site description and plant species*

139 The experiment was conducted in two growing seasons from November 2015 to June
140 2017 at an experimental farm in the village of Villarrubia (Andalusia, Spain;
141 37°49'49"N, 4°54'20"W). The field was bordered, to the north, by a commercial orange
142 orchard and various irrigated crops and, to the south, by the River Guadalquivir with
143 riverbank vegetation. Olive plantations are also located near the experimental farm.
144 The soil is a Calcaric Fluvisol with a neutral/basic pH (IUSS Working Group, 2015).
145 During the two-year study, meteorological conditions varied slightly, with a mean
146 temperature in May 2017 3°C higher than in May 2016 and rainfall in May 2017 half
147 that in May 2016 (AEMET meteorological station, 37°50'56"N, 4°50'48"W).

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

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

159 *2.2. Arthropod collection*

160 In both years of the study, we sampled three 3 x 3 m squares for every plant sown at
161 the beginning and end of May. However, the plants were sown differently each year: in
162 2016, a total of 40 plant species from 13 botanical families (Table 1) were planted in a
163 completely randomized design in three blocks. Each plant species was sown in three 3
164 x 3 m squares (replica plots), with a 1.75 m interval between replica plots in the same
165 block and a 5 m interval between replica plots in the three different blocks (total of
166 120 replica plots, Figure 1a).

167 In 2017, based on the chrysopid abundance results for 2016, 22 plant species from
168 nine botanical families were planted, 20 of which had been planted in 2016 and two
169 (*Borago officinalis* and *Papaver rhoeas*) were only planted in 2017. A single
170 randomized replica-block and replica-plot design was used for each plant species, and
171 the replica-plot design area ranged from 50 m² to 5,640 m². We collected three
172 samples (replica samples) located equidistantly from the centre of each replica plot to
173 avoid a border effect (Figure 1b).

174 The phenological stage and index of plant cover were recorded throughout the
175 growing season for each plot.

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

179 Replica plots and replica samples for each plant species were vacuumed for 40 seconds
180 using an insect aspirator (InsectaZooka, Bioquip® Products Inc., Rancho Dominguez,
181 CA, USA). We then stored the samples at -20°C, which were later sorted in the
182 laboratory. Arthropods (chrysopids and potential prey) were identified to the highest
183 taxonomic level required to determine their functional group. To assess the function of

184 each plant species at species level, we distinguished between the different
185 development stages of the chrysopids found in each plant species: preimaginal (eggs
186 and larvae) and adults (males and females) stages. Chrysopid adults were determined
187 up to species level as described according to the latest survey of the Iberian chrysopids
188 (Monserrat, 2016). It is important to note that we carried out our study in both years
189 on plants under similar conditions (phenology, location and sampling time).

190 *2.3. Statistical analysis*

191 Data analysis was carried out according to the protocol described by Zuur et al. (2010).
192 Total chrysopid abundance per plant species was expressed as the sum of adult and
193 preimaginal stages in each replica plot and replica sample, while total potential prey
194 per plant species was expressed as the sum of Acari, Aphididae, Collembola and
195 Thysanoptera in each replica plot and replica sample.

196 Differences in mean chrysopid abundance per year were tested using the Kruskal-
197 Wallis test according to the Bonferroni correction method, as the data do not follow a
198 normal distribution.

199 Total chrysopid abundance per year was separately modelled by fitting a generalized
200 linear model (GLM) with a negative binomial distribution as a function of plant species
201 and potential prey abundance. We used only plant species in which chrysopids were
202 recorded (19 in 2016 and 18 in 2017). In 2017, when total surface sown per plant
203 species differed, as recommended by Zuur et al. (2013), the rate at which events occur
204 in areas of different sizes was included in the model to offset these variations, as the
205 surfaces sown may have different levels of attractiveness to chrysopids.

206 The correlation between chrysopid abundance and the potential prey Acari, Aphididae,
207 Collembola and Thysanoptera was tested each year using the Pearson test.

208 All statistical analyses were carried out using R software version 3.5.0 (R Development
209 Core Team, 2017), and the “*agricolae*” package (De Mendiburu, 2014) was used for the
210 Kruskal-Wallis test.

211 3. Results

212 3.1. Growth of plant species

213 A total of 30 out of 42 plant species sown, which covered over 70% of the surface
214 sown, recorded adequate growth in both years of the study (Table 1). In 2016, only 5
215 out of the 40 plant species sown, belonging to four botanical families, which showed
216 unsatisfactory vegetative development, were not sampled: *Tuberaria guttata*,
217 *Helianthemum ledifolium* (Cistaceae), *Anarrhinum bellidifolium* (Veronicaceae),
218 *Aegilops geniculata* and *Aegilops triuncialis* (Poaceae). In 2017, two of the 22 plant
219 species belonging to the Fabaceae family (*Medicago polymorpha* and *Medicago*
220 *orbicularis*) did not grow correctly. Two other plant species, *Capsella bursa-pastori* in
221 2016 and *Vaccaria hispanica* in 2017, which failed to bloom during the sampling
222 period, were not included in the sample (Table 1).

223 3.2. Arthropods collected

224 An overall evaluation of the 42,130 arthropods collected (21,723 in 2016 and 20,408 in
225 2017) showed that the Neuroptera Order of insects belonging exclusively to the
226 Chrysopidae family, was a tiny minority in both sampling years (0.27% in 2016, 0.86%
227 in 2017) as compared to other taxa groups in natural enemy assemblages such as
228 parasitoids (8.56% in 2016, 5.04% in 2017), predators belonging to the Suborder
229 Heteroptera (1.7% in 2016, 5.9% in 2017) and the Order Araneae (0.94% in 2016,
230 1.25% in 2017). The mean abundance of Chrysopidae species collected each year was
231 also significantly higher in 2017 (1.54 ± 0.17 individuals/replica, $n = 114$) than in 2016
232 (0.28 ± 0.06 individuals/replica, $n = 204$) (Kruskal-Wallis Chisq = 68.83, $p < 0.001$).
233 Among the potential prey available for natural enemies, the most abundant taxa of the
234 total arthropods captured were the Orders Collembola (40.43% in 2016, 31.97% in

235 2017) and Thysanoptera (21.26% in 2016, 28.99% in 2017) (Table 2). The low and
236 irregular abundance of the Order Acari ranged from zero in many plant species to
237 75.5 ± 37.3 individuals/replica. Members of the Aphididae family, which were more
238 abundant in 2017, were present in all plant species (Supplementary Material, Table
239 A.2).

240 3.3. Chrysopid species

241 Chrysopid species diversity was low, with all 46 adults recorded in 2016 identified as
242 belonging to the *C. lucasina* species (27 females and 19 males; Table 3). 95% (63) of
243 specimens collected in 2017 were identified as *C. lucasina* (44 females and 19 males),
244 with 5% (3) of specimens identified as *Chrysoperla pallida* (Henry et al., 2002) females
245 (Table 5).

246 3.4. Plants visited by chrysopid species

247 With regard to the 36 plant species sampled, during the two years of the study, 28
248 were visited by chrysopids at the preimaginal and adult stages. Of the eight plants not
249 visited, seven were only sown in 2016, and *Calendula arvensis* was the only plant
250 species present during the two years of the study (Table 1). Of the 28 species visited by
251 chrysopids, 21 were visited by *C. lucasina* adults, while *C. pallida* adults were recorded
252 in the plant species *Echium plantagineum*, *Glebionis segetum* and *Trifolium hirtum*,
253 with *C. lucasina* only absent from *T. hirtum* (Tables 3, 5).

254 3.5. Sampling in replica plots (2016)

255 Chrysopids were collected from 19 of the 34 plant species sampled in 2016, with nine
256 of these plants presenting abundant chrysopids (up to their annual average
257 abundance), and the plant species with the highest mean chrysopid abundance were
258 *Moricandia moricandioides* and *Biscutella auriculata*. On the other hand, ten plant

259 species, from which only one chrysopid specimen was collected, showed below annual
260 average mean abundance (Table 1, 3).

261 In the 2016 sampling, the GLM model showed that chrysopid abundance depends
262 solely on plant species and not prey abundance (Table 4). However, the high variability
263 in chrysopid abundance in replica plots per plant species meant that pairwise
264 comparisons of plant species did not differ significantly. In addition, although we found
265 potential prey for chrysopids in all plant species (Supplementary Material, Table A.1),
266 chrysopid abundance did not correlate closely with potential prey (Pearson test;
267 $r < 0.04$) (Supplementary Material, Table A.2).

268 3.6. Sampling in replica samples (2017)

269 In 2017, 18 of the 19 plant species were visited by chrysopids (Table 1, 5), eight of
270 which exceeded annual average chrysopid abundance, with *B. auriculata* recording the
271 highest mean abundance of captured chrysopids. On the other hand, 11 plant species
272 showed a below annual average mean abundance of captured chrysopids (1 to 8
273 chrysopids).

274 The GLM model demonstrated that chrysopid abundance in 2017 depended on plant
275 species and prey abundance (Table 4). Pairwise comparison of plant species with
276 chrysopids showing above-average annual mean abundance (Figure 2) highlighted two
277 significantly different groups. The first group was composed of *B. auriculata*, *B.*
278 *officinalis*, *Silene colorata* and *Crepis capillaris*, while the second group comprised *E.*
279 *plantagineum*, *P. rhoeas* and *Nigella damascena*, although no differences between
280 plant species within each group were observed. All plants in both groups showed
281 abundant potential prey (Supplementary Material, Table A.3), with only the abundance

282 of Thysanoptera being positively correlated with that of chrysopids (Pearson test;
283 $r < 0.15$, $p < 0.05$) (Supplementary Material, Table A.2).

284 *3.7. Use of plant species as habitats for reproduction, feeding and/or resting*

285 In the 28 plant species visited by chrysopids, 23 eggs, 98 larvae of different ages and
286 112 adults were found. Of these, 22 contained chrysopids at the preimaginal stage,
287 indicating that these plants were used for reproduction. Adults were found in 22 plant
288 species, which were possibly used for feeding and/or rest. These activities, together
289 with reproduction, occurred in 16 of the plant species visited (Table 3, 5).

290 4. Discussion

291 Plant selection was highly effective, as 36 of the 42 species sown showed satisfactory
292 vegetative development, with blossoming occurred, before that of olive trees.

293 The abundance of the Neuroptera taxa was found to be much lower than that of other
294 predator arthropods such as spiders and coleopteran which is in line with the findings
295 of other authors (Franin et al., 2016; Mignon et al., 2003; Silva et al., 2010). More
296 specifically, different studies have also found that chrysopids, which are among the
297 most widespread and active predators, are the least abundant predators of aphids as
298 compared to ladybeetles and hoverflies (Bertolaccini et al., 2011; Hatt et al., 2017).

299 With regard to chrysopid species richness, only two species, *C. lucasina* and *C. pallida*,
300 were present in our study. *C. lucasina* was the most abundant species collected, which
301 is probably due to its wide holomediterranean distribution, effective adaptation to
302 high temperatures compared to other species (Thierry et al., 1996) and its preference
303 for spring-flowering herbaceous plants (Paulian, 2001; Villenave et al., 2005). On the
304 other hand, the limited presence of *C. pallida* could be related to its preference for
305 trees both inside and on the edge of forests despite its visits to herbaceous plants
306 (Duelli et al., 2002; Monserrat, 2016).

307 Fluctuations in the abundance of chrysopid populations over the two years studied
308 could be explained by changes in weather conditions and/or potential prey
309 (Szentkirályi, 2001a) or by the possible differential attractiveness of the surfaces sown
310 during the two years of the study. In the study area, the warmer and drier spring of
311 2017 may have favoured *C. lucasina* populations with their xerophile tendencies. In
312 addition, the colder winter of 2015 as compared to 2016 may have raised adult
313 chrysopid mortality, which, as occurs in other zones, would affect the spring

314 populations of this species (Villenave, 2006). With regard to prey, the larger presence
315 of aphids in 2017 could have benefited *C. lucasina* populations given their marked
316 aphidophagous nature (Canard et al., 1984).

317 With regard to the 36 plant species sampled during the two-year study, 28 were visited
318 by chrysopids. Although plant species was observed to be an important factor affecting
319 the presence of chrysopids, this variable did not have a clear pattern probably due to a
320 mix of factors related to inter-annual variations in arthropod populations. For example,
321 in 2016, the absence of a marked preference for any of the plant species is explained
322 by the highly variable abundance of the chrysopids captured in each replica plot.
323 Nevertheless, with the large size of areas sown and higher chrysopid abundance in
324 2017, the plant species *B. auriculata*, *B. officinalis*, *S. colorata* and *C. capillaris* were
325 found to be particularly attractive to chrysopids. Although the selection of plants by *C.*
326 *carnea* s.l. has not been reported due to its generalist and opportunistic behaviour
327 (Duelli, 1987), adult lacewings should clearly be associated with or have a preference
328 for certain plant species when seeking pollen, nectar or prey, given that their presence
329 and availability stimulate colonization (Canard et al., 1984; Devetak and Klokocovnik,
330 2016; Ruby et al., 2011). Availability of vegetal species plays a major role in visits by
331 chrysopids (Villenave et al., 2006), however we studied in both years the plant species
332 under similar conditions (phenology, location and sampling date). Other factors that
333 may affect chrysopid plant visits is flower morphology and pollen production, as *C.*
334 *carnea* s.l. is known to be most attracted to umbeliferous members of the Asteraceae
335 family and other plant species with exposed nectaries. However, the width of its head
336 and thorax and length of its antennae may limit the number of flowers capable of
337 providing nectar, which is extracted from extrafloral nectaries in some species (Nave et

338 al., 2016; Van Rijn, 2012; Wäckers and Van Rijn, 2012). With its consumption
339 apparently essential for *C. carnea* s.l. reproduction (Villa et al., 2016), the availability of
340 pollen may explain the large number of visits to species such as *B. auriculata* and *P.*
341 *rhoeas* despite their reported low nectar production (Hicks et al., 2016; Hidalgo and
342 Cabezudo, 1995).

343 Although *C. lucasina* adults are known to randomly forage on a broad plant species,
344 only consume the pollen of some plant species (Villenave, 2006; Villenave et al., 2006).
345 *C. arvensis* plant species were not visited by chrysopids during the two years study,
346 which could be due to a lack of attraction, or aversion, to the plant, a phenomenon
347 observed in other chrysopid species (Villa et al., 2016; Villenave, 2006). On the other
348 hand, the *C. lucasina* preference for low vegetation and large patches of flowering
349 plants (Villenave, 2006) led chrysopid adults to visit 22 of the plant species sampled
350 belonging to 11 botanical families, which could constitute an important source of food
351 for chrysopids.

352 Potential prey residing in the plants constitutes another resource for chrysopids. Prey
353 and/or their honeydews, produced by some prey, emit kairomones which attract *C.*
354 *carnea* s.l. adults, enabling them to locate the plant and to find optimal oviposition
355 sites (McEwen et al., 1993). Our study showed that abundant prey (Acari, Aphididae,
356 Collembola and Thysanoptera) were available on the plant species sampled, although
357 chrysopid abundance was correlated with prey abundance only in 2017. We found
358 statistical evidence that, among available potential prey, thrips positively correlate
359 with chrysopid abundance. Aphids are known to be a favourite prey of *C. carnea* s.l.
360 larvae in different crops; preoviposition flights in spring are also associated with the
361 presence of aphid colonies, although the polyphagous nature of larvae means that

362 very different types of prey are sought and consumed (Duelli, 2001; Villenave et al.,
363 2005). Bertolaccini et al. (2011) have also reported the presence of *C. carnea* in
364 numerous spontaneous plants, such as *Echium vulgare* and *C. capillaris*, which had no
365 aphids.

366 The plant species most visited by chrysopids in our study belonged to four families: *B.*
367 *auriculata* (Brassicaceae), *B. officinalis* (Boraginaceae), *S. colorata* (Caryophyllaceae)
368 and *C. capillaris* (Asteraceae), which could be related to the feeding preference of *C.*
369 *carnea*, *C. lucasina* and *Chrysoperla affinis* (Stephens, 1836) on these botanical
370 families' previously reported by Denis and Villenave (2009). Our study shows that four
371 species belonging to the genus *Trifolium* (Fabaceae) were visited by chrysopids as
372 habitats both for reproduction and probably also for feeding, in agreement with
373 findings of Villenave et al. (2005) as pollen from this family has been detected on the
374 diverticulum of *C. carnea* s.l.. Moreover some different species of Brassicaceae and
375 Fabaceae, also prevent erosion and boost crop fertility and biofumigation, being
376 commonly used as vegetal cover in olive groves (Gálvez et al., 2016). Thus the selection
377 of certain plant species could enhance different ecosystem services not only improve
378 biological control.

379 Knowledge of the function of habitats as reproduction and feeding sites is vital for
380 improving the sustainability of ecosystem services (Bianchi et al., 2013). In our study,
381 the preimaginal stage of chrysopids present in different plant species show that 22
382 species were used by chrysopids for reproduction in spring, and 22 species were used
383 for feeding or rest, a finding which is of considerable importance for managing the
384 survival and maintenance of these populations. Chrysopids were found to perform
385 both activities in 16 plant species; as most adults are female, they usually oviposit

386 where food is available, behaviour which has been observed in *C. carnea* s.l. (Duelli,
387 1984), and specifically on species such as *Trifolium pratense*, *Centaurea cyanus* and *P.*
388 *rhoeas* (Franin et al., 2016).

389 The results obtained in our study enabled us to determine the relationship between
390 chrysopids and the native plant species selected, although flower visitation rates,
391 which are relative measures, depend on the presence of other flowering species,
392 competition with other flower visitors and on previous experience (Wäckers and Van
393 Rijn, 2012). Thus, in future research, it will be important to determine their suitability
394 in terms of actual fitness benefits in relation to survival and reproduction (Wäckers and
395 Van Rijn, 2012). In this regard, different spontaneous Mediterranean flowering plants
396 have been shown in the laboratory to improve *C. carnea* s.l. adult survival rates, while
397 pollen consumption appears to be essential for reproduction (Villa et al., 2016). The
398 sugar profile and content of Mediterranean flowering plants as a food resource for *C.*
399 *carnea* adults have been evaluated, with trehalose content in pollen and nectar playing
400 a key role in *C. carnea* fecundity and longevity (Gonzalez et al., 2016).

401 Given the practical aims of our study, another factor to be considered is that the plants
402 selected do not transmit diseases to crops and/or have a positive impact on their pest
403 populations. In this study, the species *M. moricandioides* and *Hordeum murinum* were
404 observed to be used by chrysopids to feed and/or rest and reproduce. However, they
405 can present a certain level of susceptibility to the bacteria causing important olive tree
406 disease *Verticillium dahliae* or act as asymptomatic visitors, which favours the
407 maintenance and multiplication of *V. dahliae* populations in olive plantations
408 (Bejarano-Alcazar et al., 2004). Likewise, species such as *Malva sylvestris* and *E.*
409 *plantagineum* have been shown in the laboratory to positively affect the longevity

410 and/or reproduction of *Prays oleae*, one of the main pests in olive groves (Nave, 2016;
411 Villa et al., 2017).

412 **5. Conclusion**

413 In summary, our results demonstrate that 28 native plants with adequate vegetative
414 growth are used by chrysopids as habitats to reproduce, feed and/or rest. The adults
415 captured were *C. lucasina* and *C. pallida*, with a predominance of the former. In 2017,
416 visits by chrysopids were determined by the plant species and the prey present in
417 these species; among the potential prey available, thrips were shown to have a
418 positive effect on chrysopid abundance. Of the eight plant species, with above-average
419 chrysopid abundance, *B. auriculata*, *B. officinalis*, *S. colorata* and *C. capillaris* were the
420 most attractive to these lacewings. Given the attraction of chrysopids, the effect of
421 pests and disease on olive groves and satisfactory vegetative growth, in our view, *B.*
422 *auriculata*, *B. officinalis*, *S. colorata*, *C. capillaris*, *N. damascena* and *P. rhoeas* are
423 among the best species to restore ground cover for woody Mediterranean crops such
424 as olive trees and to increase populations of these key natural enemies of olive pests
425 (graphical abstract).

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433

434 **7. Author contribution statement**

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

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625

626 **Table and figure captions**

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

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

630 **Table 3.** Plants presenting chrysopids in replica plot sampling (2016). Rows in bold
631 indicate plant species with above-average mean chrysopid abundance. The only
632 chrysopid species captured was *C. lucasina*.

633 **Table 4.** Results of generalized linear model (GLM) for each year of the study, degree
634 of freedom (df), Chisq (χ^2) and *p*-value were obtained by Anova analysis of GLM
635 deviance. Significance of variables in the model is indicated as follows: *** *P* < 0.001,
636 ***P* < 0.01, * *P* < 0.05.

637 **Table 5.** Plants presenting chrysopids in replica samples (2017). Rows in bold indicate
638 plant species with above-average annual mean chrysopid abundance.

639 **Figure 1.** Diagrams showing planting and sampling design in 2016 (Fig. 1a) and 2017
640 (Fig. 1b).

641 **Figure 2.** Chrysopid abundance (mean \pm se) for each plant species studied (*n* = 6) in
642 2017. Lower case denotes significant pairwise Tukey's test differences between plant
643 species studied. Significant differences are shown only when the mean of abundance is
644 higher than average annual chrysopid abundance in 2017 (indicated by a horizontal
645 dashed line). For plant species codes, see Table 1.

646 **Supplementary Material, Table A.1.** Total abundance (mean \pm se) in 2016 of potential
647 chrysopid prey collected from each plant species (*n* = 6).

648 **Supplementary Material Table A.2.** Correlation between potential prey and chrysopid
649 abundance in both years studied (2016, 2017).

650 **Supplementary Material, Table A.3.** Total abundance (mean \pm se) in 2017 of potential
651 chrysopid prey collected from each plant species (n = 6).