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Juan Sorribas, Sandra González, Alfons Domínguez-Gento, Rosa Vercher. Abundance, movements and biodiversity of flying predatory insects in crop and non-crop agroecosystems. *Agronomy for Sustainable Development*, 2016, 36 (2), pp.34. 10.1007/s13593-016-0360-3 . hal-01324704

HAL Id: hal-01324704

<https://univ-rennes.hal.science/hal-01324704>

Submitted on 16 Feb 2017

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1 Research Article:

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3 Abundance, movements and biodiversity of flying predatory
4 insects in crop and non-crop agroecosystems
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15 *Key words:* Mediterranean agroecosystem; Organic management; Conservation Biological Control;

16 Entomophagous arthropod; Shelter habitat; Cover crop; Neuroptera; Lacewing; Citrus

17

18 **Abstract**

19 Predatory insects are key natural enemies that can highly reduce crops pest damage. However, there is a
20 lack of knowledge about the movements of flying predatory insects in agroecosystems throughout the
21 year. In particular, it is still unclear how these predators move from crop to non-crop habitats, which are
22 the preferred habitats to overwinter and to spread during the spring and if these predators leave or stay
23 after chemical treatments. Here, the Neuroptera, a generalist, highly mobile, flying predator order of
24 insects, was selected as model. We studied the effects of farming management and the efficiency of edge
25 shelterbelts, ground cover vegetation, and fruit trees canopy on holding flying predatory insects in
26 Mediterranean traditional agroecosystems. Seasonal movements and winter effects were also assessed.
27 We evaluated monthly nine fruit agroecosystems, six organic, and three pesticides sprayed, of 0.5–1 ha in
28 eastern Spain during 3 years using two complementary methods, yellow sticky traps and aspirator.
29 Results show surprisingly that the insect abundance was highest in pesticide sprayed systems, with 3.40
30 insects/ sample versus 2.32 insects/sample in organic systems. The biodiversity indices were highest in
31 agroecosystems conducted under organic management, with S of 4.68 and D of 2.34. Shelterbelts showed
32 highest biodiversity indices, S of 3.27 and D of 1.93, among insect habitats. Insect species whose adults
33 were active during the winter preferred fruit trees to spend all year round. However, numerous species
34 moved from fruit trees to shelterbelts to overwinter and dispersed into the orchard during the following
35 spring. The ground cover vegetation showed statistically much lower attractiveness for flying predatory
36 insects than other habitats. Shelterbelts should therefore be the first option in terms of investment in
37 ecological infrastructures enhancing flying predators.

38

39 **1. Introduction**

40 An agroecosystem, the basic unit of study in agroecology, can be identified as an area which includes
41 crop habitats and non-crop habitats adjacent to the crops (You et al. 2004). Intensive agriculture often
42 involves a maximum utilization of the land surface which includes removal of non-crop areas such as
43 surrounding woody vegetation (i.e. hedgerows and shelterbelts), riparian herbaceous vegetation and weeds.
44 Throughout Europe, the expansion of modern, chemical-intensive agriculture is regarded as the principal
45 cause of the widespread declines in abundance and diversity of predatory insects over the past decades (e.g.
46 Hole *et al.* 2005; Bianchi, et al. 2006). Sustainable practices such as organic farming, cover cropping and
47 hedgerows preservation may contribute to enhance predatory insects living within agroecosystems (Altieri
48 and Letourneau 1982; Östman *et al.* 2001). Because arthropod generalist predators (or entomophagous
49 arthropods) must efficiently search for preys, they can be considered ideal models for investigating
50 conservation techniques (Panzer and Schwartz 1998). Conservation biological control (CBC) is the practice of
51 enhancing natural enemies through modification of the environment or landscape of an agroecosystem
52 (Eilenberg *et al.*, 2001). The practice of CBC, which involves the manipulation of agricultural habitats to
53 favour the natural enemies, offers the possibility of simultaneously increasing insect and plant biodiversity
54 and reducing pest problems (Straub *et al.* 2008).

55 Although higher biodiversity not necessarily means better biological control, conserving natural enemy
56 species richness could increase the chances that the enemy community will contain good enemy species,
57 leading to a positive relationship between natural enemy species richness and biological control (Straub *et al.*
58 2008). This has led to growing interest in management practices that promote on-farm biodiversity such as
59 organic farming (e.g. Hole *et al.* 2005; Straub *et al.* 2008). In general, organic farming is reported to increase
60 arthropod diversity in agricultural landscapes (e.g. Bengtsson *et al.* 2005; Hole *et al.* 2005; Smukler *et al.*
61 2010). Organic farming usually increases arthropod species richness and abundance, having on average 30%
62 higher species richness and 50% more abundance than conventional farming systems (Bengtsson *et al.* 2005).
63 When compared with sprayed crops, more natural enemies establish and maintain themselves in organic crops
64 whereas arthropod herbivores usually exhibit an opposite trend (Altieri and Schmidt 1986; Östman *et al.*
65 2001).

66 Non-crop natural or semi-natural habitats inside agroecosystems such as field margins, grassy ground
67 cover, hedgerows and shelterbelts are relatively undisturbed and temporally permanent areas that may provide
68 resources that are critical to sustaining natural enemy population diversity (Landis *et al.* 2000; Bianchi *et al.*
69 2006). These patches of vegetation in agricultural landscapes can enhance natural enemies by providing foods
70 (e.g. alternate hosts for parasitoid wasps, preys for predatory insects, honeydew, pollen or nectar), modified

71 climate (e.g. windbreaks made by shelterbelts) and/or more niches (e.g. overwintering and nesting habitats)
72 Altieri and Letourneau 1982; Landis *et al.* 2000; Gurr *et al.* 2003; Bianchi *et al.* 2006). The abundance and
73 diversity of predatory insects within crop fields and orchards are closely related to the surrounding vegetation
74 (Altieri and Letourneau 1982). One of the major limitations to understand how natural enemies are affected by
75 non-crop vegetation is knowing how they move or disperse within their environment throughout the year.
76 Movement is critical to escape from disturbances and to find resources scattered in space and time. However
77 there is a lack of studies showing year-round movements of predators between croplands and surrounding
78 areas (see Rand *et al.* 2006) and the knowledge of how highly mobile flying predators overwinter in orchard
79 agroecosystems is even lower. Flying insects are ideal models since they can escape after chemical treatments
80 to surrounding non-crop habitats or stay in the field if they can stand to non-intensive treatments. Since non-
81 crop habitats provide requisites for natural enemies they may act as sinks relative to crop habitats when
82 natural enemies have a year-round preference for these habitats thus reducing the exchange of natural enemies
83 between crop and non-crop habitats (Bianchi *et al.* 2006). Appropriate landscape management in agricultural
84 systems requires an understanding of insect seasonal movements and dispersal.

85 We chose a generalist, highly mobile, flying predator order of insects, Neuroptera, as model to identify
86 the most important habitats for biodiversity conservation in Mediterranean traditional agroecosystems for
87 flying predatory insects. Neuroptera have been previously used as standard of value for generalist predators
88 and indicators of the ecological status of rural habitats due to the susceptibility of most species to pesticides
89 and their well-known environmental needs (e.g. Stelzl and Devetak 1999; Thierry *et al.* 2005). Neuroptera
90 were selected because they occupy the top of the ecological arthropod trophic pyramid, they occur in very
91 diverse habitats all year round, they can easily disperse between non-crop and crop habitats, they have
92 different feeding abilities, they need growing vegetation to feed and lay their eggs and they are sensitive
93 indicators of environmental richness, stability and local diversity (see Stelzl and Devetak 1999; Villenave *et al.*
94 2005). In commercial orchards neuropteran populations develop only when insecticide treatment is not
95 applied in intervals that are too short (Pantaleoni and Ticchiati 1988) and adult specimens can fly the distance
96 between boundary vegetation and fruit trees (some marked Neuroptera species have been collected up to 200
97 meters away from the marking point) (Long *et al.* 1998).

98 Here we hypothesize that:

- 99 a. There will be a reduction in biodiversity and abundance of natural enemies in “conventional”
100 sprayed orchards in relation to organic managed orchards.

- 101 b. Due to the larger total area and complementary food source all year round of the ground cover
102 vegetation (e.g. pollen from weeds with different flowering periods) it will be the preferred habitat
103 over woodland habitats for most species.
- 104 c. Flying predators will displace from fruit tree canopies to non-crop habitats to overwinter.
- 105

106 **2. Materials and Methods**

107 2.1 *Study area*

108 The study was performed in the south of Valencia province (eastern Spain), an area with typical
109 Mediterranean agroecosystems dominated by small fruit orchards of 0.5 - 1 ha. The landscape of the study
110 area is composed mostly of clementine mandarins *Citrus clementina* Tanaka (many of them having grassy
111 ground cover in fruit trees understory) and patches of natural or planted native woody vegetation (shelterbelts)
112 surrounding the orchards. This woody vegetation, which has been historically used to form a natural fence
113 and as windbreaks, is constituted by rows of trees and tall shrubs which can be remnants of existing
114 vegetation from cleared lands, a result of natural plant dispersal, or established via direct plantings by farmers.

115 We delimited habitat types according to vegetation structure (vegetation strata) and human agricultural
116 activities. The habitat types defined were: (1) fruit tree canopies, (2) ground cover vegetation (grassland), and
117 (3) shelterbelts of woody vegetation (surrounding fruit orchards).

118 For the study we selected nine plots constituting nine isolated agroecosystems each of them formed by
119 a citrus orchard with ground cover vegetation growing in fruit trees understory and woody shelterbelts
120 surrounding all sides of the orchards. Plots were separated a maximum of 20 lineal kilometres and about 15-
121 20 lineal kilometres away from the Mediterranean Sea coast.

122 Citrus trees inside agroecosystems of the study area were cultivated under two forms of farming
123 practice, certified organic management (six orchards) and “conventional” sprayed management (three
124 orchards). Insecticidal treatments for these orchards included phosphorate insecticides, pyrethroids and
125 acaricides which were applied twice a year under integrated pest management strategies. Both organic and
126 sprayed orchards had been under the same farming practice for the previous 7-10 years. We analyzed and
127 compared the biodiversity and abundance of lacewings in both groups.

128 Shelterbelts of the study area were rather similar and had a mixed composition of several
129 Mediterranean native perennial trees and shrubs species, predominantly *Pistacia lentiscus* L., *Nerium*
130 *oleander* L, *Viburnum tinus* L. and/or *Phillyrea angustifolia*. The distance between any of the edges and the
131 central trees of the orchard was always lower than 100 meters (inferior than Neuropters flying capacity).
132 Ground vegetation was composed of spontaneous or sown herbaceous species (grass), predominantly

133 *Cynodon* sp., *Bromus* sp., *Amaranthus* sp., *Sonchus* sp., *Chenopodium* sp., *Senecio* sp., *Calendula* sp.,
134 *Medicago sativa* L. and/or *Melilotus officinalis* L. Natural regeneration of ground vegetation was allowed
135 before mowing (twice a year).

136 2.2 *Insect material and sampling methodology*

137 Neuroptera is an insect order of polyphagous predators of many agricultural pests such as mites, scales,
138 whiteflies and aphids (Stelzl and Devetak 1999). Almost all feeding behaviours can be found within
139 Neuropteran families, omnivorous (Hemerobiidae and Chrysopidae), carnivorous-glycinophagous
140 (Coniopterygidae); phytophagous (some Chrysopidae) and pollino-glycinophagous (some Chrysopidae can
141 feed on pollen from about 40 trees) and several species are mass reared and released within classical
142 biological control programs (Stelzl and Devetak 1999; Villenave *et al.* 2005).

143 Due to its different feeding preferences and flying abilities and the diverse plant structure and
144 architecture of the three habitats evaluated we choose two very different sampling methods in order to
145 maximize catches of neuropteran insects.

146 The sampling process was performed fortnightly from May to October and monthly during the cold
147 period for this region, November to April, during three consecutive years (October 2006 - October 2009). In
148 the six organic farming orchards three habitats were sampled: fruit tree crowns, ground cover vegetation and
149 orchards surrounding shelterbelts, whereas in the three conventionally managed orchards only citrus trees
150 were sampled.

151 Aspiration sampling was carried out with a custom built suction machine composed of a commercial
152 garden two-stroke engine-powered leaf blower (Komatsu Zenoah Co., HBZ2601 model) assembled with a
153 cylindrical plastic suction mouth 30 cm high and 30 cm in diameter. This is a modification of the gasoline-
154 driven vacuum device designed by Dogramaci *et al.* (2011). The sampling process was standardized for an
155 aspiration of 2 minutes duration (equivalent to 1 - 3 trees depending on size) in all cases. All sucked insects
156 were retained in a fine mesh placed at the extreme of the suction tube. The mesh was replaced after each
157 aspiration process and insects captured were conserved inside the mesh which was annotated with a sample
158 number. Sampling with the suction device was randomly performed 3-4 times for citrus tree canopies of each
159 orchard, 3-4 times for shelterbelts and 3-4 times for the ground vegetation (depending of orchard and
160 shelterbelt size).

161 Yellow traps consist of a 10x25 cm plastic rectangle with sticky surface which were vertically hanged
162 from 2-3 citrus trees and from 2-3 hedge trees or shrubs per orchard. In the ground vegetation 2-3 traps per
163 orchard were placed on wooden posts planted in the soil at constant a height of 50 cm above the ground.
164 Traps were collected and replaced the same day as the aspiration process was performed (Fig 1).

165 Trees and ground surface for sampling were randomly selected for both methods. In the laboratory all
166 Neuroptera insects collected or trapped were observed under a stereomicroscope and classified to species or
167 higher taxonomic levels. The several species of the cryptic *carnea* group were classified into a single category
168 hereby referred to as *Chrysoperla carnea* Stephens.

169 A total of 3302 samples were collected with the suction device and 2384 yellow sticky traps from the 6
170 organic agroecosystems during the 3 years. The citrus trees of sprayed agroecosystems were sampled using
171 the suction device and yellow sticky traps following the same protocol described, with the difference that in
172 this case only the fruit trees were sampled. A total of 346 aspiration samples and 236 yellow sticky traps were
173 collected.

174 2.3. *Data analysis*

175 For the statistical analysis of the abundance of captures by the two sampling methods we performed a
176 simple Analysis of Variance (ANOVA) of all the data in all habitats (8 species and 29177 data). For the
177 comparative between D biodiversity indices and between species richness we calculated the monthly diversity
178 index and the number of species by summing up the total individuals captured monthly in each agroecosystem
179 followed by ANOVA Multiple Range Test. The comparative between abundance in organic and sprayed
180 agroecosystems was done by simple ANOVA of all data. When we compared fruit trees, ground cover and
181 shelterbelts we performed multifactor ANOVA considering year and habitat as factors for each species.

182 In order to evaluate the number of species and diversity indices, data were grouped monthly as number
183 of insects or number of species/month for each year and sampling methodology. Two of the most commonly
184 used indices were selected to quantify Neuropteran biodiversity: Taxonomic species richness [S], i.e. the
185 number of species collected and Simpson's diversity index [D].

186

187 **3. Results and Discussion**

188 3.1. *Relative abundance of lacewings*

189 The analysis of the total number of captures of all species by the two sampling methods shows that
190 when using the suction device, lacewings of Chrysopidae family (green lacewings) were the most commonly
191 captured ($F = 166.07$; $df = 7, 29$ 176; $P < 0.0001$) whereas yellow sticky traps captured, in general, much higher
192 proportion of Coniopterygidae (dusty-wings) (97% of the total lacewings captured with this method; $F =$
193 216.64 ; $df = 7, 23$ 535; $P < 0.0001$). *Chrysoperla carnea* was the most frequently captured species with the
194 aspirator whereas *Semidalis aleyrodiformis* Stephens was the most common Neuroptera on yellow sticky
195 traps (more than 5000 specimens captured). The amount of Hemerobiids (brown lacewings) was small and
196 similar with both methods. This indicates that green lacewings and dusty-wings have different flying or

197 displacement strategies and both capturing methods are complementary in order to evaluate the abundance
198 and diversity of these flying insects.

199 Out of 14318 adult lacewings collected, we identified ten species (coexisting in both organic and
200 sprayed agroecosystems) belonging to three families. Chrysopidae (green lacewings): *Ch. carnea*, *Chrysopa*
201 *septempunctata* Wesmael and two unidentified *Dichochrysa* species; Coniopterygidae (dusty-wings): *S.*
202 *aleyrodiformis*, *Conwentzia psociformis* (Curt.) and two unidentified *Coniopteryx* species; Hemerobiidae
203 (brown lacewings): *Micromus angulatus* Stephens and *Wesmaelius subnebulosus* Stephens.

204 When compared with Neuroptera abundance and species richness found by other authors in
205 agroecosystems composed of arable crops (e.g. Pantaleoni and Ticchiati 1988) we observed that it was much
206 lower than in these evergreen fruit orchards. Perennial crop systems such as fruit orchards are more stable
207 than annual systems and they are subject to lower levels of disturbance which could explain differences in
208 predator abundance and biodiversity.

209 3.2. *Species richness and biodiversity indices*

210 Values reached for species richness and Simpson Diversity Index [D] were higher in fruit orchard
211 agroecosystems conducted under organic management than in sprayed conventional agroecosystems. The
212 mean number of species [S] captured per month was significantly higher ($F= 66.13$; $df = 1, 144$; $P < 0.0001$)
213 in organic orchards (4.68 ± 0.22 species/month) than the number in sprayed orchards (2.33 ± 0.18
214 species/month). The same pattern was found for the Biodiversity index, with the organic orchards having an
215 average [D] of 2.35 ± 0.09 , significantly higher ($F= 20.05$; $df = 1, 144$; $P < 0.0002$) than the sprayed orchards,
216 1.31 ± 0.08 (Fig 2a). These outcomes agree with previous studies in other agroecosystems (see Altieri and
217 Schmidt 1986; Bengtsson *et al.* 2005).

218 When comparing the insect biodiversity associated to each habitat type we found that shelterbelts had
219 the highest values for the Biodiversity indices evaluated, followed by the biodiversity associated to fruit tree
220 canopies and lastly by ground vegetation associated insects. Biodiversity indices differences between habitat
221 types were statistically significant (S: $F= 41.70$; $df = 2, 188$; $P < 0.0001$. D: $F= 26.61$; $df = 2, 188$; $P <$
222 0.0001) (Fig 2b).

223 3.3. *Relative abundance in organic and sprayed agroecosystems*

224 When comparing organic and sprayed agroecosystems insect relative abundance (bringing together
225 data from yellow traps and aspirator) we found some significant differences (Table 1). The total mean amount
226 of adult Neuroptera captured in sprayed agroecosystems (3.40 ± 0.54 adults/sample) was significantly higher
227 ($F= 16.51$; $df = 1, 5943$; $P < 0.001$) than in organic agroecosystems (2.32 ± 0.14 adults/sample). This
228 unexpected result was mainly due to the high level of a single dominant species, *Ch. carnea*, found in sprayed

229 agroecosystems, 0.48 ± 0.07 adults/sample, compared to organic agroecosystems, 0.18 ± 0.01 adults/sample ($F=$
230 55.30 ; $df = 1, 5943$; $P < 0.001$). The analysis of the population dynamics of *Ch. carnea* showed that this
231 species was much more abundant in agroecosystems under sprayed management during summer, while their
232 relative abundance in organic agroecosystems remained rather stable all year round.

233 This implies that some species are able to resist chemical treatments up to certain degree when
234 staggered in time. The resistance of *Ch. carnea* to many pesticides and the sensibility of other Neuropteran
235 species to these pesticides was previously indicated by Stelzl and Devetak (1999). Agricultural pest-
236 management practices often lead to altered food web structure and communities dominated by a few common
237 species whereas organic farming methods mitigate this ecological damage by promoting evenness among
238 natural enemies (Crowder *et al.* 2010). This could explain why *Ch. carnea* became the dominant species
239 during summer in sprayed agroecosystems (end of spring was a period for chemical treatments) whereas in
240 ecological agroecosystems the abundance of this species kept rather constant throughout the year.

241 Among Coniopterygidae no differences were found in both management systems. The more uncommon
242 neuropters, *Ch. septempunctata*, *M. angulatus*, *W. subnebulosus* and *Dichochrysa* species were significantly
243 more abundant in organic agroecosystems (Table1).

244 3.4. Insect distribution inside organic agroecosystems

245 Considering together captures with the aspirator and traps within the organic agroecosystems, an
246 average of 2.31 ± 0.21 adult lacewings per sample were captured in citrus tree canopies, 2.51 ± 0.19 lacewings
247 per sample in surrounding trees and shrubs and only 0.11 ± 0.02 lacewings per sample in the ground cover
248 vegetation. Three distribution patterns were observed (Fig 3):

249 -Species which were more abundant in citrus tree canopies, represented by *C. psociformis* ($F= 8.77$; $df=$
250 $2, 1288$; $P < 0.001$) and *Ch. carnea* ($F= 12.38$; $df = 2, 1288$; $P < 0.001$);

251 - Species significantly more abundant in citrus tree canopies and shelterbelts than in the ground
252 vegetation, such as *S. aleyrodiformis* ($F = 12.26$; $df= 2, 1288$; $P < 0.001$) and *Coniopteryx* spp. ($F= 12.92$; $df =$
253 $2, 1288$; $P < 0.001$);

254 - Species which were present in similar proportion in the three habitat types ($F= 0.95$; $df= 2, 1288$; $P=$
255 0.3888) such as *Chrysopa septempunctata* Wesmael.

256 Unexpectedly, the herbaceous ground cover vegetation showed much lower attractiveness to lacewings
257 than the canopy of shelterbelts and fruit trees. Thus, our first hypothesis, based on the supposition that
258 lacewings would find more complementary food from the many flowering weeds of the ground vegetation,
259 which was supported on previous studies that found high abundance of many predatory insects at ground
260 vegetation level (e.g. Bianchi *et al.* 2006; Silva *et al.* 2010) was wrong. There may be several reasons

261 explaining this behaviour: the comparative higher disturbance at the ground vegetation level (mowing, fruit
262 picking, etc), the better refuge against wind and extreme temperatures that shelterbelts represent (wooded
263 habitats provide more moderate microclimate (Forman and Baudry 1984)) and/or the higher abundance of
264 non-flying competing predators in the above ground layer (some of them can act also as predators of
265 lacewings). This illustrates the importance of considering plant structure and architecture when evaluating
266 predatory insect habitats. Thus, in terms of economic investment in non-crop habitats enhancing flying
267 predators it is clear that shelterbelts should be considered as the preferable choice when assessing alternative
268 landscape configurations. Nevertheless, it is important to bear in mind that, as demonstrated by Paredes *et al.*
269 (2013), in fruit agroecosystems there may be a positive synergistic effect between shelterbelts and ground
270 vegetation in terms of beneficial predator abundance and diversity.

271 3.3. *Seasonal population dynamics*

272 We analyzed seasonal dynamics of the most abundant Neuroptera species from data collected with the
273 aspirator device within the organic agroecosystems. Yellow sticky traps were not considered for this purpose
274 since they remain in the field one month during the cold period.

275 The analysis of the three habitats evaluated allowed separating insect species in several groups (Fig 4):

276 - Species that showed seasonal migration from fruit trees to shelterbelts to overwinter: *Ch.*

277 *septempunctata*, *M. angulatus* and *W. subnebulosus*. Adult populations of these species associated to citrus
278 trees start to decline at the end of summer and beginning of autumn (September-October) at the same time
279 that populations associated with shelterbelts increased. For these species captures of adults during the winter
280 period (equivalent in the case of Valencia to the “non-growing season” from January to March) were very
281 scarce or null which mean these species spent winter as egg or larval forms.

282 - Two species, *C. psociformis* and *S. aleyrodiformis* (two dusty-wings), showing an opposite trend to
283 previous group: during winter adult captures of these species were very high in citrus tree canopies while
284 much lower in shelterbelts and very scarce or null at the ground vegetation level. These species had a second
285 similar peak of captures in May but populations declined sharply during summer.

286 - A species, *Ch. carnea*, whose captures were very high during summer and autumn both in the citrus
287 trees and in shelterbelts and very scarce during winter and beginning of spring. Seems that the more abundant
288 Chrysopidae and Coniopterygidae share the same resources via temporal niche partitioning since when the
289 former reach the peak of adult captures during summer captures of the later are minimum and the opposite
290 happens during winter.

291 - All Neuroptera species captured at the ground vegetation level reached the highest peak during the
292 spring period, captures during the rest of the year being very scarce compared to the other habitats, except for

293 *Ch. septempunctata* which showed a second important peak during august.

294 The population peaks of lacewings associated with fruit trees and shelterbelts were different in each
295 habitat type which indicates that there was a movement of species between both habitats and shifts in the
296 direction of predator dispersal throughout the year. Furthermore, most Neuroptera species that spent the
297 winter period as egg or larval forms (very low number of adults between January and March) showed the
298 same behaviour: at the end of summer or beginning autumn the adult populations associated to fruit trees
299 declined at the time that populations within shelterbelts increased indicating these species moved there to
300 overwinter. Adults of these species dispersed into the orchards during the following spring as can be deduced
301 by the peaks of captures reached in May or June. These outcomes concur with other predatory insects which
302 were found to show seasonal migration from crops to shelter habitats at different stages of their life cycle and
303 mainly at the beginning of the cold periods to overwinter (e.g. Duelli *et al.* 1990; Thomas *et al.* 2001; Pollard
304 and Holland 2006). However, species whose adults were active during winter, dusty-wings lacewings, highly
305 preferred fruit tree canopies to spend this period. In fact, during most part of the year adult populations of
306 these species were abundant in citrus tree canopies and higher than in the non-crop habitats demonstrating
307 that evergreen fruit crops can harbour predatory insects all year round. Thus, in spite of the intrinsic
308 difficulties associated to any monoculture, some generalist predators are able to find food and shelter within
309 the canopy of fruit trees all year round and persist from year to year within orchards.

310 The winter-active generalist predators play a key role on the reduction of winter pest populations and
311 the decline of the first seasonal population outbreaks of several agriculture pests since during early spring
312 most natural enemies are still in dormancy or absent. This has been previously stated for other arthropod
313 predator species which were active in fruit crops during winter (see Pekar *et al.* 2015). This highlights the
314 importance of analyzing natural enemy activity over time rather than take a “snapshot” in one or few
315 samplings which had been the most common in the bulk of the studies considering natural enemy response to
316 agroecosystem complexity (see Chaplin-Kramer *et al.* 2011).

317

318 4. Conclusion

319 Although biodiversity indices were highest, as expected, within organic orchard agroecosystems, the
320 relatively high year-round predators abundance and diversity inside sprayed tree canopies suggest that when
321 perennial fruit trees are under conventional but not chemical-intensive treatments (such as integrated pest
322 management programs) they can efficiently harbour predatory insects throughout the year.

323 Our results indicate that strategies for enhancing flying natural enemies that maximize Conservation
324 Biological Control, such as habitat management, should focus more on field margin woody vegetation rather

325 than the ground cover vegetation when considering non-crop habitats. We can say that, under Mediterranean
326 climate conditions, flying seasonal patterns of migration from agricultural lands to non-crop habitats to
327 overwinter depend on species adult winter activity. While dormant insects generally move to shelterbelts to
328 overwinter active insects remain in high proportion on fruit trees canopy. Since many flying predators move
329 from crop towards surrounding shelterbelts to overwinter presence of boundary woody vegetation can avoid
330 their migrations to other areas. Shelterbelts serve to attract flying predators to the farmland and maximize
331 survival possibilities when a perturbation occurs, allowing them to quickly re-colonize the crop afterwards.
332 More studies to address which particular shrubs or trees species that can be used to build shelterbelts are the
333 more suitable to harbour this and other key predatory insect orders are needed.

334

335 **Acknowledgements**

336 We thank two anonymous reviewers and the editors for constructive comments on the manuscript.
337 The authors are very grateful to Rosa Guaita, Pili Mañó, Anna Marco, Altea Calabuig, Bernadette Csőke and
338 Adela Cuesta for their help and collaboration with laboratory and field work and to citrus orchards owners
339 who permitted access for this study. Joan van Baaren and Ferran Garcia-Marí provided valuable comments
340 that improved the manuscript. We thank Lucy Alford and Adrien Bonvin for language corrections.

341

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417 **Figure Captions:**

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419 **Fig 1.** Schematic figure showing the type of habitats evaluated in this study (left side), the sampling methods (centre)
420 and the main species representing the main insect families found in this study (right side). From top to bottom: woody
421 shelterbelts, fruit trees canopy and ground cover vegetation (left side), yellow sticky trap and vacuum device (centre),
422 and adult specimens of Chrysopidae, Coniopterygidae and Hemerobiidae families respectively (right side).

423

424 **Fig 2.** Biodiversity indices (Species richness [S] and Simpson's diversity index [D]) of a) Neuropters living within fruit
425 orchard agroecosystems under organic and sprayed (conventional) management. b) Neuropters living within three habitat
426 types: citrus trees canopy, shelterbelts and ground cover vegetation inside fruit agroecosystems. Samples were collected
427 using a suction device and yellow sticky traps from 9 orchard agroecosystems of eastern Spain during the period 2006 to
428 2009. Vertical bars indicate standard error (SE) of the means. Values followed by the same letter are not significantly
429 different from each other according to Fisher's LSD multiple range test ($p \leq 0.05$).

430

431 **Fig. 3.** Occurrence of the most abundant Neuroptera species within three habitats (fruit trees, shelterbelts and ground
432 covers) belonging to orchard agroecosystems. Samples were collected with a suction device from 2006 to 2009 in six
433 agroecosystems of Valencia Region (eastern Spain) under organic management. Vertical bars indicate standard error
434 (SE) of the means. For each species, values followed by the same letter are not significantly different from each other
435 according to Fisher's LSD multiple range test ($p \leq 0.05$).

436

437 **Fig. 4. a-f** Population dynamics of the most abundant Neuroptera insects in fruit agroecosystems: *Chrysoperla carnea*,
438 *Chrysopa septempunctata*, *Conwentzia psociformis*, *Semidalis aleyrodiformis*, *Coniopteryx* sp. and two Hemerobiidae
439 species (*Micromus angulatus* and *Wesmaelius subnebulosus*). Samples were collected using a suction device and yellow
440 sticky traps from 2006 to 2009 in citrus trees canopy (422 samples), shelterbelts (478 samples) and ground covers (389
441 samples) within 6 organic agroecosystems of eastern Spain. Vertical bars indicate standard error (SE) of the means.

442



Fig 1. Schematic figure showing the type of habitats evaluated in this study (left side), the sampling methods (centre) and the main species representing the main insect families found in this study (right side). From top to bottom: woody shelterbelts, fruit trees canopy and ground cover vegetation (left side), yellow sticky trap and vacuum device (centre), and adult specimens of Chrysopidae, Coniopterygidae and Hemerobiidae families respectively (right side).

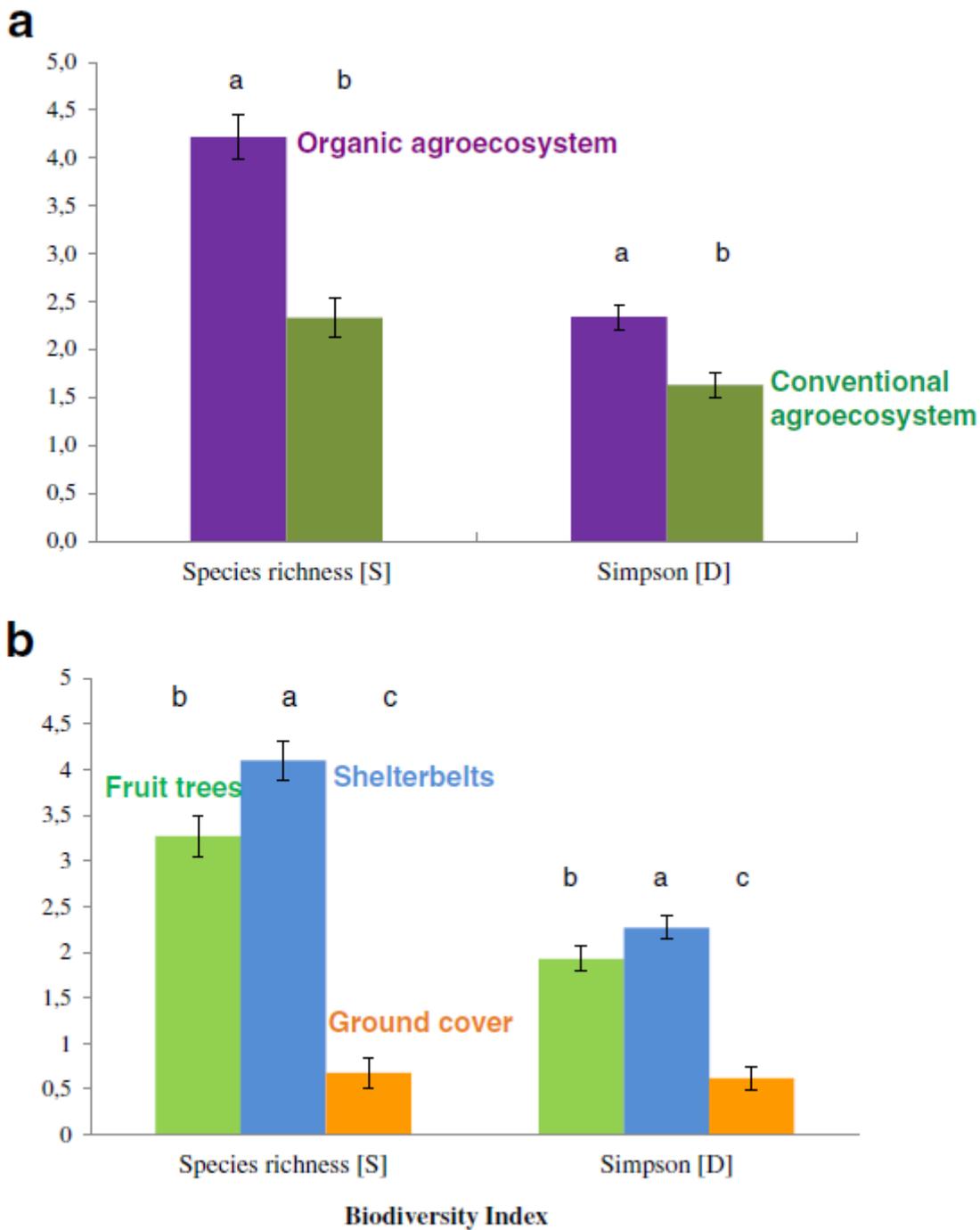


Fig 2. Biodiversity indices (Species richness [S] and Simpson's diversity index [D]) of a) Neuropters living within fruit orchard agroecosystems under organic and sprayed (conventional) management. b) Neuropters living within three habitat types: citrus trees canopy, shelterbelts and ground cover vegetation inside fruit agroecosystems. Samples were collected using a suction device and yellow sticky traps from 9 orchard agroecosystems of eastern Spain during the period 2006 to 2009. Vertical bars indicate standard error (SE) of the means. Values followed by the same letter are not significantly different from each other according to Fisher's LSD multiple range test ($p \leq 0.05$).

Means of adults/sample

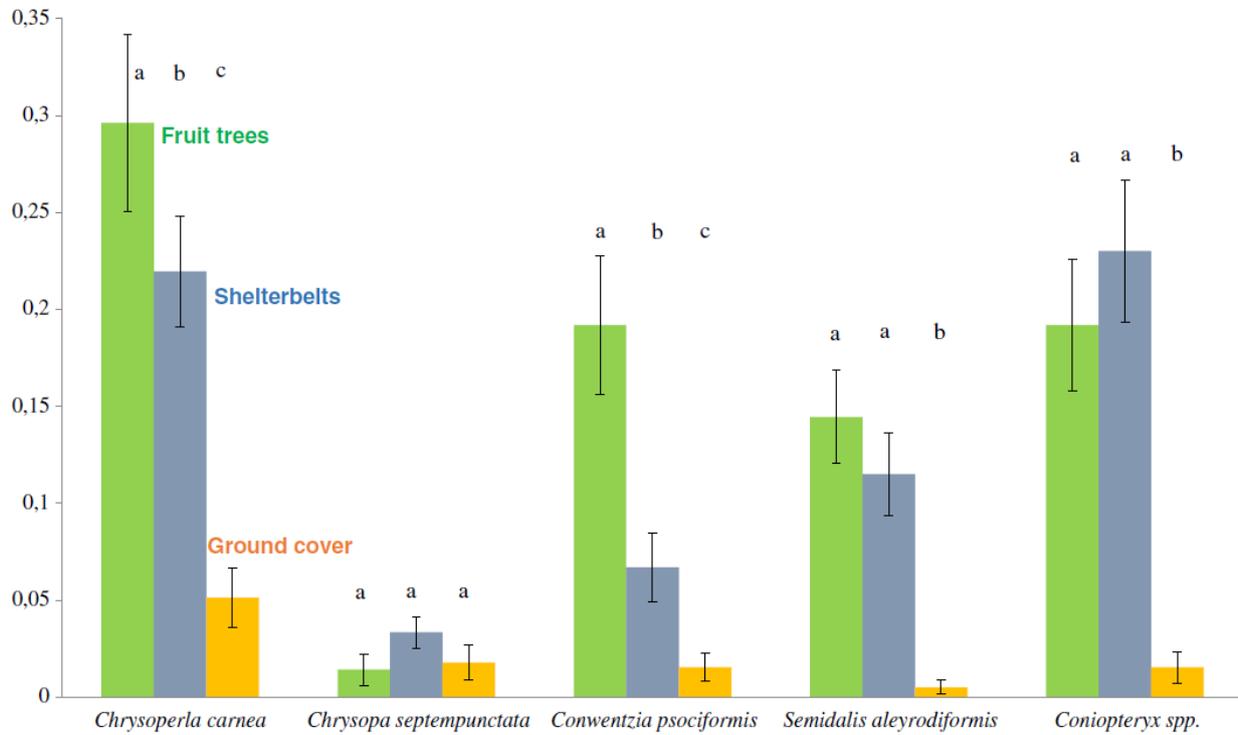


Fig. 3 Occurrence of the most abundant Neuroptera species within three habitats (fruit trees, shelterbelts, and ground covers) belonging to orchard agroecosystems. Samples were collected with a suction device from 2006 to 2009 in six agroecosystems of Valencia Region (eastern Spain) under organic management. Vertical bars indicate standard error (SE) of the means. For each species, values followed by the same letter are not significantly different from each other according to Fisher's LSD multiple range test ($P \leq 0.05$)

Mean of
adults / month

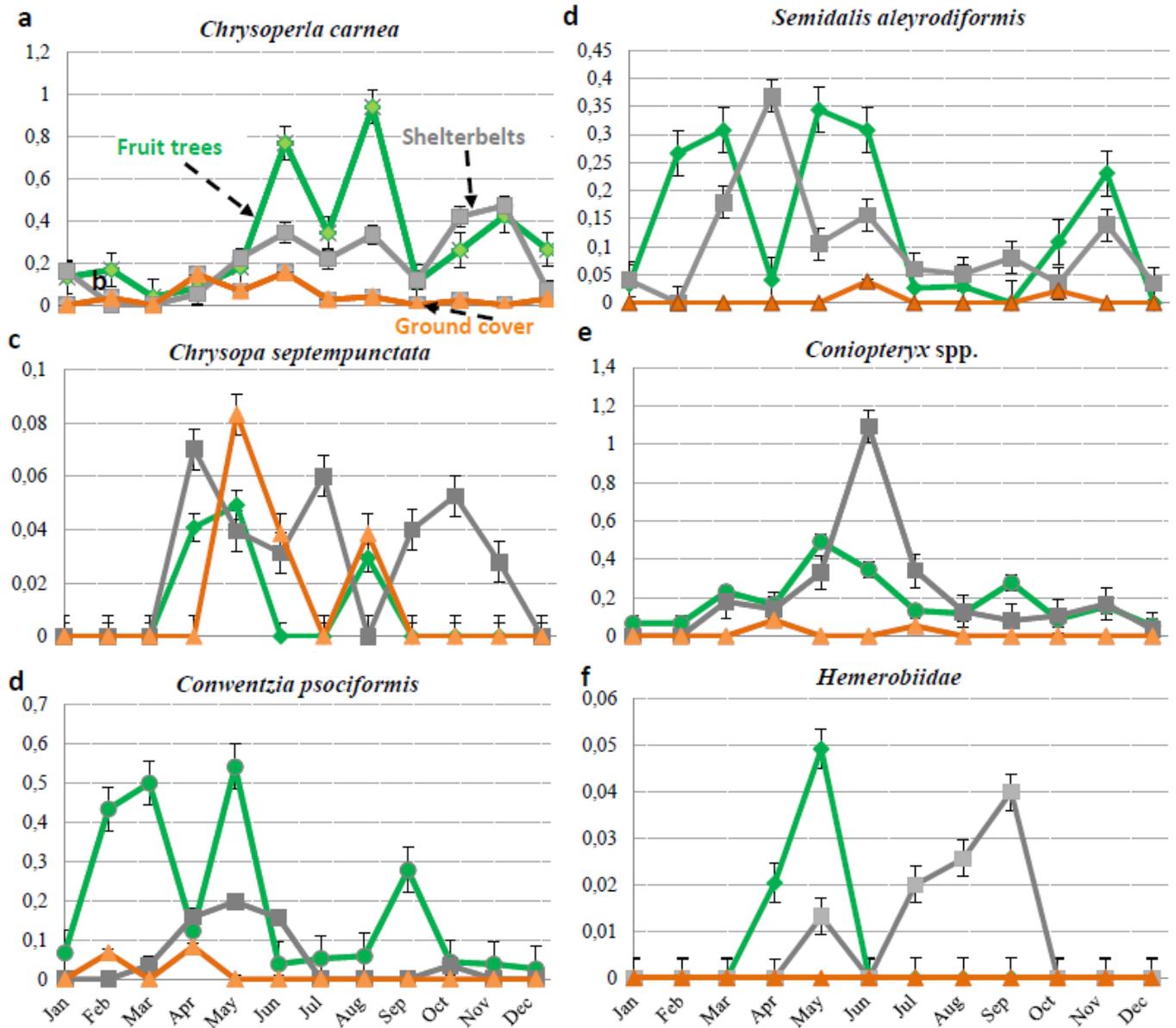


Fig. 4. a-f Population dynamics of the most abundant Neuroptera insects in fruit agroecosystems: *Chrysoperla carnea*, *Chrysopa septempunctata*, *Conwentzia psociformis*, *Semidalis aleyrodiformis*, *Coniopteryx* sp. and two Hemerobiidae species (*Micromus angulatus* and *Wesmaelius subnebulosus*). Samples were collected using a suction device and yellow sticky traps from 2006 to 2009 in citrus trees canopy (422 samples), shelterbelts (478 samples) and ground covers (389 samples) within 6 organic agroecosystems of eastern Spain. Vertical bars indicate standard error (SE) of the means.

Table 1. Mean number ($M \pm SE$) of adult Neuroptera captured per sample in fruit agroecosystems under organic and conventional (sprayed) management. Samples were collected with a suction device and yellow sticky traps from 2006 to 2009 in agroecosystems of eastern Spain. *Dichochrysa* species (Chrysopidae) were not considered due to the low number of captures.

Family	Species	Organic Agroecosystem	Conventional Agroecosystem	F	P
		M \pm SE	M \pm SE		
CHRYSOPIDAE	<i>Chrysoperla carnea</i>	0.18 \pm 0.01b	0.48 \pm 0.07a	55.30	<0.0001
	<i>Chrysopa septempunctata</i>	0.07 \pm 0.005a	0.03 \pm 0.01b	4.43	0.003
CONIOPTERYGIDAE	<i>Conwentzia psociformis</i>	0.64 \pm 0,07 a	1.02 \pm 0.36 a	0.80	0.37
	<i>Semidalis aleyrodiformis</i>	0.92 \pm 0.09 a	1.22 \pm 0.26 a	1.07	0.30
	<i>Coniopteryx sp.</i>	0.47 \pm 0,05 a	0.62 \pm 0.23 a	0.00	0.98
HEMEROBIIDAE	<i>Micromus angulatus</i> and <i>Wesmaelius subnebulosus</i>	0.02 \pm 0,003a	0.00 \pm 0.00b	9.40	0.002
Total		11488	2575		

Note: Values in rows followed by the same letter are not significantly different from each other according to Fisher's LSD multiple range test ($p \leq 0.05$).