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Herbivores, saprovores and natural enemies respond differently to within-field plant characteristics of wheat fields

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Corresponding Author:	Berta Caballero López, Ph.D University of Barcelona Barcelona, Catalonia SPAIN	
Corresponding Author Secondary Information:		
Corresponding Author's Institution:	University of Barcelona	
Corresponding Author's Secondary Institution:		
First Author:	Berta Caballero López, Ph.D	
First Author Secondary Information:		
Order of Authors:	Berta Caballero López, Ph.D	
	José Manuel Blanco-Moreno, Professor	
	Juli Pujade-Villar, Professor	
	Daniel Ventura, PhD-student	
	Josep Anton Sánchez-Espigares, Professor	
	Francesc Xavier Sans, Professor	
Order of Authors Secondary Information:		
Funding Information:	Becas Predoctorales para Personal Investigador (2005 FI)	Mrs Berta Caballero López
	Ministerio de Ciencia y Tecnología (CGL2006-c03-01/BOS)	Dr. Francesc Xavier Sans
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Abstract:	<p>Understanding ecosystem functioning in a farmland context by considering the variety of ecological strategies employed by arthropods is a core challenge in ecology and conservation science. We adopted a functional approach in an assessment of the relationship between the three functional plant groups (grasses, broad-leaved and legumes) and the arthropod community in winter wheat fields in a Mediterranean dryland context. We sampled the arthropod community as thoroughly as possible with a combination of suction catching and flight-interception trapping. All specimens were identified to the appropriate taxonomic level (family, genus or species) and classified according to their form of feeding: chewing-herbivores, sucking-herbivores, flower-consumers, omnivores, saprovores, parasitoids or predators.</p> <p>A richer plant community favours a greater diversity of herbivores and, in turn, a richness of herbivores and saprovores enhances the communities of their natural enemies, which supports the classical trophic structure hypothesis. The positive effect of grass cover on sucking-herbivores, saprovores and their natural enemies is due to</p>	

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1 Herbivores, saprovores and natural enemies respond differently to
2 within-field plant characteristics of wheat fields

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6 4 Berta Caballero-López^{1,4*}, José M. Blanco-Moreno^{2,4}, Juli Pujade-Villar³, Daniel Ventura^{5,6},
7
8 5 Josep A. Sánchez-Espigares⁷ & F. Xavier Sans^{2,4}

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10
11 6 ¹ Dept. of Arthropods, Natural Sciences Museum of Barcelona, Barcelona, Spain; ² Dept. of Plant Biology,
12 7 Faculty of Biology, University of Barcelona, Barcelona, Spain; ³ Dept. of Animal Biology, Faculty of Biology,
13 8 University of Barcelona, Barcelona, Spain; ⁴ IRBio, University of Barcelona, Spain; ⁵ Dept. of Food
14 9 Industries and Environmental Sciences, Polytechnic School, University of Vic, Vic, Spain; ⁶ Functional Ecology
15 10 and Climate Change Group (GAMES - ECOFUN), Forest Sciences Center of Catalonia (CTFC), Solsona, Spain;
16 11 ⁷ Dept. of Statistics and Operations Research (UPC), Barcelona, Spain.

17
18
19 14 *Corresponding author's address: Dept. of Arthropods, Lab. of Nature, Museu de Ciències Naturals de
20 15 Barcelona, Picasso Av., E-08003 Barcelona (Catalonia/Spain). E-mail address: bcaballerolo@bcn.cat, Phone:
21 16 (+34) 93 256 22 11.

22
23
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30 **Abstract**

1 31 Understanding ecosystem functioning in a farmland context by considering the variety of ecological
2
3 32 strategies employed by arthropods is a core challenge in ecology and conservation science. We adopted a
4
5 33 functional approach in an assessment of the relationship between the three functional plant groups (grasses,
6
7 34 broad-leaved and legumes) and the arthropod community in winter wheat fields in a Mediterranean dryland
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11 36 and flight-interception trapping. All specimens were identified to the appropriate taxonomic level (family, genus
12
13 37 or species) and classified according to their form of feeding: chewing-herbivores, sucking-herbivores, flower-
14
15 38 consumers, omnivores, saprovores, parasitoids or predators.

17 39 A richer plant community favours a greater diversity of herbivores and, in turn, a richness of herbivores and
18
19 40 saprovores enhances the communities of their natural enemies, which supports the classical trophic structure
20
21 41 hypothesis. The positive effect of grass cover on sucking-herbivores, saprovores and their natural enemies is due
22
23 42 to grasses' ability to provide – either directly or indirectly alternative resources or simply by offering better
24
25 43 conditions of environmental parameters. By the inclusion of legumes in agroecosystems we can improve the
26
27 44 conservation of beneficial arthropods like predators or parasitoids, and enhance the provision of ecosystem
28
29 45 services like the natural pest control.

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36 48 **Keywords:** functional approach, plant-arthropod interaction, biological control, legumes, ecosystem services,
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38 49 insect functional traits.

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52 Introduction

53 Although traditionally considered as mere competitors of crop plants (Albajes et al. 2011), weeds do in fact
54 play a key role in the aboveground food chain in agro-ecosystems (Clough et al. 2007) by providing resources
55 for pollinators and herbivorous insects, and by supporting prey species for natural enemies (Norris and Kogan
56 2000; Hyvönen and Huusela-Veistola 2008). Nonetheless, how herbivores and natural enemies respond to the
57 within-field plant community is still a matter of debate and the information in the literature is rather
58 contradictory. Birkhofer et al. (2008) and Harwood et al. (2001) reported more predators in weedy fields –
59 probably as a response to increased prey availability – but other authors have found that the abundance of
60 predatory invertebrates seldom responds significantly to the weed community (Fuller et al. 2005). Some authors
61 state that weedy plots do not necessarily have higher predator densities as other authors have claimed (Altieri
62 and Nicholls 1999; Amaral et al. 2013)

63 These discrepancies arise because most predictions are limited to particular species groups that are unable
64 to provide accurate generalizations of observed patterns that are applicable to the entire arthropod community
65 (Perner and Voigt 2007). Indeed, arthropods account for over 80% of all known living animal species and play a
66 wide range of functional roles in ecosystems (Maleque et al. 2006). On the other hand, complete community-
67 level assessments are rarely conducted given the huge amount of time, money and human resources (i.e.
68 taxonomists) that are required (Cardoso et al. 2004). Nevertheless, several authors have adopted a community
69 approach using higher taxonomic levels such as families as surrogates for inventories at species level (Balmford
70 et al. 1996a; Balmford et al. 1996b; Wickramasinghe et al. 2004; Biaggini et al. 2007), which is a way of
71 circumventing the enormous amount of resources required for close-to-complete inventories (Cardoso et al.
72 2004). The use of families as a taxonomic level not only allows parataxonomists to complete the required
73 classification tasks – which permits groups that had not previously been considered to be bioindicators (due to
74 taxonomic difficulties) to be included – but can also save time and money (Balmford et al. 1996a; Balmford et
75 al. 1996b).

76 Here we adopt a community approach and work at family level. We use a functional approach based on
77 species' way-of-feeding strategies and, rather than relying on traditional taxonomic analyses, we amalgamate
78 different groups according to their trophic behaviour. This combination of a community approach at family level
79 and a functional approach is novel, and provides a link between taxonomic diversity and ecosystem functioning
80 (Grimm 1995; McCann 2000; Hawes et al. 2009).

81 Assessing how within-field plant communities affect whole arthropod assemblages is therefore essential for
82 understanding local processes related to agro-ecosystem functioning, and to accomplish this task it is crucial to

83 gain a broader picture of the different players on the scene.

84 Floristic richness as well as vegetation structure has been widely recognised as key factors influencing
85 insect assemblage (Schaffers et al. 2008). As plant species richness and vegetation complexity tend to cascade up
86 to higher trophic levels leading to high invertebrate diversity (Landis et al. 2000). Therefore we would expect
87 that with a richer assemblage in the within-plant community is likely to improve the conservation of multiple
88 arthropod groups. In this study we were interested in assessing the effect of richer within-field plant communities
89 as a component of habitat restoration strategies to improve and sustain biological control in an arable cropping
90 system. The research reported here aimed to examine how contrasting within-field plant communities in wheat
91 fields affect the whole community of insects associated to this crop. We hypothesised that plant-feeders and
92 saprovores would respond to the within-field plant assemblage according to the classical diversity-trophic
93 structure hypothesis, and that the abundance and richness of potential prey items would enhance the parasitoid
94 and predator assemblages.

96 **Material and Methods**

97 Study area

98 The study was carried out about 150 km south of Barcelona (41°29'0.9"N, 1°7'16.4"E; 627 m a.s.l.). The
99 arable fields – mainly cereal crops – represented only 40% of the agricultural landscape and formed a mosaic
100 with patches of natural vegetation. Field boundaries consisted of perennial grasslands dominated by
101 *Brachypodium phoenicoides* (L.) Roemer & Schultes, as well as a mix of *Prunus spinosa* L., and *Rubus*
102 *ulmifolius* L. thickets, and *Rosmarinus officinalis* L. scrub.

103 Four organically and four conventionally managed winter wheat fields (*Triticum aestivum* L.) were selected
104 in an area of 2×2 km. First, the organic fields were randomly selected from the 12 such fields in the area and,
105 then, the conventional fields were selected, none of which were further than 1 km from or adjoining the organic
106 fields. All selected fields were flat in order to avoid any differences due to slope or aspect. The selected organic
107 fields had been managed for over a decade along Catalan organic guidelines (Consell Català de la Producció
108 Agrària Ecològica 2013) and were certified by the Catalan Council for Organic Farming following the European
109 guidelines (EEC 2007). The management of organic fields relies on mechanical weed control and organic
110 fertilisation using green manure and occasionally chicken manure. Conventional fields were regularly sprayed
111 with herbicides – but not insecticides or fungicides – and fertilised with a combination of pig slurry and mineral
112 fertilisers. Although we tried to select fields of similar size and shape, we considered the homogeneity of the
113 boundary vegetation to be more important than the homogeneity of the fields' dimensions, above all because the

114 fields were all relatively small. Even so, conventional fields were significantly larger (mean \pm SE; 4.08 ± 0.8 ha)
115 than organic fields (2.19 ± 0.3 ha, $\chi^2_{df=1} = 5.78$, P value = 0.016). By contrast, the perimeter-to-area ratio was
116 significantly greater in organic (mean \pm SE; 0.09 ± 0.01) than in conventional fields (0.06 ± 0.01 , $\chi^2_{df=1} = 4.85$, P
117 value = 0.028). All selected fields were sown with winter wheat between the 27 October and 7 November 2003
118 (for further agronomic details, see Caballero-López et al. 2010).

119 The contrast in a common area between organic and conventional cereal fields whose boundaries share the
120 same vegetation but differ in terms of the non-crop plants they host appears to be a suitable model for exploring
121 the relationship between plant and arthropod communities. In addition, the comparison of fields under organic
122 and under conventional insecticide-free management in a Mediterranean context also avoids the confounding
123 indirect effects of insecticide application on the plant-arthropod interactions (Hole et al., 2005).

124 In each field we established an 80m transect diagonally across the centre of the field, starting at 55m from
125 the edge. Within each transect, five 1m \times 1m plots at 20m intervals were surveyed. Arthropod suction-sampling
126 and plant surveys were carried out successively in each plot. In addition, three flight-interception traps (FIT)
127 were positioned along each transect at 40m intervals.

130 Sampling

131 Arthropod communities were sampled using (i) flight interception traps (hereafter FIT) to assess aerial
132 communities and (ii) a petrol-driven Blow&Vac (McCulloch BVM250, Italy; sampling cylinder 60cm high and
133 12 cm in diameter) converted to suction sampler following Stewart and Wright (1995) to survey terrestrial
134 communities.

135 Each FIT consisted of an outer white plastic cup (150 mm in height, 200 mm internal diameter) mounted on
136 a 1-m-high wooden pole and an inner plastic cup (140 \times 180 mm) with two 30 \times 30 cm Plexiglas pieces fixed along
137 their midline in a cross-shape. The inner plastic cup contained approximately 1 litre of a NaCl-solution as a
138 preservative, with a drop of detergent added to decrease the surface tension. FIT are useful for catching many of
139 the small flying insects that tend to fly downwards when they hit a wall (Koricheva et al. 2000).

140 The petrol-driven suction sampler was operated on full power to produce an estimated constant airflow of
141 0.142 m³/s (according to manufacturer's operating instructions). The pipe was held vertically and slowly passed
142 over the wheat plants in the 1-m² quadrat and suction was performed for 60 seconds. After each plot sampling,
143 the bag was removed from the machine, placed in a labelled plastic bag and stored in a portable refrigerator to
144 prevent predatory activity in the bag. The sampling campaign lasted for two days and the eight fields were

145 sampled in a random order to avoid any systematic bias due to daytime sampling. All samples were taken by the
1 146 same two people to reduce sampling variability. This method has been shown to provide a good representation of
2
3 147 all trophic levels interacting with vegetation (Letourneau and Goldstein 2001), and is used extensively to study
4
5 148 arthropods in crops (Stewart and Wright 1995; Elliott et al. 2006).

7 149 Fit trapping took place on 20 May 2004 and 26 June 2004 to coincide with the wheat's anthesis stage and
8
9 150 the mid-milk-ripe cereal development stage (Zadoks et al. 1974), respectively. In total, 24 traps were active
10
11 151 during two periods of eight days. Suction sampling was also performed twice to coincide with the two chosen
12
13 152 growth stages, the first campaign taking place on 25–27 May and the second on 24–26 June 2004, both at 10:00–
14
15 153 19:00 and under sunny weather conditions (temperature > 20°C). Thus, in all, 40 m² of plots were assessed twice
16
17 154 during the study period.

19 155 Vegetation was surveyed twice and concomitant with the suction-sampling. The cover of crop species and
20
21 156 each weed species was recorded in each plot by means of a ground cover scale. Weed species were identified
22
23 157 according to Bolòs et al. (2005). Plant species were classified into three functional groups (grasses, forbs and
24
25 158 legumes) following Koricheva et al. (2000). Legumes have been separated from the other forbs due to the
26
27 159 generally higher nitrogen content of their tissues, which would make them a higher-quality resource for
28
29 160 herbivores, whereas grasses have tough tissues with low nitrogen content and structural characteristics that deter
30
31 161 plant-feeders (Koricheva et al. 2000).

33 162

35 163 Arthropod processing

37 164 Arthropods captured by suction sampling were frozen for subsequent sorting and identification, whilst FIT
38
39 165 trap catches were preserved in 70% alcohol. All samples were hand-sorted using a dissecting microscope to
40
41 166 separate animals from debris. Catches were quantified as the total numbers of individuals (adults and immature
42
43 167 stages) and with a few exceptions most arthropods were identified to family level; due to taxonomic difficulties,
44
45 168 some taxa were only identified to superfamily level (e.g. Apoidea, Curculionoidea and Staphylinoidea) or to
46
47 169 order level (e.g. Acari and Thysanoptera). Lepidoptera were only identified to order level because specimens
48
49 170 were too badly damaged by the sampling process to be properly identified.

51 171 The use of higher taxonomic levels is particularly useful when a functional-group perspective is required as
52
53 172 the majority of family members belong to the same feeding group (see the considerations below). Nevertheless,
54
55 173 the process of amalgamating taxa into functional groups requires the acceptance of assumptions regarding the
56
57 174 importance of certain common features (Hawes et al. 2009).

175 When taxa of the same family had different feeding preferences (e.g. Drosophilidae, Opomyzidae),
176 specimens were determined to genus or species level, and the predominant feeding habit of the most abundant
177 genus or species was used to classify the entire family and its feeding group. We initially considered splitting
178 families possessing several species into similar proportions and different feeding strategies; although in the end
179 no family fulfilled this condition.

180 All identified taxa were classified into one of the seven feeding groups: chewing-herbivores, flower-
181 consumers, omnivores, parasitoids, predators, saprovores and sucking-herbivores. The definition of each feeding
182 group was based on field observations, a literature review and specialist advice (see Acknowledgements), and
183 contained different ways-of-feeding strategies. Granivores, plant-chewers and miners were included in the
184 chewing-herbivore category, while plant sapsuckers were added to the suction-herbivore category. Flower
185 consumers consisted of flower predators, pollen consumers and nectarivores. Saprovores included
186 mycetophages, plant saprovores, animal saprovores and scavengers.

187 Arthropods with different feeding preferences in larval and adult stages were counted in both feeding
188 groups in order to consider the impact of their whole life cycles. A small number of difficult-to-classify larvae
189 were taken into account only for total abundance but were excluded from the feeding group analyses. Other
190 groups were also excluded from the analyses due to their scarcity (families with less than three individuals were
191 excluded from the data) or a lack of available information about their biology. In addition, other groups such as
192 most parasitoids, which do not feed in the adult stage or whose effect is so small as to be insignificant, were
193 categorised as not having any trophic interaction (for further details, see Supplementary material). All the
194 specimens are now deposited in the Arthropod collection of the Natural Sciences Museum of Barcelona.

195 196 Data analysis

197 In order to simplify the statistical analyses and results section, the results are grouped into two categories:
198 primary and secondary consumers. Chewing-herbivores, sucking-herbivores and flower-consumers were
199 considered primary consumers and so are mainly herbivores, while parasitoids and predators were categorised as
200 secondary consumers given that they are entomophagous. Saprovores chew dead organic matter, bacteria and
201 fungi, and occasionally soil arthropods, and thus theoretically occupy an intermediate position between primary
202 and secondary consumers. However, they were included arbitrarily as primary consumers owing to the lack of
203 reliable information about their consumption rate of potential prey items.

204 The models for primary consumers and secondary consumers were analysed according to sampling method
205 (FIT vs. suction) and sampling period (first vs. second), with a common set of covariates (cover of broad-leaved

206 herbs, legumes and grasses, and total plant-species richness) as explanatory variables. Additionally, due to their
1 207 different ecological requirements, the models of secondary consumers also included certain additional variables
2
3 208 depending on the focus. For instance, when we modelled the family richness of secondary consumers we
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5 209 included the family richness of the main primary consumer groups, which could act as potential prey items or
6
7 210 hosts, and when the focus was on the abundance of secondary consumers, we included the abundance of the
8
9 211 different primary consumer groups.

10
11 212 The analyses were performed using linear mixed models with normal error distribution. ‘Field’ was
12
13 213 included as a random effect factor to account for the fact that the samples from a field were not independent
14
15 214 (Pinheiro and Bates 2000). All the models reported are full models; no model simplification was used to avoid
16
17 215 the inherent bias of stepwise regression in a measuring experiment. Prior to the analysis, the collinearity of the
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19 216 independent variables included in the models was evaluated with the variance inflation factor ($VIF = (1-R^2)^{-1}$) to
20
21 217 check the robustness of the model (Kutner et al. 2004). In the models for primary consumers, no variable present
22
23 218 a high VIF (between 1.17 and 3.7) and had to be excluded from the analyses. For parasitoids and predators, the
24
25 219 abundance/richness of flower consumers showed correlation with other predictors but it was not significant and
26
27 220 the conclusions were the same when dropping the variable from the model. Assumptions of the linearity,
28
29 221 normality and homogeneity of the variances were evaluated by examining the residuals; data were log-
30
31 222 transformed when necessary. Analyses were performed using R (R Development Core Team 2013); package
32
33 223 lme4 (Bates et al. 2008) was used for the model fitting and package languageR (Baayen 2008) was used to
34
35 224 determine the significance of the predictors using Markov Chain Monte Carlo methods.
36

37 225

38 226 **Results**

39 227 Arthropods

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41
42 228 During the sampling period, 25,518 arthropods were caught and identified. They were found to belong to three
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44 229 classes (Insecta, Entognatha, Arachnida), 14 orders and 133 families, although only 113 families were abundant
45
46 230 enough to be included in the feeding group analyses.
47

48
49 231 The number of families and abundance of individuals were greater using the FIT than the suction-sampler
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51 232 and, overall, the FIT catches were more abundant and diverse (16,587 specimens and 110 families) than the
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53 233 suction catches (8,931 individuals and 82 families). Although the majority of the families were captured by both
54
55 234 sampling methods, a considerable proportion (32%) including many dipteran, hemipteran and hymenopteran
56
57 235 families was only recorded in the FIT. The most abundant feeding groups from the FIT samples were flower-
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59 236 consumers and suction-herbivores, which were more abundant than saprovores and omnivores. In the suction
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237 catches, the suction-herbivores group was dominant, followed at a distance by saprovores and predators, and
1 238 other groups such as parasitoids or chewing-herbivores were far less abundant (see Appendix for further details).

2
3 239 Most of the feeding groups also displayed significant differences between sampling periods. The catches of
4
5 240 chewing-herbivores, flower-consumers, saprovores (Fig. 1) and parasitoids and predators (Fig. 2) were greater in
6
7 241 the first sampling period during wheat anthesis; by contrast, only suction-herbivores showed the opposite
8
9 242 pattern, with larger captures in the second period coinciding with the milk-ripening stage. Conversely, the
10
11 243 pattern for richness was slightly more diverse due to the fact that the chewing-herbivore, flower-consumer and
12
13 244 saprovores families were better represented in the first than in the second sampling period (Fig. 3); the opposite
14
15 245 trend was observed for sucking-herbivores, parasitoids and predators (Fig. 4).

17 246 Plants

18
19 247 The total plant cover was significantly higher in conventional than in organic fields due to a higher
20
21 248 percentage of crops: wheat cover represented 97.2% of grass cover in conventional fields and 91.4% in organic
22
23 249 fields. The mean total plant species richness was more than twice as high in organic than in conventional fields;
24
25 250 legumes thrived exclusively in organic fields, either as weeds or volunteer crops (see Caballero-López et al.
26
27 251 2010 for further details).

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29 252

31 253 Arthropod-plant links

32
33 254 The abundances of flower-consumers, saprovores, parasitoids and predators captured reveal a significant
34
35 255 and positive correlation with grass cover. Greater cover of legumes also enhanced the abundance of parasitoids
36
37 256 and predators but only marginally benefited the populations of flower-consumers (Tables 1 and 2). By contrast,
38
39 257 there were no differences between the abundances of chewing-herbivores and sucking-herbivores according to
40
41 258 plant community (Table 1). Greater abundances of parasitoids and predators occurred in plots with greater
42
43 259 abundances of sucking-herbivores (Table 2).

44
45 260 The number of families of flower-consumers, sucking-herbivores, saprovores, parasitoids and predators
46
47 261 were significantly and positively correlated to greater grass cover (Tables 3 and 4). Additionally, the family
48
49 262 richness of sucking-herbivores was favoured in plots with greater plant species richness (Table 3). The family
50
51 263 richness of parasitoids was closely and positively associated to the cover of grasses and legumes but in the case
52
53 264 of predators was only significantly associated with grass cover (Table 4). Furthermore, sucking-herbivore and
54
55 265 saprovores richness showed a significant and positive effect on the family richness of both parasitoids and
56
57 266 predators, suggesting that a relationship exists between these groups. The family richness of predators was also
58
59 267 enhanced by the chewing-herbivores richness (Table 4).

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1 **269 Discussion**

2
3 270 The arthropod community found in wheat fields was dependent above all on the sampling method used, the
4
5 271 sampling period considered and the interaction between these variables, although clear patterns relating to local
6
7 272 factors such as intra-field plant community variables and the primary-secondary consumer interactions were also
8
9 273 present. The functional approach presented here shows that there are consistent responses in plant and arthropod
10
11 274 trophic groups to differences in habitat conditions.

12
13 275
14
15 276 *Primary consumers*

16
17 277 The numbers of sucking-herbivores across fields were similar regardless of vegetation parameters, although
18
19 278 the family richness of sucking-herbivores was positively associated to the plant species richness. These findings
20
21 279 were in accordance with previous studies showing that the diversity of plant-feeders was related to the diversity
22
23 280 of their resources (Murdoch et al. 1972; Siemann 1998; Knops et al. 1999). In addition, the sucking-herbivore
24
25 281 community – with aphids (Homoptera) as the most abundant representatives – was also richer where the grass
26
27 282 cover was greater, which usually occurred in the conventional fields, where wheat crop represents the 97% of the
28
29 283 grass cover. This can be explained by the fact that conventional farmers apply more fertilisers, and to the higher
30
31 284 mean yields in conventional (4,000- 4,100 kg ha⁻¹), than in organic (2,000–2,200 kg ha⁻¹) fields (farmers *pers.*
32
33 285 *com.*). Given that many components of the Homoptera groups benefit when the nitrogen fertiliser supply
34
35 286 increases (Hasken and Poehling 1995; Duffield et al. 1997; Ghorbani et al. 2010; Rostami et al. 2012), the
36
37 287 enrichment of grass aphids community in conventional fields is not surprising. However, our study did not
38
39 288 enable us to identify whether grass cover or nitrogen supply was the most relevant factor for explaining the
40
41 289 sucking-herbivores pattern.

42
43 290 The saprovores community was found to be richer and more abundant where the grass cover was greater, as
44
45 291 in the studied conventional fields. This reinforces the findings of previous authors (Moreby et al. 1994; Mäder et
46
47 292 al. 2002), who suggest that taxa involved in decomposition are likely to benefit from organic fertilisation, which
48
49 293 in the studied systems only occurred on organic fields. However, pig slurry is an abundant and cheap organic
50
51 294 fertiliser in Catalonia and is commonly used in conventionally managed fields. Our results also support the
52
53 295 findings of Clough et al. (2007), who showed that a higher activity-density and diversity of saprovores in
54
55 296 conventional fields indicates good soil health and high potential productivity, as shown above by the mean yield
56
57 297 values.

298 Flower-consumer abundance is expected to be positively related to legume cover since this group benefits
1 299 from floral food resources such as nectar and pollen (Bianchi and Wäckers 2008). Nonetheless, our data provides
2
3 300 only limited support for this relationship. However, both the abundance and richness of the flower-consumer
4
5 301 community are enhanced with increasing grass cover. Given that flower-consumers do not feed on grasses, this
6
7 302 effect is most probably due to the greater plant cover offered by wheat, which generates a more complex plant
8
9 303 community with more and better places to shelter. This phenomenon may reflect that plant architecture is likely
10
11 304 to be an important component of the predation risk, and that plant-feeders have a better chance of escaping from
12
13 305 predators in complex plant architectures (Moreby et al. 1994; Norris and Kogan 2000; Casas and Djemai 2002).
14
15 306 In addition, it is also known that plant structure determines microclimatic conditions, which may also affect the
16
17 307 movement patterns of both herbivores and predators (Willmer et al. 1996; Souza and Martins 2004) and also lead
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19 308 to considerable variation in microhabitat temperatures that can regulate the larval development (Wilson et al.
20
21 309 2014).

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23 310

24 25 311 *Secondary consumers*

26
27 312 Predators and parasitoids probably benefited from the abundance of their potential prey items (see Table 2).
28
29 313 Consequently, a greater abundance of sucking-herbivores probably led to higher predator and parasitoid
30
31 314 abundances, which may indicate an aggregation response to prey distribution (Müller and Godfray 1998; Evans
32
33 315 2008; Vucic-Pestic et al. 2010). This scenario agrees with the patterns of correlation among herbivores, predators
34
35 316 and parasitoids found by previous studies (Koricheva et al. 2000; Haddad et al. 2001).

36
37 317 Parasitoid richness appears to be closely associated with the sucking-herbivore and saprovores richness,
38
39 318 whereas predators were only significantly correlated to the family richness of chewing-herbivores, sucking-
40
41 319 herbivores and saprovores. These findings reflect those of Haddad et al. (2001) and Wardle et al. (1999). Our
42
43 320 findings support the results of Wardle et al. (1999), i.e. secondary consumers could switch between prey items
44
45 321 found in decomposition soil food-webs and those in leaf-based food-webs. Nonetheless, the relationship
46
47 322 between herbivores and natural enemies has created much more controversy and attention than the interaction
48
49 323 between natural enemies and saprovores assemblages due to the implications for pest management (Wardle et al.
50
51 324 1999).

52
53 325 The presence of legumes in organic cereal fields seems to play a key role in enhancing both the abundance
54
55 326 and richness of parasitoid communities, a fact that could be explained by the direct enrichment of alternative
56
57 327 food supplies such as nectar, pollen and sap (Norris and Kogan 2000; Banks et al. 2008; Bianchi and Wäckers
58
59 328 2008). We also observed a positive correlation between the number of predators and legume cover. This supports
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65

329 existing evidence that consuming flowers and extrafloral nectaries improves the survival and nutrient reserves of
1 330 predators during periods of prey scarcity, and that the availability of nectar during these periods improves the
2
3 331 long-term reproductive capacity of predators (Hodek and Honek 1996; Norris and Kogan 2000; Isaacs et al.
4
5 332 2009; Lundgren and Seagraves 2011; Amaral et al. 2013).

7 333 The positive effect of grass cover on predator and parasitoid communities may be due to plants' role as
8
9 334 indirect providers of non-host resources to natural enemies (e.g. by supporting alternative hosts) or simply as
10
11 335 structures for oviposition and/or protection (Moreby et al. 1994; Norris and Kogan 2000; Souza and Martins
12
13 336 2004; Nicholls and Altieri 2012; Amaral et al. 2013). On the other hand, the response to grass cover might also
14
15 337 been justified with better conditions of environmental parameters because as Antvogel and Bonn (2001)
16
17 338 suggested the composition of the ground beetle assemblage was strongly influenced by microclimatic parameters
18
19 339 and vegetation structure. In addition to this, as not all relationships are trophic ones, maybe some of the patterns
20
21 340 described in our study may also being associated with a resource-based habitat approach hypothesis (Shreeve et
22
23 341 al. 2001). However, our approach did not allow us to distinguish among these different responses.

24
25 342

27 343 **Conclusions and implications**

29 344 The clear response by the different feeding groups to local factors such as grass and legume cover indicates
30
31 345 that the weed-herbivore-natural enemy system must be taken into account if we are to improve our
32
33 346 understanding of the interactions between organisms at different trophic levels. Our results show that the
34
35 347 conservation of farmland insect biodiversity is possible through the maintenance of within-field plant diversity in
36
37 348 agroecosystems. Our findings also provide evidence that inclusion of legumes in agroecosystems can improve
38
39 349 the conservation of beneficial arthropods like predators or parasitoids, which are the key players in order to
40
41 350 support the correct ecosystem functioning. This type of studies should encourage policies with a more weed
42
43 351 tolerant perspective, because by the inclusion of additional flower traits within the crop fields, we are enhancing
44
45 352 arthropod conservation and guaranteeing the provision of ecosystem services, like natural pest control.

47 353 The functional approach tested is a robust tool with two major advantages and one disadvantage. Firstly, it
48
49 354 can be adopted relatively easily for use by parataxonomists, thereby saving time and money over multi-taxa
50
51 355 approaches. Secondly, the adoption of a feeding-group approach gives a broader picture of the different players
52
53 356 operating in functional agro-ecosystems. Nonetheless, working with the whole arthropod community means to
54
55 357 sort out, identify, and count a considerable volume of groups, and it's not feasible to work at landscape scale
56
57 358 approach, in the general context of a resource limited project. Therefore, the next step could be the selection of a
58
59 359 wide variety of groups that represents different feeding groups. Having a wider perspective could improve our
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360 understanding of agro-ecosystem functioning, and thus enable the design of crop management strategies that
1 361 ensure conservation of the different arthropods' trophic groups and their functional role.

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5 363 **References**

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500 **FIGURE CAPTIONS**

1 501 **Figure 1.** Total number of individuals of primary consumers caught by interception traps (FIT) and suction
2
3 502 sampling (VAC) in May and June. CH = Chewing-herbivores, FC = Flower-consumers, SH = Sucking-
4
5 503 herbivores, S = Saprovores and O= Omnivores. Symbols indicate mean values and bars indicate the standard
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7 504 error.

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10
11 505 **Figure 2.** Total number of individuals of secondary consumers caught by interception traps (FIT) and
12
13 506 suction sampling (VAC) in May and June. Pa = Parasitoids and Pr = Predators. Symbols indicate mean values
14
15 507 and bars indicate the standard error.

16
17
18 508 **Figure 3.** Total family richness of primary consumers caught by interception traps (FIT) and suction
19
20 509 sampling (VAC) in May and June. CH = Chewing-herbivores, FC = Flower-consumers, SH = Sucking-
21
22 510 herbivores, S = Saprovores and O = Omnivores. Symbols indicate mean values and bars indicate the standard
23
24 511 error.

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26
27 512 **Figure 4.** Total family richness of secondary consumers caught by interception traps (FIT) and suction
28
29 513 sampling (VAC) in May and June. Pa = Parasitoids, and Pr = Predators. Symbols indicate mean values and bars
30
31 514 indicate the standard error.

Figure 1 Abundance Primary Consumers

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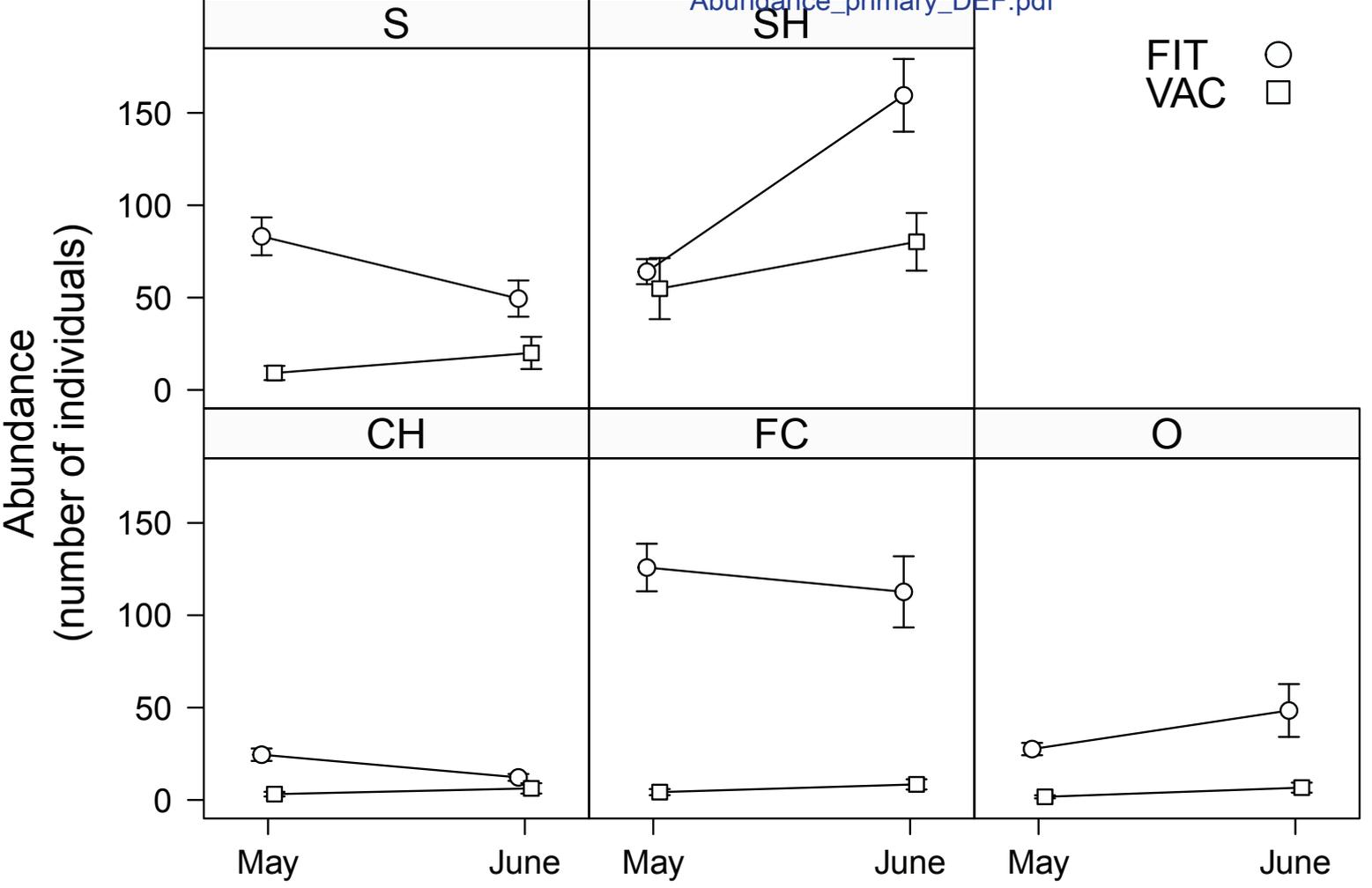


Figure 2 Abundance Secondary Consumers

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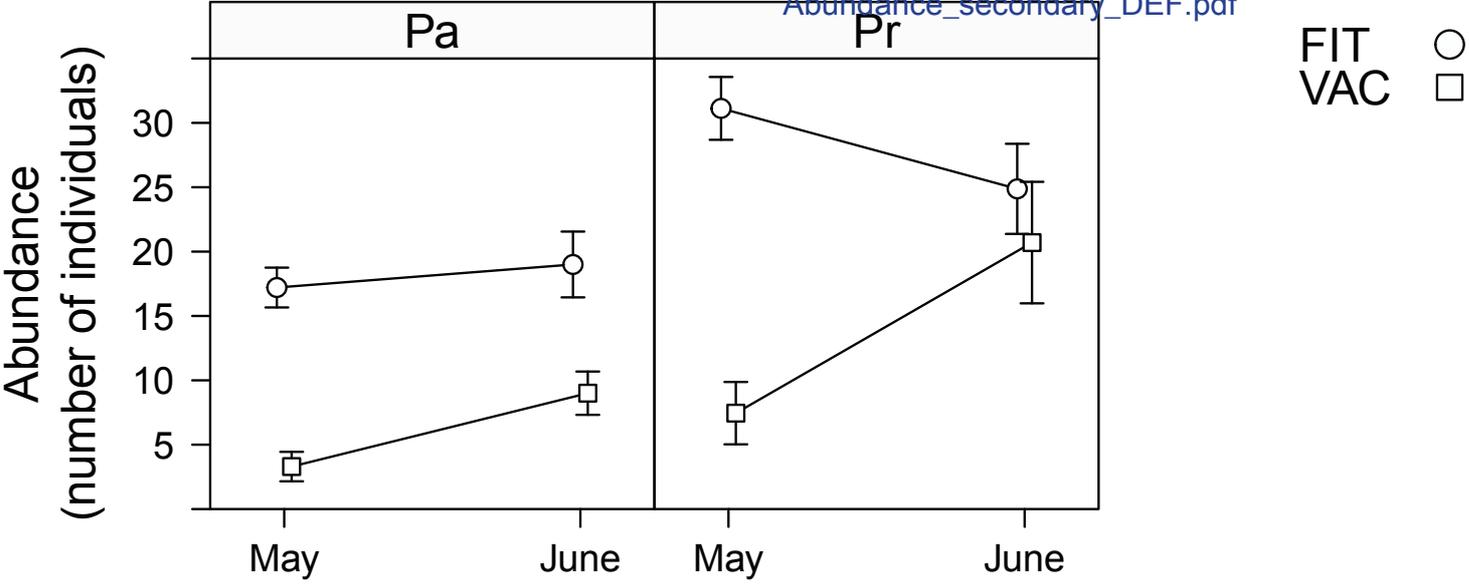


Figure 3 Richness Primary Consumers

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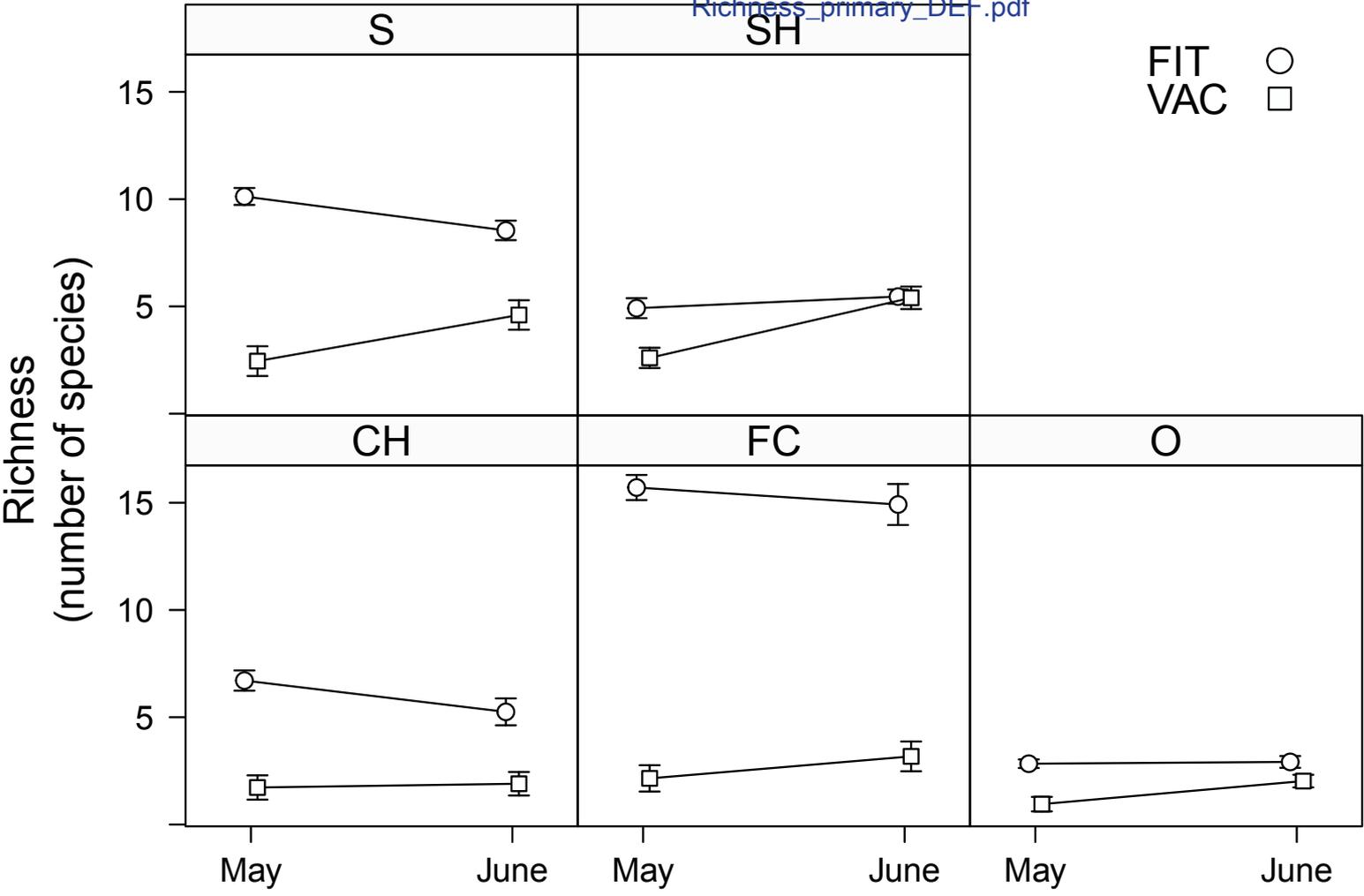


Figure 4 Richness Secondary Consumers

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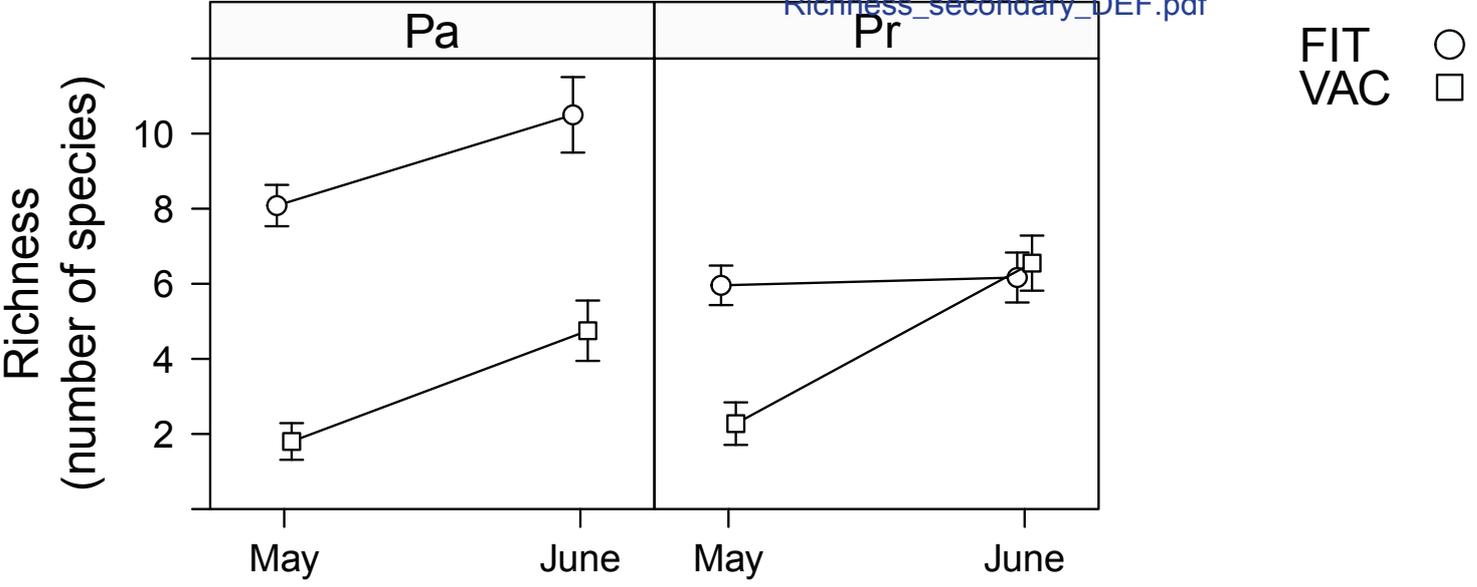


Table 1 Effects of sampling method (SM), sampling period (SP), their interaction (SM*SP) and plant descriptors such as plant species richness (SR), legume cover (LC), broad-leaved herb cover (BC) and grass cover (GC) on the abundance of primary consumers. The level of significance for the different predictors included in the models was obtained using Markov Chain Monte Carlo methods.

	Chewing-herbivore abundance		Flower-consumer abundance		Suction-herbivores abundance		Saprovores abundance	
	X ± SE	P	X ± SE	P	X ± SE	P	X ± SE	P
Intercept	2.62 ± 0.52	0.000	4.09 ± 0.38	0.000	6.12 ± 1.78	0.001	2.43 ± 0.42	0.000
SM	-2.09 ± 0.18	0.000	-3.27 ± 0.15	0.000	-1.33 ± 0.65	0.044	-2.61 ± 0.19	0.000
SP	-0.66 ± 0.20	0.002	-0.12 ± 0.17	0.470	4.62 ± 0.73	0.000	-0.51 ± 0.22	0.020
SM*SP	1.02 ± 0.25	0.000	0.64 ± 0.21	0.002	-2.46 ± 0.92	0.010	1.53 ± 0.27	0.000
SR	-0.02 ± 0.04	0.519	-0.02 ± 0.03	0.490	0.06 ± 0.15	0.827	0.06 ± 0.04	0.154
LC	0.02 ± 0.02	0.320	0.03 ± 0.02	0.052	0.05 ± 0.07	0.483	0.02 ± 0.02	0.285
BC	0.01 ± 0.01	0.491	0.00 ± 0.01	0.580	0.02 ± 0.03	0.530	0.01 ± 0.01	0.435
GC	0.01 ± 0.01	0.058	0.01 ± 0.00	0.003	0.02 ± 0.02	0.468	0.02 ± 0.00	0.000

Table 2 Effects of sampling method (SM), sampling period (SP), their interaction (SM*SP) and plant descriptors such as plant species richness (SR), legume cover (LC), broad-leaved herb cover (BC) and grass cover (GC) on the abundance of parasitoids and predators. The abundance of primary consumers was also included in this model. CH = Chewing-herbivores, FC = Flower-consumers, S = Saprovores, SH = Sucking-herbivores (see text for further details). The level of significance for the different predictors included in the models was obtained using Markov Chain Monte Carlo methods.

	Parasitoids abundance			Predators abundance		
	X ± SE	P		X ± SE	P	
Intercept	1.51 ± 0.28	0.000		1.53 ± 0.38	0.000	
SM	-1.13 ± 0.22	0.000		-1.07 ± 0.29	0.000	
SP	-0.03 ± 0.18	0.869		-0.37 ± 0.24	0.107	
SM*SP	0.76 ± 0.22	0.001		1.33 ± 0.29	0.000	
SR	0.00 ± 0.02	0.818		0.04 ± 0.03	0.240	
LC	0.03 ± 0.01	0.027		0.03 ± 0.01	0.033	
BC	-0.00 ± 0.00	0.886		0.00 ± 0.00	0.798	
GC	0.01 ± 0.00	0.001		0.01 ± 0.00	0.002	
Ab.CH	0.01 ± 0.01	0.138		-0.00 ± 0.01	0.971	
Ab.FC	-0.00 ± 0.00	0.898		0.00 ± 0.00	0.561	
Ab.SH	0.00 ± 0.00	0.000		0.00 ± 0.00	0.005	
Ab.S	0.00 ± 0.00	0.204		0.00 ± 0.00	0.165	

Table 3 Effects of sampling method (SM), sampling period (SP), their interaction (SM*SP) and plant descriptors such as plant species richness (SR), legume cover (LC), broad-leaved herb cover (BC) and grass cover (GC) on the richness of primary consumers. The level of significance for the different predictors included in the models was obtained using Markov Chain Monte Carlo methods.

	Chewing-herbivore richness		Flower-consumer richness		Suction-herbivores richness		Saprovores richness	
	X ± SE	P	X ± SE	P	X ± SE	P	X ± SE	P
Intercept	1.87 ± 0.24	0.000	2.68 ± 0.15	0.000	2.53 ± 0.70	0.001	2.03 ± 0.14	0.000
SM	-0.92 ± 0.08	0.000	-1.34 ± 0.07	0.000	-2.27 ± 0.32	0.000	-1.00 ± 0.07	0.000
SP	-0.19 ± 0.09	0.051	-0.04 ± 0.08	0.653	0.64 ± 0.36	0.078	-0.11 ± 0.07	0.124
SM*SP	0.25 ± 0.12	0.047	0.23 ± 0.10	0.018	-2.25 ± 0.46	0.000	0.53 ± 0.09	0.000
SR	0.01 ± 0.02	0.715	-0.01 ± 0.01	0.372	0.19 ± 0.07	0.005	0.00 ± 0.01	0.720
LC	0.01 ± 0.01	0.158	0.01 ± 0.01	0.158	0.06 ± 0.03	0.074	0.01 ± 0.01	0.153
BC	0.00 ± 0.00	0.968	0.00 ± 0.00	0.419	-0.01 ± 0.01	0.272	0.00 ± 0.00	0.411
GC	0.00 ± 0.00	0.129	0.00 ± 0.00	0.011	0.02 ± 0.00	0.004	0.01 ± 0.00	0.000

Table 4 Effects of sampling method (SM), sampling period (SP), their interaction (SM*SP) and plant descriptors such as plant species richness (SR), legume cover (LC), broad-leaved herb cover (BC) and grass cover (GC) on the richness of parasitoids and predators. The richness of primary consumers was also included in this model. CH = Chewing-herbivores, FC = Flower-consumers, S = Saprovores, SH = Sucking-herbivores (see text for further details). The level of significance for the different predictors included in the models was obtained using Markov Chain Monte Carlo methods

	Parasitoids richness		Predators richness	
	X ± SE	P	X ± SE	P
Intercept	1.51 ± 0.20	0.000	0.81 ± 0.21	0.000
SM	-0.46 ± 0.17	0.006	-0.14 ± 0.17	0.463
SP	0.25 ± 0.07	0.000	0.12 ± 0.07	0.115
SM*SP	0.03 ± 0.10	0.785	0.41 ± 0.11	0.000
SR	0.00 ± 0.01	0.970	0.01 ± 0.01	0.519
LC	0.01 ± 0.00	0.026	0.01 ± 0.01	0.093
BC	-0.00 ± 0.00	0.999	0.00 ± 0.00	0.384
GC	0.00 ± 0.00	0.009	0.01 ± 0.00	0.001
R.CH	0.02 ± 0.01	0.318	0.03 ± 0.02	0.039
R.FC	-0.00 ± 0.00	0.815	-0.00 ± 0.01	0.787
R.SH	0.04 ± 0.01	0.012	0.05 ± 0.02	0.010
R.S	0.03 ± 0.01	0.026	0.04 ± 0.02	0.012