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3 **Field evaluation of *Cryptolaemus montrouzieri* (Mulsant) (Coleoptera:**  
4**Coccinellidae) as biological control agent of the mealybug *Delottococcus aberiae* De**  
5 **Lotto (Hemiptera: Pseudococcidae)**

6

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### 33Abstract

34*Delottococcus aberiae* De Lotto (Hemiptera: Pseudococcidae) is one of the latest invasive  
35mealybugs in Europe. It causes severe fruit distortion and reduced fruit size leading into  
36important economic losses in citrus. *Cryptolaemus montrouzieri* (Mulsant) (Coleoptera:  
37Coccinellidae) is probably one of the most-used predators of mealybugs in biological control  
38programs worldwide. However, its impact on *D. aberiae* is still unknown. Here, we conducted a  
39two-year field study in nine citrus orchards located in eastern Spain in order to describe the  
40population dynamics of *D. aberiae* and *C. montrouzieri* and evaluate the effect of the predator  
41on *D. aberiae* using different approaches. Our results showed that *C. montrouzieri* and *D.*  
42*aberaie* had two main synchronised population peaks per year: early spring and summer.  
43Although *D. aberiae* and *C. montrouzieri* seasonal trends were synchronised, *C. montrouzieri*  
44neither reduced mealybug density within the same year nor prevented fruit damage, which  
45occurs early in the season. Moreover, *D. aberiae* population growth rates were not correlated  
46with *C. montrouzieri* density. When two consecutive years were analyzed, the increase of *D.*  
47*aberaie* in the second year was negatively correlated with the density of *C. montrouzieri* in  
48summer of the previous year. Based on our two years of data, *C. montrouzieri* was not able to  
49regulate *D. aberiae* on its own or prevent the damages produced by the mealybug but might  
50become a valuable addition to the natural enemy guild when combined with other natural  
51enemies and rational control measures.

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54**Keywords:** conservation biological control, predator–prey interaction, coccinellid, exotic pests.

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60 **Key message**

- 61 • *Delottococcus aberiae* is an invasive citrus pest in Europe and its predators are still  
62 unknown.
- 63 • This study evaluated the potential use of *Cryptolaemus montrouzieri* as a  
64 biological control agent of *D. aberiae*.
- 65 • *D. aberiae* and *C. montrouzieri* seasonal trends were synchronized but the predator  
66 alone did not control the mealybug or prevent fruit damage.
- 67 • The abundance of *C. montrouzieri* in summer affected the increase of *D. aberiae*  
68 density the following year.
- 69 • The utilization of *C. montrouzieri* might be considered complementary to classical  
70 biological control.

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## 83 1. Introduction

84 *Delottococcus aberiae* De Lotto (Hemiptera: Pseudococcidae) is one of the latest exotic  
85 mealybug species introduced in citrus in the Mediterranean basin (Beltrà et al., 2012; Pérez-  
86 Rodríguez et al., 2017a). Likely native to Southern Africa, it was first recorded in 2009 in  
87 eastern Spain, in the region of Les Valls, Valencia (Beltrà et al., 2012). Since then, *D. aberiae*  
88 has been spreading to the surrounding areas, becoming a significant citrus pest (Martínez-Blay  
89 et al., 2018a; Pérez-Rodríguez et al., 2017; Tena et al., 2017). Unlike other species of citrus-  
90 inhabiting mealybug, *D. aberiae* causes severe fruit distortion and size reduction leading to  
91 major economic losses (Pérez-Rodríguez et al., 2017). The damaging period ranges from April  
92 to July, during the fruit set, when *D. aberiae* alters fruit cell division while feeding (Martínez-  
93 Blay et al., 2018b). Generally, *D. aberiae* is distributed throughout the entire tree canopy, but  
94 aggregate on fruits when they become available, resulting in direct damage (Pérez-Rodríguez et  
95 al., 2017). In the early spring, gravid *D. aberiae* females descend down the trunk into the soil  
96 searching for shelter in the subterranean crown (Franco et al., 2009; Martínez-Blay et al.,  
97 2018b). Once in the soil, the females deposit ovisacs, and, upon emergence, nymphs climb  
98 again to the upper part of the tree (Martínez-Blay et al., 2018a).

99 Integrated pest management (IPM) of *D. aberiae* mainly relies on the application of broad-  
100 spectrum insecticides such as chlorpyrifos or chlorpyrifos-methyl. Recently, the environmental  
101 economic injury level for *D. aberiae* has been established as 12% of fruit occupation between  
102 petal fall and July. When more than 12% of fruits are occupied by *D. aberiae*, a chemical  
103 treatment is recommended (Pérez-Rodríguez et al., 2017). Biological control is currently not an  
104 option because native parasitoids, the most important group of biological control agents of  
105 mealybugs, cannot develop in *D. aberiae*, and the role of predators is poorly known (Tena et al.,  
106 2017). Recently, the predatory mite *Gaeolaelaps aculeifer* (Canestrini 1883) (Acari:  
107 Laelapidae) has been recorded as a potential enemy of young instars of *D. aberiae* in the soil  
108 because it feeds on the first instar under semi-field conditions (Pérez-Rodríguez et al., 2018),  
109 but the impact of other generalist predators is still unknown.

110 Among mealybug predators, *Cryptolaemus montrouzieri* Mulsant (Coleoptera:  
111Coccinellidae) has been used worldwide in many biological control programs (Kairo et al.,  
1122000; Stiling, 2004; Maes et al., 2014). It is native to the Australasian zoogeographical region  
113and has been introduced to more than 64 countries to suppress important mealybug pests (Kairo  
114et al., 2013). In the citrus-growing areas of the Mediterranean Basin such as France, Greece,  
115Italy, and Turkey, *C. montrouzieri* has been introduced and/or inoculatively released to control  
116*Planococcus citri* Risso (Hemiptera: Pseudococcidae) (Ripollés et al., 1995; Katsoyannos, 1996;  
117Franco et al., 2004; Jacas et al., 2006; Villalba et al., 2006; Mani, 2018). In Spanish citrus, *C.*  
118*montrouzieri* was first introduced in 1927 (Gómez-Clemente, 1928) from California. Since then,  
119it has been reared and inoculatively released because winter temperatures, prey scarcity, and the  
120overuse of chemical control decrease *C. montrouzieri* densities during winter (Boyeró et  
121al., 2005; Villalba et al., 2006; Planes et al., 2013). However, it has been shown that *C.*  
122*montrouzieri* is able to overwinter in pesticide-free citrus orchards (Martínez-Ferrer, 2003;  
123Franco et al., 2004).

124 The larvae and adults of *C. montrouzieri* are voracious feeders and prey on all stages of *P.*  
125*citri* (Rosas-García et al., 2009; Attia et al., 2011). However, the earlier larvae of *C.*  
126*montrouzieri* prefer to feed on eggs and young nymphs while older larvae, which have a higher  
127predation rate, feed on mealybugs of any size (Heidari and Copland, 1992; Attia et al., 2011;  
128Mani, 2018). For instance, fourth instar larvae have been found to consume up to 3,330 eggs or  
129250 young instars of *P. citri* at 28° C (Gosalwad et al., 2009; Kairo et al., 2013). Adults of *C.*  
130*montrouzieri* become smaller or even infertile when prey is scarce (Torres and Marcano, 2015)  
131and engage in cannibalism when prey is absent (Mani, 2018).

132 In order to locate their prey, *C. montrouzieri* larvae require physical contact whereas adults  
133use visual and chemical stimuli (Heidari and Copland, 1992; Kairo et al., 2013). The wax  
134secretions and honeydew produced by mealybugs act as both attractants and oviposition  
135stimulants for *C. montrouzieri* females (Merlin et al., 1996), which are able to lay viable eggs as  
136long as they can prey on mealybugs (Finlay-Doney and Walter, 2012). A single adult female

137lays about 400 eggs in 40 days of oviposition (Babu and Azam, 1987; Siddhapara et al., 2013)  
138and this quantity can increase if multiple mating occurs (Xie et al., 2014).

139 In the Mediterranean, *C. montrouzieri* has four generations per year and it can overwinter  
140depending on the climatic conditions (Kaneko, 2017; Toorani et al., 2017). Apart from *P. citri*,  
141it has been observed feeding on other mealybug species as well as soft scales (Hemiptera:  
142Coccidae), aphids (Hemiptera: Aphididae), and whiteflies (Hemiptera: Aleyrodidae) (Saikia and  
143Balasubramanian, 2000; Attia et al., 2011; Maes et al., 2014; Francis et al., 2016). In the main  
144citrus producing areas of Spain, *C. montrouzieri* follows a predator–prey population dynamic  
145with its main prey *P. citri* (Llorens, 1990; Martínez-Ferrer, 2003; Villalba et al., 2006) and it is  
146considered a key predator in the system (Mani and Krishnamoorthy, 2008; Kairo et al., 2013) .

147 During the past few years, *C. montrouzieri* has been observed feeding on *D. aberiae* in the  
148field, but its impact as a biological control agent of this citrus invasive pest is unknown. In this  
149study, we surveyed nine citrus orchards during two consecutive years in order to: i) describe the  
150population dynamics of *D. aberiae* and *C. montrouzieri*; ii) evaluate the effect of *C.*  
151*montrouzieri* density on the population levels of *D. aberiae* within the same year and among  
152years; iii) evaluate the influence of *C. montrouzieri* as well as the mean temperature per day and  
153citrus variety on *D. aberiae* population growth rates; and vi) describe damages produced by *D.*  
154*aberiae* throughout the year. We used these data to discuss the potential of *C. montrouzieri* as  
155biological control agent of *D. aberiae*.

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## 1572. Material and methods

### 1582.1 Survey sites and procedure

159The study was carried out in the core of the citrus producing area of eastern Spain (Valencian  
160Community). A total of nine orchards were monitored during 2014 and 2015. Five orchards  
161consisted of *Citrus reticulata* Blanco (mandarins): three were Clemenules and two were Oroval  
162cultivars. The remaining four consisted of *Citrus sinensis* (L.) Osbeck: Navelate cultivar.

163Orchards monitored ranged from 0.4 to 3 ha and all were drip-irrigated. The surveyed area was  
164pesticide-free during the study.

165Eight to ten trees were observed twice a month from March to November and monthly from  
166December to February. Sampling occurred with less frequency from December to February due  
167to the reduced insect activity during the winter. Trees were selected at the beginning of the  
168surveys if they were infested only with *D. aberiae* during previous years. In each tree, two  
169different strata were surveyed: canopy and trunk. In the canopy, four 20-cm long twigs with  
170flowers or fruits or both were collected and each twig belonged to a different cardinal  
171orientation (i.e., one twig randomly selected in each orientation). All samples of a tree were  
172placed in individual plastic bags, sealed, and immediately transported in a cooler to the  
173laboratory. Within the next 24 h, twigs, four leaves, and a maximum of eight flowers or fruits  
174per twig were examined under a stereomicroscope. Leaves, flowers, and fruits were selected at  
175random within the twig. All nymphs and adult females of *D. aberiae* as well as all the larvae  
176and adults of *C. montrouzieri* were counted. In the trunk stratum, sampling consisted of visual  
177counts lasting 2 min. All *D. aberiae* and *C. montrouzieri* individuals present on the trunk (from  
178the ground up to 60 cm in height) were recorded. During fruit formation, we also recorded  
179whether the fruit was damaged by *D. aberiae*. We considered damaged fruit as those with a size  
180reduction or deformation that completely depreciated them from a commercial view (Pérez-  
181Rodríguez et al., 2017).

## 1822.2 Data analyses

### 1832.2.1 Prey-Predator dynamics and impact of *C. montrouzieri* on *D. aberiae*.

184 In order to represent the population dynamics of *D. aberiae* and *C. montrouzieri*,  
185sampling data of the different strata were averaged per tree and afterward per orchard. The ratio  
186of fruit damaged by *D. aberiae* was also averaged per tree and afterward per orchard. The  
187maximums of *C. montrouzieri* density throughout the two years of the study were correlated  
188using Kendall tests (Kendall, 1975). The same analysis was used to determine correlations

189between the maximums of *C. montrouzieri* density and the fluctuations of *D. aberiae* density  
190among generations (or maximum peaks). These and all subsequent analyses were conducted  
191using the software R (version 3.4.4, The R Foundation).

## 1922.2.2 Population growth rates

193 Population growth was expressed as the intrinsic rate of growth,  $r$ , calculated as  
194 $\ln(N_{t+1}/N_t)$ , in which  $N$  represents the total number of all developmental *D. aberiae* stages per  
195tree at time  $t$  and  $t + 1$ . The  $r$ -value was expressed normally using the units  $d^{-1}$  by dividing  
196 $\ln(N_{t+1}/N_t)$  by the period of time in days between the survey date  $t$  and the subsequent survey  
197date  $t + 1$ . The relative density of *C. montrouzieri* was calculated as  $C. montrouzieri / (D.$   
198 $aberiae + C. montrouzieri)$ , which is the fraction of *C. montrouzieri* in an isolated predator–prey  
199community (per tree).

200 A linear mixed-effects model was used to quantify the effect of *C. montrouzieri* on *D.*  
201 $aberiae$  population growth. The model incorporated predator density, mean temperature per  
202day, and citrus species as main effects, and orchard and tree as nested random effects to account  
203for repeated measures. The data were also analyzed for any delayed effects by plotting the slope  
204of *D. aberiae* population growth and *C. montrouzieri* density as a function of increasing the  
205magnitude of time (incremental increase in sampling period) between measuring *C.*  
206 $montrouzieri$  density and the associated *D. aberiae* population growth rate. Thus, as the time  
207delay becomes more extreme (considered as increasing values along an  $x$ -axis), this represents a  
208larger delay in the effect of *C. montrouzieri* on *D. aberiae*. For example, a 365-day delay  
209correlates *D. aberiae* population growth with *C. montrouzieri* densities surveyed one year prior.  
210Citrus cultivars were analyzed separately in this variation of the model because sampling  
211periods differed across cultivars.

212

## 2133. Results

### 2143.1. Prey-predator population dynamics and impact of *C. montrouzieri* on *D. aberiae*

215 The population densities of *D. aberiae* and *C. montrouzieri* exhibited two major peaks  
216 in both years, and their populations were synchronized except in the summer of 2014, when the  
217 mealybug population peaked earlier than the predator (Figure 1). The first major infestation was  
218 at the end of May and the second occurred between July and August.

219 The maximum number of *C. montrouzieri* in the first and second peaks had a positive  
220 correlation both years (2014:  $Z = 2.04$ ,  $df = 1$ ,  $70$ ,  $P = 0.042$ ,  $\tau = 0.19$ ; 2015:  $Z = 2.69$ ,  $df = 1$ ,  
221  $70$ ,  $P = 0.007$ ,  $\tau = 0.27$ ) (Table 1). Other correlations between different peaks of *C.*  
222 *montrouzieri* were not significant (Table 1).

223 When we analysed the effect of *C. montrouzieri* density on changes in peak *D. aberiae*  
224 abundance, the number of predators in the second peak of 2014 had a negative relationship with  
225 the increase of *D. aberiae* in 2015 [increase between the first (May) and second peak (July-  
226 August);  $Z = -3.75$ ,  $df = 1$ ,  $70$ ,  $P < 0.001$ ,  $\tau = -0.31$ ] (Table 2). Other correlations between *C.*  
227 *montrouzieri* density and changes in *D. aberiae* abundance were not significant (Table 2).

### 228 3.2. Fruit damaged by *D. aberiae*

229 During both years, the ratio of fruit that could be categorized as damaged by *D. aberiae*  
230 increased exponentially from the end of May until the end of June (Figure 2), and by the last  
231 week of June, approximately 70% of the fruit was damaged.

### 232 3.3. Analyses of population growth rates

233 Changes in *D. aberiae* population growth rate were associated with changes in temperature  
234 and *C. montrouzieri* density, but not citrus variety (Figure 3; Table 3). *Delottococcus aberiae*  
235 population growth rate tended to decrease with increasing temperature but to increase with  
236 declining *C. montrouzieri* population density. Similarly, analyses of a subset of the data  
237 spanning 1 May to 30 September (outbreak and decline of *D. aberiae* densities) exhibited  
238 similar trends, except that *D. aberiae* population growth rate was not associated with changes in  
239 *C. montrouzieri* density in 2014 (Table 3).

240 Figure 4 summarizes the time lag of predator impact on *D. aberiae* population growth rates.  
241 While the slope was positive when *C. montrouzieri* density was delayed 15 days, it tended to be  
242 zero later on.

243

#### 2444. Discussion

245 The two-year field study showed that the seasonal abundance of *C. montrouzieri* (the lady  
246 beetle mealybug destroyer) was synchronized with that of the invasive mealybug *D. aberiae*.  
247 The mealybug and the predator had two major peaks in population density per year; the first one  
248 was in the spring and the second in the summer. The populations of *D. aberiae* and *C.*  
249 *montrouzieri* were synchronised for both peaks during the two years of the study. This prey-  
250 predator synchrony, as well as the absence of alternative mealybug species, suggests that *C.*  
251 *montrouzieri* is able to locate and survive by preying upon *D. aberiae* in the field just a few  
252 years after the mealybug established in Europe. It is worth mentioning that, although *P. citri* is  
253 abundant and widely distributed in Mediterranean citrus (Tena and García-Mari, 2011), *D.*  
254 *aberaiae* was the predominant mealybug species in the monitored orchards; only one other  
255 mealybug, *Pseudococcus longispinus* (Targioni Tozzetti) (Hemiptera: Pseudococcidae), was  
256 recovered occasionally in one of the orchards.

257 The peaks in the densities of *D. aberiae* and *C. montrouzieri* tended to overlap, contrary to  
258 other prey–predator dynamics. Generally, predators peak a few weeks after their prey, showing  
259 a temporal mismatch between population cycles (Holling, 1965; Tansky, 1978; Martin and  
260 Ruan, 2001). The reason for this overlap might be due to the preference of *C. montrouzieri*  
261 adults of laying their eggs near mealybug ovisacs, just before the new generation of the prey  
262 emerge and peak (Whitcomb, 1940; Merlin et al., 1996). In fact, *C. montrouzieri* adults  
263 withhold their eggs in the oviducts, delaying oviposition when mealybug ovisacs are not present  
264 (Maes et al., 2014).

265 Although *D. aberiae* and *C. montrouzieri* seasonal trends were synchronised, our results  
266 indicated that *C. montrouzieri* was not able to prevent fruit damage by the mealybug. Damages

267produced by *D. aberiae* were observed by May and increased exponentially in June, at which  
268point nearly 70% of fruits were damaged, so it does not appear that *C. montrouzieri* would have  
269been able to prevent the damages produced by *D. aberiae*. *Delottococcus aberiae* damages the  
270fruit when it feeds on flower ovaries or on very small, tender fruits (Martínez-Blay 2017). The  
271most plausible explanation for this lack of damage control is the high susceptibility of the fruit  
272to be damaged even at low mealybug densities. As with other sap feeders, *D. aberiae* might  
273interfere with fruit cell division by injecting toxic enzymes (Sharma et al., 2014; Martínez-Blay  
274et al., 2017). During this period, which occurs during May and June, the mealybug is poorly  
275aggregated and relatively low in abundance, which may not be favourable to *C. montrouzieri*  
276population growth (Pérez-Rodríguez et al., 2017).

277 *Cryptolaemus montrouzieri* was not able to regulate the populations of *D. aberiae* within  
278the same year. Density fluctuations of the mealybug between spring and summer, as well as its  
279population growth rates were independent of the density of the coccinellid. One possible  
280explanation could be that *D. aberiae* is an unsuitable prey for *C. montrouzieri*. The nutritional  
281value of some prey can be insufficient to allow the development of their predators (Hodek et al.,  
2822012), and the nutritional value of *D. aberiae* for *C. montrouzieri* still needs to be evaluated.  
283Coccinellids are not able to distinguish between adequate food and a less suitable prey  
284(gustatory discrimination) (Nielsen et al., 2002; Synder and Clevenger, 2004; Nedvêd and  
285Salvucci, 2008). Therefore, *D. aberiae* could be a less suitable prey for *C. montrouzieri* than  
286other citrus mealybugs such as *P. citri*, which density levels within the same year depend on the  
287coccinellid (Martínez-Ferrer, 2003). Another possible factor that might explain this lack of  
288regulation is temperature. The coccinellid is adapted to tropical temperatures and requires a  
289minimum temperature of 21° C to feed or lay eggs and is unable to complete development  
290between 0 and 17° C (Kairo et al., 2013). Although the minimum temperature threshold of *D.*  
291*aberae* is unknown, the mealybug might have a lower threshold than *C. montrouzieri* because it  
292is active during our Mediterranean winter (mean maximum temperature per month around 17° C  
293(MAPAMA, 2018) and a male flight occurs in February (Martínez-Blay et al., 2018a,b). These

294different temperature requirements might contribute to the lack of top-down regulation within  
295the same year. Finally, bottom-up regulation may be more important than top-down regulation  
296and mask the effect of *C. montrouzieri*. As with all mealybugs, *D. aberiae* is likely a phloem  
297feeder. In citrus, the two highest concentrations of amino acids in the phloem occur in early  
298spring (March) and during the fruit setting period (June-July) (Moreno and García-Martínez,  
2991983; Yang and Sadof, 1995; Sétamou et al., 2016), both of which correspond to the two main  
300peaks of *D. aberiae*. The increase of amino acids might accelerate *D. aberiae* development and  
301increase its reproduction in spring compared to *P. citri*, which likely has a higher minimum of  
302temperature threshold.

303 Another detrimental factor that could disrupt the prey-predator dynamic between *C.*  
304*montrouzieri* and *D. aberiae* is the presence of ants in citrus. In a mutualistic association, ants  
305obtain carbohydrates and other nutrients from the mealybug honeydew in exchange for  
306providing protection against their natural enemies (Tollerup et al., 2004; Majerus et al., 2007;  
307Styrsky and Eubanks, 2007; Nelson and Daane, 2008; Tena et al., 2013; Zhou et al., 2015;  
308Calabuig et al., 2015; Beltrà et al., 2017). In Spanish citrus orchards, the two dominant ant  
309species are *Lasius grandis* (Forel) (Hymenoptera: Formicidae) and *Pheidole pallidula* (Nyl)  
310(Hymenoptera: Formicidae). They attend the main citrus mealybug species *P. citri* (Pekas et al.,  
3112011; Calabuig et al., 2015) and have been reported attacking *C. montrouzieri* larvae (Mansour  
312et al., 2012; Kairo et al., 2013). However, it is unclear whether *L. grandis* and *P. pallidula*  
313disrupt the biological control of *D. aberiae* because we observed them attending *D. aberiae*  
314only occasionally (Pérez-Rodríguez, personal observations). Further studies should assess the  
315effect of these ant species on *D. aberiae* population dynamics.

316 Despite the lack of correlation between *C. montrouzieri* and *D. aberiae* populations within  
317the same year, the increase in the density of *D. aberiae* in 2015 was negatively related to the  
318density of *C. montrouzieri* in the summer of 2014. *Cryptolaemus montrouzieri* has been largely  
319considered in conservation biological control programmes of other mealybug species because it  
320complements the action of parasitoids (Prokopenko, 1982; Longo and Benfatto, 1987; Moore,

3211988; Martínez-Ferrer, 2003; Kairo et al., 2013), which suggests that *C. montrouzieri* could  
322contribute to regulate *D. aberiae* once a successful parasitoid is introduced in Spain. At this  
323time, biological control of *D. aberiae* is limited because the mealybug encapsulates the eggs of  
324the native or naturalized parasitoids in Spanish citrus (Tena et al., 2017). Recently, two new  
325parasitoid species of *D. aberiae* have been described in its native area of South Africa:  
326*Anagyrus aberiae* Guerrieri sp.nov and *Anagyrus antoniae* Guerrieri sp.nov. (Hymenoptera:  
327Encyrtidae) (Beltrà et al., 2015; Guerrieri and Cascone, 2018), and the introduction of these  
328parasitoid species within a classical biological control program might contribute to the  
329management of *D. aberiae*. Another promising control measure could be the augmentative or  
330inoculative releases of *C. montrouzieri* larvae during winter, or before the first main population  
331peak of *D. aberiae*. Because late nymphal and adult female *D. aberiae* aggregate to and disperse  
332down the trunk during February and March (Martínez-Blay et al., 2018b), *C. montrouzieri* could  
333be inoculatively released at the base of the trunk during this time. Further research in the field is  
334needed to test this potential strategy and whether *C. montrouzieri* survive and search for *D.*  
335*aberiae* under the winter conditions of the Mediterranean basin (Maes et al., 2014).

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### 342 **Author contribution statement**

343 AS, JM and AT conceived and designed the research. JPR and VM collected field data. JP,  
344JRM and AT analyzed the data. JPR, JRM and AT wrote the first version of the manuscript. All  
345authors read and contributed to the last version of the manuscript.

346

### 347 **Conflict of interest**

348 The authors declare that they have no conflict of interest.

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554 **Table 1.** Correlation between the densities of the predatory coccinellid *Cryptolaemus*  
 555 *montrouzieri* in different maximum peaks of 2014 and 2015. Significant *P*-values are presented  
 556 in bold (N = 71 trees).

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<i>C. montrouzieri</i> density		<b>Z</b>	<b>P</b>	<b>T</b>	<b>slope</b>
<b>(x-Axis)</b>	<b>(y-Axis)</b>				
	2 <sup>nd</sup> peak 2014	2.04	<b>0.04</b>	0.19	1.29
1 <sup>st</sup> peak 2014	1 <sup>st</sup> peak 2015	1.62	0.11	0.16	0.16
	2 <sup>nd</sup> peak 2015	0.05	0.96	0.01	-0.12
2 <sup>nd</sup> peak 2014	1 <sup>st</sup> peak 2015	-0.43	0.67	-0.04	-0.001
	2 <sup>nd</sup> peak 2015	-1.24	0.21	-0.12	-0.04
1 <sup>st</sup> peak 2015	2 <sup>nd</sup> peak 2015	2.69	<b>0.01</b>	0.27	0.46

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568 **Table 2.** Effect of *Cryptolaemus montrouzieri* density on *Delottococcus aberiae* increase  
 569 among different maximum peaks of 2014 and 2015. Significant *P*-values are presented in bold.  
 570 The significant interactions are graphically represented in Fig. 2.

571

<i>C. montrouzieri</i> density	Population fluctuations of <i>D. aberiae</i>	<i>Z</i>	<i>P</i>	<i>T</i>	slope
1 <sup>st</sup> peak 2014	2 <sup>nd</sup> peak 2014 – 1 <sup>st</sup> peak 2014	-1.43	0.15	-0.13	-13.52
	1 <sup>st</sup> peak 2015 – 2 <sup>nd</sup> peak 2014	0.35	0.72	0.032	9.83
	2 <sup>nd</sup> peak 2015 – 1 <sup>st</sup> peak 2015	-1.62	0.11	-0.14	-14.30
2 <sup>nd</sup> peak 2014	1 <sup>st</sup> peak 2015 – 2 <sup>nd</sup> peak 2014	-1.13	0.26	-0.10	-1.68
	2 <sup>nd</sup> peak 2015 – 1 <sup>st</sup> peak 2015	-3.75	<b>&lt;0.001</b>	-0.31	-3.50
3 <sup>rd</sup> peak 2015	2 <sup>nd</sup> peak 2015 – 1 <sup>st</sup> peak 2015	-0.79	0.43	-0.07	0.09

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576**Table 3.** Effect of the density of *C. montrouzieri*, mean temperature per day and citrus variety  
 577on *Delottococcus aberiae* population growth rates during 2014–2015. Significant *P* values are  
 578presented in bold and represented graphically in Fig. 3.

579

<b>Time period</b>	<b>Factor</b>	<b>df</b>	<b>F-value</b>	<b>P-value</b>
2014–2015	<i>C. montrouzieri</i>	1, 2502	10.32	<b>0.001</b>
	temperature	1, 2502	35.67	<b>&lt;0.0001</b>
	citrus variety	1, 6	1.880	0.219
May–Sep 2014	<i>C. montrouzieri</i>	1, 749	1.500	0.221
	temperature	1, 749	53.00	<b>&lt;0.0001</b>
	citrus variety	1, 6	1.134	0.328
May–Sep 2015	<i>C. montrouzieri</i>	1, 647	17.05	<b>&lt;0.0001</b>
	temperature	1, 647	9.939	<b>0.002</b>
	citrus variety	1, 6	3.356	0.117

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584 **Figure legends**

585 **Figure 1.** Population density (mean  $\pm$  SE) of the invasive mealybug *Delottococcus aberiae* and  
586 its predatory coccinellid *Cryptolaemus montrouzieri* in nine citrus orchards from Spain in 2014  
587 and 2015.

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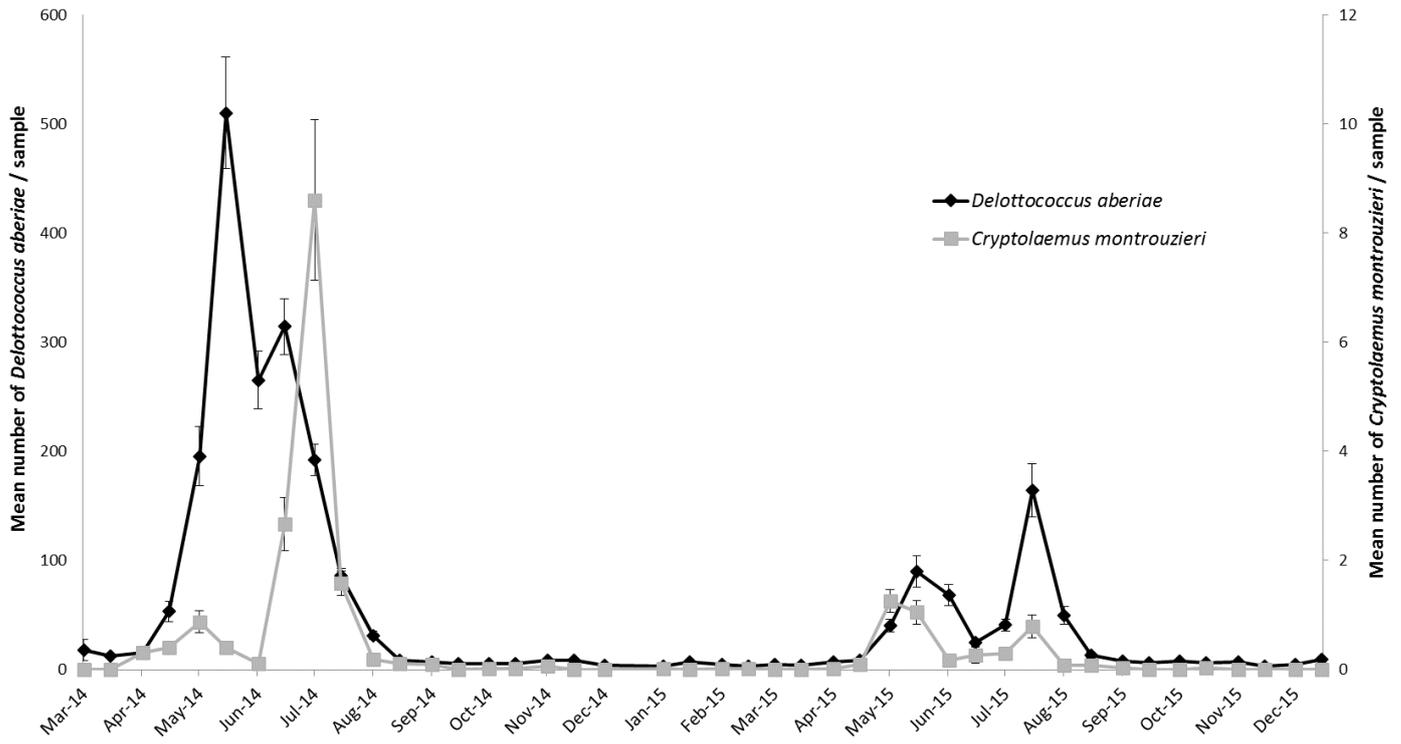
589 **Figure 2.** Fruit damaged (mean ratio  $\pm$  SE) by *Delottococcus aberiae* in nine citrus orchards  
590 from Spain throughout 2014 and 2015.

591

592 **Figure 3.** a) Population density and b) population growth rate of *Delottococcus aberiae*  
593 represented per day and tree. Different colours represent mean daily temperature. c) Population  
594 growth rate of *D. aberiae* as a function of relative density of *Cryptolaemus montrouzieri* and d)  
595 mean temperature during 2014 and 2015. Dashed line plots the slope  $\beta_1$  from the linear mixed  
596 models presented in Table 3.

598 **Figure 4.** Slope ( $\beta_1$ ) of *Delottococcus aberiae* population growth rate ( $r$ ) vs. the relative  
599 *Cryptolaemus montrouzieri* density as a function of offsetting the temporal relationship between  
600 *D. aberiae* and *C. montrouzieri* density from 2014–2015. The  $x$ -axis maps incremental delays in  
601 surveyed periods. Slopes significantly different than zero are indicated by open circles. The  
602 dashed line represents no correlation between *C. montrouzieri* and *D. aberiae* population  
603 density.

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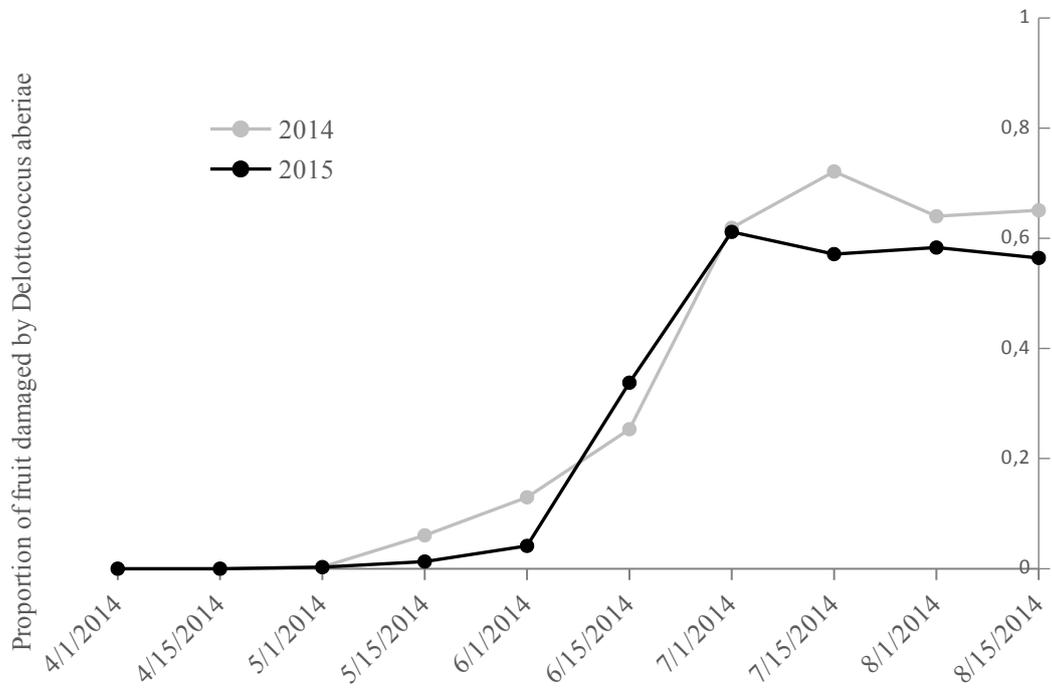
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606 Fig. 1

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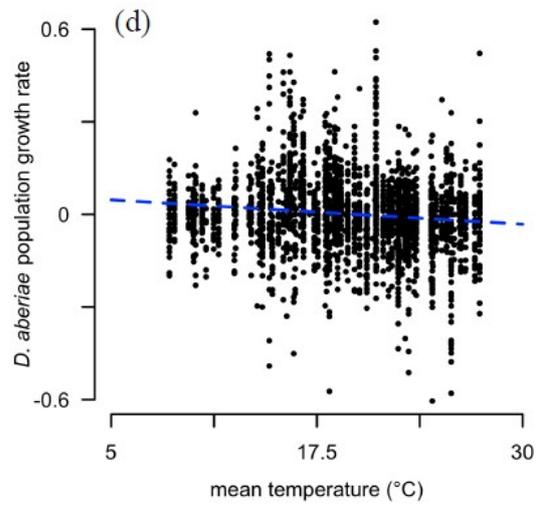
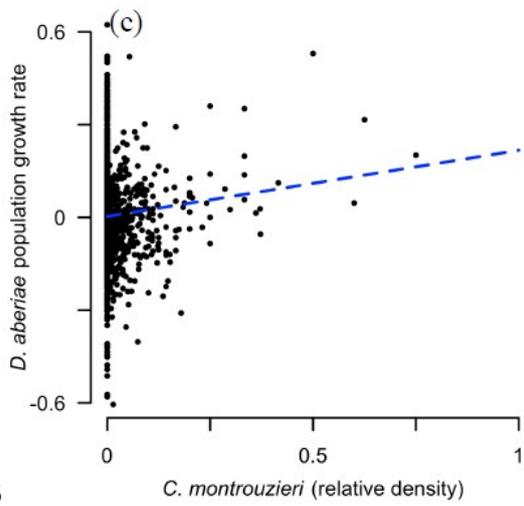
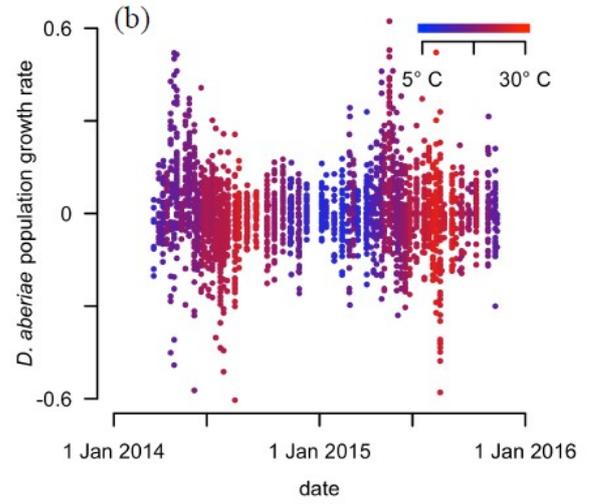
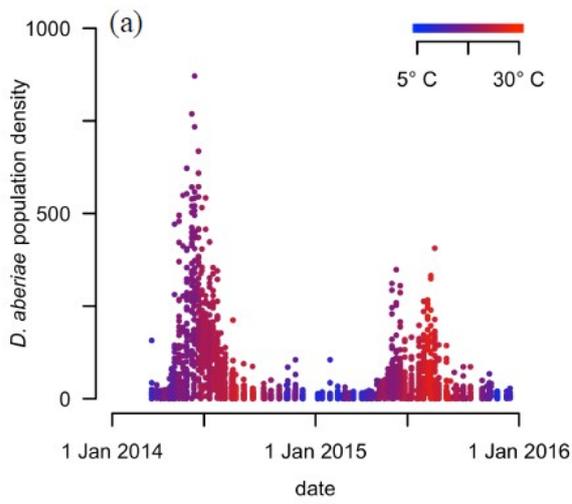
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614 **Fig. 2**

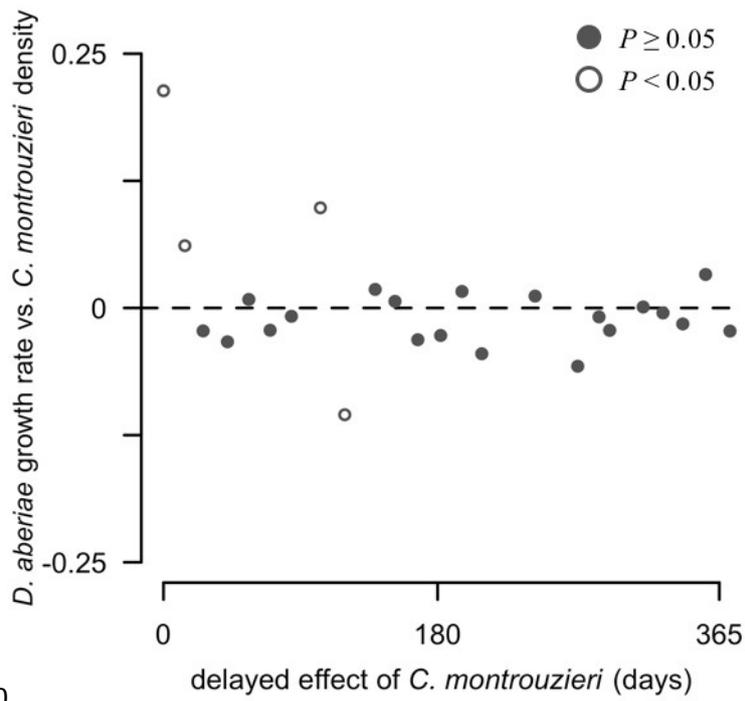
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616

617 **Fig. 3**

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621

622 Fig. 4.

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