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RESEARCH ARTICLE

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Phenology and interspecific association of *Forficula auricularia* and *Forficula pubescens* in apple orchards

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Abstract

The European earwig *Forficula auricularia* L. (Dermaptera: Forficulidae) has been widely studied as a key predator of pests in temperate regions, but its phenology and behavior may differ in warmer areas such as the Mediterranean. Here we assessed the phenology, aggregation, and interspecific association of *F. auricularia* and *Forficula pubescens* Gené, the only two species found consistently in both ground and canopy shelters in Mediterranean apple orchards. In addition to *F. auricularia* and *F. pubescens,* three other earwig species, namely *Labidura riparia* Pallas, *Nala lividipes* Dufour and *Euborellia moesta* Gené, were found occasionally. The mature stages of *F. auricularia* were observed mainly from May to November in tree shelters and immature ones from October to June in ground shelters. Adult individuals of *F. pubescens* were observed year-round and nymph instars were detected from April to June in ground as well as in tree shelters. The suitability of the current degree-days models for temperate regions was evaluated for the prediction of European earwig phenology in a Mediterranean climate. Regarding interspecific association, *F. auricularia* and *F. pubescens* co-occurred in canopies without apparent competition. This study provides useful weekly data about the phenology of the two earwig species throughout the year that can be used to detect the key periods during which to enhance their populations in pip fruit orchards or to control them in stone fruit crops. Furthermore, our results are of relevance for the development of new phenological models of earwigs in Mediterranean areas where nymphs hibernate, a feature that makes current models inaccurate.

Additional key words: biological control; Dermaptera; earwig; Forficulidae; Mediterranean; pest

Abbreviations used: BB (Les Borges Blanques); DD (degree-days); FA (*Forficula auricularia*); FP (*Forficula pubescens*); IU (Ivars d'Urgell); MI (Miralcamp); MO (Mollerussa); N1 to N5 (1st to 5th nymph instars); RAA (Rosy apple aphid); WAA (Woolly apple aphid)

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Introduction

The role of the European earwig, *Forficula auricularia* Linnaeus (Dermaptera: Forficulidae), as a generalist predator in orchards has been widely cited. For instance, it has been reported to predate on pear psylla *Cacopsylla pyri* Linnaeus (Hemiptera: Psyllidae) (Lenfant *et al.*, 1994; Sauphanor *et al.*, 1994; Höhn *et al.*, 2007), codling moth *Cydia pomonella* Linnaeus (Lepidoptera: Tortricidae) (Glenn, 1977; Jones *et al.*, 2012; Sauphanor *et al.*, 2012), apple leaf-curling midge *Dasineura mali* Kieffer (Diptera: Cecidomyiidae) (He *et al.*, 2008), diaspidid scale insects (Hill *et al.*, 2005; Logan *et al.*, 2007), the leafroller *Epiphyas postvittana* Walker (Lepidoptera: Tortricidae) (Suckling *et al.*, 2006; Frank *et al.*, 2007), and aphids (Hemiptera: Aphididae) such as the woolly apple aphid (WAA) *Eriosoma lanigerum* Hausmann (Mueller *et al.*, 1988; Asante, 1995; Nicholas *et al.*, 2005), the rosy apple aphid (RAA) *Dysaphis plantaginea* Passerini (Brown & Mathews, 2007; Dib *et al.*, 2010) and the green apple aphid *Aphis pomi* DeGeer (Carroll & Hoyt, 1984; Hagley & Allen, 1990). Therefore the promotion of *F. auricularia* populations in pip fruit crops seems to be an effective biocontrol strategy.

However, due to their omnivorous diet, European earwigs can cause economic damage to stone fruit crops (Albouy & Caussanel, 1990; Kuthe, 1996; Grafton-Cardwell *et al.*, 2003; Huth *et al.*, 2011). In nectarines, the action threshold is considered when any trap in the orchard contains five or more earwigs (Hetherington, 2006), while in cherries, no predictive relationship between the number of earwigs in traps and the level of damage has been found (Allen, 2013). In addition, the frass produced by earwigs can negatively influence the aroma and flavor of some wines (Burdet *et al.*, 2013). To control earwigs in conventional fruit production, growers spray orchards with commonly used pesticides such as chlorpyrifos and spinosad (Hetherington, 2006; Peusens & Gobin, 2008; Vogt *et al.*, 2010; Fountain *et al.*, 2013). In organic fruit production, alternative strategies, such as mass trapping and exclusion by setting glue around the base of tree trunks, are used (Hetherington, 2006; Alston & Tebeau, 2011; Saladini *et al.*, 2012).

Another earwig species, *Forficula pubescens* Gené, has been reported to be phytophagous or omnivorous (Albouy & Caussanel, 1990); however, it has also been observed to prey on pear psyllids (Debras *et al.*, 2007) and RAA (Dib *et al.*, 2010). Few studies have been devoted to the phenology of *F. pubescens* (Herter, 1964; Romeu-Dalmau *et al.*, 2011). Most studies on earwigs have been conducted on *F. auricularia* in central-northern Europe (Phillips, 1981; Helsen *et al.*, 1998; Kocarek, 1998; Gobin *et al.*, 2008; Moerkens *et al.*, 2009), New Zealand (Burnip *et al.*, 2002; Suckling *et al.*, 2006), and North America (Fulton, 1924; Crumb *et al.*, 1941; Lamb, 1975, 1976; Lamb & Wellington, 1975); however, little is known about these insects in Mediterranean apple orchards, where they may also act as key predators in pip fruit and citrus orchards but as pests in stone fruit orchards and vineyards.

The European earwig forages at night and seeks shelter during the day (Albouy & Caussanel, 1990; Helsen *et al.*, 1998). Given that these insects are important biocontrol agents, the use of additional shelters to enhance their populations has been assessed in apple, pear, and kiwifruit orchards (Solomon *et al.*, 1999; Gobin *et al.*, 2006; Logan *et al.*, 2011). As earwigs have a univoltine life cycle, any disruption in their cycle in one year can have long-lasting repercussions on populations (Gobin *et al.*, 2006; Peusens & Gobin, 2008; Peusens *et al.*, 2010). To minimize negative effects on vulnerable life stages of earwigs, the prediction of their phenology will contribute to determining the precise timing for spray applications and soil tillage, thereby improving orchard management (Peusens *et al.*, 2010; Belien *et al.*, 2012, 2013; Moerkens *et al.*, 2012). For instance, common pesticides sprayed in orchards, such as chlorpyrifos, deltamethrin, indoxacarb and spinosad, have been reported to have lethal effects on the European earwig (Peusens & Gobin, 2008; Peusens *et al.*, 2010; Vogt *et al.*, 2010; Fountain *et al.*, 2013). Software applications and prediction models have been developed to optimize orchard management techniques geared to promoting the European earwig (Helsen *et al.*, 1998; Moerkens *et al.*, 2011; Belien *et al.*, 2012, 2013). However, these studies have been conducted in colder regions, and earwig phenology and behavior may differ in warmer areas such as the Mediterranean.

Here we assessed the phenology, aggregation, and interspecific association of *F. auricularia* and *F. pubescens* in Mediterranean orchards, with the aim to promote their populations in crops where they served as biocontrol agents but also to optimize their control in crops where they are pests. We evaluated the suitability of the current degree-days models for temperate regions to predict the phenology of the European earwig in a Mediterranean climate.

Material and methods

Phenology

Trials were conducted in four apple orchards under organic management located in Catalonia (NE Spain): BB, Les Borges Blanques (41º30'23.06''N; 0º51'05.93''E); MO, Mollerussa (41º36'51.13''N; 0º52'22.75''E); IU, Ivars d'Urgell (41º41'06.19''N; 0º58'06.09''E); and MI, Miralcamp (41°36'31.89"N; 0°52'24.62"E). The climate is semi-arid Mediterranean, with a mean annual rainfall of 350 mm.

BB was an IRTA (Institute of Research and Technology, Food and Agriculture) experimental orchard of 'Fuji Kiku 8' apple grafted onto M9, planted in 2003, and trained to a central leader with 4 × 1.4 m spacing. MO was a commercial orchard of 'Golden Smoothee' apple grafted onto M9, planted in 1985, and trained to a double-axis system with 4 × 1.2 m spacing. IU was a commercial orchard of 'Golden Smoothee' apple grafted onto M9, planted in 1993, and trained to a central leader with 4 × 1.1 m spacing. MI was a commercial orchard of 'Golden Smoothee' apple grafted onto M9, planted in 2000, and trained to a central leader with 4 × 1.2 m spacing.

BB was sampled for 4 years (2010-2013), MO and IU for 3 (2011-2013), and MI for 2 (2012-2013). For each orchard from 2010 onwards, 10 shelters were set on the second scaffold limb of various trees (tree shelters). From 2012 onwards, 10 additional shelters were tied at the base of 10 supplementary trees in each or-

chard (ground shelters) in an attempt to capture earwigs in younger stages that do not climb on trees. Following Lordan *et al.* (2014a), shelters were prepared by rolling a piece of corrugated cardboard into cylinders (12 cm height × 9 cm diameter), which were protected from rain and adverse conditions by a PVC tube (15 cm height × 9.5 cm diameter). Similar shelters have been used in studies of European earwigs elsewhere (Phillips, 1981; Helsen *et al.*, 1998; Solomon *et al.*, 1999; Burnip *et al.*, 2002; Gobin *et al.*, 2006; Logan *et al.*, 2007; He *et al.*, 2008; Moerkens *et al.*, 2009). Every week throughout the year, the species, number, phenological stage, and sex of adult earwigs for each shelter were recorded, and earwigs were then released at the base of the assessed tree. Presence of wings was used to distinguish between *F. auricularia* and *F. pubescens* adults (Albouy & Caussanel, 1990). Cerci dimorphism was used to distinguish sex while size and number of antennal segments and the apparent wing buds on the 3rd segment of the thorax were used to distinguish nymph stages (Albouy & Caussanel, 1990).

Evaluation of the degree-days models

The European earwig phenological degree-days model (Model) designed by Moerkens *et al.* (2011) was tested in our region. The daily minimum and maximum temperatures required to run the model were obtained from the closest automatic weather station of the Meteorological Service of Catalonia (*Meteocat, Departament de Territori i Sostenibilitat, Generalitat de Catalunya*). For BB, data were from the Castelldans station 8.5 km away, for IU from the Castellnou de Seana station 3 km away and for MO and MI from the Mollerussa station 0.5 km and 1 km away respectively. From 2011 onwards, daily soil temperatures at a depth of 5 cm were also available but only from the Mollerussa station, which is 12 km from BB and 10 km from IU; these distances were within the range used to construct the model described by Moerkens *et al.* (2011). Thus, the model was run with soil temperature data from MO for all the orchards. The model was checked for 2012-2013 based on the dates of first appearance and peak of each developmental stage observed in the field.

The sum of degree-days (DD) up to the first and maximum number of N3, N4 nymph instars, and adults was calculated for each orchard and year and compared with those reported by Helsen *et al.* (1998). The minimum and maximum temperatures from each weather station were used to calculate the effective temperature for each orchard and year. The effective temperature sum in DDs was calculated through the sine wave approximation (Rabbinge, 1976), using a lower threshold of 6°C and taking 1st January as the biofix. These parameters were chosen following Helsen *et al.* (1998).

Data analysis

Data from April to July—when more earwigs were recorded—were used to compare among years within orchards. Replicates were the weekly mean number of earwigs in the 10 tree shelters. *F. auricularia* data were log-transformed and ANOVA assumptions (normality and homoscedasticity) were confirmed before analysis. Means were compared at the $p = 0.05$ level, and a Tukey HSD test was used to separate means. Due to heterogeneity of variance, *F. pubescens* data were analyzed by Welch's test.

To compare earwig species, data from April to July in tree shelters were used. Replicates were the weekly mean number of earwigs in the 10 tree shelters, and in this case they were compared within orchards by Welch's test.

Data from June and July—when more adults were recorded in tree shelters—were used to calculate and analyze the sex ratio for *F. auricularia* and *F. pubescens* within orchards. Data were log-transformed and analyzed by a nonparametric Wilcoxon test. Homogeneity of variance was also confirmed before each analysis.

Aggregation in shelters was evaluated by fitting data to Taylor's power law (Taylor, 1961):

$$S^2 = a \cdot m^b \quad [1]$$

where S^2 is the variance, m is the sample mean, a is a sampling factor, and b indicates whether the population distribution is regular ($b<1$), random ($b=1$) or aggregated ($b>1$). For *F. auricularia*, the weekly mean data of the 10 shelters from June to July from all the years and orchards were used, while for *F. pubescens* the data used were from IU 2011-2012 and MI 2012. Equation [1] was log-log transformed to estimate a and b.

To evaluate the interspecific association between *F. auricularia* and *F. pubescens*, data from IU 2011-2012 and MI 2012 were used. Tree and ground shelters were assigned to one of the following categories on the basis of insect presence: (a) both earwig species; (b) only *F. auricularia*; (c) only *F. pubescens*; and (d) without earwigs. For each month, the number of shelters within each category was used to calculate the interspecific association coefficient (*Cas*) following Yule's formula (Yule, 1912):

$$Cas = (ad-bc) / (ad + bc) \quad [2]$$

Cas varies from -1 to +1. A negative value shows competition, zero no interaction, and a positive value an association between species (Legendre & Legendre, 1984; Sauphanor & Sureau, 1993).

Data were analyzed using the JMP statistical software package (Version 9; SAS Institute Inc., Cary, NC, USA).

Results

Phenology

F. auricularia was very common in all the orchards during the study period, whereas *F. pubescens,* although observed in all the orchards, was not captured all the years (Suppl. Table S1 [pdf online] and Fig. 1). Both species were found in tree and ground shelters (Suppl. Table S1). Higher numbers of *F. auricularia* than *F. pubescens* were observed in all the orchards (Figure 2). The abundance of *F. auricularia* did not change along the years in BB, IU or MI, whereas the population increased in MO over the years ($F_{2,48}=19.75$; $p=0.0001$) (Figure 1). The abundance of *F. pubescens* decreased in IU ($F_{2,20}=35.44$; $p\leq0.0001$) and MI ($F_{1,19}=9.49$; $p=0.006$) (Figure 1).

In addition to *F. auricularia* and *F. pubescens,* three other earwig species, namely *Labidura riparia* Pallas, *Nala lividipes* Dufour and *Euborellia moesta* Gené, were found occasionally but only in ground shelters.

F. auricularia was found throughout the year (Figure 3a-b and Suppl. Table S1). From January to June, N2, N3 and N4 instars were found in ground shelters. At the end of January the population peaked with an average of 3 N3 instar individuals (Figure 3b). The presence of the N4 instar rose from mid-March to the end of May, after which no more N4 instars were observed in ground shelters (Figure 3b). The presence of the N2 instar was intermittent during winter and early spring and more regular from May to June; however, the population peak was observed in December, with an average close to 3 individuals per ground shelter (Figure 3b). Adults were found in ground shelters from May to November, but their abundance was lower than that of nymphs (Figure 3b). In fact, adults were more abundant in the tree shelters than in the ground shelters (Figure 3a). In tree shelters, they were captured from April to November, but a greater presence of adults was observed from mid-May to the beginning of July, with a peak of 23 individuals per shelter (Figure 3a). N4 was the most abundant instar in tree shelters from the end of March to mid-May, with a population peak of 14 individuals per shelter in mid-May (Figure 3a). The N3 instar was also observed in tree shelters one month after the N4 instar was found. The abundance of the N3 instar was much lower, with an average of 3 individuals per tree shelter (Figure 3a).

Regarding *F. pubescens*, adults were found in ground shelters mainly from mid-January to April, and after that N2, N3, N4 and N5 instars were successively observed either in ground or tree shelters until July (Figure 3c-d). The N2 instar of *F. pubescens* was more common in ground shelters, while it was barely observed in tree shelters. In contrast, the N1 instar was not found in tree or ground shelters (Figure 3c-d). Adults of *F. pubescens* were observed from March to April and from June to December in canopies, with a maximum of 2 individuals per shelter (Figure 3c).

Captures dropped for both earwig species during molting into adults (Figure 3). In both species, the sex ratio was not significantly different from 1:1 ($p>0.05$, Wilcoxon test).

Aggregation behavior and interspecific association

The relationship between the variance and the mean was studied by Taylor's law. The distribution of *F. auricularia* in shelters was observed to be aggregated, as the *b* coefficient was higher than 1 in all the orchards (Table 1). On the other hand, for *F. pubescens*, the *b* coefficient was higher than 1 in IU, also indicating an

Table 1. Taylor's parameters for each orchard and species; *b* indicates when the population in shelters was regular ($b<1$), random ($b=1$) or aggregated ($b>1$).

Species	Orchard	n	*b*	SE	t ratio	Prob>t	CI 95%		R^2
Forficula auricularia	BB	33	1.43	0.06	22.52	<0.0001	1.30	1.56	0.94
	IU	25	1.73	0.07	25.96	<0.0001	1.59	1.87	0.97
	MO	25	1.48	0.06	23.22	<0.0001	1.35	1.61	0.96
	MI	17	1.73	0.08	22.56	<0.0001	1.57	1.90	0.97
Forficula pubescens	IU	16	1.24	0.17	7.48	<0.0001	0.88	1.60	0.80
	MI	7	0.92	0.48	1.94	0.1103	–0.30	2.14	0.43

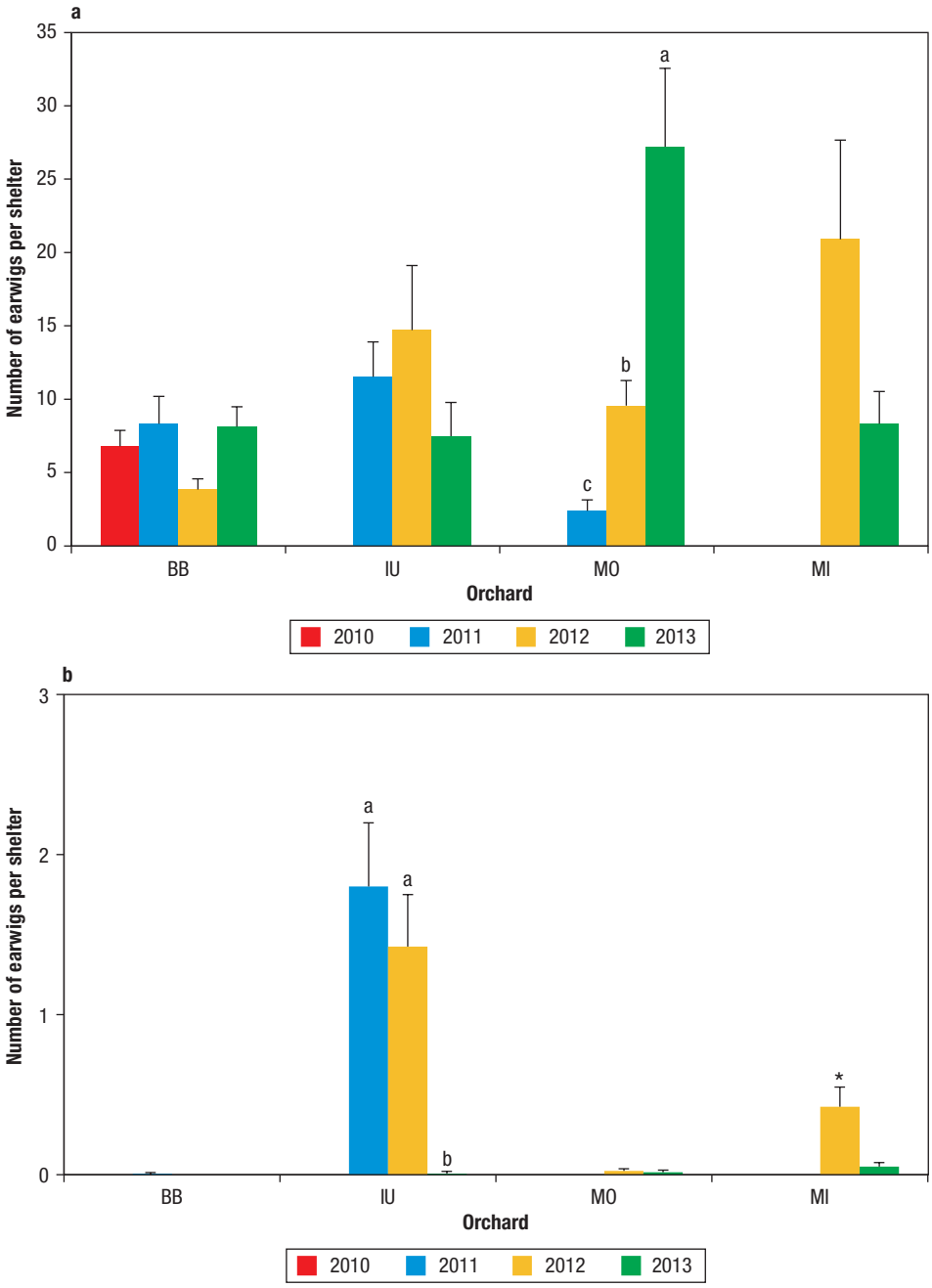

Figure 1. Number (mean ± SE) of *Forficula auricularia* (a) and *Forficula pubescens* (b) from April to July per year in the four orchards, BB, IU, MO and MI. Column bars marked with different letter or asterisk indicate significant differences among years within each orchard according to the Tukey HSD or Welch's tests (p<0.05). Note that y-axis scales are different.

aggregated distribution. In contrast, in MI this distribution could not be confirmed (Table 1). *F. auricularia* and *F. pubescens* showed mainly a positive association (Fig. 4). A few negative values were observed (Fig. 4).

Evaluation of the degree-days models

No matches among observed and estimated dates were found for any of the developmental stages detected in tree or ground shelters when running Moerkens' model (2011) (Table 2). Regarding Helsen's model (1998), the N3 instar was observed to appear at 215 DD; however, large differences between orchards were found (Table 3). Although smaller differences were observed for the N4 instar (264 DD) and adult stage (250 DD), there were no matches between observed and estimated dates (Table 3). We found some coincidences only when predicting the maximum number of N4 (613 DD) and adult individuals (1035 DD), with a

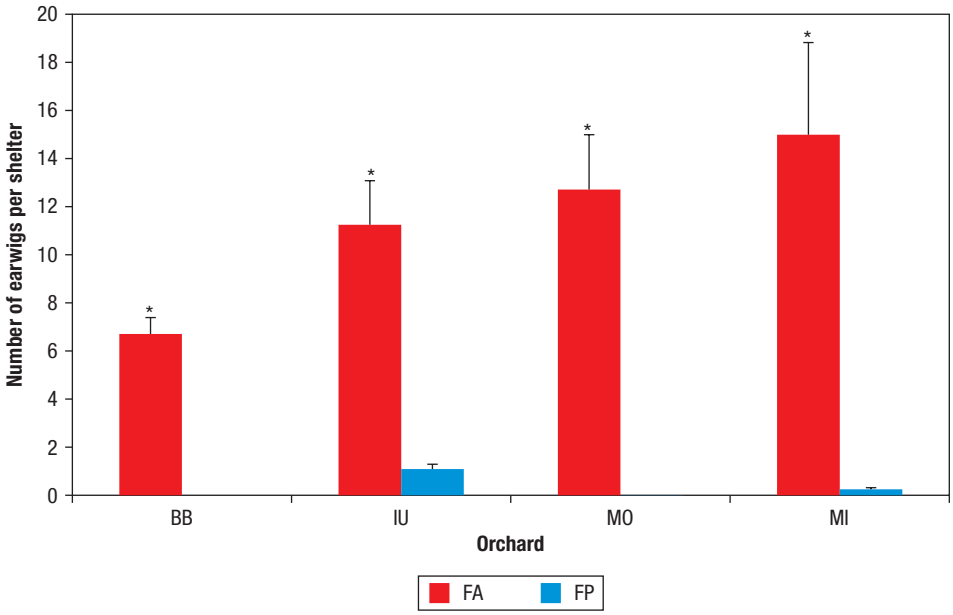

Figure 2. Number (mean ± SE) of *Forficula auricularia* and *Forficula pubescens* per orchard. Column bars market with an asterisk indicate significant differences among earwig species within orchards according to Welch's test ($p<0.05$).

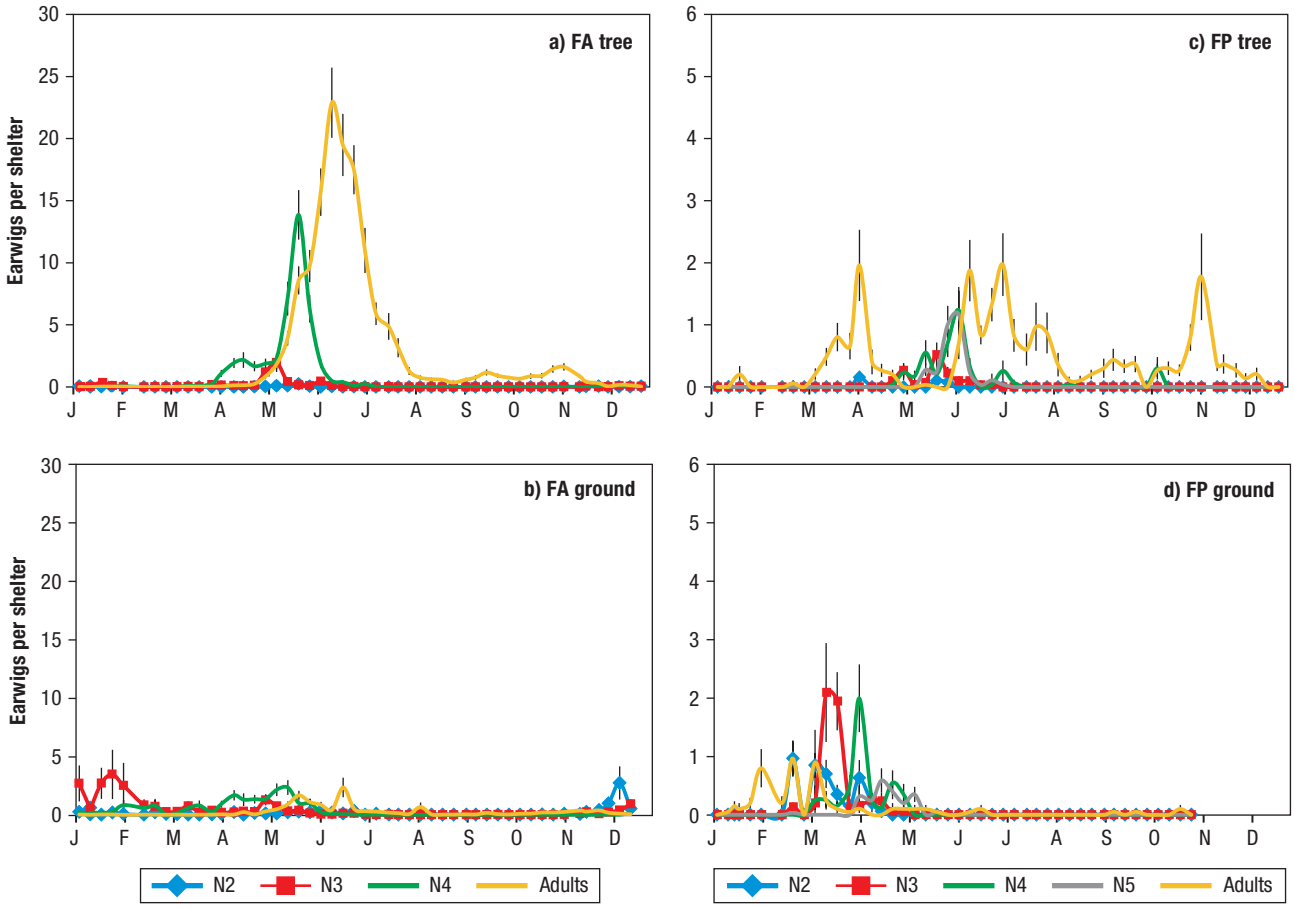

Figure 3. Weekly mean earwig individuals per tree and ground shelters for *Forficula auricularia* (FA) and *Forficula pubescens* (FP) throughout the year for nymph stages (N2, N3, N4 and N5) and adults. Note that y-axis scales are different. FA figures were calculated with data from all the orchards and years, whereas FP figures were calculated on the basis of IU 2011-2012 and MI 2012.

Table 2. Estimated appearance dates for the first and maximum number of individuals of each European earwig developmental stage according to the degree-days model (Model) and observations (Tree and Ground).

Orchard	Year	N1			N2			N3			N4			Adult		
		Model	Tree	Ground	Model	Tree	Ground	Model	Tree	Ground	Model	Tree	Ground	Model	Tree	Ground
1st individual																
MO	2012	24-Mar	–	10-Dec	10-Apr	3-Jan	5-Mar	27-Apr	5-Mar	27-Mar	10-May	27-Mar	27-Mar	24-May	5-Mar	16-Apr
MO	2013	21-Feb	–	21-Jun	12-Mar	14-Jan	2-Jan	1-Apr	21-Jan	2-Jan	21-Apr	7-Feb	2-Jan	17-May	31-Jan	2-Jan
BB	2012	24-Mar	–	5-Dec	10-Apr	2-Jan	15-Nov	27-Apr	17-Jan	28-Feb	10-May	20-Mar	6-Mar	23-May	17-Apr	24-Apr
BB	2013	21-Feb	–	3-May	13-Mar	22-Apr	20-Feb	30-Mar	3-Jan	3-Jan	17-Apr	3-Jan	3-Jan	10-May	13-Mar	14-Feb
IU	2012	24-Mar	–	–	10-Apr	10-Apr	10-Apr	28-Apr	25-Apr	10-Apr	11-May	2-Apr	3-May	25-May	15-Mar	10-Apr
IU	2013	21-Feb	3-May	3-May	12-Mar	3-May	4-Apr	31-Mar	4-Mar	3-May	17-Apr	21-Mar	3-May	12-May	21-Jan	4-Apr
MI	2012	24-Mar	–	–	10-Apr	21-May	21-May	27-Apr	16-Apr	16-Apr	10-May	10-Apr	10-Apr	24-May	27-Mar	19-Mar
MI	2013	21-Feb	21-Jun	23-May	12-Mar	31-May	26-Mar	1-Apr	22-Apr	3-May	21-Apr	9-May	9-May	17-May	21-Jan	31-Jan
Maximum																
MO	2012	24-Mar	–	10-Dec	10-Apr	27-Nov	10-Dec	27-Apr	21-May	17-Dec	10-May	15-May	15-May	24-May	21-May	6-Aug
MO	2013	21-Feb	–	21-Jun	12-Mar	6-Nov	8-Jan	1-Apr	3-May	31-Jan	21-Apr	23-May	21-Feb	17-May	13-Jun	21-Jun
BB	2012	24-Mar	–	5-Dec	10-Apr	17-Jan	11-Dec	27-Apr	24-Jan	18-Dec	10-May	11-Apr	11-Apr	23-May	22-May	22-May
BB	2013	21-Feb	–	3-May	13-Mar	20-Nov	12-Apr	30-Mar	26-Mar	21-Jan	17-Apr	12-Apr	12-Apr	10-May	28-Jun	31-May
IU	2012	24-Mar	–	–	10-Apr	24-May	10-Apr	28-Apr	3-May	3-May	11-May	24-May	7-May	25-May	13-Jun	16-May
IU	2013	21-Feb	3-May	3-May	12-Mar	31-May	5-Jun	31-Mar	9-May	9-May	17-Apr	31-May	31-May	12-May	13-Jun	31-May
MI	2012	24-Mar	–	–	10-Apr	21-May	21-May	27-Apr	30-Apr	21-May	10-May	21-May	7-May	24-May	11-Jun	4-Jun
MI	2013	21-Feb	21-Jun	13-Jun	12-Mar	31-May	28-Jun	1-Apr	6-Jun	28-Jun	21-Apr	31-May	13-May	17-May	28-Jun	28-Jun

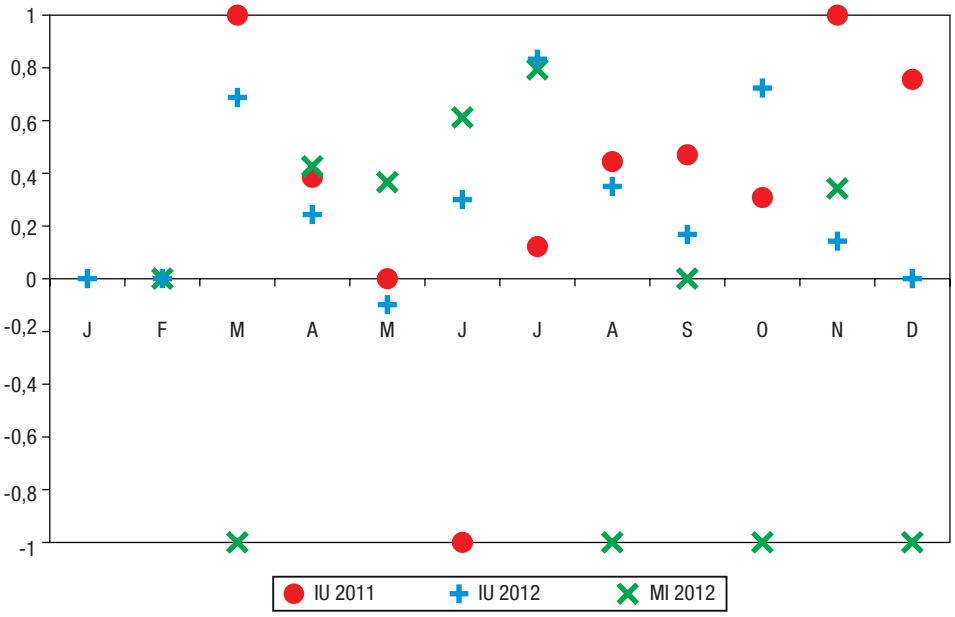

Figure 4. Monthly interspecific association coefficients between *F. auricularia* and *F. pubescens* for IU and MI orchards (2011-2012). A negative value indicates active competition, zero no interaction, and a positive value an association between species.

range from 0 to 29 days between observed and estimated date (Table 3).

Discussion

In our study the average number of *F. auricularia* was higher than that of *F. pubescens*, whereas in citrus orchards the opposite was observed (Romeu-Dalmau *et al.*, 2011). However, as different sampling methods were used in each study, it is difficult to draw conclusions about the relative abundance of the two species. In general terms, the abundance of *F. auricularia* among years within orchards did not change, and only in one orchard was an increase detected, while the abundance of *F. pubescens* decreased. Moerkens *et al.* (2009) reported large variations in population density among orchards and years for *F. auricularia*.

Table 3. Observed and accumulated degree-days (DD>6°C, from 1 January on) for first and maximum number of European earwig individuals for each developmental stage found in tree canopies.

Orchard	Year	Date	DD > 6ºC (1 Jan)	Observed - Estimated	Date	DD > 6ºC (1 Jan)	Observed - Estimated
		1st N3			Max N3		
MO	2011	5-Dec	3473	270	12-Dec	3486	236
MO	2012	5-Mar	126	–5	21-May	721	31
MO	2013	21-Jan	27	–49	3-May	491	13
BB	2010	23-Mar	199	13	31-Mar	250	–20
BB	2011	22-Mar	235	12	5-Apr	350	–15
BB	2012	17-Jan	34	–53	24-Jan	47	–87
BB	2013	3-Jan	3	–67	26-Mar	251	–25
IU	2011	13-Apr	397	34	4-May	582	14
IU	2012	25-Apr	433	46	3-May	502	13
IU	2013	4-Mar	124	–6	9-May	573	19
MI	2012	16-Apr	370	37	30-Apr	480	10
MI	2013	22-Apr	424	43	6-Jun	807	47
Average		10-Mar			20-Apr		
Average (Mean ± SE)			215.49 ± 50.30			459.48 ± 66.70	
		1st N4			Max N4		
MO	2011	11-Apr	391	19	9-May	659	–1
MO	2012	27-Mar	243	4	14-May	647	4
MO	2013	7-Feb	63	–45	23-May	669	13
BB	2010	31-Mar	250	8	26-Apr	434	–14
BB	2011	5-Apr	350	13	19-Apr	492	–21
BB	2012	20-Mar	230	–3	11-Apr	380	–29
BB	2013	3-Jan	3	–80	12-Apr	370	–28
IU	2011	30-Mar	250	7	18-May	749	8
IU	2012	2-Apr	293	10	24-May	761	14
IU	2013	21-Mar	203	–2	31-May	749	21
MI	2012	10-Apr	340	18	21-May	721	11
MI	2013	9-May	559	47	31-May	732	21
Average		22-Mar			9-May		
Average (Mean ± SE)			264.47 ± 41.88			613.42 ± 43.57	
		1st Adult			Max Adult		
MO	2011	2-May	576	46	14-Jun	1129	1
MO	2012	5-Mar	126	–12	21-May	721	–23
MO	2013	31-Jan	47	–46	13-Jun	904	0
BB	2010	26-Apr	434	40	22-Jun	1115	9
BB	2011	19-Apr	492	33	14-Jun	1177	1
BB	2012	17-Apr	413	31	22-May	789	–22
BB	2013	13-Mar	188	–4	28-Jun	1174	15
IU	2011	30-Mar	250	13	22-Jun	1240	9
IU	2012	15-Mar	174	–2	13-Jun	1078	0
IU	2013	21-Jan	27	–56	13-Jun	916	0
MI	2012	27-Mar	243	10	11-Jun	1055	–2
MI	2013	21-Jan	27	–56	28-Jun	1117	15
Average		16-Mar			13-Jun		
Average (Mean ± SE)			249.73 ± 54.41			1034.54 ± 47.40	

In 2012, heavy hail seriously damaged the whole crop, thus destroying some of the natural shelters, such as fruit clusters. These circumstances increased the likelihood of earwigs using the artificial shelters. The following year, as consequence of the hail, the trees showed more vegetative growth but less crop load, thus also reducing the number of natural shelters. Moerkens *et al.* (2009) reported an increase in the number of adults in the shelters immediately after the harvest of pears, thereby pointing to the relevance of natural shelters. Regarding the variations observed for *F. pubescens*, although significant differences were observed, the variation was less than one individual per trap.

For both species, the presence of males and females was similar, with a sex ratio of 1:1, coinciding with observations made by Romeu-Dalmau *et al.* (2011) in citrus orchards.

Concerning earwig phenology, we found individuals throughout the year in apple orchards. The mature stages of *F. auricularia* were observed mainly from May to November in tree shelters and immature ones from October to June in ground shelters. Most published studies have been based on tree sampling, reporting the presence of *F. auricularia* individuals from May to October, with a May-June peak for N3 and N4 instars, and the abundance of adults in July (Lamb & Wellington, 1975; Phillips, 1981; Helsen *et al.*, 1998; Gobin *et al.*, 2008; Moerkens *et al.*, 2009, 2011). Romeu-Dalmau *et al.* (2011) also observed a longer active period in Mediterranean citrus orchards—an observation that coincides with our results. The decrease in tree shelter captures during the summer months may be explained by the increased availability of natural shelters during this period. For instance, Helsen *et al.* (1998) observed that an increase in the size of apples leads to greater numbers of earwigs in fruit clusters, thus reflecting the availability of alternative shelters in the tree canopy.

In our study, the N2, N3 and N4 instars of *F. auricularia* were not found in a consecutive order along the months of the year in tree or in ground shelters. These findings may indicate the coexistence of single brood and double brood strategies, as observed by Helsen *et al.* (1998), Gobin *et al.* (2008), and Moerkens *et al.* (2009) in pip fruit orchards in central-northern Europe. The single brood strategy has been reported to be more susceptible to cold temperatures than the double brood one (Moerkens *et al.*, 2012). Therefore, depending on the strategy type prevailing in each area, distinct population fluctuations might be observed. Although low temperatures can be considered a crucial determinant of earwig mortality (Moerkens *et al.*, 2012), in Mediterranean orchards nymphs were also found during winter, thereby indicating that earwig development in these conditions does not stop, as nymphs also hibernate. Due to these differences in phenology, the predictions of population dynamics through the available degree-days models are not appropriate in Mediterranean orchards.

Adult individuals of *F. pubescens* were observed year-round (except in May in tree shelters) and nymph instars were detected from April to June in ground as well as in tree shelters. However, Romeu-Dalmau *et al.* (2011) observed individuals only from May to December. This finding could be attributed mainly to the sampling method, as the earlier earwig instars on the ground could not be detected by the beating technique used by those authors.

The occurrence of the different nymph instar stages of *F. pubescens* in apple orchards has not, to the best of our knowledge, been reported previously. The N1 instar was never observed. This could be attributed to the fact that this stage is very short and the nymphs probably remained in the nest with the female (Albouy & Caussanel, 1990). We found the N2 instar mainly in ground shelters from April to mid-May. After this time, the successive instars were also detected in tree and ground shelters. We found nymph instars only from April to July, thus indicating a single reproductive period per year. Similar observations were made by Romeu-Dalmau *et al.* (2011).

For both earwig species, after the peak numbers of last nymph instars (N4 or N5), we observed a population decline during molting into adults. Moerkens *et al.* (2009) proposed that this decrease was caused by competition for limited resources, such as hiding places and food, when the population increases, but also by an increase in cannibalism and intraguild predation, as insects are highly vulnerable during molting.

The distribution of *F. auricularia* in field shelters was clearly aggregated, coinciding with the findings of Sauphanor & Sureau (1993) in laboratory trials. In contrast, the distribution of *F. pubescens* in these shelters was not aggregated, although these authors found the opposite behavior in laboratory conditions. These differences may be due to the fact that *F. pubescens* was not abundant in field shelters, thus the opportunity to aggregate was lower than in lab trials, where more individuals per shelter were present. This observation is consistent with those of Taylor *et al.* (1978), who reported that in most species the degree of aggregation is density dependent. In addition, under laboratory conditions, the only shelters available were artificial. In contrast, the field provides a variety of alternative natural shelters, which may reduce the chance of detecting aggregation.

Both *F. auricularia* and *F. pubescens* were found together in only two orchards and with a low population of *F. pubescens*. On the basis of these data, we propose that there is only a tendency of *F. auricularia* and *F. pubescens* to associate or at least not to compete. The few negative values that we observed appeared only in months when the insects were barely found in the shelters. Sauphanor & Sureau (1993) observed a positive association, estimating a coefficient value of 0.75. High association values were observed when more earwigs were found in the shelters, thus resembling the conditions tested by Sauphanor & Sureau (1993) in lab trials. Even in the field, Debras *et al.* (2007) reported the absence of competition between *F. auricularia* and *F. pubescens*. We can assume that when these two earwig species are found in high numbers in the shelters, no competition occurs. This may be linked to high availability of food or to the different diet preferences of

each species, which prevent interspecific competition. In this regard, Debras *et al.* (2007) observed that *F. pubescens* concentrated predation on younger pear psylla instars, whereas *F. auricularia* showed a preference for older ones.

The occasional presence of *L. riparia*, *E. moesta,* and *N. lividipes* can be explained by their low aggregation coefficient and, in some cases, solitary behavior (Albouy & Caussanel, 1990; Sauphanor & Sureau, 1993). The observation that these species were found only in ground shelters is consistent with their low appearance in literature as biocontrol agents in fruit orchards, as those surveys addressed mainly tree canopies. *L. riparia*, *N. lividipes,* and *E. moesta* have been described as important biocontrol agents in cereal and cotton crops (Shepard *et al.*, 1973; Albouy & Caussanel, 1990). As ground dwelling insects, these species may predate on pests that have developmental stages on the ground, such as WAA, the codling moth, and the Mediterranean fruit fly (*Ceratitis capitata* Wiedemann; Diptera: Tephritidae) (Urbaneja *et al.*, 2006; Jacas *et al.*, 2008; Boreau de Roince *et al.*, 2012; Lordan *et al.*, 2014b).

F. auricularia and *F. pubescens* were present throughout the year either in ground or tree traps, *F. auricularia* being the most abundant. These two species may co-occur in canopies of pip fruit orchards where they can serve as biocontrol agents as a result of their early appearance and long activity period. This long period may also explain the damage they cause to peaches, nectarines, apricots and cherries. In Mediterranean apple orchards, as the nymphs of *F. auricularia* also hibernate, the phenology of this species cannot be predicted by the current models developed in colder areas of central northern Europe. New degree-days models better fitted to Mediterranean conditions are required in order to improve the protection of earwigs in pip fruit canopies and to control them in stone fruit orchards and vineyards. This study provides useful data about the weekly phenology of earwigs throughout the year that can be used to develop new phenological models for Mediterranean areas.

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