# Spider predation on rosy apple aphid in conventional, organic and insecticide-free orchards and its impact on aphid populations

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Abstract: Spiders dwelling in the canopy of apple trees may contribute to the control of the rosy apple aphid (Dysaphis plantaginea). They are expected to be very efficient early in season during aphid colony establishment. However, their predation on aphids may be impaired by insecticide treatments. We aimed to assess the effectiveness of spider predation on D. plantaginea in apple orchards. For this purpose, we monitored D. plantaginea abundance and sampled a total of 1281 canopy spiders in 8 orchards under IFP (Integrated Fruit Production), organic or insecticide-free management in early and mid-season. Using DNA analyses of the spider gut with specific D. plantaginea PCR primers we investigated which taxa had eaten this aphid pest. Lastly, we assessed effectiveness of aphid suppression by spiders in insecticide-free orchards. The most abundant spiders belonged to Philodromidae, Salticidae and Anyphaenidae. Spiders were more abundant in the insecticide-free orchards than in the other orchards in mid season but not in early season. Spiders detected positive for D. plantaginae DNA were observed in 8 out of 12 families and occurred in all orchards. The probability that a spider was positive did not depend on its size. Lastly, the increase in the number of aphid colonies early in season related negatively to the abundance of Philodromus spp. All these results showed that numerous spider taxa participate to the control of D. plantaginae in orchards and that Philodromus spp may be particularly efficient in early season in absence of insecticide treatments.

**Cover Letter**

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Avignon, March 15th 2016.

Dear editor

Please find in this submission a manuscript entitled "Spider predation on rosy apple aphid in orchards under insecticide-free, organic and integrated management, and its impact on aphid populations" that we would like to submit for publication in Biological Control. In this study we combined field monitoring of aphids and spiders with PCR analyses of spider gut content to investigate predation of the rosy apple aphid by canopy spiders. The study was carried out in orchards under three different management strategies and at four dates (February-June) during the growing season. We present evidence that spiders predate aphids in all types of orchards. Based on results in insecticide-free, we further highlight a role of Philodromidae in aphid suppression in early season.

We hope that you will find this manuscript suitable for your journal,

Sincerely

Claire Lavigne

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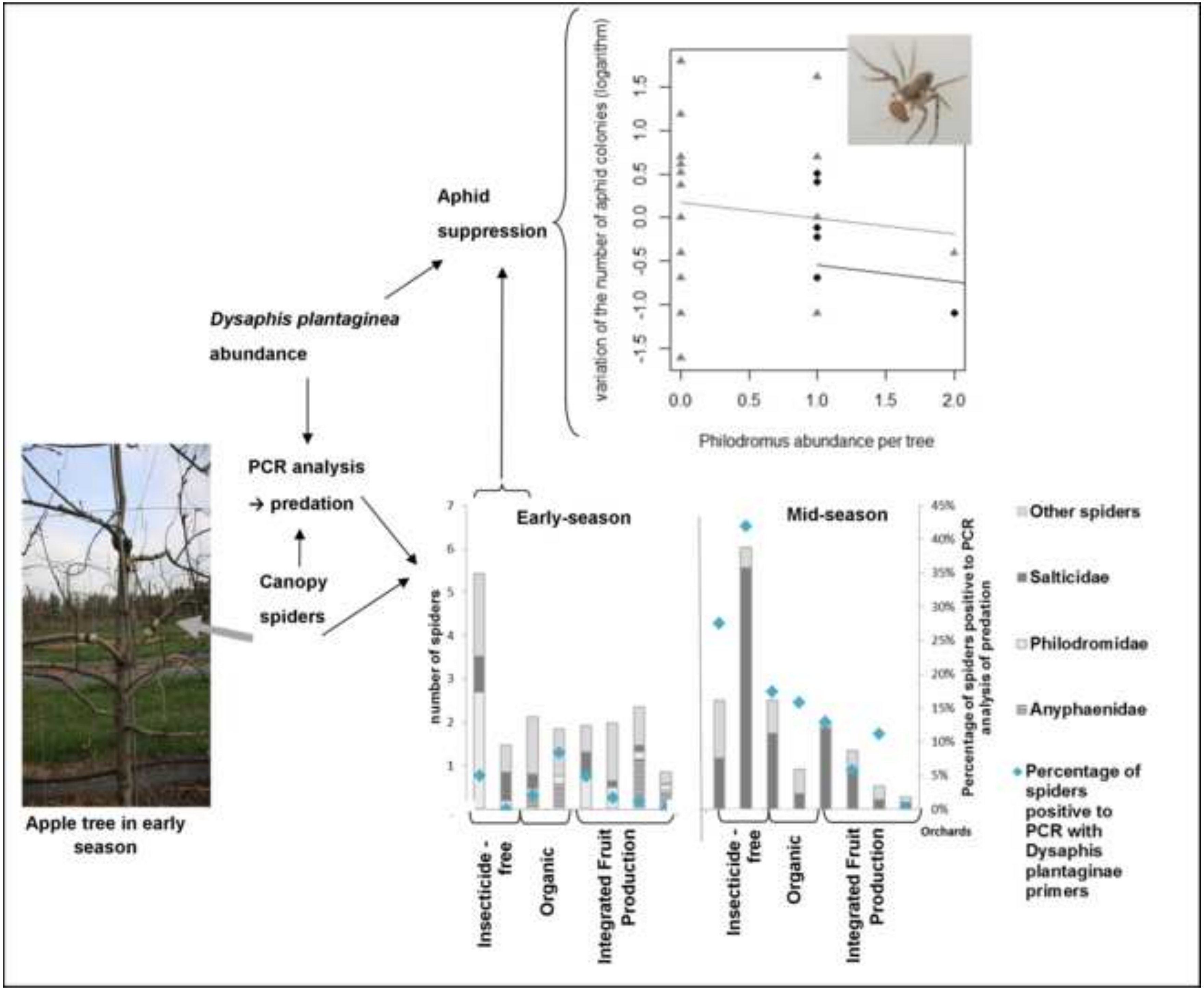
**Graphical Abstract**



***Highlights (for review)**

- We monitored cursorial spiders and *Dysaphis plantaginea* abundance in apple orchards
- PCR gut content analyses showed that 8 of 12 spider families predated *D.plantaginea*
- Predation occurred in integrated production, organic and insecticide-free orchards
- Early-season variation in aphid colony numbers related to *Philodromus spp* abundance

# Spider predation on rosy apple aphid in orchards under insecticide-free, organic and integrated management, and its impact on aphid populations.

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## Abstract

Spiders dwelling in the canopy of apple trees may contribute to the control of the rosy apple aphid (*Dysaphis plantaginea)*. They are expected to be very efficient early in season during aphid colony establishment. However, their predation on aphids may be impaired by insecticide treatments. We aimed to assess the effectiveness of spider predation on *D. plantaginea* in apple orchards. For this purpose, we monitored *D. plantaginea* abundance and sampled a total of 1281 canopy spiders in 8 orchards under IFP (Integrated Fruit Production), organic or insecticide-free management in early and mid-season. Using DNA analyses of the spider gut with specific *D. plantaginea* PCR primers we investigated which taxa had eaten this aphid pest. Lastly, we assessed effectiveness of aphid suppression by spiders in insecticide-free orchards. The most abundant spiders belonged to Philodromidae, Salticidae and Anyphaenidae. Spiders were more abundant in the insecticide-free orchards than in the other orchards in mid season but not in early season. Spiders detected positive for *D. plantaginea* DNA were observed in 8 out of 12 families and occurred in all orchards. The probability that a spider was positive did not depend on its size. Lastly, the increase in the number of aphid colonies early in season related negatively to the abundance of *Philodromus spp*. All these results showed that numerous spider taxa participate to the control of *D. plantaginea* in orchards and that *Philodromus spp* may be particularly efficient in early season in absence of insecticide treatments.

## Key words

Agroecology; *Anyphaena accentuata*; conservation biological control; gut content analysis; *Philodromus spp*.; prosoma size; spider community.

## Introduction

Aphids are one of the main groups of apple tree pests and they are responsible for production loss, smaller fruits, and long term damages on apple trees. In apple orchards, the rosy apple aphid *Dysaphis plantaginea* (Passerini) is the main aphid pest with the wooly apple aphid *Eriosoma Lanigerum. D. plantaginea* can be most detrimental, causing yield reductions from 30% (Blommers et al., 2004; Deberardinis et al., 1994) to 80% (Qubbaj et al., 2005). The apple tree is its primary host. In the Mediterranean region, the eggs start to hatch in March and aphid colonies develop from asexual reproduction. The migration of *D. plantaginea* winged adults to their secondary host, the plantain herb, begins in May and lasts until the end of June (Bonnemaison, 1959). Alate individuals return to apple trees in autumn and females lay eggs close to buds.

Aphids are prey of a large number of arthropod predators. Among these, generalist predators may be of particular interest for aphid control. Their ability to feed on a range of prey allows them to persist in crops when pest numbers are low (Symondson et al., 2002) and thus prevent pest outbreaks early in the season before specialist natural enemies are abundant (Landis et al., 2000). Timing of predator arrival is a key point for aphid suppression because of their exponential population growth in season (Costamagna et al., 2015). Among generalist predators that feed on aphids, canopy dwelling spiders are of particular interest: some canopy spider species are active despite low temperatures in winter or early spring (Korenko et al., 2010). Thus, they could predate prey very early during aphid colony establishment (Boreau de Roince et al., 2013). Such mechanism is at the basis of the efficient suppression of psyllids in pear orchards (Pekár et al., 2015). Aphid predation can be characterized by several technics: field observations, laboratory tests of food preference, ELISA analyses of gut content, and more recently gut content analyses by PCR (Harwood and Obrycki, 2005). Further than predation, aphid suppression (sensu (Schellhorn et al., 2014)) is the key of natural biological control. Promising results showed that the abundance of spiders cumulated from March to May limited the presence of aphid colonies on apple trees (Boreau de Roince et al., 2013).

Aphid predation by spiders may be affected both by the species composition of spider communities, by the distribution of their ecological traits and by the availability of alternative preys (Madsen et al., 2004). First, spider species may differ intrinsically in their appetence for aphids: the canopy spiders of genus *Philodromus* have a high appetence for aphids compared to other insects (Michalko and Pekar, 2015a) while some ground spiders prefer fruit flies to cereal aphids (Toft, 1995); second, prey consumption by wandering and active hunters depends on local prey abundance (Michalko and Pekar, 2015a) and may exhibit an aggregative response (Riechert and Lockley, 1984); third, aphids are considered as low food value for spiders, which may need alternative preys to complement their diet (Madsen et al., 2004); fourth, selection is likely to enhance a specialization of generalist arthropod predators on the most abundant prey present in their environment (Rana et al., 2002). Further than taxonomy, traits such as individual size also appear relevant to explain prey preferences. Both inter and intra-specific size differences may be relevant, because active hunters and wandering spiders are likely to eat preys within a certain range of predator-prey body size ratio (Michalko and Pekar, 2015b). Besides, the anti-predator behavior of the prey can be related to the predator-prey body size ratio (Binz et al., 2014).

To prevent multiplication of the fundatrices in apple orchards, treatments with mineral oils or insecticides are applied early in season. Such insecticide treatments may impair the spontaneous aphid biocontrol by natural enemies (Cross et al., 2015). Insecticides may affect spider communities directly by reducing prey availability, reducing their fitness, and modifying their behavior (Marc et al., 1999) resulting in lower abundance of canopy spiders in treated orchards as compared to untreated ones (from spring to autumn (Mansour, 1987; Marko et al., 2009; Pekar, 1998), and in winter (Pekár, 1999)) but in no difference between organic and conventional orchards (spring to autumn (Pekár and Kocourek, 2004)). Among treated orchards, species diversity of canopy spiders, however, was higher in organic orchards than in orchards treated with broad-spectrum insecticides or following IPM (integrated pest management) guidelines  (Pekár and Kocourek, 2004). The environment surrounding the orchard may also influence strongly the abundance and community composition of canopy spiders within orchard, in particular in autumn because of the recolonization of the orchard after insecticides spraying stops (Lefebvre et al., 2016; Marko et al., 2009; Wisniewska and Prokopy, 1997). Winter/early spring communities that may be responsible for early aphid control may thus depend less on crop protection practices than later communities. Further than a taxonomical characterization, orchard management can change the distribution of spiders' ecological traits. The mean body length of canopy spiders was larger in untreated orchards than in IPM orchards (Wisniewska and Prokopy, 1997). Similarly, conventional and IPM orchards hosted communities of ground spiders with a higher proportion of small individuals than organic or abandoned orchards in spring and summer (Mazzia et al., 2015). As a consequence, although spiders were shown to eat aphids in organic apple orchards from March (when aphids are at the fundatrix stage) to May (Boreau de Roince et al., 2013), this does not entail that they do so to a similar extent in orchards treated with chemical insecticides.

In the present study, our objective was to assess which canopy spiders ate the pest aphid *D. plantaginea* according to individual size and species, in IFP (Integrated Fruit Production), organic and insecticide-free orchards. We thus first assessed the impact of orchard management on spider abundances, sizes and species composition and then characterized their predation on *D. plantaginea* using PCR gut content analyses. We further assessed effectiveness of aphid suppression by spiders in insecticide-free orchards at two periods independently: early and mid-spring.

## Material and methods

### 2.1 Sampled orchards

Sampling and monitoring were carried out in 2014 on 8 apple orchards from 4 experimental farms in France. Five orchards were located in three farms in south-eastern France, under a Mediterranean climate; and the last 3 orchards were located in one farm in the north-western part of France, under a temperate oceanic climate.  Two south-eastern farms only comprised one insecticide free orchard (*Ifree1* and *Ifree2*); the other two farms comprised two orchards under Integrated Fruit Production management (*S_IFP1, S_IFP2*, for the south-eastern region and *N_IFP1, N_IFP2* for the northern region) and one organic orchard (respectively *S_orga* and *N_orga*) (figure 1, supplementary material table S1).

The organic orchards were distant of approximately 500m from the IFP orchards that were distant of approximately 50m from each other in both farms. All orchards were grown with vertical axis training of the cultivar, “Ariane”. The IFP orchards received 3 or 4 chemical insecticides from March to May, while organic orchards received paraffinic and vaseline oils and/or natural pyrethrins. The Ifree orchards did not receive any insecticide and only synthetic fungicides and thinning products during this period (Details on orchard descriptions in supplementary material: table S1 and table S2).

### 2.2 Sampling of spiders

Spiders were sampled on four occasions. Sampling dates were chosen in each farm to match *D. plantaginea* stages: eggs in February; fundatrices in March; young colonies in April; mature colonies in May. 18 to 45 apple trees were sampled per orchard, on a regular canvas. Sampled trees were distant of approximately 6 trees and distributed on 3 up to 7 rows according to the orchard size (supplementary material: table S1).

Spiders were collected using cardboard trap bands (10 x 30cm) wrapped around apple tree branches. These bands were replaced by new ones on each sampling occasion. Two trap bands per tree were first placed in January. In February, spiders were collected from the all trap bands; in March, April and May spiders were collected alternately from one of the two bands per tree. Despite being non exhaustive in terms of spider species that were caught, this method was chosen because it did not disturb aphids in branches, contrarily to the beating method.

To ensure DNA conservation for later PCR analyses, spiders were immediately placed individually in Eppendorf tubes with Ethanol 90°, and then stored in the freezer (-20°C) in the laboratory approximately 1hour later. All the spiders were identified by first author to species if possible and to genus in other cases. Their prosoma widths (Michalko and Pekar, 2014) were measured using a binocular loupe set with 125x magnification (the precision considered is 0.1mm).

### 2.3 Aphids monitoring

*D. plantaginea* was monitored on trees used for the sampling of spiders and at the same dates. To assess aphid infestation at tree level, we counted all the growing shoots from the basis of each tree to 1m70 height and recorded the presence or absence of aphid fundatrices or aphid colonies on each of them. From these we obtained the variable "*number of aphid colonies*" per tree. The size of each colony was characterized visually by an index ranging from 1 to 4 and was later summarized by the median number of aphids of the index classes (1=1-5, median 3; 2=5-50 median 28; 3=50-250 median 150; 4≥250 median 300). The total number of aphids per tree was approximated by the sum of colony sizes and was called the "*infestation index*" of the tree in further analyses.

Aphid growth was estimated between March and April (growth rate called *r1*) and/or between April and May (called *r2*). The growth rates were calculated as the ratio (Aphid(t+1) +1) / (Aphid(t) +1), where Aphid(t) is the *number of aphid colonies* at time *t* .

### 2.4 PCR-based analysis of aphid predation

The assessment of *D. plantaginea* predation by the spiders was carried on 1017 individuals out of the 1281 spiders collected. The 1017 selected spiders belonged to the most abundant genus or species taxa (at least 20 individuals per taxa). Total DNA of each spider individual was extracted using the DNeasy® 96 blood & tissue kit (Qiagen, Germany) following the manufacturer's protocol. The entire spider body was previously ground using an agitator-ball mill excluding the legs of the biggest individuals. To assess aphid predation, PCR were performed on each spider individual with specific *D. plantaginea* DNA primers (Boreau de Roincé, 2012) (see supplementary material S3 for details on primer design and specificity). PCR amplifications were carried out in a 10 µl reaction volumes containing 2 µl of DNA template, 1 unit of GoTaq® Flexi DNA Polymerase (Promega) 2.5 mM MgCl2, 0.1 mg/ml Bovine Serum Albumin, 20 mM $(NH4)_2SO_4$, 200 mM of each dNTPs, 1X Promega PCR buffer, and 0.4 mM of each *D. plantaginea* specific primer (*Dp*-F: GTTATCAAATAATATTGCACAC labeled on 5' with Rhodamine Atto-565 dye and *Dp*-R: CAAATAAAATTAATTGCTCCTAG). The PCR were performed on a Mastercycler thermocycler with the following conditions: initial denaturation at 95°C for 3 minutes followed by 35 cycles at 95°C for 30s, 56°C for 30s, and 72°C for 30s and a final elongation step at 72°C for 20 min. Each PCR product was diluted (0.4% dilution with 0.02% GeneScan™- 600 LIZ® Size standard in HiDi formamide, Applied Biosystems) and 2µl of this dilution was injected on an ABI 3730xl DNA Analyzer using the POP-7 polymer. Specific amplifications of *D. plantaginea* (105pb DNA fragments) were scored using Genemapper® V4.1 Analysis Software (Applied Biosystems). Amplification in the spider samples with intensity upper than control amplifications with 1pg of *D. plantaginea* DNA were considered as positive.

### 2.6 Statistical analyses

All analyses were performed using packages implemented in the R software (R 3.0.1; R Development Core Team 2012). Linear and generalised linear mixed effect models were performed by the functions lmer and glmer of R package lme4. Significances of the fixed effect were tested by model comparison by dropping successively each independent variable of the full model (drop1 function). When a qualitative fixed effect (factor) with more than two levels was significant according to model comparison, pairwise multiple comparisons by Tukey test (function glht, R package multcomp) were performed to quantify its effect.

#### 2.6.1 Response to management of spider abundances and size of individuals

The effect of the orchard management (IFP, organic or insecticide-free) was tested on three characteristics of the spider communities: (1) the total abundance of spiders captured per trap band (generalised mixed model with a Poisson distribution and log link function); (2) the size of the spiders measured by their prosoma width (linear mixed model); (3) the cumulated size of the spiders per trap band (linear mixed model). For all analyses, two mixed models examined independently the early-season data (February +March) and the mid-season data (April +May).  A random effect described the orchard where sampling occurred.

#### 2.6.2 Traits of the spiders and orchard management affecting the predation

We performed generalized linear mixed models to assess if the probability of detecting *D. plantaginea* DNA in the spider guts depended on orchard management and spider traits, in mid-season only. In early-season, two few spiders were detected positive to PCR analyses (see below) for statistical analyses. The dependent variable took value 1 if a spider was positive in the PCR assessment and 0 otherwise. A random effect described the orchard where sampling occurred. We also tested for overdispersion in the data by adding an individual random effect but this was never significant and it was removed from further analyses. Because the rate of positive spiders may primarily depend on aphid availability, we included the log (*infestation index* + 1) as a covariate in all models. The fixed independent variables of interest in the models were either (1) the orchard management (insecticide-free, organic or IFP) or (2) the prosoma width of the spider individuals.

### 2.6.3 Effectiveness of aphid suppression

The impact of spiders on growth of aphid colonies was analyzed in insecticide-free orchards only. Indeed, in organic and IFP orchards, we considered that the effect of insecticides, in particular on aphid fundatrices, was too strong to observe an effect of spiders on aphid increase. To assess the effect of spiders on the variation of aphid abundances, linear mixed model were performed to explain the log of the aphid growth rates. Early season aphid variations (log(r1)) were analyzed considering all the spiders collected in February and March ; mid-season aphid variations (log(r2)) were analyzed considering spiders collected in April. A random effect described the orchard where sampling occurred. Fixed effects of interest were tested in independent models. They were the abundances per trap at time *t* of either all spiders or of some spider taxa that were most numerous in insecticide-free orchards. In the models which analyzed early season growth rates, spider taxa were either 'All spiders', Philodromidae (*Philodromus spp),* Salticidae or 'Other spiders'; in models that analyzed the mid-season growth rates, taxa were 'All spiders', Salticidae or 'Other spiders'.

To question the effect of cumulated spider sizes on the variation of aphid abundances, similar models were performed with the per tree cumulated prosoma widths as independent variable.

## Results

### 3.1 Aphid infestation of the orchards

All orchards harbored similar numbers of fundatrices in March. N_IFP1 and N_IFP2 did not have any aphid colonies later, and S_IFP1 and S_IFP2 harbored very few in April and May (Table1). In organic and Ifree orchards, from 30 to 73% of the apple trees in April, and from 50 to 94% in May, harbored an aphid colony. One of the insecticide free orchards was as much infested by *D. plantaginea* in May as the organic orchards, but the second insecticide-free orchard was more infested (Table1).

### 3.2 Phenology and diversity of the spiders captured according to the management.

Spiders differed according to sampling date. In February, Philodromidae (with the unique species *Philodromus cespitum* and *Philodromus aureolus)* and Anyphaenidae (with the unique species *Anyphaena accentuata)* were abundant in traps and all the orchards harboured at least one of those two taxa independently of region or management (Figure 2). Further than those taxa, abundant taxa differed among orchards with no clear pattern. March communities were intermediate between those of February and of mid-season (April and May), particularly because of the capture of Salticidae, Thomisidae and Gnaphosidae (data not shown). In mid-season (April and May), most of the spiders captured were Salticidae that mated in silken retreats and laid eggs in the trap bands. The Salticidae species varied according to the orchard with no clear pattern (supplementary material table S4). Overall, 'Other spiders' represented 4 to 40% of the spiders in mid-season according to the orchard, but no family of this category comprised more than 10 individuals per orchard at that period (supplementary material table S4).

### 3.3 Abundance per trap and size of the spiders

On average, 0.8, 1.3, 1.9 and 1.7 spiders were captured per trap band, in February, March, April and May. Considering all the taxa, the abundance of spiders and the cumulated prosoma width per tree did not depend on orchard management in early-season (deltaAIC=3.1, p=0.62) but did in mid-season (abundance and cumulated prosoma width respectively: deltaAIC=-1.1 p=0.07 ; -3 p=0.02): at that period spiders were more abundant in insecticide-free orchards than in IFP orchards which resulted in a higher cumulated prosoma width (pairwise comparison Ifree-IFP for abundance: estimate=0.84 p=0.04 ; for cumulated prosoma width : estimate= -2.5 p=0.016); their abundance and cumulated prosoma width in organic orchards was intermediate (Figure 2).

The prosoma width of the spiders was (mean±SE) 1.47±0.028 mm in early season and 1.53±0.026 mm in mid-season. It did not depend on the orchard management in either season (early and mid-season respectively: deltaAIC=4, p=0.81; deltaAIC=3, p=0.71). Besides, *Philodromus spp*, the single taxon that occurred in a sufficient number of orchards for statistical analyses, had similar prosoma widths in Ifree and IFP south-eastern orchards (number of *Philodromus*, mean prosoma width in mm and sd: S_Ifree1: n=51, 1.05±0.026; S_Ifree2: n=10, 1.1±0.06; S_IFP1: n=36, 1.06±0.005; S_IFP2: n=22, 1.06±0.05).

### 3.4 Predation detected by PCR

The probability of detecting *D. plantaginea* DNA in the spider gut depended on aphid infestation, i.e log(*infestation index*+1), in the three analyzed models (ΔAIC in [-18;-15] and pvalue in [1. $10^{-5}$; 4.$10^{-5}$], estimate in [0.17; 0.18], sd=0.04). In addition to the effect of the infestation index, the probability of detecting *D. plantaginea* DNA depended on orchard management (ΔAIC=-6, pvalue=6.$10^{-3}$): it was significantly higher in insecticide-free orchards compared to the organic and the IFP orchards and did not differ between the organic and IFP orchards (pairwise comparison estimate and pvalue: Ifree-Organic= 1.0 p<1.$10^{-3}$, Ifree-IFP= 1.0 and p=$10^{-2}$, IFP-Organic=-0.1 p= 0.96). Besides, the probability of detecting *D. plantaginea* DNA in the spider gut did not depend on their prosoma width (ΔAIC=1, pvalue=0.33).

Considering all spider taxa, the percentages of spiders that were positive to PCR analysis in early-season varied from 0 to 13% according to the orchard. They were high in March in IFP orchard (S_IFP1 and S_IFP2) and remained stable later (Table 1). In insecticide-free orchards, the percentage of positive spiders increased strongly between March, April and May, reaching 50 and 60% of the tested spiders. Organic orchards showed intermediate pattern (Table 1). Positive spiders were observed for 8 out of the 12 families for which more than 10 individuals were analyzed (table2, table S4). In early season (February and March), 9 individuals of Anyphaenidae, 3 individuals of Philodromidae, 3 individuals of the Salticidae and 3 of 'other spiders' were positive to *D. plantaginea* primer (Table 2). The number of positive individuals was higher in mid-season for Salticidae (26% positive i.e 102 individuals) and 'other spiders' (19% i.e 19 individuals). It could not be estimated for Anyphaenidae and Philodromidae because these taxa were too few in traps. At genus level, all taxa from which more than 10 individuals were tested, had at least one individual that was positive to PCR except *Nursia albomaculata*, *Olios argelasius*, *Lathys humilis* and *Synaema globosum* (Table 2).

### 3.5 Effectiveness of aphid suppression in insecticide-free orchards

The variations between March and April of the *number of aphid colonies* r1 related negatively to the total number of spiders per tree, among which Philodromidae (*Philodromus spp)* were dominant. The abundance of Philodromidae alone explained better than 'All spiders' the decrease of r1 (better pvalue, deltaAIC and stronger estimate)(Table 3, Figure 3). Contrarily, r1 did not depend significantly on the early season abundance per tree of Salticidae, of 'Other spiders', or on the 'cumulated prosoma width'. In mid-season, r2 did not depend significantly on any spiders' abundance or on the 'cumulated prosoma width' per tree (Table 3).

## Discussion

Because of their predatory behavior, the diversity of their hunting strategies and their abundance in orchards, spiders have long raised an interest as generalist predators of pests (Nyffeler and Benz, 1987). Our results confirm their potential effectiveness for controlling *D. plantaginea* thanks to PCR analyses of gut content (Harwood and Obrycki, 2005) and monitoring of aphid growth and spider abundances in insecticide free orchards. Besides, we highlighted that predation of aphids occurred in insecticide-free, organic and IFP orchards when aphids were present.

The species we captured were canopy spiders frequently found in orchards of southern Europe (Bogya et al., 1999; Isaia et al., 2010, 2006; Pekár, 1999). They were mostly represented by wandering spiders in early season (February, March) and jumping spiders later in spring. Early-season species were similar between north-western and south-eastern orchards, but the species captured in mid-season were different, confirming the effect of geography on agrobiont spiders (Samu et al., 2011). The same species were present in IFP and organic orchards in north-western orchards; contrarily, the species present in the IFP, the organic and the insecticide-free south-eastern orchards differed to a large extent (table1, figure2). This absence of pattern is consistent with the observation that local and landscape scale environment may influence spider species composition further than the management of the orchard (Herrmann et al., 2010; Lefebvre et al., 2016).

The pattern was clearer concerning spider abundance. In early season, spider abundance did not differ according to the orchard management, and in mid-season, it tended to be higher in insecticide-free orchards (Tables 3 and S6). This pattern is consistent with the reported higher abundances in untreated orchards compared to treated ones in spring and summer (Mansour, 1987; Marko et al., 2009; Pekar, 1998) and the similar abundances in organic, IFP and conventional orchards (Pekár and Kocourek, 2004) at the same period. The absence of differences in early season could result from immigration and/or reproduction of individuals in late-summer, autumn and winter that would allow populations from treated orchards to recover from the decrease in abundance caused by spring and summer insecticides spraying (Pekár, 1999). Note, however, that the observed pattern of abundance may be partly oversized by the trapping method because the mid-season pattern was mainly observed on Salticidae while the early season pattern was mainly observed on the winter-active spiders *Philodromus spp* (Philodromidae) and *A. accentuata* (Anyphaenidae) (Korenko et al., 2010). *Philodromus spp* are little sensitive to synthetic and organic insecticides (Rezac et al., 2010), they may be abundant during summer in IPM orchards (Wisniewska and Prokopy, 1997) but they were not caught by our trap bands at that period. Beating is a more appropriate technique for their capture in late-spring and summer; however, beating was not performed on the sampled trees to avoid disturbing aphid colonies. Less information is available about the ecology *A. accentuata* and its sensitivity to pesticides or orchard management. This species is hardly caught by any technique in late spring in orchards of the study region. We could thus not assess if *Philodromus spp* (Philodromidae) and *A. accentuata* taxa were as abundant in IFP as in untreated orchards in mid-season, as was observed in early-season.

Gut content molecular analysis is becoming a popular way of quantifying predation under naturally occurring conditions, including for spider species (Gurr et al., 2012; Harwood and Obrycki, 2005). Among the 25 genera of spiders tested by PCR in the present study, 19 were detected positive for predation on *D. plantaginea* (Table 2). Besides, in all the orchards but one in early season and one in mid-season, the most abundant taxon predated on *D. plantaginea* (table 2). This confirms that a diversity of cursorial spiders may contribute to aphid control. We assessed predation by wandering spiders, ambush spiders and active hunters forage on aphid colonies, which must be complemented by the action of web spiders that capture passively alate aphids (Birkhofer et al., 2008; Boreau de Roince et al., 2013; Dib et al., 2010; Marc and Canard, 1997). Further, PCR positive individuals were observed in orchards whatever their management strategy (IFP, insecticide-free, organic) indicating that spiders may act as biocontrol agent in different types of orchards.

Although results appear straightforward, interpreting similarities or differences in rates of positive individuals among management strategies in terms of potential pest control is difficult. Indeed many factors may affect these rates. First, differences in the rate of positive spiders may result from differences of prey availability (Kerzicnik et al., 2012) and indeed rates increased with aphid infestation in the present study. Nevertheless, in mid-season, the probability of detecting aphid DNA was still highest in insecticide-free orchards after accounting for aphid infestation. It is possible, that spiders of conventional and organic orchards are less frequently positive as they switch to other preys than aphids because of aphid rarity as compared to alternative prey (Koss and Snyder, 2005; Pearce and Zalucki, 2006). It is also possible that IFP orchards were inhabited by spiders' species, or spiders with functional traits less likely to predate on aphids than spiders inhabiting insecticide free orchards. We only measured spider size as functional trait and it is unlikely to explain the observed differences because spiders size did not differ between management, and it did not relate to the probability of aphid predation (as detected by PCR). Constraints on prey/predator size for hunting spiders exists (Michalko and Pekar, 2014; Sanders et al., 2015) but aphids are a small prey that is likely to be eaten by both small and bigger canopy spiders (Michalko and Pekar, 2015b).

The impact of spiders on aphid suppression, defined as an effect on aphid population growth (Desneux et al., 2006), was only assessed here in insecticide free orchards to avoid confounding effects of insecticides. This impact was expected to be stronger when aphids were not abundant because later in season many other natural enemies may affect aphid growth, including more efficient species such as syrphids and coccinelids (Minarro et al., 2005). Consistently with expectations, we found a positive effect of the abundance of the dominant spider taxon, *Philodromus* spp, on the decrease of the number of aphid colonies in early season, despite only few *Philodromus* individuals (3/129) were positive to *D. plantaginea*. That few individuals were positive early in season, although *Philodromus* appeared to affect aphid population, is consistent with low aphid abundance. Further, pest suppression can also be due to non-consumptive or trait-mediated non-lethal effects (Beleznai et al., 2015; Bucher et al., 2015) such as individuals dropping or losing energy due to disturbance. Few studies report aphid suppression by natural enemies in the field by relating the temporal variation of aphids with that of predators or parasitoids (e.g. Boreau de Roince et al., 2013; Chaplin-Kramer et al., 2013; Dib et al., 2010). To our knowledge only Boreau et al. (2013) specifically addressed the role of canopy spiders on aphids ’colonies in spring and the authors did not report this possibly important role of *Philodromus spp*. This role is consistent with the high appetence of *Philodromus* for aphids (Michalko and Pekar, 2015b). Such appetence for aphids is not observed for all spider species. Aphids were, for example, shown to be of low food value to some ground species (Toft, 1995) and euryphagous species (i.e. with a large diet breadth) need alternative preys to complement their diet (Madsen et al., 2004). But other studies suggest that the diet of generalist predators, during aphids’ infestation pic, is mainly based on aphids in cultivated fields (Staudacher et al., 2015). Further than the abundance of total predators or of specific taxa, the functional composition of predator assemblages has been suggested be a more pertinent indicator of their potential impact on preys (Long and Finke, 2014). Here we found no effect of the cumulated sizes of spiders on aphid suppression (table 3), possibly because aphid are small preys (see above), but also possibly because larger predators are those that exert more intra-guild predation (Rusch et al., 2015).

Our result, using a combination of field observations and molecular analyses thus demonstrate the potential of spiders for reducing aphid populations in insecticide-free orchards, particularly very early in season. Further, our observations in treated orchards indicate that spiders in these orchards are also abundant early in season and that they predate on aphids, suggesting that their potential effect could be taken into account in decision rules governing early season insecticide treatments.

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## Figure legend

**Figure 1**: Location of the sampled orchards within France. IFP: orchards under integrated fruit production; organic: orchards under organic management; Ifree: insecticide-free orchards. N: north-western orchards; S: south-eastern orchards.

**Figure 2**: Mean abundance per trap band of different spider taxa. Values are cumulated for the two months of each season (early and mid-season), for the different orchards. Groups of orchards with different letters are significantly different based on glmer tests comparing the abundance per trap band according to the management of the orchard and pairwise multiple comparisons by Tukey tests.

**Figure 3**: Relation between Log(r1), the ratio of the number of aphid colonies between March and April, and the number of *Philodromus* spp individuals captured per tree in February and March. In black, data from Ifree1; in grey, data from Ifree2.The lines represent predictions from the linear models considering the random orchard effect.

## Tables

**Table 1**: *D. plantaginea* abundance in orchards and results of PCR tests: percentage of spiders that were found positive for *D. plantaginea* consumption (Pos), total number of spiders tested by PCR (PCR); means and standard deviations (sd) of aphid infestation calculated as log(infestation index +1) (Inf) and of the number of colonies (c ).

| | Feb | | March | | | | April | | | | | | May | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Pos | PCR | Pos | PCR | c | sd | Pos | PCR | Inf | sd | c | sd | Pos | PCR | Inf | sd | c | sd |
| Ifree1 | 4.3% | 23 | 5.1% | 59 | 0.7 | (0.9) | 17.9% | 28 | 1.8 | (2.1) | 2.0 | (1.8) | 50.0% | 12 | 1.2 | (1.7) | 1.4 | (1.7) |
| Ifree2 | 0.0% | 13 | 0.0% | 32 | 1.3 | (1.9) | 24.7% | 89 | 1.1 | (1.2) | 2.7 | (4.1) | 60.0% | 85 | 3.1 | (2.9) | 13 | (10) |
| S_orga | 2.4% | 41 | 1.8% | 57 | 0.8 | (0.7) | 10.5% | 57 | 0.5 | (0.9) | 1.0 | (2.7) | 23.4% | 64 | 1.2 | (1.4) | 3.2 | (5.9) |
| S_IFP1 | 0.0% | 28 | 8.8% | 34 | 0.9 | (0.8) | 8.6% | 35 | 0.0 | 0 | 0.0 | (0) | 18.5% | 27 | 0.1 | (0.3) | 0.1 | (0.2) |
| S_IFP2 | 0.0% | 30 | 3.4% | 29 | 2.6 | (3.6) | 5.9% | 17 | 0.1 | (0.4) | 0.1 | (0.4) | 5.6% | 18 | 0.0 | 0 | 0 | (0) |
| N_orga | 13.2% | 53 | 0.0% | 31 | 0.3 | (0.7) | 14.3% | 14 | 0.3 | (0.6) | 2.5 | (2.8) | 20.0% | 5 | 1.1 | (1.0) | 5.3 | (4.4) |
| N_IFP1 | 2.4% | 41 | 0.0% | 48 | 0.8 | (1.0) | 0.0% | 8 | 0.0 | (0) | 0.3 | (0.6) | 100.0% | 1 | 0.0 | (0.2) | 0.7 | (2.6) |
| N_IFP2 | 0.0% | 27 | 0.0% | 8 | 0.4 | (0.7) | 0.0% | 3 | 0.0 | 0 | 0.0 | 0 | 0.0% | 1 | 0.0 | 0 | 0 | (0) |

**Table 2**: Taxa captured and PCR results in early and mid-season. Number of individuals captured (N); number of individuals tested (PCR) and number of individuals positive to PCR analysis (+).

| | | early-season | | | mid-season | | |
|---|---|---|---|---|---|---|---|
| | | N | PCR | + | N | PCR | + |
| Amaurobidae | *Nursia albomaculata* | 42 | 29 | 0 | | | |
| Anyphaenidae | *Anyphaena accentuata* | 157 | 148 | 9 | 1 | 1 | 0 |
| Araneidae | spp | 74 | 21 | 1 | 25 | 11 | 2 |
| Clubionidae | *Clubiona sp* | 34 | 24 | 0 | 17 | 15 | 2 |
| Dictynidae | spp | 48 | 24 | 0 | 8 | 4 | 0 |
| Eutichuridae | *Cheiracanthium mildei* | 9 | 9 | 0 | 14 | 11 | 4 |
| Gnaphosidae | spp | 11 | 6 | 0 | 23 | 20 | 6 |
| Linyphidiidae | spp | 2 | 0 | | 3 | 0 | |
| Liocranidae | spp | 3 | 0 | | 1 | 0 | |
| Philodromidae | *Philodromus spp* | 162 | 130 | 3 | 4 | 3 | 1 |
| Salticidae | spp | 122 | 89 | 5 | 402 | 387 | 102 |
| Segestridae | *Segestria senoculata* | 0 | 0 | | 5 | 0 | |
| Sparassidae | *Olios argelasius* | 23 | 20 | 0 | 2 | 2 | 0 |
| Theridiidae | *spp* | 36 | 19 | 0 | 15 | 6 | 2 |
| Thomisidae | *spp* | 29 | 17 | 0 | 9 | 3 | 0 |

**Table 3**: Test of variables (taxa or traits) affecting aphid suppression measured as the variation of the *number of colonies* in early and mid-season (r1 and r2). Estimates of effects and their standard deviations are provided together with the variation of AIC when removing each factor from the full model, and the corresponding p-value. Independent variables were tested in different models (see material and methods).

| | r1 | | | r2 | | |
|---|---|---|---|---|---|---|
| | Estimate (sd) | $\Delta$AIC | p-value | Estimate (sd) | $\Delta$AIC | p-value |
| Philodromidae | **-0.18 (0.06)** | **-6** | **4. 10$^{-3}$** | | | |
| Salticidae | -0.05 (0.15) | 2 | 0.7 | -0.08 (0.05) | 0 | 0.14 |
| Other spiders | -0.1 (0.2) | 1 | 0.4 | -0.17 (0.2) | 2 | 0.4 |
| All spiders | **-0.08 (0.05)** | **-3** | **0.03** | -0.09 (0.05) | 0 | 0.1 |
| Cumulated prosoma width | -0.04 (0.04) | 0.6 | 0.2 | -0.03 (0.02) | 0.8 | 0.09 |

Figure1

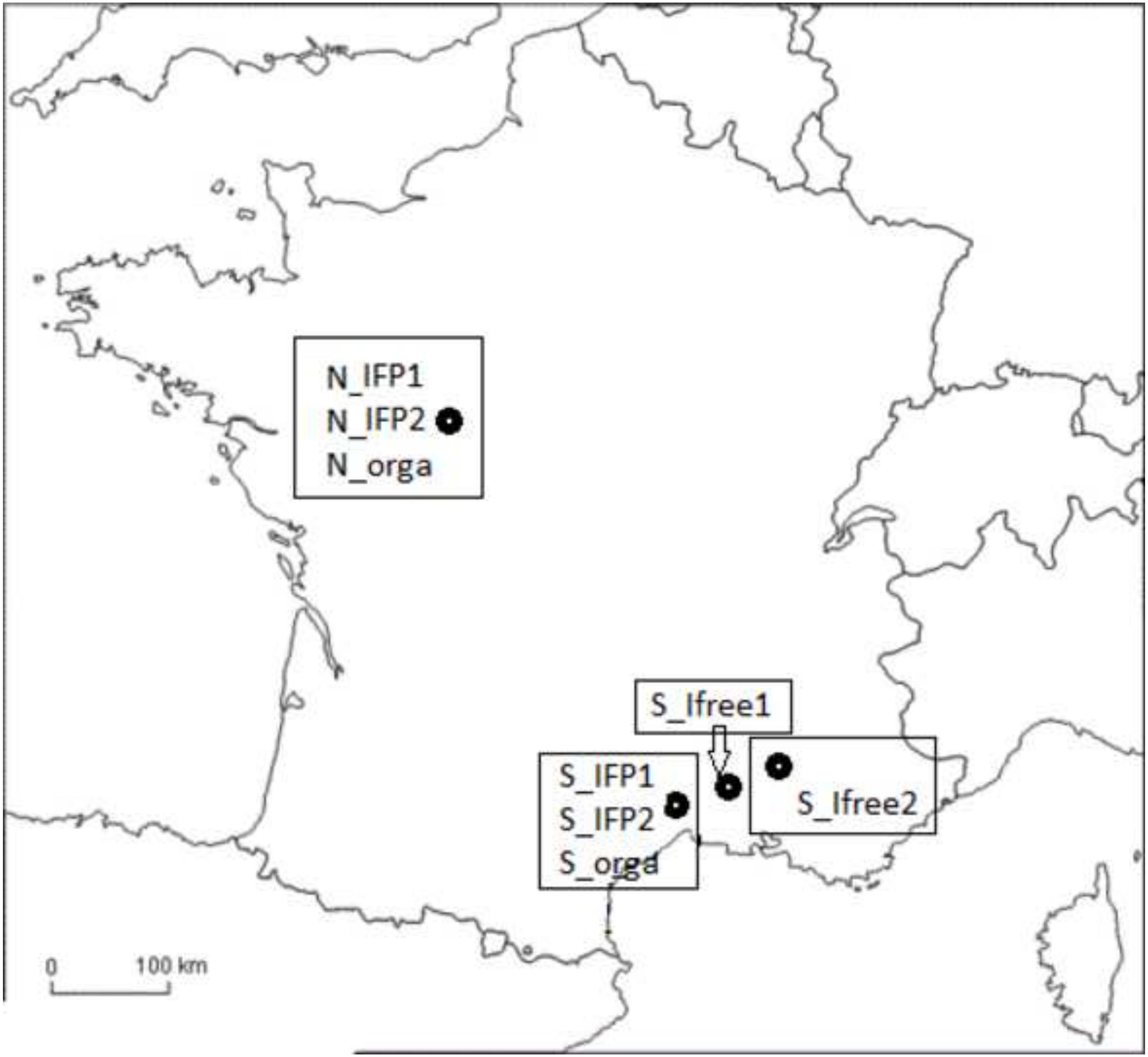
N_IFP1
N_IFP2
N_orga
S_Ifree1
S_IFP1
S_IFP2
S_orga
S_Ifree2
0
100 km

Figure2

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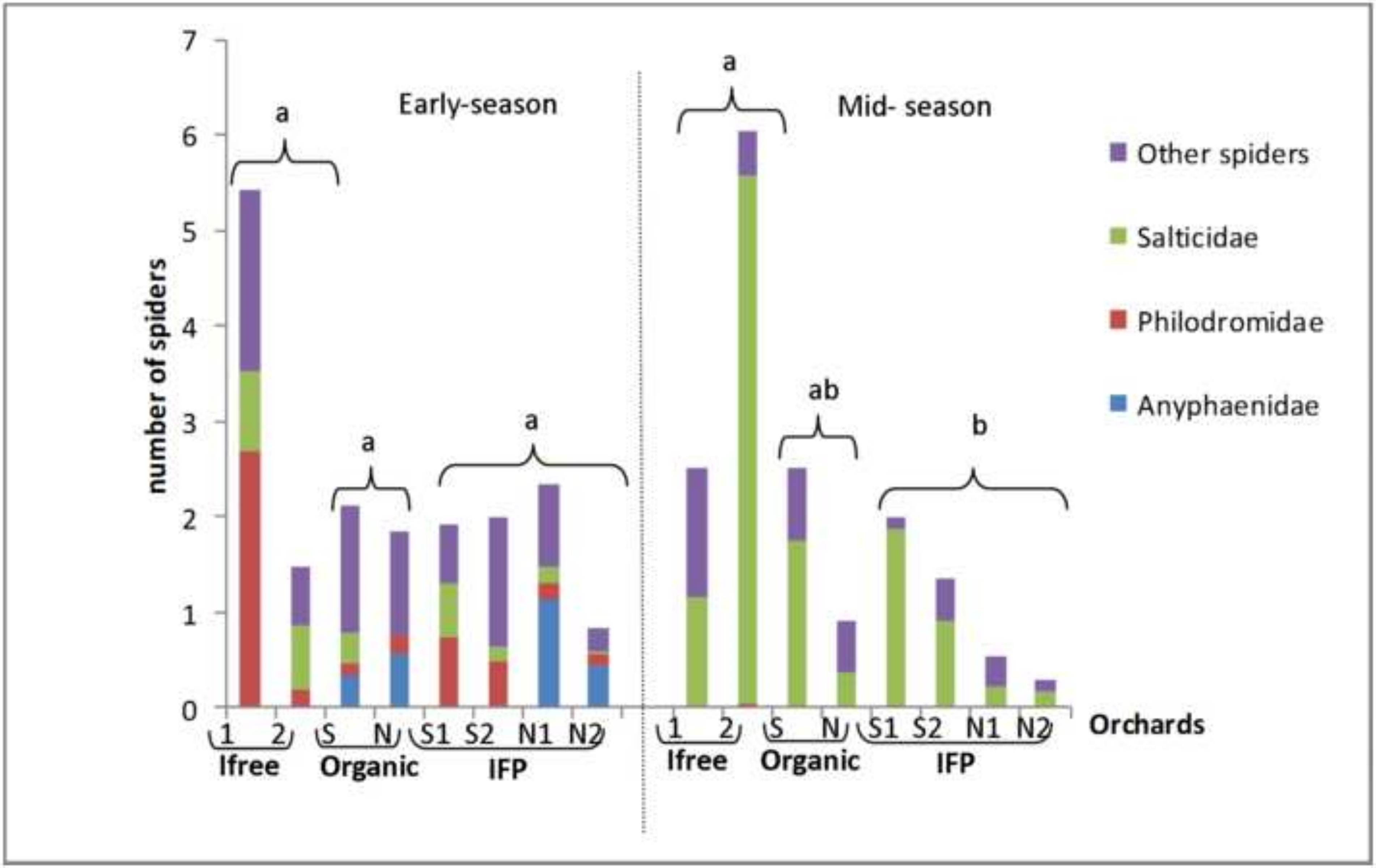

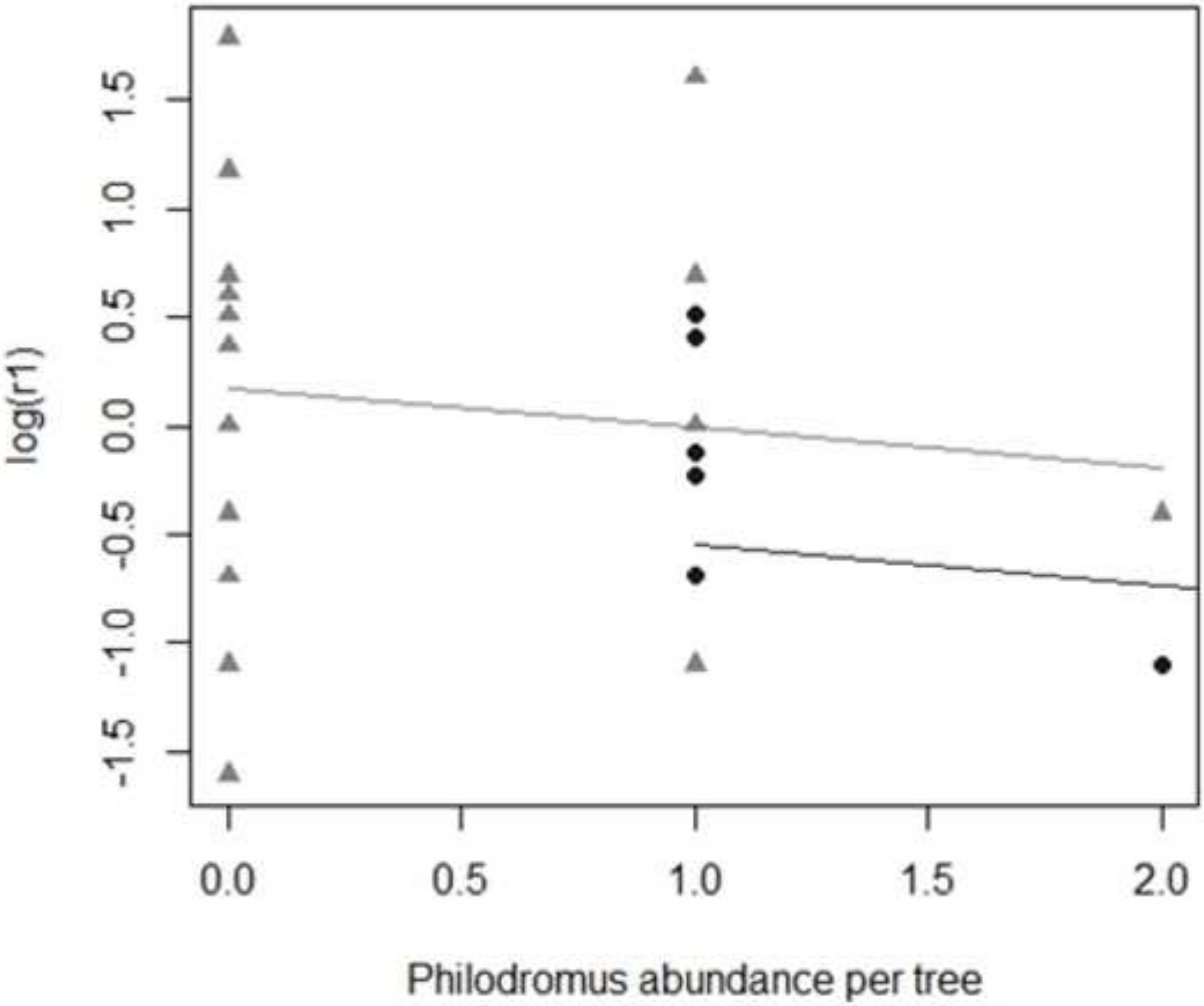
log(r1)
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
0.0
0.5
1.0
1.5
2.0
Philodromus abundance per tree