Impact of agricultural management on spider populations in the canopy of olive trees

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Abstract

In the province of Granada (southern Spain) spiders were studied in olive-tree canopies, in olive orchards under similar environmental conditions but different management systems: organic, integrated and conventional. Monthly samplings (March to October) was performed in the canopy by the beating method. Spider abundance proved significantly higher in the organic than in the conventional orchard. An intermediate disturbance level in the integrated regime increased spider diversity, while the conventional management favoured higher dominance of the family Oxyopidae. Four families (Thomisidae, Oxyopidae, Salticidae, and Theridiidae) comprised more than 83% of the specimens captured, of which Thomisidae and Salticidae declined in abundance between organic and conventional management, whereas the family Oxyopidae was favoured as management disturbance increased.

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1. Introduction

Some 96% of the world’s olive orchards (Olea europaea, Linneus) are situated in the Mediterranean area. Spain is the leading producer of olive oil worldwide, with 32.6% of the production, 80% belonging to Andalusia, on a surface area that has been increasing in recent years (Civantos, 1997).

Different types of orchard management, including different planting, irrigation, pruning, harvesting, and soil treatment (Campos and Civantos, 2000), can have diverse effects, positive or negative, on pest species as well as on useful arthropod groups. Of the three common types of management in Spain (conventional, integrated and organic), the organic and integrated systems had the advantage of higher soil quality and potentially lower negative environmental impact than in the conventional system (Reganold et al., 2001).

Many arthropods species take refuge, more or less permanently, in the olive orchards, including some 100 herbivorous insect species and others considered useful or neutral (Arambourg, 1986; Campos and Civantos, 2000; Cirio, 1997; Ruiz and Montiel, 2000; Varela and González, 1999). Notable among these arthropods are spiders, which as an order represent one of the most abundant and diverse groups of predators in this crop (Morris, 1997; Morris et al., 1999; Pantaleoni et al., 2001; Sacchetti, 1990).

These generalist predators can significantly reduce the populations of various insect pests (Marc et al., 1999; Nyffeler and Sunderland, 2003; Wyss et al., 1995). However, spiders tend to be highly sensitive to non-specific pesticides, such as dimethoate or deltametrine (Yardim and Edwards, 1998). In addition, these treatments have an indirect negative
effect on spiders by lowering the number of arthropod prey (Boga and Markó, 1999). The different spider families appear to be affected by these treatments in different ways. For example, spiders that spin webs appear to be less affected by chemicals than are those that actively hunt their prey (Marc et al., 1999). Also, spiders that construct complex webs show better resistance against pesticides (Pékár, 1999). Spiders do not appear to be affected by treatments based on Bacillus thuringiensis or growth regulators, though they are particularly sensitive to pyrethroids (Bajwa and Aliniaee, 2001). These inorganic pesticides, in addition to affecting abundance also alter species composition (Mansour et al., 1980). Species richness, as well as the density of spider communities, is greater in crops under integrated pest management than in conventional cultivation, although the two parameters do not appear to be affected in the same way (Bogya et al., 2000).

The goal of the present study was to elucidate the impact of the different management systems on abundance and diversity of the spider community in the canopy of olive trees.

2. Materials and methods

The study was conducted from 1999 to 2000 in three great commercial olive-growing zones, with orchards of different owners, some 20 km north of the city of Granada (southern Spain). The olive orchards studied were located in a large olive-growing area of 370 ha conventional, 525 ha integrated, and 230 ha organic. The zones were flood irrigated twice in summer and ploughed deeply in late May and early June. The trees were drip irrigated twice weekly in summer, ploughed lightly (10 cm) from late May to early June, and neither B. thuringiensis nor permitted pesticides were used during our study period, and no pesticide residues were found for this orchard (Ruano et al., 2004).

The experimental sampling design was established as follows: three large olive grove zones, one per management (even orchards of different owner per zone); 5 olive orchards sampled per zone, called blocks; and 5 sampling trees per block, each tree separated from the other by an unsampled tree, so the distance between sampled trees was 20 m. Each block was considered as a true replication because of the large size of the studied olive zones and that distance between blocks (a minimum of 0.5 km) ensures independence between them.

Sampling was conducted from March to October in 1999 and 2000, by beating four limbs per tree (one for each cardinal direction) five times over an insect net 50 cm in diameter. The specimens collected were identified to the family level.

The data from this design were analyses (Cunningham and Lindenmayer, 1999) by applying a Poisson log-linear model in order to compare spider abundance according to the type of management and year. Because outliers distort the fit, they were detected and removed according to the criterion $d(x, \{Q_3/Q_1\}) > 1.5(Q_3 - Q_1)$ in each sub-group (46 outliers, i.e. 3.8% of the total number of values). Most of dropped values came from the Organic group data, what means variability in this group is greater than the others group one (Fig. 1).

Filtered data were not over-dispersed (variance = mean), making a Poisson model appropriate (McCullagh and Nelder, 1983). Furthermore several Chi-square goodness of fit tests were performed to ensure that the distributional assumptions held.

To check over-dispersion, a quasi-Poisson model was considered, taking the dispersion parameter value 1.2152, so that over-dispersion would not be a problem. The coefficients of the models show that we can drop the factor block of the proposed model. The coefficients were calculated by the statistical program R (R Development Core Team, 2005).

The diversity of spider families in the different management systems was calculated by the PIE Hurlbert’s diversity index

$$\text{PIE} = \left( \frac{N}{N-1} \right) \left( 1 - \sum_{i=1}^{t} \frac{p_i^2}{i} \right).$$

The index was calculated by the computer program Eco-Sim 7.0 (Gotelli and Entsminger, 2004). Dominance was
also calculated as simply the fraction of the collection that is represented by the most common families. Dominance can be a useful index of resource monopolization by a superior competitor (Gotelli and Entsminger, 2004).

The diversity and dominance data were analysed by the Kruskal–Wallis non-parametric test because the index values could not be transformed to provide a normal distribution. The data analysed were from 1999 to 2000, with a mean of the two years of sampling.

3. Results

A total of 1200 beating samples were analysed, of which 51.3% contained spiders. The number of individuals captured was 1242. In both study years, the total number of specimens collected was significantly higher in the organic orchard, followed by the integrated, while the conventional orchard had the lowest number ($P < 2.2e−16$; Fig. 2). The number of spiders captured was 114.6% higher in the organic and 43.5% higher in the integrated compared to the conventional orchard.

As only 3 points had a high residual, the model can be considered to have a good fit. The coefficients for the adjusted model, reveal statistically significant differences between olive orchard types and between years.

Following the classification by Uetz (1977), among web-building spiders, the families of the specimens collected were Theridiidae (Sundevall), Linyphiidae (Blackwall) and Araneidae (Simon), while the wandering spiders found were from Thomisidae (Sundevall), Oxyopidae (Thorell), Salticidae (Blackwall), Gnaphosidae (Pocock), Philodromidae (Thorell) and Clubionidae (Wagner). Of the families identified, the abundance of the family Thomisidae was noteworthy, followed by Oxyopidae, Salticidae, and Theridiidae (Table 1). These four families represented 83.4% of the captures.

In the integrated management, 9 families were represented, while, in the conventional and in the organic, 8 families

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Fig. 1. Box plot show extreme values (grey dots) and severely extreme values (black dots). Variables considered in the data are abundance (total spiders), management, year (1999, 2000) and blocks (randomized blocks for each type of olive orchard).

Fig. 2. Spider abundance under each orchard management Abundance expressed as mean number of spiders. Error bars means SE.
were represented in the two study years, but there were no significant differences were found among managements.

Thomisidae and Salticidae presented a mean number of individuals that differed significantly between management regimes ($P < 2.5\times10^{-11}$; $P < 2.1\times10^{-11}$, respectively), declining from organic to conventional (Figs. 3 and 4). Theridiidae showed no clear trend (Fig. 5), do not reaching significant differences between types of management ($P = 0.07144$). The family Oxyopidae, for which the mean number of individuals differed significantly between management systems ($P < 5.1\times10^{-05}$), increased from organic to conventional, with greater differences between integrated and conventional (Fig. 6).

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Mean number of spiders per 100 samples in different olives orchard in the two years of study</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Organic Mean (SD)</td>
</tr>
<tr>
<td>Araneidae</td>
<td>2.3 (1.4)</td>
</tr>
<tr>
<td>Clubionidae</td>
<td>0 (0)</td>
</tr>
<tr>
<td>Gnaphosidae</td>
<td>10.8 (5.9)</td>
</tr>
<tr>
<td>Linyphiidae</td>
<td>1.0 (1.1)</td>
</tr>
<tr>
<td>Oxyopidae</td>
<td>22.0 (9.8)</td>
</tr>
<tr>
<td>Philodromidae</td>
<td>5.8 (3.3)</td>
</tr>
<tr>
<td>Salticidae</td>
<td>33.3 (4.7)</td>
</tr>
<tr>
<td>Theridiidae</td>
<td>26.5 (4.5)</td>
</tr>
<tr>
<td>Thomisidae</td>
<td>44.0 (16.1)</td>
</tr>
<tr>
<td>Spiders totals</td>
<td>145.5 (25.5)</td>
</tr>
</tbody>
</table>

Fig. 3. Abundance of Thomisidae spiders under different management. Thomisidae is expressed as mean number of spiders of this family. Error bars means SE.

Fig. 4. Abundance of Salticidae spiders under different management. Salticidae is expressed as mean number of spiders of this family. Error bars means SE.
With respect to general population trends, maximums for spider populations according to taxonomic order (in mean number of individuals collected) were reached during August in the organic and IPM system, and September in conventional in 1999 and during March in IPM and October in organic and conventional managements in 2000 (Fig. 7). Minima occurred in May for organic and integrated, and June for conventional management, in 1999. For the 2000 minima occurred during April in conventional and organic management and during September in IPM management.

The most abundant family collected, Thomisidae, reached its abundance maximum under organic management in June 1999 and October 2000, and minimum in October 1999 and April 2000. For integrated, October 1999 and May 2000 registered the maxima, and minima in May in both years. In the conventional orchard, the peak was registered in October in both years, and the trough in May (no specimen collected in both years studied) (Fig. 3).

The family Oxyopidae diverged from the general trend of the most abundant families Thomisidae and Salticidae. In all three management systems, the lowest number of specimens was collected in May 1999 and in March 1999 for IPM and April for the conventional and organic management. The lowest number of individuals were collected in March, April, and especially May in all the management regimes, with increases in number beginning in the summer months and early autumn under conventional management (September and October) (Fig. 6).

The family Salticidae showed a similar trend to the Thomisidae one in the sense that the greatest abundance for organic was registered in September 1999 and October 2000 and for integrated management August 1999 and March 2000 registered the peaks. Minima occurred during
March in organic and IPM management in March 1999 and during April for organic management and May for IPM in 2000. On the contrary, under conventional management, abundance was lower in all months, with several months registering no specimens (Fig. 4).

There were significant between-year differences in Thomisidae ($P < 1.6 \times 10^{-7}$), Salticidae ($P < 6.2 \times 10^{-8}$), but not in Oxyopidae ($P = 0.0776$) or Theridiidae ($P = 0.83554$).

The results for diversity, calculated by Hurlbert’s PIE diversity index, indicated higher diversity in the integrated olive orchard (mean = 0.804, SD = 0.03), followed by the organic (mean = 0.792, SD = 0.02) and the clearly lowest in the conventional orchard (mean = 0.705, SD = 0.09), differences proving significant between management regimes (Kruskal–Wallis test; $P < 0.05$), but there was no difference between the organic and integrated orchards (Kruskal–Wallis test, $P > 0.05$).

With respect to dominance, 4 families represented more than 80% of the captures, when the dominance index values were calculated for the three management systems. The greatest dominance was found under the conventional management (mean = 0.455, SD = 0.13), followed by integrated (mean = 0.305, SD = 0.03) and organic (mean = 0.302, SD = 0.06). The highest dominance value was found under the conventional regime in which the most abundant family was Oxyopidae. Differences proved significant between management systems (Kruskal–Wallis test; $P < 0.05$).

4. Discussion

The fact that Thomisidae, Oxyopidae, and Salticidae were the three most abundant families may be explained by the fact that the salticids, oxiopids and other hunting spiders prefer warm regions (Nyffeler and Sunderland, 2003), such as the Mediterranean, where the study was conducted. With respect to abundance under the three management regimes, the differences found indicate that the cultivation methods affect spider abundance (Feber et al., 1998; Miliczky et al., 2000; Samu, 2003) either directly or indirectly, by lowering the number of prey or reducing competition with individuals of other spider families or with other arthropods. Abundance was greater during summer months in the organic and integrated regimes because in the conventional regime the spider populations remained low until the pesticides applied disappeared from the environment.

The family Thomisidae was notably affected by the type of management and by the chemical products applied. In addition, this family was clearly harmed by the pesticides in the conventional management, given that its lowest abundance corresponded to May and its population declined in the months following the treatments in July. This might be owed to a decrease in the number of prey.

Conventional regimes could directly benefit Oxyopidae, but, more probably, conventional management would lower competition of individuals of this family with other predatory arthropods, including spiders of other families. This fact could indirectly improve the survival of individuals of the family Oxyopidae, which maintained the same dynamic in the three types of management throughout the year. On the contrary, in the organic regime, the family Oxyopidae was affected by the competition with species of other spider families and therefore their numbers would be lower, and regional differences could be more important determinants of spider community structure in orchards than is insecticide use (Brown et al., 2003). These results agree with findings by Mansour et al. (1980), who, studying spider abundance in apple orchards and differentiating...
between chemically treated and untreated crops, found spiders of the family Oxyopidae present in treated orchards only. Oxyopids, like *Oxyopes salticus*, Hentz, 1845, have been shown to be resistant to insecticides in other systems (Young and Lockley, 1985).

The family Salticidae showed the greatest sensitivity to dimethoate and pyrethroid, reflected in the sharp decline in the mean number of individuals between in the conventional compared to the organic regime. The reason appears to be that these products usually have a stronger effect on hunting spiders than on web-building spiders (Baattrup and Bayley, 1993; Bajwa and Aliniazee, 2001; Marc et al., 1999). In addition, spiders that actively hunt their prey make contact with more chemical product (Mansour and Nentwig, 1988).

In the family Theridiidae the April treatment (dimethoate) appeared to have an excessive effect, while the June treatment (pyrethroid) lowered the number of individuals during the summer months. This could be explained in a similar way as that applied to the foregoing family, since pyrethroid can be moderately to highly harmful (depending on the dosage) for individuals of this family whereas they are less susceptible to dimethoate (Bajwa and Aliniazee, 2001; Marc et al., 1999). In addition, the lack of response to dimethoate could also be due to the webs acting as collectors of harmful products, protecting the spider from contact with the chemicals (Hose et al., 2002; Pekár, 1999).

In terms of the different years, no clear trend was discernible, because the most abundant families showed different trends that apparently depended on the climatic variability between the two study years.

The results of diversity and dominance show a significant variation between the three types of management, and therefore depend on the agricultural practices used. Diversity tends to diminish with an increasing the number of disturbances, as happens from organic to conventional management, but an intermediate number of disturbances (integrated) appears to favour diversity (Lenz et al., 2004).

The type of olive orchard management was found to be related to abundance, diversity, and dominance of spiders. The conventional management negatively affected abundance and fomented dominance, while integrated management encouraged diversity.

The response of the spider families in the canopy of the olive orchard differed according to management practices; Thomisidae, Salticidae, and Theridiidae were negatively affected by the conventional regime while the family Oxyopidae increased in abundance under this type of management.

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