Deltamethrin application on colonized olive logs: Effect on the emergence of the olive bark beetle *Phloeotribus scarabaeoides* Bernard 1788 (Coleoptera: Scolytidae) and its associated parasitoids

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Abstract

The olive bark beetle, *Phloeotribus scarabaeoides*, is a pest of olive trees causing severe injuries near inhabited foci. The pyrethroid insecticide, deltamethrin, has been tested at different doses during 3 years in olive logs already colonized by this scolytid, by monitoring the emergence of *P. scarabaeoides* adults and their parasitoids. In 2005 due to unusual low winter temperatures, the insect population was very low, precluding drawing any conclusion. The insecticide doses in 2004 and 2006 affected the emergence of the olive bark beetle, with a reduction ranging from 1% to 13%. The doses of 2006 also controlled the emergence of another olive pest, *Leperisinus varius*. The incidence on the hymenopteran parasitoids was, in general, high at all the tested deltamethrin doses, ranging from 0.0025% to 0.01% active ingredient. The lowest dose employed in 2006, corresponding to 0.00125%, reduced pest emergence without a significant effect on the hymenopteran parasitoids population, except for *Cheiropachus quadrum*.

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1. Introduction

Two major insect pests affect olive culture, the olive fly (*Bactrocera oleae* (Gmelin 1790)) and the olive moth (*Prays oleae* (Bernard 1788)). Among other so-called minor pests, the olive bark beetle, *Phloeotribus scarabaeoides* Bernard 1788 (Coleoptera: Scolytidae) is acquiring an increasing importance. This scolytid is a species spread in the entire Mediterranean zone, as well as in Syria and Asia Minor (Arambourg, 1984; de Andrés, 1992; Civantos, 1999).

In Spanish olive orchards the olive bark beetle adults overwinter on the living olive trees in which they excavate subcortical feeding galleries. In spring the adults disperse from overwintering sites to reproduce in olive logs coming from the annual pruning (Arambourg, 1984; Campos and Lozano, 1994). In late spring the emerging brood adults disperse from the logs towards the olive trees. The pest damage is mainly produced when the new adults fly to the olive trees to dig feeding galleries. In adult olive groves, the damages can reach up to a 75% of the final crop (González and Campos, 1994), while in young groves the tree survival is sometimes endangered.

The olive bark beetle can also affect olive oil quality (Humanes and Civantos, 1992) as well as induce considerable economic losses in a culture of high socio-economic importance, since it constitutes 11% of the Spanish agricultural surface, representing about $2.44 \times 10^3$ ha. In Andalusia, with ca. 60% of the total national production, olive oil in the 2003 campaign accounted for ca. $1.45 \times 10^3$ Mg. Similarly, the problem described here is even worse in olive groves in countries from North Africa (Morocco, Tunisia, etc.) where high temperatures favour the existence of multivoltinism (Benazoun, 1992; Lozano et al., 1998).

The control of this pest can be approached with cultural methods such as the advance of pruning, so that the logs lose water content and become unsuitable for insect

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reproduction, logs destruction or their use as a lure and their consequent destruction when the colonization is completed (Civantos, 1998). Olive logs, however, have an economic value as domestic and industrial source of energy and sometimes are stored without care, becoming a focus of pest dispersion and infestation.

Nevertheless, the main control method is the application of insecticides, both to the olive logs and to the living olive trees. In general, organophosphorous insecticides are applied to the olive trees in a band of 200–250 m around the population nuclei (Civantos and Sánchez, 1993; Civantos, 1999). In this sense, the treatment of logs with synthetic insecticides is a better approach than the treatment of trees, since a negligible effect on health or environment would be derived if logs are sealed in an appropriate place. In olive logs the olive bark beetle can be controlled by avoiding the start of reproduction galleries (Peña et al., 1998) or by treating the logs once the galleries have been initiated but before the emergence of brood adults. One of the advantages of the latter strategy is that no repulsion occurs, because the insect pest is already inside them. A repulsion effect has already been reported for various pyrethroid insecticides in the control of different coleopteran (Kohnle et al., 1992; Peña et al., 1998; Rodríguez et al., 2003; Rose et al., 2005). Therefore, the treatment when log colonization is completed, avoiding the repellency from the pyrethroid insecticide, would reduce the spread of *P. scarabaeoides* to other non-protected logs.

Pyrethroid insecticides, such as deltamethrin, are being applied for the control of the autophagous generation of the olive moth, *P. oleae* and the olive fly, *B. oleae*. According to Metcalf (1994) conservation of natural enemies could be attained when applying more selective pesticides, less toxic to natural enemies, with lower residual activity and in minimal doses. Hence, the use of deltamethrin at low doses, even lower than those recommended, may be sufficient to control the insect pest and at the same time have less impact on beneficial insects (Longley and Jepson, 1997). Finally, the use of experimental conditions as similar as possible to the field provides a useful tool to approach more natural conditions (Rodríguez et al., 2003; Santos et al., 2007). Bioassays in the laboratory generally represent a worst-case situation, in which insects are confined without the possibility of escaping, which is definitely the opposite to field scenarios (Longley and Jepson, 1997). Incorporation of more realistic features into laboratory and semi-field tests will certainly increase the realism of risk prediction for parasitoid population in the field.

The aim of this paper is to study the effect of reducing deltamethrin concentration for the control of the olive bark beetle, monitoring at the same time the impact on the parasitoids associated with the scolytid. The experiments were carried out on olive logs once colonization was complete, to avoid the repellent effect demonstrated by some pyrethroid insecticides.

### 2. Material and methods

#### 2.1. Treatment of the olive logs

The log treatments were carried out for 3 years (2004–2006). The logs were sprayed to runoff with a formulation containing deltamethrin at 2.5% as an emulsifiable concentrate (EC) (Decis, Bayer CropScience). Each year an experimental design was independently carried out. Each experiment consisted in four different insecticide concentrations applied to an experimental unit (five olive logs) with four replicates.

Treatments were applied when the emergence of *P. scarabaeoides* from olive logs was first detected in the field. In 2004, the logs were treated on the 24th of June, in 2005, on the 20th of June and in 2006, due to the higher temperatures, the treatment was shifted to the 2nd of June. Table 1 shows the doses employed through the years.

Olive logs colonized by *P. scarabaeoides* with similar attack levels were collected in different log piles placed in the vicinity of Granada (southern Spain). Before the treatment, the logs were taken to the laboratory and numbered. Reproduction galleries were counted and the surface of the logs was calculated by measuring their length and diameter and considering them as a cylinder. No statistical differences were found (*P > 0.05*) among the number of initial galleries or among the surface of the olive logs neither for any of the years nor for the different treatments (Table 2).

Logs corresponding to a single insecticide concentration, i.e. a treatment, were placed at random in PVC tubes, closed at one of its ends and the other one connected, through a plastic funnel, to a transparent plastic vial. Emerging insects, i.e., olive bark beetles, parasitoids and predators, moved by phototaxis to the plastic vials, where they were periodically collected. The insects were counted and conserved in Eppendorf vials with alcohol until their identification was finished.

To verify what stages of *P. scarabaeoides* were primarily affected by the insecticide, the logs were inspected at the end of the experiment. The bark was separated with a knife, the number of the holes corresponding to emerged beetles was counted, as well as the non-emerged individuals which had died before emergence.

#### 2.2. Insecticide analysis

Each year and once the experiment was over, about 4 months after the treatment had elapsed, samples from the

<table>
<thead>
<tr>
<th>Year</th>
<th>Control</th>
<th>LD*</th>
<th>MD*</th>
<th>HD*</th>
</tr>
</thead>
<tbody>
<tr>
<td>2004</td>
<td>Water</td>
<td>0.0025</td>
<td>0.005</td>
<td>0.01</td>
</tr>
<tr>
<td>2005</td>
<td>Water</td>
<td>0.0006</td>
<td>0.00125</td>
<td>0.0025</td>
</tr>
<tr>
<td>2006</td>
<td>Water</td>
<td>0.00125</td>
<td>0.0025</td>
<td>0.005</td>
</tr>
</tbody>
</table>

*a: LD: low dosage; MD: medium dosage; HD: high dosage.*
olive logs were taken for the analysis of the residual insecticide concentration. One log per replicate and treatment was selected and two superficial samples were taken from each log with a file. In 2004, in addition to the superficial sample (to a depth of 0–0.5 cm), a deeper sample was collected (0.5–1 cm) from the logs receiving the highest dose (0.01%), to verify the penetration ability of deltamethrin. Analyses were carried out by gas chromatography with electron capture detector (GC-ECD) under conditions previously described for $\alpha$-cypermethrin adapted to deltamethrin (Pen˜a et al., 2006).

2.3. Statistical analysis

The mean number of emerged $P.\ scarabaeoides$, Leperisinus varius Fabricius 1775 and hymenopteran parasitoids was compared with the non-parametric Kruskal–Wallis test at $P_{<}0.05$ with three degrees of freedom. A Box-and-Whisker plot was used to discriminate among means.

3. Results and discussion

3.1. Effect on $P.\ scarabaeoides$

3.1.1. 2004

Results show (Fig. 1a) that the highest number of emerged bark beetles corresponded to the control logs, to which no insecticide was applied, followed by logs treated with deltamethrin at increasing concentrations: $C \gg D0.0025\% \gg D0.005\% \gg D0.01\%$. The comparison of total olive bark beetles emerged from the different treatments showed that there was a significant difference ($P_{<}0.05$), being the control different from the insecticide treatments, among which no statistical difference was found (Table 2).

3.1.2. 2005

A reduction in the emergence of $P.\ scarabaeoides$ with insecticide treatments was also observed (Fig. 1b). This reduction was more evident for the high (0.0025%) and the intermediate doses (0.00125%), from which 47.5% and 45.5% emerged, respectively, with regard to control logs.

Although the number of logs was the same as in 2004, the total number of emerged $P.\ scarabaeoides$ was much lower than the data corresponding to the previous year (Table 2). For instance, in control logs the total number of emerged olive bark beetles was ca. 600 in 2005 vs. ca. 12000 in 2004, which corresponds to a 20-fold reduction. The adverse climatic conditions during winter, with minimal temperatures as low as—10°C prolonged for several days, explain the low insect emergences. These unusually low temperatures in Southeastern Spain produced severe damage to the olive trees (even the death of young olive

Table 2
Mean values of $P.\ scarabaeoides$ and $L.\ varius$ individuals emerged, initial galleries and logs surface ($\pm$ SD), according to the different treatments along the years

<table>
<thead>
<tr>
<th>Treatment</th>
<th>$P.\ scarabaeoides$</th>
<th>$L.\ varius$</th>
<th>Number of initial galleries</th>
<th>Olive log surface (cm$^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2004</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>2939.8 ± 1143.6a</td>
<td>*</td>
<td>702 ± 33.8</td>
<td>6594.2 ± 1630.5</td>
</tr>
<tr>
<td>0.0025%</td>
<td>388.3 ± 132.4b</td>
<td></td>
<td>89.3 ± 46.9</td>
<td>7036 ± 869.7</td>
</tr>
<tr>
<td>0.005%</td>
<td>242.5 ± 158.2b</td>
<td></td>
<td>86.8 ± 6.6</td>
<td>7056 ± 1494.0</td>
</tr>
<tr>
<td>0.01%</td>
<td>144.8 ± 78.8b</td>
<td></td>
<td>69.8 ± 17.3</td>
<td>6524.9 ± 536.6</td>
</tr>
<tr>
<td>2005</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>153.3 ± 178.0</td>
<td>*</td>
<td>29.0 ± 11.0</td>
<td>5319.1 ± 511.2</td>
</tr>
<tr>
<td>0.0006%</td>
<td>115.0 ± 146.3</td>
<td></td>
<td>27.8 ± 5.6</td>
<td>5173.3 ± 360.9</td>
</tr>
<tr>
<td>0.00125%</td>
<td>83.5 ± 31.1</td>
<td></td>
<td>22.5 ± 1.7</td>
<td>5807.3 ± 862.0</td>
</tr>
<tr>
<td>0.0025%</td>
<td>80.5 ± 78.4</td>
<td></td>
<td>33.0 ± 8.8</td>
<td>6396.0 ± 748.5</td>
</tr>
<tr>
<td>2006</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>3140.5 ± 274.5a</td>
<td>662.3 ± 249.0a</td>
<td>45.9 ± 7.5</td>
<td>5493.8 ± 1944.3</td>
</tr>
<tr>
<td>0.00125%</td>
<td>93.3 ± 53.3b</td>
<td>86.3 ± 99.6b</td>
<td>51.2 ± 10.1</td>
<td>6346.7 ± 2403.4</td>
</tr>
<tr>
<td>0.0025%</td>
<td>19.3 ± 19.3b</td>
<td>4.8 ± 2.6b</td>
<td>40.4 ± 8.2</td>
<td>5547.6 ± 367.7</td>
</tr>
<tr>
<td>0.005%</td>
<td>30.0 ± 24.1b</td>
<td>28.0 ± 17.4b</td>
<td>43.2 ± 7.7</td>
<td>6597.3 ± 1293.5</td>
</tr>
</tbody>
</table>

Treatments represent deltamethrin a.i. applied.

Different letters in the same column and year represent statistical differences at $P_{<}0.05$ (Kruskal–Wallis test).

*Leperisinus varius* emerged in low numbers (0 in 2004 and 1 in 2005) from all the logs.
As in 2004, the treatment with the insecticide strongly reduced pest emergence (Fig. 1c). The emergence from the treated logs represented between 1% and 3% of the individuals emerged from control logs. The attack level this year resembled that of 2004, if the emerged scolytids from treated logs represented between 1% and 3% of the individuals was also monitored. For this pest, the efficacy of pyrethroid insecticides on the beneficial entomofauna (Hym., Pteromalidae). Their abundance and prevalence varied among years. The following species were found: Dendrosoter protuberans (Nees 1834), Euphilus silesiacus (Ratzeburg 1848) (Hym., Braconidae), Eurytoma morio Boheman 1836 (Hym., Eurytomidae), Cheiropachus quadrum (Fabricius 1787), Rhaphitelus maculatus Walker 1834 and Cerocelpha eccoptoasstri Masi 1921 (Hym., Pteromalidae). Their abundance and prevalence varied among years.

3.2.1. 2004

As it has been described for other insect pests, the effect of pyrethroid insecticides on the beneficial entomofauna seems to be important (Table 3, Fig. 2). A clearly higher number of beneficial insects emerge from the control logs compared to the treated logs, as shown in Table 3 for total hymenopteran species. A closer inspection of the results shows that the insecticide effect was not the same for all the insect species considered. D. protuberans and E. silesiacus were the species which emerged in largest numbers from the control logs (Table 3; Fig. 2). However, their populations suffered an almost complete depletion at any concentration assayed.
The statistical analysis showed that *D. protuberans* exhibited significant responses to deltamethrin with abundance decreasing relative to control logs (*P* < 0.05), while the difference encountered for *E. silesiacus* was not significant, due to the dispersion in the replicated experiments. Both species showed a high sensitivity to the treatment with this insecticide, being the emergence from the treated logs only 0.2% and 3.8% with respect to the control logs for *D. protuberans* and *E. silesiacus*, respectively (Fig. 2).

*E. silesiacus* and *D. protuberans* have been described as common parasitoids of other bark beetles (Kennedy, 1970; Hostetler and Brewer, 1976; Maksimović, 1979). *E. silesiacus* caused 55% of the total number of elm bark beetles parasitized and was a dominant parasitoid of oak bark beetle (Marković and Stojanović, 2003). This species is an ectoparasitoid of early instars of bark beetle larvae. *D. protuberans* has also parasitized *Scolytus multistriatus* (Marshan 1802) up to 19.3% parasitization, and other elm bark beetles (Merlin, 1984). *D. protuberans*, a late instar parasite, stretched over most of the summer period and even in early autumn, as Merlin (1984) described for this parasitoid in Belgium. *E. silesiacus* also emerged in large numbers during August and in the first half of September. For both parasitoids thin bark was most suitable for parasitism (Hostetler and Brewer, 1976; Manojlovic et al., 2000), since the ratio ovipositor length/bark thickness affects oviposition efficiency. This behaviour may favour parasitization of *P. scarabaeoides*, small sized and that excavates galleries just under the bark.

*R. maculatus* and *C. quadrum* were less common species, since they emerged in low numbers: 64 *R. maculatus* and only 3 *C. quadrum* from all the logs. The emergence of *C. quadrum* occurred in a short period, corresponding to the first half of July. It has been reported that it attacks late instars of other scolytids, like *S. scolytus* (Fabricius 1775), occurring early in the season (May–June) (Merlin, 1984). Both *E. silesiacus* and *R. maculatus* have also been described as parasitoids of elm bark beetles in Serbia (Stojanović and Marković, 2007).

Finally *E. morio* emerged in the first days for the low deltamethrin dose (0.0025%) at a rate similar to that of the

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Table 3
Mean numbers of hymenopteran species emerged per treatment along the years

<table>
<thead>
<tr>
<th></th>
<th>Total hym.</th>
<th><em>E. morio</em></th>
<th><em>R. maculatus</em></th>
<th><em>D. protuberans</em></th>
<th><em>E. silesiacus</em></th>
<th><em>C. quadrum</em></th>
<th><em>C. eccopt.</em></th>
</tr>
</thead>
<tbody>
<tr>
<td>2004</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>410.5</td>
<td>6.8</td>
<td>4.3</td>
<td>124.3a</td>
<td>264.3</td>
<td>0.3</td>
<td>9.8</td>
</tr>
<tr>
<td>0.0025%</td>
<td>19.3</td>
<td>2.5</td>
<td>2.8</td>
<td>0.3b</td>
<td>4.8</td>
<td>0.5</td>
<td>4.5</td>
</tr>
<tr>
<td>0.005%</td>
<td>11.5</td>
<td>0.0</td>
<td>9.0</td>
<td>0b</td>
<td>2.3</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0.01%</td>
<td>3.8</td>
<td>0.3</td>
<td>0</td>
<td>0b</td>
<td>3.0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2005</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>27.8</td>
<td>2.5</td>
<td>0</td>
<td>0.8</td>
<td>14.3</td>
<td>6.8</td>
<td>0.8</td>
</tr>
<tr>
<td>0.0006%</td>
<td>71.8</td>
<td>4.5</td>
<td>0.3</td>
<td>0.5</td>
<td>47.3</td>
<td>10.5</td>
<td>3.5</td>
</tr>
<tr>
<td>0.00125%</td>
<td>93.8</td>
<td>9.0</td>
<td>1.0</td>
<td>3.5</td>
<td>46.0</td>
<td>28.3</td>
<td>0</td>
</tr>
<tr>
<td>0.0025%</td>
<td>74.8</td>
<td>13</td>
<td>1.0</td>
<td>0.3</td>
<td>23.8</td>
<td>25.0</td>
<td>0</td>
</tr>
<tr>
<td>2006</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>665.0a</td>
<td>130.5a</td>
<td>71.5a</td>
<td>4.0</td>
<td>1.5</td>
<td>120.8a</td>
<td>100.8a</td>
</tr>
<tr>
<td>0.00125%</td>
<td>444.0b</td>
<td>117.9a</td>
<td>56.8a</td>
<td>0.3</td>
<td>0</td>
<td>31.5b</td>
<td>67.0a</td>
</tr>
<tr>
<td>0.0025%</td>
<td>21.0c</td>
<td>6.5b</td>
<td>4.3b</td>
<td>0</td>
<td>0</td>
<td>2.0b</td>
<td>0.5b</td>
</tr>
<tr>
<td>0.005%</td>
<td>56.0c</td>
<td>11.5b</td>
<td>12.3b</td>
<td>0</td>
<td>0</td>
<td>7.8b</td>
<td>1.3b</td>
</tr>
</tbody>
</table>

Different letters in the same column and year represent statistical differences at *P* < 0.05 (Kruskal–Wallis test).

*Total emerged hymenopteran individuals.*

*C. eccoptogastri.*
control, but after 40 days its population was drastically reduced. This behaviour may reflect a low deltamethrin incidence on individuals in pupal phase being higher for eggs or larval stages. Although parasitism or predation could take place after the treatment under field conditions, this situation was not possible in our experimental design since logs were brought to the laboratory just before the treatment and introduced in PVC tubes.

3.2.2. 2005

The hymenopteran population in 2005 was very low, probably because of host shortage (Table 3). The most abundant parasitoids in 2005 were *E. silesiacus*, *E. morio* and *C. quadrum*, followed by *D. protuberans*, *C. eccoptogastri* and *R. maculatus*. In general, the doses used in this experiment led to the absence of differences between the control logs and the logs sprayed with deltamethrin (\(P > 0.05\)) (Table 3).

As in the previous year, *E. silesiacus* was the parasitoid which emerged in largest numbers for every treatment. Unlike the preceding year, this parasitoid was not especially affected by deltamethrin at the concentrations used in this experiment, with the highest emergencies corresponding to the two lowest insecticide doses, 0.00125% and 0.0006%. On the contrary, *D. protuberans*, which was also abundant in the control logs of 2004, was not very frequent in 2005, maybe affected by the low temperatures reached during winter as reported in other studies (Hostetler and Brewer, 1976), since its emergence was low even from control logs.

3.2.3. 2006

The total number of hymenopteran individuals emerged from control logs was similar to or even greater than that of 2004 (Table 3), although a different pattern of emergence for the different parasitoid species occurred.

First of all, only six individuals of *E. silesiacus* were collected from control logs, but no individuals from treated logs. *D. protuberans* also emerged in low numbers (a total of 17). For the rest of hymenopteran species, *E. morio*, *C. quadrum*, *R. maculatus* and *C. eccoptogastri*, an increase in their emergence from control logs was observed (Table 3; Fig. 3).

The different parasitoid abundance and prevalence, apart from the use of a lower insecticide concentration, could be explained by the pile location, the different treatment date and the period of host availability for parasitoids development.

The application of deltamethrin at the two highest insecticide concentrations prompted a significant reduction (\(P < 0.05\)) of parasitoid emergence for all the species (Table 3). On the contrary, the total parasitoid emergence from the logs treated with the lowest dosage, 0.00125% active ingredient was statistically higher than those corresponding to the other insecticide treatments, but also differed statistically from the emergence from control logs (Table 3).

The inspection of the different species monitored indicates that the lower dosage did not have a significant effect on most of the parasitoid species emergence, although a relatively high reduction in their numbers was observed, especially for *E. morio*, *R. maculatus* and *C. eccoptogastri* (Table 3). Only in the case of *C. quadrum* the emergence was significantly reduced with respect to control logs. It seems that a deltamethrin concentration around this value could attenuate the effect on parasitoid population.

![Fig. 3. Number of the most abundant hymenopteran parasitoids emerged from the olive logs along time as a function of insecticide dosage. 2006. C, HD, MD and LD as in Table 1.](image-url)
3.3. Analysis of insecticide residues

The results indicate that the residual insecticide amounts were proportional to the concentrations of the treatments applied ($r^2 = 0.9978$ for 2004, 0.9903 for 2005 and 0.9262 for 2006). It has been reported that deltamethrin is able to penetrate rapidly and that the presence of additives in the insecticide formulation may increase insecticide penetration (Youssef et al., 2004). Our results show, as it was found for cypermethrin in elm bark (Jin and Webster, 1998), that the penetration power of deltamethrin through the bark of the olive logs was very low. The concentration found in the first mm was 9–12 times higher than the one determined in the zone located immediately below. Therefore, since the bark beetles dig their reproduction galleries just below the bark, the insecticide could be effective either during the digging of galleries or during emergency, when beetles would get in contact with the bark. Another possibility is that laid eggs could enter in contact with the insecticide during gallery digging below the olive bark.

To verify which mechanism was taking place, when the experiment was over in 2005, log barks were separated with a knife to inspect the galleries. In logs which received insecticide application, the insect larvae had developed into adults, many of which remained dead in the galleries when trying to go through the bark to emerge. The percentage of dead individuals under the bark with respect to the total number of emerged bark beetles in a treatment was significantly higher ($P<0.05$) for the higher insecticide dose (44.1%), whereas for the two lower dosages and the control no significant differences were found (13.9, 21.3 and 17.9% for LD, MD and control, respectively). This is an indirect confirmation that *P. scarabaeoides* individuals may develop to an adult stage in the galleries under the bark, to which the insecticide does not penetrate, but they die on emergence.

4. Conclusions

Deltamethrin, like other pyrethroid insecticides (Loch, 2005), is a fast knockdown insecticide, which reduces the emergence of the olive bark beetle with a single application. The control of *P. scarabaeoides* on logs already colonized by the insect pest is a good strategy for different reasons: first, because it avoids pest dispersion due to the repellent effect induced by this insecticide; second, because the logs are not used for human consumption and no health effect may be derived from the insecticide application; and third, because the insect population can be reduced before the olive trees are attacked.

Despite the success of deltamethrin to control the olive bark beetles, the broad-spectrum nature of this insecticide caused in general a high mortality to non-target beneficial arthropods. Among the parasitoids found *E. silesiacus* and *D. protuberans* were abundant in 2004. Other species, such as *E. morio*, *C. quadrum*, *R. maculatus* and *C. eccoptogastri*, were more frequent in 2006. The results corresponding to 2005 have to be considered with caution due to the low numbers of insects collected. The effect of different insecticide doses on the pest and on beneficial insects has shown that a compromise could be reached between a sufficient pest control and an acceptable effect on beneficial insects. Parasitoids have been reported to have a noticeable effect on the regulation of different bark beetle populations; thus, they should be treated with care to avoid a sound reduction of their populations. Although some further refinement of the insecticide dose is required, and considering the economic and ecological implications, our data suggest that limiting insecticide applications to a deltamethrin concentration close to 0.00125% is a viable technique for olive protection as well as conservation and recovery of a rich complement of natural enemies.

Different variables may affect parasitoid composition and prevalence (Longley and Jepson, 1997; Pekár, 1999; Shah et al., 2003; Furlong, et al., 2004; Araújo et al., 2004). The moment of deltamethrin treatment and the presence of different maturation stages in the host population are two added sources of variability for the parasitoid assemblage.

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