Management of Black Scale and Apple Weevil in Olives
Management of Black Scale and Apple Weevil in Olives

by Sonya Broughton and Stewart Learmonth

August 2012

RIRDC Publication No. 12/019
RIRDC Project No. PRJ-000475
Foreword

Black scale and apple weevil have been identified as the key pests of Australian olive groves in a recent study and their control and management are a high priority for industry. Both pests can be managed using integrated pest management (IPM) techniques. This study investigates the use of IPM to address these pests in Australia.

This project was funded from voluntary industry revenue and RIRDC core funds provided by the Australian Government. The Western Australian Department of Agriculture also provided in-kind funding through the Horticulture Program. Western Australia olive growers, whilst not providing direct funds for the project, assisted with the research. This included spraying commercial-sized blocks, collecting samples and checking weevil bands. The Spray Adjuvant Company of Australia provided cash for the first year of the project.

This report is an addition to RIRDC’s diverse range of over 2000 research publications and it forms part of the Olives R&D program, which aims to:

- provide information which establishes the benefits of Australian olive products
- maintain the current high quality product while improving productivity, profitability and environmental management through all stages of the supply chain
- develop strategies for existing and new olive producers to reduce the effects of climate change and variability
- build and educated, collaborative, innovative and skilled industry workforce and a cost effective, well funded RD&E program.

Most of RIRDC’s publications are available for viewing, free downloading or purchasing online at www.rirdc.gov.au. Purchases can also be made by phoning 1300 634 313.

Craig Burns
Managing Director
Rural Industries Research and Development Corporation
Acknowledgments

We gratefully acknowledge the contributions made by the following individuals and groups:

Mike Baker
Elizabeth Blincow
Peter Burnett
Helen Collie
Brad Harnett
David Cousins
Deb and Mal Dickie
Peter Gaebler
Peter Grainger and Garrick Burl
Steve Hale and Wayne Lange
Jessica Harrison
Brad Harnett
John Higgins
Robert Jack
Peter Needs
Hugh Patterson
Jane Speijers
Mark Stanaway
Dick Taylor
Nigel Thompson and Debra Archdeacon
Judith Williams
James Altmann ( Biological Services, South Australia) for providing Metaphycus spp.
Andrew Matthews of SACOA for providing funding and support
The Western Australian Olive Growers Association for supporting this project, and for providing in-kind funding

Abbreviations

APVMA Australian Pesticides and Veterinary Medicines Authority
IPM Integrated pest management
NRA National Registration Authority
IGR Insect growth regulator
SACOA Spray Adjuvant Company of Australia
SEM Standard error of the mean
WA Western Australia
# Contents

Foreword ............................................................................................................................................... iii  
Acknowledgments ................................................................................................................................. iv  
Abbreviations ........................................................................................................................................ iv  
Executive Summary.............................................................................................................................. ix  
**Black scale** ........................................................................................................................................ 1  
  
  Introduction and background ........................................................................................................... 1  
  Objectives ........................................................................................................................................ 6  
  Methodology .................................................................................................................................... 7  
  Results and discussion ................................................................................................................... 10  
  Recommendations for black scale control ..................................................................................... 23  
**Apple weevil** ......................................................................................................................................... 24  
  
  Introduction and background ........................................................................................................... 24  
  Objectives ...................................................................................................................................... 26  
  Management of apple weevil in commercial groves ..................................................................... 26  
  Timing of egg laying ..................................................................................................................... 52  
  Diurnal movement of apple weevil adults ..................................................................................... 53  
  General discussion ......................................................................................................................... 55  
  Recommendations for apple weevil control .................................................................................. 58  
**Appendices** ........................................................................................................................................ 59  
  
  Appendix A: List of biocontrol agents released for control of black scale in Australia (adapted from Waterhouse and Sands 2001) ................................................................................. 60  
  Appendix B: 2005 Survey of Western Australian olive groves for black scale parasitoids and predators.................................................................................................................. 62  
  Appendix C: Publications/communication .................................................................................... 64  
**Glossary** ............................................................................................................................................ 65  
**References** ........................................................................................................................................ 66
Figures

Figure 1  Heavy infestation of black scale in Western Australia showing sooty mould on trunk, twigs and leaves .......................................................................................................................................... 1

Figure 2  Scale insects occurring on olives in Australia ................................................................................................................................................. 2

Figure 3  Mean number of live black scales of different stages per sample per month ................................................................. 10

Figure 4  Mean number of crawlers compared to the numbers of females with either eggs or crawlers ................................................................. 11

Figure 5  Mean number of crawlers per branch per sample per season .................................................................................................................. 12

Figure 6  Mean number (± SEM) of live black scale (all stages) per sample per season ........................................................................................................ 12

Figure 7  Mean (± SEM) percentage of black scale on leaves during different developmental stages ................................................. 13

Figure 8  Percentage of larvae that died as a result of parasite activity compared to death from unknown causes ............................................................................................................................................... 14

Figure 9  Percentage of parasitised second and third instar black scale. Columns with the same letters do not differ at P=0.05 ............................................................................................................................................... 14

Figure 10  Top, percentage parasitism of female scales at different developmental stages. Middle, mean number of live females and females with eggs per sample per month. Bottom, mean number of live Scutellista caerulea larvae and pupae per sample ............................................................................................................................................... 15

Figure 11  The number of specimens of each of eight species of wasp parasitoid and one hyperparasitoid reared from black scale collected from four olive groves from October 2006 to October 2009 .................................................................................................................. 16

Figure 12  Mean number (± SEM) of specimens per sample per season .................................................................................................................. 17

Figure 13  *Metaphycus* ....................................................................................................................................... 18

Figure 14  *Scutellista caerulea*, egg predator .................................................................................................... 19

Figure 15.  A–F. Apple weevil life cycle stages G. Comparison of three weevil species ............................................................................................... 25

Figure 16  Apple weevil damage to olives ............................................................................................................................................... 26

Figure 17  Physical barriers to apple weevil ............................................................................................................................................... 29

Figure 18  The kaolin clay product Surround® was applied to the trunk (left panel) and canopy (right panel) of olive trees to test whether it would protect them from attack by apple weevil adults .................................................................................................................. 30

Figure 19  The abundance of apple weevil adults (square root transformed) in monitoring bands on (a) young and (b) mature olive trees treated with insecticides applied as a butt drench (Alpha = α-cypermethrin (Dominex®); Fip = fipronil (Regent®); Bif = bifenthrin (Talstar®)), or as a foliage application (Indox = indoxacarb (Avatar®) at two different rates) ............................................................................................................................................... 33

Figure 20  The abundance of apple weevil adults (square root transformation) in monitoring bands on (a) young and (b) mature olive trees treated with ‘soft’ options as an exclusion band on the tree trunk (Glue = Barrier Glue; Fluffy = unbonded artificial fibre; Baked = bonded artificial fibre in sheet form; SurButt = Surround® applied to the trunk of olive trees), or as a foliar application (SurFol = Surround® applied to the foliage) ............................................................................................................................................... 34

Figure 21.  The severity of leaf feeding based on a scoring system (refer text; data presented as square root transformation) by apple weevil adults on (a) young and (b) mature olive trees treated with insecticides applied either as a butt drench (Alpha = α-cypermethrin (Dominex®); Fip = fipronil (Regent®); Bif = bifenthrin (Talstar®)) or as a foliar application (Indox = indoxacarb (Avatar®) at two different rates) ............................................................................................................................................... 35

Figure 22.  The severity of leaf feeding based on a scoring system (refer text; data presented as square root transformation) by apple weevil adults on (a) young and (b) mature olive trees treated with ‘soft’ options as an exclusion band on the tree trunk (Glue = Barrier Glue; Fluffy = unbonded artificial fibre; Baked = bonded artificial fibre in sheet form; SurButt = Surround® applied to the trunk of olive trees), or as an application to the foliage (SurFol = Surround® applied to the foliage) ............................................................................................................................................... 36
Figure 23. Abundance of apple weevil adults (square root transformation) in monitoring bands in olive trees treated with three rates of the insecticides as a butt drench: (a) Alpha = α-cypermethrin (Dominex®), (b) Fip = fipronil (Regent®) and (c) Bif = bifenthrin (Talstar®) during the 2007/08 season, Witchcliffe, WA. The arrow indicates the date of application. .......................... 38

Figure 24. The abundance of apple weevil adults (square root transformation) in monitoring bands in olive trees where untreated bonded (baked) and unbonded artificial fibre bands (FF) were placed on the main trunk with further trees receiving the unbonded fibre bands sprayed with products (see Table 12 for details) during the 2007/08 season, Witchcliffe, WA. ............................. 39

Figure 25. The abundance of apple weevil on olive trees either untreated or treated with an insecticide butt drench early in the season (E), late in the season (L) or at both times (E+L) during the 2007/08 season, Witchcliffe, WA. Arrows indicate dates of insecticide application. ......................... 40

Figure 26. Abundance of apple weevil adults (square root transformation) in monitoring bands in olive trees where untreated bonded (baked) and unbonded (fluffy) artificial fibre bands were placed on the main trunk. Other treatments included bonded fibre bands sprayed with Azidol® (neem), or trunks and canopies treated with other products (see Table 13 for details), Kendenup, WA. …….. 44

Figure 27. Adult apple weevil abundance in monitoring bands in olive trees where untreated bonded and unbonded (fluffy) artificial fibre bands from the previous season (‘Old’) were compared with weevil numbers in trees where ‘New’ bands were placed. ......................................................... 45

Figure 28. Adult apple weevil abundance (square root transformation) in monitoring bands in olive trees where a range of exclusion bands were applied to trunks (see Table 14 for details). .......................... 45

Figure 29. The frequency distribution of leaf damage score (see text for details) and average tip damage score (data square root transformed) for apple weevil damage to tips of olive trees where different weevil exclusion treatments were applied (see Table 14 for details) at Kendenup, WA. 46

Figure 30. Apple weevil adults abundance (square root transformed) in monitoring bands where a range of exclusion bands were applied to trunks (see Table 15 for details) at Kendenup, WA. .................. 47

Figure 31. Apple weevil adults abundance (square root transformed) in monitoring bands where a range of exclusion bands were applied to trunks (see Table 16 for details) at Kendenup, WA. …….. 48

Figure 32. The abundance of apple weevil on olive trees where unbonded fibre trunk bands were placed and were either untreated or sprayed with ‘Vegie’ chilli extract during 2008 Kendenup, WA. …… 49

Figure 33. Apple weevil adults abundance (square root transformed) in unbonded fibre trunk bands where a range of exclusion bands were applied to trunks (see text for details) during the 2006/07 season, at Mumballup, WA. .......................... 50

Figure 34. Apple weevil adult abundance (square root transformed) in cardboard monitoring bands comparing foliar applications of indoxacarb and Cyazypyr™ insecticides and day- or night-spraying (see Table 17 for details) at Frankland, WA. .......................... 51

Figure 35. The abundance of apple weevil adults in trunk bands on olive trees and the percentage of weevils with eggs and the average number of eggs per female at (a) Kendenup, (b) Mumballup and (c) Witchcliffe, during the period December 2006 to June 2007. .......................... 53

Figure 36. Left image, Trunk of an olive tree after a season where a black plastic band had been attached. Right image, Olive trees with multiple artificial fibre bands attached successively during a season; exposure to field conditions seemed to reduce the band’s ability to trap and exclude apple weevils from entering the tree canopy. …………………….. 56
Tables

Table 1. Biological control projects on black scale worldwide. ................................................................. 6
Table 2. Insecticides and label rates. .......................................................................................................... 8
Table 3. Parasites recovered during the study. .......................................................................................... 17
Table 4. Main species of predatory insect occurring during the study. ..................................................... 20
Table 5. Ant species submitted for identification during study. .............................................................. 21
Table 6. Classification of insecticides based on egg bioassays. ............................................................... 22
Table 7. Effect of insecticides on instar duration, pupal duration and adult weight. ............................... 22
Table 8. Classification of insecticides based on egg bioassays. ............................................................... 23
Table 9. Details of insecticide treatments applied to olive trees to assess their efficacy for the control of apple weevil, Witchcliffe, WA, in the 2006/07 season. ......................................................... 27
Table 10. Details of ‘soft’ treatments applied to olive trees to assess their efficacy for the control of apple weevil, Witchcliffe, WA, in the 2006/07 season......................................................... 28
Table 11. Details of insecticide treatments applied as a drench to the trunks of olive trees to assess their efficacy for the control of apple weevil, Witchcliffe, WA, in the 2007/08 season. ................. 31
Table 12. Details of treatments applied to unbonded artificial fibre trunk bands on olive trees to assess their efficacy for the control of apple weevil, Witchcliffe, WA, in the 2007/08 season ......... 32
Table 13. Details of insecticide treatments applied to olive trees to assess their efficacy for the control of apple weevil, Kendenup, WA, in the 2006/07 season............................................................ 41
Table 14. Details of treatments applied to olive trees to assess their efficacy for the control of apple weevil, Kendenup, WA, in the 2007/08 season............................................................ 42
Table 15. Details of treatments superimposed on treatments in the same trial area and season for # treatments in Table 14 that had not controlled apple weevil Kendenup, WA, in the 2007/08 season. ............................................................ 43
Table 16. Details of treatments applied on 11 December 2007 to different trunk fibre bands on olive trees to prevent apple weevil adults accessing the tree canopy, Kendenup, WA, 2007/08. ............... 43
Table 17. Details of treatments applied on 3 and 4 March 2010 to the canopy of olive trees to compare the efficacy of a new insecticide for control of apple weevil at Frankland, WA............................................. 51
Table 18. Numbers of apple weevil adults in monitoring bands of olive trees where Barrier Glue had been applied on 22 March 2010 between the upper, middle and lower monitoring bands at Frankland, WA. ............................................................................................................... 54
Executive Summary

What the report is about

This report provides olive growers with monitoring, and organic and conventional control methods for black scale and apple weevil. The information generated by this project also provides new methods to improve control of apple weevil.

Who is the report targeted at?

This report is targeted at Australian olive growers who are having problems controlling black scale and/or apple weevil. An understanding is required of how to monitor, the biology of the pests, and the correct growth stages to target for control. Organic and conventional pesticide control methods are provided for black scale and apple weevil, allowing growers to choose methods that are most suitable for their situation.

Where are the relevant industries located in Australia?

Olives are grown throughout Australia, with the largest plantings in New South Wales followed by Western Australia, Victoria, South Australia and Queensland (RIRDC 2002). The majority of trees (approximately 70 per cent) are managed as project development groves, with 89 per cent of growers having 5000 trees or less (RIRDC 2002).

The following table shows the distribution of the planted area between groves of different sizes.

<table>
<thead>
<tr>
<th>Grove scale</th>
<th>Number growers (% of total)</th>
<th>Hectares</th>
</tr>
</thead>
<tbody>
<tr>
<td>Large (&gt;100 ha)</td>
<td>35 (1.57%)</td>
<td>14 000</td>
</tr>
<tr>
<td>Medium (10–100 ha)</td>
<td>200 (8.95%)</td>
<td>7 000</td>
</tr>
<tr>
<td>Small (&lt;10 ha)</td>
<td>2 000 (89%)</td>
<td>9 000</td>
</tr>
</tbody>
</table>

Growers with smaller olive groves tend to be more limited in their choice of management tools, due to lower input costs. In particular, growers producing organic olives are limited in their choice of control methods for insect pests, as most are based on pesticides which are not acceptable for organic production.

Background

A national survey of olive growers on pests and their management was undertaken in 2002 (Spooner-Hart et al. 2005). Of the 206 growers that responded to the survey, four important arthropod pests of olives were identified. In decreasing order of importance, these were black scale (Saissetia oleae, 69 per cent of respondents) and associated ants, olive lace bug (Froggattia olivinia, 34 per cent), grasshoppers (29 per cent) and Curculio beetle/apple weevil (Otiorhynchus cribicollis, 18 per cent). Apple weevil was reported as the second most important insect pest of olives by growers in Western Australia and South Australia (Spooner-Hart 2005).

This project arose from Western Australia (WA) olive growers seeking assistance with the correct timing of pesticide sprays to control black scale, and for alternative methods for black scale and apple weevil control.
Aims/objectives

This project aims to improve the control of black scale and apple weevil through a series of activities:

- delivery of workshops to assist WA growers in identifying the correct stage of black scale to target for application, monitoring methods, and identification of natural enemies
- surveys of organic and non-organic groves for parasites and predators of black scale, to evaluate existing biological control in WA olive groves
- evaluation of the effect of pesticides on beneficial insects occurring in olive groves
- evaluation of chemical and non-chemical control methods on apple weevil populations.

Methods used

Black scale
To survey for black scale and their natural enemies in the field, two strategies were employed. First, growers were provided with boxes to rear parasites and data sheets to record the information. Second, surveys of olive groves were carried out by the Department of Agriculture and Food Western Australia at four sites in south-west WA for one to three years, by collecting twigs and rearing out parasites in the laboratory. The efficacy of pesticides applied for black scale control was assessed through field observations, and the effect of pesticides on beneficials were evaluated in a series of laboratory trials.

Apple weevil
The biology of apple weevil was determined by dissecting weevils collected every two to four weeks. The presence of eggs was noted and the number of eggs of a size that indicated they were near maturity was counted. The efficacy of trunk, butt drenches (e.g. α-cypermethrin (Dominex®); bifenthrin (Talstar®), fipronil (Regent®)) and foliar applications (e.g. Myco-Force™, indoxacarb (Avatar®)) were evaluated over one to three seasons at four sites. Sticky or fibrous barriers left unsprayed, or sprayed with soft chemicals (e.g. kaolin (Surround®), chilli solution, synthetic or natural pyrethroids) were also evaluated. Efficacy was determined by counting the number of adult weevils and the levels of leaf damage and feeding on fruit stalks.

Results/key findings

Black scale
Two main generations of black scale occur per year, with a main reproductive peak during mid-summer (December–January), and a smaller peak in autumn (April–May). This finding agrees with Altmann and Baker (2009) for South Australian and Victorian black scale populations. The main crawler emergence period is in summer (December), with a smaller, second peak in autumn (April–May). Egg duration is approximately three months.

For optimum control of black scale, sprays should be timed to coincide with the main summer reproductive peak, though further control of the autumn peak may be required if populations of black scale are very high. Observations of field control measures indicate that oil sprays, methidathion (Supracide®, Suprathion®) and insect growth regulators (IGRs) (fenoxycarb, Insegar®; pyriproxyfen, Admiral®) are all highly effective against black scale. Oils are the only pesticides acceptable for use by organic growers and are regarded to be IPM compatible. Lab trials indicate that fenoxycarb and pyriproxyfen are moderately to extremely toxic to ladybird species present in olive groves, and should only be considered for spot treatment of infested areas.

Partial to complete biological control of black scale has been achieved in olives in California, USA, Europe, Israel and South America through the release and conservation of natural enemies, particularly of Metaphycus species. Surveys of olive groves in Western Australia and South Australia indicate that the egg predator, Scutellista caerulea, is most common; and M. helvolus and M. anneckei are poorly established. Biological control of black scale in olives appears to be low, as the effectiveness of S. caerulea is limited. Ant control is required where growers are interested in pursuing biological control, as ants harvest honey dew from black scale, and protect the scale from parasites and predators.
Apple weevil

Apple weevils are most abundant in early summer, but breeding is delayed until late summer. Control strategies are required at both times—to protect trees from attack and to reduce weevil breeding potential. α-Cypermethrin, bifenthrin and fipronil applied as butt drenches showed good activity against apple weevil. Indoxacarb, regarded to be a ‘reduced-risk insecticide’ was also highly effective when applied as a foliar application. It may be possible to reduce the apple weevil breeding population in early summer such that pesticide use may be reduced, or not required the following season. This was partially demonstrated at one field site using a larger treatment plot.

Unbonded bands (barriers) were generally more effective than baked artificial fibre bands for weevil exclusion. By spraying trunk bands with synthetic or natural pyrethroids or chilli products, the exclusion effect of the fibre bands can be further enhanced.

Implications for relevant stakeholders

It is estimated that 66 per cent of the Australian olive industry applies petroleum/mineral sprays for black scale control, and 15.5 per cent apply methidathion. The temporary permit for methidathion (PER 8858) expired in September 2009. Methidathion is likely to be replaced with IGRs, particularly on large-scale operations. However, growers interested in adopting integrated pest and disease management programs should limit their use of IGRs to spot treatments, as IGRs are moderately to extremely toxic to beneficials. Both large and small-scale operations can improve their control of black scale by applying treatments during summer, when the main scale generation is being produced.

The third most common insecticide used by olive growers against apple weevil is α-cypermethrin (17 per cent) as a butt spray. This study has demonstrated that additional pesticides including bifenthrin, fipronil and indoxacarb are also efficacious against apple weevil. If growers want to reduce their pesticide use, they should use unbonded bands.

Recommendations

- Establish *M. helvolus* and *M. lounsburyi* in olive groves for control of black scale. However, there may be problems with obtaining insects for release since there is no current commercial production of *Metaphycus*
- Pursue investigations of ant control in olive groves as a means of biological control. Ants harvest honeydew from black scale, and protect the scale from parasites and predators. No insecticides are registered in olives for this purpose. Overseas, bait stations with liquid sugar and boric acid (organically acceptable) are available for ant control
- Confirm on a commercial scale that by controlling apple weevil in early summer, the use of insecticides may not be required the following season
- Pursue the application for full registration of α-cypermethrin as a butt drench for control of apple weevil in olives. Registration should also be sought for bifenthrin and fipronil to supplement and complement the use of α-cypermethrin, and for insecticide resistance management
- Indoxacarb, as Avatar®, is registered for use against apple weevil in other horticultural crops and residue studies should be undertaken to investigate if some level of registration such as a minor use permit can be obtained
- Undertake further measurements to clarify the pest status and action threshold for controlling apple weevil in both newly planted and mature olive groves
- Further studies in apple weevil movement between the soil and olive trees may lead to more efficient and less insecticide-dependent methods for protecting olive trees from this pest.
Black scale

Introduction and background

Black scale (*Saissetia oleae* (Olivier)) or Mediterranean black scale as it is also known, is classified as a ‘soft scale’ (Family: Coccidae). Black scale is thought to originate from South Africa (De Lotto 1976), though other authors such as Morillo (1977) suggest that it is native to the Mediterranean. Black scale is found throughout the tropical and subtropical regions of the world and is considered to be an important pest of olive and citrus (Pellizzari 1997). In Australia, black scale is considered to be a major pest of olives (Spooner-Hart 2005), and a minor to major pest in citrus (Smith et al. 1997).

Damage

Scale insects have a long, filamentous mouth part which they insert into the plant to feed on the sap. As they feed, they excrete a sugary substance known as honeydew which is produced as a by-product of their feeding. Sooty mould fungi grow on top of the honeydew, coating leaves, twigs and fruit in a black powder (Figure 1). Sooty mould can interfere with plant photosynthesis, reducing tree vigour and yield, tainting the oil, increasing fruit washing costs at harvest, and requiring higher spray costs. Severe infestations can cause early leaf-fall, die-back of the branches and even a lack of fruit for a few years (Tena 2007).

Figure 1 Heavy infestation of black scale in Western Australia showing sooty mould on trunk, twigs and leaves

Other scales occurring on Australian olives include parlatoria (*Parlatoria oleae* (Colvée)), red scale (*Aonidiella aurantii* (Maskell)), latania (*Hemiberlesia lataniae* (Signoret)), Ross’s black scale (*Lindingaspis rossi* (Maskell)) and circular black scale (*Chrysomphalus aonidum* (Linnaeus)) (Spooner-Hart et al. 2007; Figure 2). These species are classified as armoured scales (Family: Diaspididae) since they have a fibrous, protective scale cover: all are regarded to be minor olive pests.
Figure 2  Scale insects occurring on olives in Australia

A. Circular black scale, 1.5–2.5 mm in diameter, dark brown or bluish-black, reddish brown centre. B. Latania scale, 2–2.5 mm in diameter, circular, flat, usually dark brown to black. C. Parlatoria scale, 1–2.0 mm in diameter, circular to elliptical, white to very light grey. D. Red scale, 1.5–2.0 mm in diameter, flat, orange, red-brown. E. Black scale, 3–5 mm in diameter, dark brown or black, with a prominent H-shaped ridge.

Identification of black scale and developmental stages

Black scale adult females are 3–5 mm in diameter, dark brown or black, with a prominent H-shaped ridge, though the H can become less distinct as they mature (Figure 2). Armoured scales are smaller than black scale; generally, armoured scales are about 2 mm in diameter (Figure 2).

There are four immature stages and an adult stage of black scale (see below). All stages can be found on leaves, twigs, branches and fruits. Identification of the correct developmental stage of black scale is important for chemical control. The immature stages-crawler and first instar-are most susceptible to insecticides. Most parasitoids (organisms which spend much of their life cycle attached to or within the body of a host, ultimately killing it) will also only attack the immature stages.
**Black scale development stages**

**Egg:** Eggs are laid under the body of the female. They are 0.2–0.3 mm long and initially pale orange in colour, turning pink before hatching. Eyespots are visible within the eggs before they hatch as crawlers.

**Crawler:** This is main dispersive stage, responsible for spread within and between olive groves. They can be dispersed passively such as by wind or on farm machinery, and actively when the crawlers wander onto leaves and twigs. Although crawlers can wander for up to 36 hours, they usually settle within 2–3 hours. Most crawlers settle onto the mid-rib of the leaf, usually near the mother scale. Crawlers are light pink–orange with black eyes, 0.2–0.3 mm long.

**First instar:** Once settled, crawlers shed their skin (moult) and become first instars. However, it can be hard to discriminate between the crawler and first instar stage without the aid of a microscope. First instars have legs and can move, though the legs tend to be tucked up under the body. First instars are 0.6–0.75 mm long and 0.2–0.35 mm wide.

**Second instar:** A longitudinal ridge begins to take shape along the middle of the scale in second instars. The body is pale brown in colour, and four dark brown patches have appeared. Second instars are 0.6–0.8 mm long and 0.3–0.4 mm wide.

**Third instar:** Ridges are clearly present in third instars. The body is white to light brown and darkens with age; the dark patches are much bigger than on the previous instar. They are 1–1.6 mm long and 0.5–0.8 mm wide.

**Adult female:** After the third moult, the female increases in size and becomes nearly circular. The ridges of the letter H become distinctly outlined. As the female approaches the egg-laying stage, the scales become dark, mottled gray which is referred to as the ‘rubber stage’.
When egg laying commences, the scale surface becomes smoother, darkening in colour to black. Eggs are laid under the body of the female. The female dies after laying eggs, though the body remains on the leaves or twigs.

Unmated females produce female offspring and two or three generations occur in Australia per year, depending on temperature and humidity. In subtropical conditions where winters are milder, there are more generations per year (Waterhouse and Sands 2001).

Chemical control of black scale

In conventional olive groves, growers use a combination of narrow-range mineral or petroleum oils and/or an insecticide (organophosphate or carbamate) to control black scale, whilst organic growers are restricted to oils (Zalom et al. 2009). Correct timing of sprays is essential for successful control of black scale, since insecticides are only effective against young scales (crawlers and first and second instars). However, older chemical insecticides such as organophosphates and carbamates are being removed or restricted from agricultural use due to human health and environmental concerns. For example, methidathion is under chemical review in Australia (NRA 2002), and has been classified as highly hazardous by the World Health Organization, highly toxic by the US Environmental Protection Agency, and very toxic by the European Union (NRA 2002) where it is no longer authorised for use (EFSA 2010).

Reduced-risk insecticides

The insect growth regulators (IGRs) fenoxycarb (e.g. Insegar®), buprofezin (e.g. Applaud®) and pyriproxyfen (Esteem®) are registered for control of black scale in olives in the USA (Crop Data Management Systems 2010). All are classified as reduced-risk insecticides because their modes of action are safe for humans. Fenoxycarb and pyriproxyfen control black scale by mimicking the action of juvenile hormones which control moulting (shedding of the skin) and reproduction in insects. The target stage is the young scale stage, with death occurring at moulting and pupation. Treated adults may also lay eggs that fail to hatch. Fenoxycarb is also used for the control of some beetle (coleopteran) and moth (lepidopteran) pests in rice, stored wheat, and for control of pests of tree crops such as armoured scales (Dhadialla et al. 1998) and in deciduous fruit tree crops in Australia. Pyriproxyfen has activity against scales (soft and armoured), whiteflies and aphids (Dhadialla et al. 1998). Anecdotal observations of field trials conducted by commercial growers in Gingin, WA, suggest that pyriproxyfen is highly efficacious against black scale.

Buprofezin disrupts moulting by preventing chitin development (required for insects to develop). It is active primarily against sucking insects such as scales, whiteflies, mealybugs and leafhoppers, although it also has activity against beetles (Grafton-Cardwell et al. 2005). For black scale, it is active against the young scales (first and second instar), and reduces egg production and egg viability (Yarom et al. 1988). Buprofezin also has activity against red scale (Grout and Richards 1991), which is an occasional pest of olives.

Australia

Growers have had access to mineral spray oil (PER3821, PER6459) and methidathion (Supracide®, PER6538, PER6459) under minor-use permits issued by the Australian Pesticides and Veterinary Medicines Authority (APVMA). However, these permits expired in 2005 and 2009 respectively (APVMA 2010). The permit for methidathion has not been renewed. The Australian Olive Association has listed fenoxycarb and buprofezin as insecticides which they would like registered for use in the control of black scale. Fenoxycarb is available under minor-use permit PER1939 to December 2011. Imidacloprid and thiamethoxam are listed as non-preferred options, since other control options are available (Australian Olive Association 2008). At present, Eco-oil, paraffinic oil (Trump™ Spray Oil) and pyriproxyfen (Admiral®) are the only pesticides registered for control of black scale in Australia.
Summary of chemical control of black scale

- Reviews of pesticides in the USA, Europe, and Australia will likely result in the removal or restriction of older chemistial insecticides such as organophosphates and carbamates. These will be replaced with reduced-risk pesticides (considered safe for humans).
- In Australia, methidathion (Supracide®, organophosphate) is no longer available for use by olive growers.
- Two IGRs are available to olive growers under registration, Admiral® (pyriproxifen) and permit, Insegar® (fenoxycarb; PER11939). However, they may have an impact on beneficial insects such as ladybirds.
- Organic growers are restricted to horticultural oils for chemical control of black scale.

Biological control of black scale

Since olive production does not usually support high input costs (Pellizzari 1997), most international research has focused on classical or augmentative biological control for black scale. Organic growers are particularly reliant on classical biological control. Classical biological control involves the importation and release of exotic beneficial insects. Once these insects establish, no further releases are required. Beneficial insects that are successful in one country are frequently imported into another country.

Augmentative biological control requires on-going releases of mass-reared insects, such as every season. Worldwide, biological control of black scale in olives has been based on classical biological control. Augmentative releases of the wasp Metaphycus helvolus (Compere) have been made in central California olive orchards (Daane et al. 1991) with some success. Van Lenteren and Bueno (2003) also report that the wasps Metaphycus, Coccophagus, and green lacewings (Chrysoperla) are released for the control of pests in olives. Metaphycus lounsburyi was reared to augment biological control of black scale in Egypt (Abd-Rabou 2004), and Metaphycus species are reared in Europe for biological control of scale in ornamentals (EPPO 2010).

Partial to substantial biological control of black scale has been achieved in olives in California, Europe, Israel and South America (Table 1). The strategies are based on the introduction and establishment of a complex of parasitoids and predators, rather than a single species. In California, over 50 species have been released since 1890, with 15 species established (Daane et al. 1991). In Israel, 17 species were released from 1975 to 1982 (Argov and Rossler 1993). In the Mediterranean basin, beneficials were first released in 1953 in France. In the 1960s there were further releases of beneficials (mainly from South Africa) to improve biological control of black scale (Tena 2007).

Biological control of black scale in Australia

Black scale has been the subject of biological control projects in the Australian citrus industry since 1902 (Smith et al. 1997). From 1902 to 1947, 24 species of beneficial insects (22 parasites, 2 predators) were released for its control (Waterhouse and Sands 2001; Appendix A). This included Metaphycus anneckei in 1902 from South Africa and M. helvolus in 1943–1947 from the USA. From 1998 to 2003, M. helvolus and M. lounsburyi were released in citrus as part of a Horticulture Australia Ltd-funded project (Altmann 2004).
Table 1  Biological control projects on black scale worldwide

<table>
<thead>
<tr>
<th>Country</th>
<th>Beneficials</th>
<th>Degree of control</th>
<th>Reference</th>
</tr>
</thead>
</table>
| Argentina | *Wasps:* *Metaphycus helvolus*  
*S. caerulea (= S. cyanea)*  
*Scutellista caerulea*  
*Diversinervus elegans*  
*S. caerulea* | Partial            | Pellizzari 1997   |
| California (USA) | *Wasps:* *M. helvolus,*  
*M. lounsburyi (= M. bartletti)*  
*Diversinervus elegans*  
*S. caerulea* | Substantial (coast)–partial (interior) | Daane et al. 1991 |
| Chile     | *Wasp:* *Metaphycus lounsburyi* | Partial            | Altieri & Nichols 1999 |
| Cyprus    | *Wasps:* *M. lounsburyi (= M. bartletti,*  
*M. annecki)*  
*M. helvolus* | Substantial        | Orphanides 1993     |
| France    | *Wasps:* *M. helvolus*  
*M. lounsburyi (= M. hageni?)* | ?                  | Tena 2007            |
| Greece    | *Wasp:* *M. helvolus*  
*Ladybird:* *Rhyzobius forestieri Mulsant* | ?                  | Argyriou & De Bach 1968;  
Katsoyannis 1997 |
| Israel    | *Wasp:* *M. lounsburyi (= M. bartletti)* | Substantial       | Argov & Rossler 1993   |
| Italy     | *Wasp:* *M. lounsburyi (= M. hageni?)* | ?                  | Viggiani & Mazzone 1980 |
| Peru      | *Wasps:* *M. lounsburyi (= M. hageni)*  
*M. helvolus*  
*Lecaniobius utilis*  
*S. caerulea* | Partial            | Altieri & Nichols 1999 |
| Spain     | *Wasps:* *S. caerulea, M. flavus,*  
*M. lounsburyi (= M. hageni)* | Partial            | Tena et al. 2007; Tena  
2007                 |

**Summary of biological control of black scale**

- Overseas, biological control success of black scale ranges from partial to substantial.
- A complex of beneficial insect species is required. More than one species is needed if black scale is living in several different environments, or if one species is only effective in a part of the range in which black scale is found.
- The most successful combinations for biological control of black scale are the parasites *Metaphycus helvolus* and *M. anneckei*, and an egg predator, *Scutellista caerulea*.
- It is difficult for some parasitoids to become established where black scale development is univoltine (population with one generation per year) and synchronous, because of the long periods in which suitable host stages are not commonly found.

**Objectives**

The objectives of this project were to develop monitoring and management programs to reduce the impact of black scale in olive groves. These objectives were to be achieved by answering the following questions:

1. How long is the egg stage in black scale? For both chemical and biological control to be effective, growers need to target the young scale stages. If this period is prolonged, then more than one application of insecticide may be required.

2. What beneficial insects are present in olive groves? For biological control to be effective, a complex of species is required. Little information is available on which beneficial insects have become established in olives in Australia.
3. Conventional insecticides such as methidathion are being replaced overseas and in Australia with reduced-risk insecticides such as insect growth regulators, e.g. fenoxycarb (Insegar®). What effect do reduced-risk insecticides have on beneficials?

Methodology

Grove location

Four commercial olive groves were sampled for a period ranging from six (three groves) to 96 months (one grove). All groves were located in the south-west of Western Australia and had high infestations of black scale (>5 scale/branch). Although attempts were made to increase the number of groves sampled by contacting members of the WA Olive Association, there were either too few black scale available for sampling (<1 scale/branch, five groves), or groves had been treated with insecticides (three groves). Groves were sampled once a week during periods of rapid scale growth (October–April), and monthly during winter (May–September).

Seasonal trend and scale mortality

On each sampling date, 15 cm long twigs with leaves were randomly collected from a minimum of five different trees. The twigs were selected among the most heavily infested branches. Infested twigs were enclosed in plastic bags and placed in a portable fridge for transport to the laboratory. In the laboratory, twigs and leaves (both sides) were examined under a stereomicroscope.

The total number of live and dead scales was segregated into the three nymphal instars according to the description of Morillo (1977) (see also ‘Black scale developmental stages’ section above) and three stages of adult females in order to determine the phenology of black scale populations and the mortality of different developmental stages. Adult female stages were classified as:

- young females (before oviposition)
- females with eggs
- females with crawlers.

Mortality rates were calculated as the number of dead scales divided by the total number of scales (alive or dead). Mortality rates were calculated separately for each developmental stage of *S. oleae* and only when the number of scales alive and dead in that stage was higher than 20 (Tena 2007).

Beneficial insects

Infested twigs were placed in parasitoid emergence containers and held at 25°C in a constant temperature cabinet for four to ten weeks. Emergence containers were constructed from a 10 L clear plastic container, 260 mm long, 250 mm wide and 15 mm high (Starmaid). Two holes (50 mm diameter) were cut into the lid and covered with fine mesh (105 microns) for ventilation and humidity control. Emerging parasitoids and predators such as ladybirds were collected and stored in 70 per cent ethanol for later identification.
Ants

Ants collect honeydew from scales and are known to interfere with predation and parasitism of black scale (Barzman and Daane 2001). Correct identification of ants associated with scale is important as management options will vary with particular species. Growers were encouraged to send ant specimens in for identification by Peter Davis and Marc Widmer (Social Insect Group, Department of Agriculture and Food Western Australia).

Identification

Beneficial insects were examined under a dissecting microscope (50X magnification). The parasitoid wasp specimens were identified using keys in An Illustrated Guide to the Parasitic Wasps Associated with Citrus Scale Insects and Mealybugs in Australia (Malipatil et al. 2000).

Effect of insecticides on beneficials

Aphids

Aphid colonies were reared in separate Plexiglass aphid-proof cages (350 mm deep, 400 mm high and 300 mm wide) in a glasshouse at the Department of Agriculture and Food, South Perth. Species reared included green peach (Myzus persicae (Sulzer)) and corn aphid (Rhopalosiphum maidis (Fitch)).

Ladybirds

Common spotted ladybird (Harmonia conformis) colonies which are found in olive groves were initiated from adults collected from olives in 2009. Ladybirds were reared in controlled temperature and light cabinets (12 hours light, 12 hours dark, 25°C). Adults (~10 adults per cage) were housed in transparent 850 mL plastic cages (110 mm high, 83 mm base diameter, 110 mm upper diameter, Genfac Plastics). The cage lid was fitted with muslin for ventilation and humidity control. Adults were given an ad libitum supply of live green peach and corn aphids. Cages were checked daily for eggs. If present, eggs were removed and placed into transparent containers (60 mm high, 55 mm base diameter, 70 mm upper diameter, Genfac Plastics) for larval rearing. Within 24 hours of second instar eclosion, larvae were removed from the cage with a fine paintbrush and placed into separate transparent plastic cages (37 mm high, 28 mm base diameter, 42 mm upper diameter, Huhtamaki, New Zealand). The lid of the cage was fitted with a 5 mm x 5 mm square of muslin for ventilation.

Insecticides

Insecticides and rates tested are listed in Table 2. Methidathion was included as a negative control as it is regarded to be highly toxic to beneficial insects. Test solutions were prepared by diluting the insecticide with the appropriate volume of water.

<table>
<thead>
<tr>
<th>Insecticide</th>
<th>Trade name</th>
<th>Formulation</th>
<th>Label rate</th>
<th>Supplier</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paraffinic oil</td>
<td>Biopest</td>
<td>815 g/L paraffinic oil</td>
<td>0.5%</td>
<td>Sacoa</td>
</tr>
<tr>
<td>Fenoxycarb</td>
<td>Insegar®</td>
<td>250 g/kg fenoxycarb</td>
<td>40 g/100 L</td>
<td>Syngenta</td>
</tr>
<tr>
<td>Pyriproxyfen</td>
<td>Admiral®</td>
<td>100 g/L pyriproxyfen</td>
<td>50 mL/100 L</td>
<td>Sumitomo Chemical Australia</td>
</tr>
<tr>
<td>Methidathion</td>
<td>Supracide®</td>
<td>400 g/L methidathion</td>
<td>125 mL/100 L</td>
<td>Syngenta</td>
</tr>
</tbody>
</table>
**Bioassays**

**Eggs**

Ladybirds were provided with freshly picked olive leaves on which to lay their eggs. Egg batches were collected within 24 hours of laying and dipped into insecticide solutions for 30 seconds (or water for the control), then placed into a plastic container (60 mm high, 55 mm base diameter, 70 mm upper diameter, Genfac Plastics) until eggs had hatched. Ladybird larvae were transferred into separate plastic cages approximately 48 hours after hatching. They were fed on live aphids (green peach, corn aphids), replenished daily for the duration of the experiment. There were three egg batches per treatment, and egg batches were randomly assigned to a treatment. The experiment was repeated twice.

**Larvae**

Freshly picked olive leaves were dipped into insecticide solution for 30 seconds, then placed into separate containers (60 mm high, 55 mm base diameter, 70 mm upper diameter, Genfac Plastics). Twelve first instar ladybird larvae were transferred into the container and exposed for 24 hours, then transferred into separate cages.

**Assessments**

Larvae were assessed each day until they either died or pupated. Death was defined by failure to move when stimulated with a fine brush. Ladybirds with abnormal symptoms such as body contractions or paralysis were monitored for possible recovery before being included in the number of dead. The dates that larvae pupated and emerged were recorded. Ladybird adults were weighed within 24 hours of emergence.

**Statistical analysis**

Percentage survival rates and developmental times (days) were analysed using GENSTAT software (12th edition). Mortality and eclosion rates were analysed using an analysis of variance, with the data transformed where necessary using an arcsine or log for reciprocal transformation to stabilise variances prior to analysis. The LSD mean separation test was used to compare means within significant ANOVAs ($P < 0.05$). Untransformed means and SEMS are shown in tables.

The results of the insecticidal treatments were compared with those of the control. Based on results (mortality, pupation), insecticides were classified into three evaluation categories according to the degree of harm that they cause the test species (Horne et al. 2009):

- green, low harm (< 25 per cent mortality)
- orange, moderately harmful (25–75 per cent mortality)
- red, harmful (> 75 per cent mortality).
Results and discussion

Seasonal trends in black scale abundance

The numbers of live scale (instars 1–3) and live mature females (data transformed to log scale) are shown in Figure 3. Immature stages were always more abundant than mature females, females with eggs or females with crawlers. Based on this data, there appears to be two populations of black scales at coastal sites per year. Populations of black scale reach a peak in December, approximately one month after an egg-laying period in October–November. This peak is composed mainly of second and third instars. There is a second smaller population peak between April and June, the result of a second egg-laying period in February–April composed mainly of second and third instars. During winter (June–September) all stages of black scale are present.
Crawler emergence

Figure 4 compares the mean number of crawlers with the mean number of mature females. The data have been transformed (log x + 1). The data suggest that crawler emergence is better monitored by counting the number of females with eggs than by counting mature females. In Spain, Tena (2007) found that eggs can hatch before females have finished the egg-laying period. By the time that females with crawlers are found during sampling, crawlers have already begun to emerge from eggs.

The egg duration period lasts approximately three months, though females with eggs can be present year-round. Crawlers can be found throughout the year, but populations are lowest in August–September. Significantly more crawlers are present in summer and autumn (December–April) than at any other time of the year (F=4.4, df=3, P=0.009; Figure 5). This agrees with previous findings by Spooner-Hart (2005).

Based on these seasonal trends, chemicals should be applied in December when the main crawler emergence occurs. However, growers may need a second application to control the second, smaller crawler emergence in April.

Movement of scale between leaves and twigs

More scales were present in summer than in any other season (F=12.8, df=3, P<0.001) (Figure 5) and significantly more black scale were found on the leaves than twigs (F=15.39, df=1, P<0.001) (Figure 6). Figure 7 shows that immature black scales initially settle on leaves and move to twigs as they mature; at the beginning of their development, approximately 80 per cent of first instars occur on leaves, but only 41 per cent of females are found on leaves.
Figure 5  Mean number of crawlers per branch per sample per season

Figure 6  Mean number (± SEM) of live black scale (all stages) per sample per season
Causes of black scale death

**Destructive sampling: immature stages**

No parasitised crawlers or first instar larvae were found. This was not unexpected since most parasitoids attack second and third instar larvae. The causes of death (instars 1–3) are shown in Figure 8. Death of crawlers could not be attributed to any major cause, and more crawlers died in summer and autumn than spring or winter (data not shown). Similarly, most immature stages died of unknown causes with 35 per cent of first instars, 32 per cent of second instars and 25 per cent of third instars dying. The percentage of larvae that were parasitised was lower: 2.5 per cent of second instars and 6 per cent of third instars. Other researchers have shown that immature stages are killed by high temperatures and low humidity, which is also likely to have been the main cause of death in our study.

Parasitism rates varied between seasons. Significantly more second instar larvae were parasitised in autumn and winter than spring and summer (F=3.41, df=3, P=0.02; Figure 9). For third instar larvae, parasites appeared to be more active in summer and autumn. However due to high variation within seasons, these results were not statistically significant (P>0.05).

**Destructive sampling: female scale**

The results of destructive sampling for parasites and predators of female black scale are shown in Figure 10. The major parasite of female scale was *Scutellista caerulea*. *S. caerulea* is unusual in that it is classified as a parasitoid of the female scale, and also as an egg predator, since it feeds on the eggs. Authors such as Tena (2007) list *S. caerulea* as a female parasitoid, which is a convention that has been adopted for this report.

Predation rates of *S. caerulea* reached high values (>60 per cent) at the end of black scale development. Mature females and females with eggs were more highly parasitised than females with crawlers (Figure 10). *Scutellista* larvae and pupae occurred year round, though populations peaked in March–April. There appears to be a correlation between the number of live females and live females with eggs and *S. caerulea* larvae and pupae (Figure 10). For example, a peak in the number of live females in February 2008 was followed by a peak in *S. caerulea* abundance in March 2008.
Figure 8  Percentage of larvae that died as a result of parasite activity compared to death from unknown causes.

Figure 9  Percentage of parasitised second and third instar black scale. Columns with the same letters do not differ at $P=0.05$. 

Figure 10  Top, percentage parasitism of female scales at different developmental stages. Middle, mean number of live females and females with eggs per sample per month. Bottom, mean number of live *Scutellista caerulea* larvae and pupae per sample.
Rearing out method

During the study, a large number of specimens were recovered using the rearing out method. Parasitoids belonged to seven species, with the genus *Metaphycus* comprising 12.3 per cent (Figure 11). *Scutellista caerulea* comprised 74.5 per cent of the total fauna. Nineteen *Metaphycus* specimens could not be identified to species as they were missing body parts required for identification (Table 3). *Metaphycus luteolus* was the most abundant *Metaphycus* species (7.1 per cent). The next most abundant species, *Moranila californica*, another egg predator of female black scale, comprised 3.4 per cent of the sample (Table 3). *Diversinervus elegans* was recovered from 1.1 per cent of samples and two of the four groves. It was originally introduced into Australia to control white wax scale (*Ceroplastes destructor*) in citrus (Waterhouse and Sands 2001), but has also been used for control of black scale overseas (Prinsloo 1997).

Hyperparasitoids

The hyperparasitoid, *Coccidoctonus dubius*, was collected from two of the four groves. The hyperparasitoid develops on mature larvae of *Moranila californica*, leaving behind a brown, cocoon-like remnant of the larval skin (Waterhouse and Sands 2001). Baker and Hardy (2005) similarly found hyperparasites including *C. dubius* in their survey. Since the number of hyperparasites appeared to be low and were rarely encountered during destructive sampling, they are unlikely to reduce the effect of primary parasitoids.

![Bar chart showing the number of parasitoid specimens per species](image)

Figure 11  The number of specimens of each of eight species of wasp parasitoid and one hyperparasitoid reared from black scale collected from four olive groves from October 2006 to October 2009

Seasonal occurrence

The seasonal occurrence of the three main species is shown in Figure 12. *Metaphycus* were found throughout the year, though were most abundant in winter. *Moranila californica* was also found throughout the year, but were most abundant in autumn. Interestingly, *Scutellista* were only recovered from samples in spring, but were found in destructive samples year round.
Figure 12  Mean number (± SEM) of specimens per sample per season

Table 3  Parasites recovered during the study

<table>
<thead>
<tr>
<th>Species</th>
<th>Origin</th>
<th>% of sample</th>
<th>Stage of black scale attacked</th>
<th>Grove presence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hymenoptera: Pteromalidae</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scutellista caerulea (Fonscolombe)</td>
<td>Introduced in 1903 from South Africa</td>
<td>74.5</td>
<td>Egg predator</td>
<td>4/4</td>
</tr>
<tr>
<td>Moranita californica (Howard)</td>
<td>1902 USA</td>
<td>3.4</td>
<td>Egg predator</td>
<td>3/4</td>
</tr>
<tr>
<td>Hymenoptera: Encyrtidae</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coccidoctonus dubius Girault</td>
<td>Native</td>
<td>1.9</td>
<td>Hyperparasitoid*</td>
<td>3/4</td>
</tr>
<tr>
<td>Metaphycus spp.</td>
<td></td>
<td>2.1</td>
<td>Hyperparasitoid*</td>
<td>4/4</td>
</tr>
<tr>
<td>M. helvolus (Compere)</td>
<td>1943–47 from the USA, 2003–09</td>
<td>2.1</td>
<td>Immature scales, adults</td>
<td>3/4</td>
</tr>
<tr>
<td>M. lounsburyi (Howard)</td>
<td>1988 South Africa via Israel &amp; Holland (as M. bartletti)</td>
<td>&lt;1</td>
<td></td>
<td>2/4</td>
</tr>
<tr>
<td>M. luteolus Timberlake</td>
<td>2001 from USA</td>
<td>7.1</td>
<td>3rd instar, mature, and ovipositing female black scale</td>
<td>3/4</td>
</tr>
<tr>
<td>Diverservus elegans Silvestri</td>
<td>1935–38 from Uganda, Kenya</td>
<td>1.1</td>
<td>Adults</td>
<td>2/4</td>
</tr>
<tr>
<td>Hymenoptera: Aphelinidae</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Euryischomyia flavithorax Girault</td>
<td>Native</td>
<td>&lt;1</td>
<td>Hyperparasitoid</td>
<td>2/4</td>
</tr>
</tbody>
</table>

* Parasitises and develops on the primary scale parasitoid.
Metaphycus species

At least four species of *Metaphycus* have been released into Australia for classical biological control of black scale. These include *M. anneckei* in 1902 in Western Australia, *M. helvolus* in 1943–1947 in New South Wales, Queensland and South Australia and *M. lounsburyi* in 1998 in Queensland (Appendix A). *M. luteolus* was released in 1999 to control soft brown scale and more recently for control of black and soft brown scale in citrus (Altmann 2004). *M. helvolus* and *M. lounsburyi* were released in olive groves in 2003 and 2004 (Spooner-Hart 2005). There is some confusion in the scientific literature about the correct identification of *Metaphycus*. *M. lounsburyi* was originally introduced into Australia as *M. barletti* (Waterhouse and Sands 2001), and *M. lounsburyi* is regarded to consist of two species: *M. hageni* and *M. anneckei* (Daane et al. 2000). Daane et al. (2000) suggest that *M. anneckei* is a more effective parasite than *M. hageni* and is dominant in coastal regions, whilst *M. hageni* is likely to be present where *M. lounsburyi* is recorded to have established, but has failed to control black scale. James Altmann (Biological Services) considers Australian *M. lounsburyi* to belong to the ‘lounsburyi-annekei complex’. *M. hageni* has never been released in Australia (J Altmann 2010, pers. comm.).

*Metaphycus* comprised 12.3 per cent of the total specimens collected, and were present at all four monitoring sites (see previous section). Three species were recovered: *M. helvolus*, *M. lounsburyi-annekei* complex and *M. luteolus*. With the exception of one grove where releases of *Metaphycus* had been made in 2008 and 2009, *Metaphycus* are likely to have established from releases in olive groves in Margaret River in 2003 (Spooner-Hart 2005). A larger survey of 26 olive groves in south-western Western Australia in 2005 yielded *Metaphycus* from only one site (Appendix B). In comparison, Baker and Hardy (2005) found that *Metaphycus* comprised 26 per cent of total specimens, and were collected from 78 per cent of the surveyed groves in South Australia. *M. helvolus* is reported to be an effective black scale parasitoid, especially in regions with a mild winter climate and where overlapping of scale generations occurs (Argyroiu and DeBach 1968).
Destructive sampling of black scale suggests that *Metaphycus* attack second and third instar larvae. Mean percentage parasitism was 1–6 per cent of second instars, and 2–8 per cent of third instars. *Metaphycus* were most abundant in autumn and winter. Substantial control of black scale was achieved in one organic grove in our study, with augmentative releases of *M. helvolus* and *M. luteolus*. Parasites were released on five occasions between 2008 and 2009 (January, April, August and November 2008, June 2009). An inspection of the site in 2010 found very little live black scale.

**Biology and description**

*Metaphycus* are small wasps, brownish-yellowish or yellow in colour and 0.8–1.7 mm in length (Figure 13). *Metaphycus* are released as adults, but are dispatched as parasitised pupae inside soft scales bodies. The adult females attack the young stages (first and second instars) of black scale, though Waterhouse and Sands (2001) report that they will also attack adults. Eggs are laid into the developing scale (internal parasite), and one or more adult wasps can develop from a single scale, depending on its size (Avidov and Podoler 1968; Kapranas 2006). Some *Metaphycus* species also kill scales by ‘host-feeding’; the female inserts her ovipositor (used for egg laying) into the scale and feeds on the scale’s body fluids as they ooze out.

**Scutellista caerulea**

![Figure 14](image)  

*Scutellista caerulea* was first released in Western Australia in 1902–1905 and in New South Wales in 1935–1938 (Appendix A). *Scutellista* comprised 74.5 per cent of the total fauna collected during our study, and from all four field sites. In south-western Western Australia in 2005, *S. caerulea* was found in 20 per cent of surveyed groves (Appendix B), and 70 per cent of the surveyed groves in South Australia (Baker and Hardy 2005).

Our study showed that *Scutellista* larvae and pupae occur year-round, with populations peaking in March–April. Parasitism exceeded 60 per cent in June 2007, but was usually around 20 per cent. Mature females and females with eggs were more highly parasitised than females with crawlers. There
appeared to be a correlation between the number of live females and live females with eggs and *S. caerulea* larvae and pupae, with peaks in the number of live females followed by a peak in *S. caerulea* abundance.

The importance with which *S. caerulea* is regarded as a biocontrol agent varies. Waterhouse and Sands (2001) list it as an effective biological control, whilst Spooner-Hart (2005) and Tena (2007) report that though *S. caerulea* can parasitise over 80 per cent of adult scale, its impact may be low. Spooner-Hart (2005) and Tena (2007) suggest that the effectiveness of *S. caerulea* is limited, because populations build up too late to prevent scale outbreaks. This is because the size of the *S. caerulea* population is controlled by the size of the black scale population (i.e. the availability of prey).

**Biology and description**

*Scutellista caerulea* originates from Africa, and is a predator of the eggs of several scale species (Smith et al. 1997). The adult is black, with bluish reflections, and appears beetle-like in profile (Figure 14). The female lays eggs among the scale eggs, or between the bottom of the scale and the leaf or branch surface before the scale has started to lay eggs. The larvae hatch in 4 to 5 days and feed on the scale eggs. Approximately 200 scale eggs are required for the larvae to complete development (15 to 20 days, longer if eggs are absent; Waterhouse and Sands 2001). After 14 to 21 days, the adult emerges through a hole that it cuts in the top of the scale.

**Predators**

Six species of predatory insects were collected during the three year study (Table 4). This included two species of lacewing and four species of ladybird; all have previously been recorded from black scale in Australia and are considered to be generalist predators (Waterhouse and Sands 2001). All feed on a wide range of prey that includes scale. In the 2005 WA survey, all ladybird species had previously been recorded with *Parapriasus australasiae* the most common. The scale-eating caterpillar, *Catoblepma dubia* (= *Mataeomera dubia*) (found at four of 26 groves in 2005) was not recovered in the current study.

Although ladybirds and lacewings are reported to feed on immature stages only, predation of black scale by ladybirds (adults or larvae) was recorded from female black scale (34), females with eggs (133), females with crawlers (3), as well as second (3) and third instar larvae (4). Predation is likely to have been underestimated since predators may consume the entire scale.

**Table 4. Main species of predatory insect occurring during the study.**

<table>
<thead>
<tr>
<th>Species</th>
<th>Stage attacked</th>
<th>Notes and reference</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Neuroptera: Chrysopidae</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Green lacewing, <em>Mallada</em> sp.</td>
<td>L</td>
<td>Native</td>
</tr>
<tr>
<td>Tasman’s lacewing, <em>Micromus tasmaniae</em> (Walker)</td>
<td>L</td>
<td>Native</td>
</tr>
<tr>
<td><strong>Coleoptera: Coccinellidae</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Common spotted ladybird, <em>Harmonia conformis</em> (Boisduval)</td>
<td>L</td>
<td>Native to WA</td>
</tr>
<tr>
<td><em>Menochilus sexmaculatus</em> (Fabricius)</td>
<td>L</td>
<td>Wilson 1960</td>
</tr>
<tr>
<td><em>Parapriasus australasiae</em> (Boisduval)</td>
<td>L</td>
<td>Native, Wilson 1960</td>
</tr>
</tbody>
</table>

*L = larvae.*
**Ants**

Six species of native ant were found in association with black scale in olives (Table 5). Though no exotic ant species were identified, only a small number of growers sent in samples and it cannot be assumed that exotic ant species are not problems in olive groves. The most common species in olive groves were *Iridomyrmex greenslade* and *I. discors* (Table 5). More than one species of ant can be found in a single grove, with four species occurring at a grove in Beverley for example. *Iridomyrmex* species are known to interfere with the biological control of honeydew-producing insects in Australian citrus orchards (Stevens et al. 1998), and are often found in areas where there is bare ground. In citrus, ant activity declines in winter, reaching minimal levels between June and August before increasing again during spring. Similar ant activity has been recorded from the south-west of Western Australia (Majer and Koch 1982). Stevens et al. (1998) consider that ant control should be carried out in late August–September for optimal control.

Control options include the use of physical or chemical barriers, and pruning of tree branches in contact with the ground to prevent ants from gaining access to trees and accessing their food sources. Physical barriers such as Teflon, applications of Tanglefoot, and treated tape can also be applied to the trunk, but may not be effective if ant populations are high. Frequent reapplication may also be required.

Growers can also spray ant nests directly with insecticide. However, as holes in nest complexes may not be interconnected, as many ant holes as possible should be sprayed. Ant baits such as a mixture of insecticide and sugar or honey and water may also be effective on some species. At present, no insecticides are registered for ant control in olives.

**Table 5. Ant species submitted for identification during study.**

<table>
<thead>
<tr>
<th>Species name</th>
<th>Grove presence</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Iridomyrmex greenslade</em></td>
<td>3/6</td>
</tr>
<tr>
<td><em>I. chasei concolor</em></td>
<td>1/6</td>
</tr>
<tr>
<td><em>I. rufoniger suchieri</em></td>
<td>1/6</td>
</tr>
<tr>
<td><em>I. discors</em></td>
<td>2/6</td>
</tr>
<tr>
<td><em>I. bicknelli</em></td>
<td>1/6</td>
</tr>
<tr>
<td><em>Rhytidoponera metallica</em></td>
<td>1/6</td>
</tr>
</tbody>
</table>

**Effect of insecticides on beneficials**

**Eggs**

The effect of insecticides on the survival of common spotted ladybird eggs 48 hours after exposure to insecticides is shown in Table 6. Control mortality was 37.1 ± 10.4 per cent. As expected, methidathion was the most toxic insecticide killing all eggs and was classified as harmful. Paraffinic oil was similarly highly toxic to eggs, killing the developing larvae by preventing air exchange.
Table 6. Classification of insecticides based on egg bioassays.

<table>
<thead>
<tr>
<th>Mortality of eggs</th>
<th>Treatment</th>
<th>Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>100.0%</td>
<td>Methidathion (Supracide®)</td>
<td>Harmful</td>
</tr>
<tr>
<td>82.5%</td>
<td>Fenoxycarb (Insegar®)</td>
<td>Moderately harmful</td>
</tr>
<tr>
<td>92.8%</td>
<td>Paraffinic oil (Biopest)</td>
<td>Harmful</td>
</tr>
<tr>
<td>54.7%</td>
<td>Pyriproxyfen (Admiral®)</td>
<td>Moderately harmful</td>
</tr>
</tbody>
</table>

Longer-term effects of the insecticides included an increase in the duration of the second to third instar stage and increased weight of emerged adults (Table 7). Larvae took 2 to 3 days to develop from first to second instars. Development of larvae from second to third instars took 4.4 days for the control, pyriproxyfen-treated larvae took 5.4 days, and fenoxycarb-treated larvae 8.4 days. Lengthening of an instar stage can occur when larvae are deprived of food until the requisite number of prey has been consumed. However, all larvae were fed similar amounts of aphids and it was more likely an effect of the insecticide on larval development. There were little differences between treatments from the development of third to fourth instars and duration of the pupal stage. Larvae took 3 to 3.5 days to develop from third to fourth instars, and the pupal duration stage lasted 6 to 7 days.

Table 7. Effect of insecticides on instar duration, pupal duration and adult weight.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Duration instar 1</th>
<th>Duration instar 2</th>
<th>Duration instar 3</th>
<th>Duration instar 4</th>
<th>Adult weight (mg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>2.8</td>
<td>4.4</td>
<td>3.2</td>
<td>6.3</td>
<td>0.016</td>
</tr>
<tr>
<td>Pyriproxyfen (Admiral®)</td>
<td>2.4</td>
<td>5.4</td>
<td>3.0</td>
<td>6.8</td>
<td>0.022</td>
</tr>
<tr>
<td>Fenoxycarb (Insegar®)</td>
<td>2.7</td>
<td>8.4</td>
<td>3.6</td>
<td>6.6</td>
<td>0.016</td>
</tr>
</tbody>
</table>

The weight of adults varied with treatment, with adult ladybirds from the pyriproxyfen-treated group heavier than adults from the control or fenoxycarb groups (F=8.41, 2f, P<0.001; Table 7). However, compared to the control (51 individuals), fewer eggs treated with fenoxycarb (25 adults) or pyriproxyfen (10 individuals) survived to adulthood.

**Larvae**

The effect of insecticides on the survival of common spotted ladybird first instar larvae 48 hours after exposure to insecticides is shown in Table 8. Control mortality was 16.7 per cent. Methidathion, fenoxycarb and pyriproxyfen were highly toxic, killing all larvae. Paraffinic oil was less toxic to larvae than eggs, and most larvae that survived treatment survived to adulthood.
Table 8. Classification of insecticides based on egg bioassays.

<table>
<thead>
<tr>
<th>Mortality</th>
<th>Treatment</th>
<th>Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>100%</td>
<td>Methidathion (Supracide®)</td>
<td>Harmful</td>
</tr>
<tr>
<td>100%</td>
<td>Fenoxycarb (Insegar®)</td>
<td>Harmful</td>
</tr>
<tr>
<td>100%</td>
<td>Pyriproxyfen (Admiral®)</td>
<td>Harmful</td>
</tr>
<tr>
<td>15.4%</td>
<td>Paraffinic oil (Biopest)</td>
<td>Low harm</td>
</tr>
</tbody>
</table>

Our studies confirm previous findings that pyriproxyfen is moderately to extremely toxic to ladybird species (Biobest 2010; Koppert 2010; Altmann 2009, pers. comm.). Pyriproxifen is regarded to be extremely toxic to ladybirds for extended periods (>6 months; Smith et al. 1999; Grafton-Cardwell et al. 2006) and should only be considered for spot treatment of infested areas.

Pyriproxyfen appears to be moderately toxic to black scale parasites (*Metaphycus bartletti* Annecke & Mynhardt, and *Microterys flavus*) and some predators (ladybirds, lacewings) (Mangoud 2008; Koppert 2010). Little published information was available on fenoxycarb, though Peleg (1983) found that fenoxycarb had no effect on the development of *Metaphycus bartletti*.

**Recommendations for black scale control**

- Chemical control with horticultural oils or insect growth regulators can be highly effective, but must be correctly timed to target the crawler and immature stages. There are two to three black scale populations in Australia per year and populations are often overlapping, with all stages present at the same time. Egg duration is approximately three months and the main crawler emergence period is in summer (December), with a smaller, second peak in autumn (April-May). Chemical control should target the first (summer) scale generation, though further control of the autumn generation may also be required.

- Two insect growth regulators (IGRs) are currently available to olive growers under registration, Admiral® (pyriproxifen) and permit, Insegar® (fenoxycarb; PER11939). Both are applied as foliar sprays. Pyriproxifen and fenoxycarb were classified as harmful to common spotted ladybird (*Harmonia conformis*) eggs and larvae in our laboratory trials. Overseas, pyriproxyfen is moderately to extremely toxic to ladybird species, and is regarded to be extremely toxic to ladybirds for extended periods (>6 months) in citrus. For this reason, we recommend that IGRs should only be considered for spot treatment of infested areas and in addition, the effect of pyriproxifen and fenoxycarb on *Metaphycus helvolus* and *M. anneckei*, and *Scutellista caerulea*, requires evaluation.

- Oils are acceptable for use by organic growers and are regarded to be IPM compatible. However, oils will kill any beneficial insects present on contact, though there is no residual activity.

- Ant control is required where growers are interested in biological control, as ants harvest honey dew from black scale and protect the scale from parasites and predators. No insecticides are registered in olives for this purpose. Overseas, bait stations with liquid sugar and boric acid (organically acceptable) are available for ant control.

- Surveys of olive groves in Western and South Australia indicate that the egg predator, *Scutellista caerulea*, is most common; *M. helvolus* and *M. anneckei* are poorly established. Effectiveness of *S. caerulea* is limited, because populations build up too late to prevent scale outbreaks. The establishment of *M. helvolus* and *M. louns buryi* in olives is recommended. However, there may be problems with obtaining insects for release.
Apple weevil

Introduction and background

Apple weevil (Otiorhynchus cribricollis Gyllenhaal) is an introduced insect in Australia, originating from the Mediterranean region of Europe. Apple weevil also has been reported in the USA (California) and New Zealand. The first record in Australia was in 1890 on olives in South Australia by Koebele (in Andrewartha 1933). It has been present in Western Australia since around 1900. In Western Australia, apple weevil is a pest of olives, has been recorded in pastures and on deciduous fruit tree crops, grapevines, potatoes, citrus, strawberries, vegetable brassicas crops and blue gums. Early studies on the weevil were undertaken by Andrewartha (1931, 1933).

Identification, biology and control

Apple weevil (Figure 15) has been reported as the second most important insect pest of olives by growers in Western Australia and South Australia (Spooner-Hart 2005). In Europe apple weevil is listed as a relatively minor pest with only occasional cause for concern in its region of origin (López-Villalta 1999). In olive groves the adult stage of apple weevil is the most damaging, feeding on leaves and girdling stems near the growing tips (Figure 16). This feeding can reduce the survival of young trees and can decrease tree vigour in older trees. By chewing pedicels (fruit stalks) (Figure 16), apple weevils can also directly reduce yield, though this feeding activity is secondary in importance to feeding on the vegetative parts of olive trees. The larval stage of apple weevil is soil-borne, feeding on the root system of olive trees and some of the ground cover crops within groves. This feeding is not considered damaging to olive trees, but the large number of adults that can occur in olive groves indicates root feeding may have some impact in such situations.

As far as natural control agents for apple weevil are concerned, only the entomopathogenic bacteria Serratia marcescens was reported to occur in its region of origin (López-Villalta 1999). Egg parasitoids are known for other pest weevils that occur in Australian horticultural situations—for garden weevil (Phlyctinus callosus) (Barnes 1987) and Fuller’s rose weevil (Pantomorus cervinus) (Madge et al. 1992). Details of apple weevil oviposition in the field are not known, but in the laboratory adults lay eggs singly on leaf surfaces. If this were the case in the field, then an egg parasitoid would be a very useful biocontrol agent. A search in its countries of origin would be of benefit in this regard.

Control of apple weevil in olive groves in Europe is based on the application of synthetic pyrethroid insecticide as a trunk drench. This is the only method currently registered for use in Australian groves and is available as a minor-use permit from the Australian Pesticides and Veterinary Medicines Authority (APVMA, PER 11781). In Australia, apple weevil is also a pest in deciduous fruit tree crops where, as well as trunk drenching, foliar application of indoxacarb insecticide is registered (Sutton et al. 2008).
Figure 15. A–F. Apple weevil life cycle stages G. Comparison of three weevil species (from left to right Fuller’s rose weevil (few hairs), garden weevil (few hairs) and apple weevil adult (has many short spines over the body and legs which makes the weevil likely to be trapped in the artificial fibre trunk bands).
Current control methods for apple weevil in olive groves rely on butt drenching with broad spectrum insecticide or physical exclusion with trunk barriers of synthetic fibre. One option considered by growers was the use of a polybutene sticky material available as Tac Gel or Bird Off®. When applied directly to the trunk of olive trees Tac Gel was found to be phytotoxic. In research on this type of product in deciduous fruit tree orchards against apple weevil, the product was found to perform well initially, but because the weevils are not repelled by the material and have to get stuck in it, the exclusion effect only lasted as long as the sticky material was not covered by bodies of trapped weevils (Williams et al. 2000). This is different to the case of a related pest garden weevil against which the sticky bands are very effective because they act primarily as a repellent and only in a minor way as a trap. The polybutene bands are no longer used by olive growers.

New methods for weevil control based on softer insecticides and new trunk barriers have been used by some olive growers or suggested as possible management options.

**Objectives**

The main objective was to assess the efficacy and practicality of a range of options for controlling apple weevil in commercial olive groves, to provide more sustainable and effective control. Methods suitable for conventional and organic groves were assessed.

During these assessments, the aspect of seasonal egg laying activity of apple weevil was investigated, because it has implications for the timing of implementation of management actions. A short study was also undertaken on diurnal movement of adult weevils to and from the canopy of olive trees.

**Management of apple weevil in commercial groves**

The management of apple weevil was examined in commercial olive groves with a history of problems with this pest. These groves were in the south-west of Western Australia where it is regarded to be an important pest. Olive groves in warmer production regions north of Perth are not subject to infestation of pest populations. Replicated field trials were undertaken to assess the efficacy and practicability of different control methods. Different trunk bands and foliar applied products were assessed on their ability to exclude weevils.
As part of this study on management and biology of apple weevil in olives, the pest status of the weevil was to be assessed on both newly-planted and mature trees. In one newly planted grove, extra olive trees were inter-planted among the commercial planting. In this way, untreated young trees could be sacrificed if weevil numbers were high enough to kill the young trees without affecting the commercial grove. Unfortunately, weevil numbers were low in this part of the grove and the study was abandoned. Assessment of damage to mature trees is described in the sections below. Each section describes the materials and methods, results and discussion by field site.

**Site 1. Witchcliffe, WA (323170.6mE 6233131.43mN)**

**2006/07 season**

The first trial at this site compared the efficacy of a range of insecticides as a trunk drench and foliar application of indoxacarb in young and mature olive trees. A second trial in the same site and season compared a range of ‘soft’ options in preventing apple weevil accessing the tree canopy, also in young and mature olive trees.

The insecticide treatments in the first trial are listed in Table 9. The trial was set up as a randomised complete block design with single trees as plots and five replications. The trial was undertaken on mature and young trees. The trunk drenches were applied with a HARDI backpack sprayer using a hand lance with a single nozzle calibrated to deliver 1 L spray solution per trunk to the mature trees and 0.5 L per trunk to the young trees. The insecticide solution was applied from the crotch of the tree and over the trunk down to ground level. The foliar application was made with a motorised sprayer with a dual nozzle hand lance to run off. Insecticides were applied once only on 7 December 2006. Because Avatar® (indoxacarb) is not registered for use on olives, no olives from the treated trees were included in the harvest from the grove.

<table>
<thead>
<tr>
<th>Product and type of application</th>
<th>Active ingredient</th>
<th>Rate/100 L water</th>
</tr>
</thead>
<tbody>
<tr>
<td>Untreated</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Dominex® butt drench</td>
<td>α-cypermethrin 10%</td>
<td>100 mL</td>
</tr>
<tr>
<td>Regent® butt drench</td>
<td>fipronil 20%</td>
<td>100 mL</td>
</tr>
<tr>
<td>Talstar® butt drench</td>
<td>bifenthrin 10%</td>
<td>100 mL</td>
</tr>
<tr>
<td>Avatar® foliar</td>
<td>indoxacarb 30%</td>
<td>17 g</td>
</tr>
<tr>
<td>Avatar® foliar</td>
<td>indoxacarb 30%</td>
<td>25 g</td>
</tr>
</tbody>
</table>

The trunk exclusion and foliar treatments in the second trial are listed in Table 10. These treatments included some products that are considered to be ‘soft’ compared to those in the insecticide trial. They are less residual and more narrow-spectrum in the range of pests and natural enemies that they might affect; some would also be acceptable for organic producers. The trial was set up as a randomised complete block design with single trees as plots, and five replications per treatment.

Barrier Glue (Figure 17) was obtained from South Africa where it is used as a trunk treatment to exclude garden weevil (*Phlyctinus callosus* Boheman) in deciduous fruit tree orchards and vineyards (C Jackson, South Africa, 2005, pers. comm.). The components of the glue were not disclosed, but it is grease-like and probably consists largely of petroleum-based products. Because of concerns over phytotoxicity, the glue was not applied directly to the trunk of olive trees but onto a 5 cm wide strip of black plastic attached around the trunk with a staple gun. Barrier Glue was applied to the black plastic in a strip approximately 2 cm wide.
Table 10  Details of ‘soft’ treatments applied to olive trees to assess their efficacy for the control of apple weevil, Witchcliffe, WA, in the 2006/07 season

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Type of application</th>
<th>Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Untreated</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Barrier</td>
<td>Glue on tape</td>
<td>Applied to black plastic band on trunk</td>
</tr>
<tr>
<td>Fluffy unbonded artificial fibre on trunk</td>
<td>Trunk band</td>
<td>-</td>
</tr>
<tr>
<td>White baked bonded artificial fibre on trunk</td>
<td>Trunk band</td>
<td>-</td>
</tr>
<tr>
<td>Surround® (kaolin clay)</td>
<td>Foliar application</td>
<td>First @ 5 kg/100 L, then 2.5 kg/100 L</td>
</tr>
<tr>
<td>Surround® (kaolin clay)</td>
<td>Butt drench</td>
<td>5 kg/100 L</td>
</tr>
</tbody>
</table>

Polyester fibre from the Tontine company was available as a ‘baked’ version (Figure 17), where the fibres were essentially welded together using heat to form sheets of bonded artificial fibre about 1 cm thick, or ‘unbaked’ (fluffy, bundle of entangled fibres) (Tontine, Imperial UNB (unbonded) Product Code 431554). Both types of artificial fibre trunk bands were attached at the centre of the band to the trunk of olive trees with electrical tape.

All exclusion bands were located approximately half way between the ground and the crotch of the tree. They were deployed just after the commencement of weevil emergence, but ideally should be placed on trees before weevil emergence in late spring/early summer.

Surround® (kaolin) is an emulsifiable form of refined kaolin clay and manufactured in the USA. It has activity against insects but is also applied as a sun screen to fruit trees to protect fruit from sunburn. Surround® was applied either to the trunks (in the same way as for the insecticide trunk drenches described above only using a motorised sprayer with a spray return to keep the Surround® in suspension in the spray solution) or to the canopy of the tree (using the same hand lance used to apply Avatar®) (Figure 18). For applications of Surround® to the foliage, the first application was at 5 kg per 100 L water and subsequent applications were applied at half this rate. All applications of Surround® to the trunk were at the higher rate of 5 kg per 100 L.

All treatments in the ‘soft’ products trial were applied initially on 7 December 2006. Surround® was reapplied in both treatments at rates indicated above and in Table 10 on 12 January and 7 March 2007. The efficacy of the treatments was compared on the basis of weevil abundance and damage to leaves and fruit.
Figure 17  Physical barriers to apple weevil A. Barrier glue applied over plastic. B. If applied directly to the bark it can kill the tree, as seen on this young tree showing poor top growth and shooting below where the glue was applied (between arrows). C. Artificially bonded and D unbonded (fluffy) fibre bands to prevent access to the canopy by apple weevil adults. E. Fluon/Teflon painted onto a black plastic. F. Relative abundance of apple weevil adults was monitored by placing cardboard bands on the trunk or leader of the tree and removing it over a cloth placed around the base of the tree to catch falling weevils.
The abundance of apple weevil adults in the canopy of olive trees was assessed with single-faced waxed cardboard bands. These bands were 10 cm wide and 30 cm long and were held in place on one of the leader branches of the olive trees with hook-and-loop Velcro strips stapled to the band. The corrugated side of the band was innermost on the leader. Because the weevils seek shelter during the day, a proportion of adults move under the bands. A cloth sheet was placed on the ground directly below each band before the band was removed to count the number of weevils sheltering there (Figure 17F). Apple weevil adults release their grip on the bands as they are removed from the tree and fall to the ground. If a cloth was not placed on the ground beforehand, the weevils would not be counted accurately.

Damage to leaves was assessed on a scoring system based on the visual severity of the characteristic leaf scalloping (Figure 16) resulting from feeding by adults. Because damage to last season’s foliage was still evident, feeding on new foliage only was assessed for this trial. The scoring system used was: 0 = no or very minor leaf scalloping; 1 = minor leaf scalloping within the leaf canopy; 2 = obvious leaf scalloping; 3 = severe leaf scalloping. Near harvest, fruit in the old part of the grove only was examined for both trials. Apple weevil adults have the reputation of girdling fruit stems in deciduous fruit tree orchards. Whether this was also the case in olive groves was assessed in this trial. Fruit was examined only on untreated trees and those treatments resulting in the greatest reduction of weevil numbers—the Talstar® butt drench in the insecticide trial and the fluffy unbonded artificial fibre band in the ‘soft’ trial. Where present, a maximum of 100 fruit were examined per tree. Fruit stems were assessed as being undamaged, partially chewed or completely girdled.

2007/08 season

Two further trials and one demonstration study were conducted in the 2007/08 season at the same olive grove in Witchcliffe using different olive trees near the mature olive trees of the 2006/07 trials.

The first trial compared the efficacy of a range of rates of the insecticides used as trunk drench treatments in the 2006/07 season. The insecticide treatments are listed in Table 11. The trial was set up as a randomised complete block design with single trees as plots and with five replications. The trunk drenches were applied at 1L spray solution per tree as stated above for the first trial. Insecticides were applied once only on 12 December 2007.
The second trial, located adjacent to the first trial, compared the efficacy a range of products applied to a trunk band consisting of unbonded artificial fibre in preventing apple weevil adults accessing the tree canopy. The trial was set up as a randomised complete block design with single trees as plots and with five replications. The products for comparison are listed in Table 12. These treatments included some products considered to be ‘soft’ compared to those in the insecticide trunk drench trial because they are less residual and more narrow-spectrum in the range of pests and natural enemies they might affect. While confirmation of organic accreditation would be required, all but Talstar are considered to be acceptable for organic production of olives. Abrace® as the trade name implies, relies on activity through desiccation by wearing away the insect cuticle. It is registered for use against larvae of Helicoverpa and Plutella and various stored-grain pests. Azamax® and Pyganic® are insecticides with anti-feedant and contact activity. These treatments were applied at 1 L per band and once only on 12 December 2007.

Table 11 Details of insecticide treatments applied as a drench to the trunks of olive trees to assess their efficacy for the control of apple weevil, Witchcliffe, WA, in the 2007/08 season

<table>
<thead>
<tr>
<th>Product</th>
<th>Active ingredient</th>
<th>Rate/100 L water</th>
</tr>
</thead>
<tbody>
<tr>
<td>Untreated</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Talstar®</td>
<td>bifenthrin 10%</td>
<td>50 mL</td>
</tr>
<tr>
<td>Talstar®</td>
<td>bifenthrin 10%</td>
<td>100 mL</td>
</tr>
<tr>
<td>Talstar®</td>
<td>bifenthrin 10%</td>
<td>200 mL</td>
</tr>
<tr>
<td>Dominex®</td>
<td>α-cypermethrin 10%</td>
<td>50 mL</td>
</tr>
<tr>
<td>Dominex®</td>
<td>α-cypermethrin 10%</td>
<td>100 mL</td>
</tr>
<tr>
<td>Dominex®</td>
<td>α-cypermethrin 10%</td>
<td>200 mL</td>
</tr>
<tr>
<td>Regent®</td>
<td>fipronil 20%</td>
<td>50 mL</td>
</tr>
<tr>
<td>Regent®</td>
<td>fipronil 20%</td>
<td>100 mL</td>
</tr>
<tr>
<td>Regent®</td>
<td>fipronil 20%</td>
<td>200 mL</td>
</tr>
</tbody>
</table>

The demonstration study undertaken at Witchcliffe had the objective of determining whether control of apple weevil in one season could lead to reduced insect abundance the following season. This involved recording the abundance of adults on trees treated with one of four treatments: untreated; butt drenched with insecticide early in the season as weevils commenced emergence; butt drenched later in the season as weevils commenced activity after the summer quiescence; and insecticide application both at emergence and in summer.

The insecticide treatment was a butt drench with 1 mL/L of Talstar® 80% EC at 1 L spray solution per tree. Treatment plots were a grid of three trees by three trees, with tree spacing of 5 m between trees along a row and 8 m between rows. Because of the relatively large plot size, this demonstration consisted of two replications only with no intent to statistically analyse the results. Weevil abundance was monitored with cardboard bands on a leader above the crotch of the tree.
Table 12  Details of treatments applied to unbonded artificial fibre trunk bands on olive trees to assess their efficacy for the control of apple weevil, Witchcliffe, WA, in the 2007/08 season

<table>
<thead>
<tr>
<th>Trunk band + product</th>
<th>Active ingredient</th>
<th>Rate mL/100 L water</th>
</tr>
</thead>
<tbody>
<tr>
<td>Untreated</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>White baked bonded artificial fibre on trunk</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Fluffy unbonded artificial fibre (FF) on trunk</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>FF + Talstar®</td>
<td>bifenthrin 10%</td>
<td>100</td>
</tr>
<tr>
<td>FF + # Abrade®</td>
<td>amorphous silica 50%</td>
<td>10 000</td>
</tr>
<tr>
<td>FF + *Azamax®</td>
<td>azadirachtin A &amp; B 1.18%</td>
<td>1 200</td>
</tr>
<tr>
<td>FF + *Pyganic®</td>
<td>pyrethrins 1.3%</td>
<td>1 200</td>
</tr>
<tr>
<td>FF + Azamax® + Pyganic®</td>
<td>See above</td>
<td>1 200 + 1 200</td>
</tr>
</tbody>
</table>

# Abrade® distributed by Grow Choice P/L; * Azamax® supplied by Organic Crop Protectants P/L; * Pyganic® supplied by MGK Asia-Pacific P/L.

Results and discussion

2006/07 season

The abundance of apple weevil adults in the young and mature olive trees where insecticides were applied is shown in Figure 19. In the early part of the season, apple weevil was much more abundant in the mature trees than in the young trees, but the abundance of the weevil was more similar towards the end of the season. All insecticide treatments reduced the abundance of weevil adults at least initially compared to unsprayed trees. This effect was more prolonged in the mature trees. Of the butt drench insecticides, the insecticide that consistently resulted in the lowest number of weevils recorded in the bands for both young and mature trees was Talstar®. The use of Avatar® as a foliar application performed as well as the butt drenches on mature trees, but its effect was not as prolonged in the young trees.

The abundance of apple weevil adults in the young and mature olive trees where the ‘soft’ treatments were applied is shown in Figure 20. These treatments were applied to trees adjacent to those in the insecticide trial. Therefore the difference in weevil abundance between the mature and young tree parts of the grove described above also applies for this trial. While weevil abundance was greatest in untreated trees, not all ‘soft’ treatments resulted in a reduction in weevil numbers. Unbonded artificial fibre bands resulted in the greatest reduction in weevil abundance which persisted for the duration of the season. Barrier Glue and foliar application of Surround® were among the better performing of the other treatments.

The level of leaf scalloping by adult apple weevils for insecticide treatments in the young and mature trees is shown in Figure 21. The relatively low numbers of weevils in the young part of the olive grove resulted in only low levels of leaf feeding even in untreated trees. Least feeding occurred in trees that had been treated with the butt drenches compared with the two foliar application treatments using Avatar®. In the mature trees, apple weevil feeding was reduced most in trees receiving the Talstar® butt drench and the two foliar application treatments using Avatar®. In none of these treatments was the leaf damage any greater than minor to obvious.

The level of leaf scalloping by adult apple weevils for ‘soft’ treatments in the young and mature trees is shown in Figure 22. As was the case in the insecticide trial, there was only a low level of leaf feeding even in untreated trees. At various times the Barrier Glue and unbonded artificial fibre bands resulted in the least feeding. In the mature trees, apple weevil feeding was reduced most consistently where Barrier Glue, fluffy bonded artificial fibre bands and foliar-applied Surround® were used.
Figure 19  The abundance of apple weevil adults (square root transformed) in monitoring bands on (a) young and (b) mature olive trees treated with insecticides applied as a butt drench (Alpha = α-cypermethrin (Dominex®); Fip = fipronil (Regent®); Bif = bifenthrin (Talstar®)), or as a foliage application (Indox = indoxacarb (Avatar®) at two different rates).

See Table 9 for details of treatments. Arrow indicates the date of insecticide application. Bars on graphs are LSD=0.05 and levels of statistical significance: ns = not significant; * = P<0.1; ** = P<0.01; *** = P<0.001.
Figure 20  The abundance of apple weevil adults (square root transformation) in monitoring bands on (a) young and (b) mature olive trees treated with ‘soft’ options as an exclusion band on the tree trunk (Glue = Barrier Glue; Fluffy = unbonded artificial fibre; Baked = bonded artificial fibre in sheet form; SurButt = Surround® applied to the trunk of olive trees), or as foliar application (SurFol = Surround® applied to the foliage).

See Table 20 for details of treatments. Arrows indicate the time of first application of all treatments and two follow up applications of Surround®. Arrows indicate the dates of product application. Bars on graphs are LSD=0.05 and levels of statistical significance: ns = not significant; * = P<0.1; ** = P<0.01; *** = P<0.001.
Figure 21. The severity of leaf feeding based on a scoring system (refer text; data presented as square root transformation) by apple weevil adults on (a) young and (b) mature olive trees treated with insecticides applied either as a butt drench (Alpha = α-cypermethrin (Dominex®); Fip = fipronil (Regent®); Bif = bifenthrin (Talstar®)) or as a foliar application (Indox = indoxacarb (Avatar®) at two different rates).

See Table 9 for details of treatments. Bars on graphs are LSD=0.05, levels of statistical significance: ns = not significant; * = P<0.1; ** = P<0.01; *** = P<0.001.
Figure 22. The severity of leaf feeding based on a scoring system (refer text; data presented as square root transformation) by apple weevil adults on (a) young and (b) mature olive trees treated with ‘soft’ options as an exclusion band on the tree trunk (Glue = Barrier Glue; Fluffy = unbonded artificial fibre; Baked = bonded artificial fibre in sheet form; SurButt = Surround® applied to the trunk of olive trees), or as an application to the foliage (SurFol = Surround® applied to the foliage).

See Table 10 for details of treatments. Bars on graphs are LSD=0.05, levels of statistical significance: ns = not significant; * = P<0.1; ** = P<0.01; *** = P<0.001.

Assessing the level of feeding on fruit stalks in the trial in the mature part of the grove showed that feeding was minor. In untreated trees in the insecticide and the ‘soft’ trial, the proportion of fruit where stalks had some level of feeding was 9.1 and 11 per cent respectively. On trees receiving the Talstar® drench and fluffy bonded artificial fibre bands, the proportions were 0.4 and 0.6 per cent respectively. Only one fruit was seen to have its stalk completely girdled. The level of stem feeding was generally restricted to a nick in the pedicel and the fruit did not appear to be adversely affected.
The stalk also appeared strong, suggesting that fruit with stalks of this level of feeding were unlikely to fall prematurely.

2007/08 season

The abundance of apple weevil adults in the trial where trunk drenches with the insecticides α-cypermethrin, bifenthrin and fipronil were applied at a range of rates are given in Figure 23. All insecticides reduced weevil abundance, with bifenthrin and fipronil being more effective. For all insecticides, the higher the application rate the greater the reduction in apple weevil abundance. This was most apparent for α-cypermethrin, and to a lesser extent, fipronil.

The resumption of apple weevil activity in late summer could have been a result of weevils not controlled by the trunk drenches. Alternatively, weevil activity could have been the result (at least partially) of immigration from surrounding trees that had not been treated with insecticide, bearing in mind that only single tree plots were used in this trial. Should the late summer/autumn resurgence of weevil activity be from weevils not controlled with the butt drench in early summer, a second trunk drench in late February to early March may have given even better control of apple weevil. This may mean that an insecticide application the following season may have been unnecessary, given that egg laying activity of apple weevil only commences towards the end of summer (see section below on egg laying activity for apple weevil).

There was a significant difference in the abundance of apple weevil adults at the start of the following season, but this appeared to be due to the higher numbers in the trees which had been treated with α-cypermethrin the previous season. Essentially, the abundance of apple weevil adults appears to have become relatively uniform across this trial site.

The abundance of apple weevil adults in the olive trees where bonded and unbonded artificial fibre trunk bands were either untreated, or other trees with unbonded bands with bands sprayed with different products are shown in Figure 24. Results for the treatments are presented in two graphs for clarity.

The treatments that resulted in the least number of weevils were bifenthrin and Pyganic® alone applied to the unbonded artificial fibre bands. The untreated white baked and unbonded artificial fibre bands resulted in minor reduction of weevil abundance early, with resurgence in weevil numbers in late summer/autumn. The early high occurrence of weevils in these untreated bands could have been due to bands being placed on trees after some weevil emergence, with adults already having ascended the trees. Alternatively, or in addition, spray treatments may have resulted in some mortality or repellence of weevils at the base of trees since a considerable proportion of the spray solution dripped from the unbonded artificial fibre to the ground during application.

Whether there was an inconsistency in treatment effects or a high level of variability in weevil abundance across the trial site, the combination treatment of Azamax® and Pyganic® did not perform as well as Pyganic® applied alone. Azamax® applied alone seemed to increase the efficiency of the unbonded artificial fibre bands in excluding weevils from the olive tree.
Figure 23. Abundance of apple weevil adults (square root transformation) in monitoring bands in olive trees treated with three rates of the insecticides as a butt drench: (a) Alpha = α-cypermethrin (Dominex®), (b) Fip = fipronil (Regent®) and (c) Bif = bifenthrin (Talstar®) during the 2007/08 season, Witchcliffe, WA. The arrow indicates the date of application.

Bars on graphs are LSD=0.05 and levels of statistical significance: ns = not significant; * = P<0.1; ** = P<0.01; *** = P<0.001.
Figure 24. The abundance of apple weevil adults (square root transformation) in monitoring bands in olive trees where untreated bonded (baked) and unbonded artificial fibre bands (FF) were placed on the main trunk with further trees receiving the unbonded fibre bands sprayed with products (see Table 12 for details) during the 2007/08 season, Witchcliffe, WA.

Results separated into two graphs for clarity. The arrow indicates the date of application of products to bands. Bars on graphs are LSD = 0.05 and levels of statistical significance: ns = not significant; * = P<0.1; ** = P<0.01; *** = P<0.001.

The application of Abrade® to the unbonded artificial fibre bands did not appear to improve their ability to exclude weevils from entering the tree canopy. There was a significant difference in the abundance of apple weevil adults at the start of the following season but unlike the insecticide trial, trees that were untreated in the 2007/08 trial had the greatest number of weevils present. All treatment trees had fewer weevils present.

The results of the demonstration study to determine whether different levels of weevil control in one season achieved with different timing of insecticide butt drench applications would carry over into the following season are given in Figure 25. In the season of insecticide application, the abundance of apple weevil was reduced accordingly. Although only one count was undertaken in the following
season, the indication was that weevil abundance was greatest in the area untreated the previous season. Further monitoring would have clarified whether there were differences between the insecticide treatments which were designed to determine if the late application at the time of egg laying (see section of this report on egg laying) would be sufficient to reduce numbers of weevils the following season.

Figure 25. The abundance of apple weevil on olive trees either untreated or treated with an insecticide butt drench early in the season (E), late in the season (L) or at both times (E+L) during the 2007/08 season, Witchcliffe, WA. Arrows indicate dates of insecticide application.

This effect of control of the weevil between seasons indicates that a concerted effort of weevil management in one season could be of benefit in control not being required the following season at least. Whether good control in one season would last for more than one following season would depend on the level of control achieved initially and the breeding potential of the weevil.

Site 2. Kendenup, WA (559516.17mE; 6181871.3mN)

2006/07 season

One trial was conducted in the 2006/07 season at an organic olive grove planted in 2001 at Kendenup. Apple weevil had been a pest in this grove and bonded bonded artificial fibre bands were used to help exclude weevils from the canopy of trees. The grower claims that although bands trapped many weevils, it was still a pest in the grove. Bands that had been newly placed on trees early in the season in September 2006 were removed on 8 December 2006 from the part of the grove where the trial was conducted. These bands were retained and the dead weevils in them counted to assess weevil pressure there. An average of 379 (± 37) weevils per band was recorded.

The efficacy of a range of trunk barriers and foliar sprays of products were compared to assess whether improved control of apple weevil could be achieved. Treatments are listed in Table 13. Details of some of these treatments and methods of application have been given above in the description of the trials at Witchcliffe. Myco-Force™ is a product from Nutri-Tech Solutions P/L (www.nutri-tech.com.au). The company description and claims in relation to this product are: “Myco-Force™ is a talc-based formulation containing the beneficial fungal species *Beauveria bassiana*, *Metarhizium anisopliae*, and *Verticillium lecanii*. This product also contains a growth promoting bacteria *Bacillus polymyxa*. The inclusion of these four species together in one product may prove to be extremely effective”. Azidol® is produced by Eco-Growth International P/L (www.ecogrowth.com.au/) and contains the neem extract azadirachtin; in text, tables and figures below, reference to ‘neem’ is synonymous with the products Azidol® and Azamax®, being the
primary active ingredient of these products. The trial was set up as a randomised complete block design with single trees as plots and with five replications.

Table 13. Details of treatments applied to olive trees to assess their efficacy for the control of apple weevil, Kendenup, WA, in the 2006/07 season.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Type of application</th>
<th>Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Untreated</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Barrier Glue</td>
<td>To black plastic band on trunk</td>
<td>25 mm wide band of glue</td>
</tr>
<tr>
<td>Fluffy unbonded artificial fibre</td>
<td>Trunk band</td>
<td>-</td>
</tr>
<tr>
<td>White bonded artificial fibre (baked)</td>
<td>Trunk band</td>
<td>-</td>
</tr>
<tr>
<td>Surround®</td>
<td>Foliar (to run off)</td>
<td>5 kg/100 L, then 2.5 kg/100 L</td>
</tr>
<tr>
<td>Surround®</td>
<td>Butt drench (1 L/tree)</td>
<td>5 kg/100 L</td>
</tr>
<tr>
<td>Myco-Force™</td>
<td>Foliar (to run off)</td>
<td>200 g/100 L</td>
</tr>
<tr>
<td>Azidol® (neem)</td>
<td>Drench on baked fibre trunk band</td>
<td>1.5 L/100 L</td>
</tr>
</tbody>
</table>

All treatments were applied on 8 December 2006. Surround® was reapplied on 20 December 2006, 16 January and 30 March 2007. The Myco-Force™ foliar spray and Azidol® (neem) butt drench were reapplied on 20 December 2006 and 30 March 2007. The effectiveness of treatments on the abundance of apple weevil was assessed as described above.

2007/08 season

The first trial examined the duration of effectiveness of the two types of artificial fibre bands placed on the olive trunks in the 2006/07 season. For this, the original bonded and unbonded (fluffy) artificial fibre bands were left on the tree from the previous season. The ability of these bands to prevent apple weevil gaining access to the canopy of olive trees during weevil emergence for the 2007/08 season was compared with new fibre bands of each type placed on trees where two of the treatments did not prevent apple weevil entering the tree canopy in the previous season. These ineffective treatments were the foliar applications of Surround® and Myco-Force™.

The abundance of weevils was monitored to mid-December only. It was apparent by this time that apple weevil adults were not prevented from accessing the olive tree canopy where either of these artificial fibre bands had been placed on trees (see Figure 27). This weevil pressure but apparent lack of weevil control was in complete contrast to results the previous season both at Witchcliffe and Kendenup. As a result of this outcome, a further trial was set up in this same part of the olive grove. This was considered acceptable because many of the treatments investigated in the 2006/07 season did not result in significantly different weevil numbers to untreated trees—see Figure 26 below.

This new trial examined the use of placing extra bands of fluffy unbonded fibre on the tree trunk as well as a comparison of a range of other trunk application treatments. Details of these treatments are given in Table 14. As well as placing up to three fluffy fibre bands on trunks of olive trees, the other trunk exclusion treatments assessed included painting Fluon on a black plastic trunk bands and various formulations of natural chilli plant extract either sprayed onto fluffy bands or applied directly to the trunk of olive trees.

Fluon is an ingredient used to produce the non-stick surface of frypans and is used in some formulations of paint. The product, which is a suspension, has a milky appearance but dries to a powder on contact with air (see Figure 17). The result is a very smooth surface over which insects have difficulty gaining a foothold. Such a product is most effective in preventing insect movement when applied to a vertical surface. In order to achieve this effect the product must be applied to an already smooth surface such as black plastic. On olive trees, black plastic was cut into strips 100 mm
wide and of appropriate length to fit around the olive trunk and held in position using a staple gun. The Fluon was applied using a paint brush.

Ultra Wax and ‘Vegie’ chilli are both products containing chilli extract and were supplied by Organica Australia Pty Ltd. The main difference between the products is that ‘Vegie’ chilli contains plant-extracted natural pyrethrum. Both products were reputed to have repellent and toxic activity against insects (Robert Jack, pers. comm.). While they may be applied to foliage, we restricted their use to application to the trunk of olive trees either directly or to artificial fibre bands attached to the trunk. The design of the trial was a randomised complete block with five replications per treatment. Individual plots were a single olive tree.

Table 14 Details of treatments applied to olive trees to assess their efficacy for the control of apple weevil, Kendenup, WA, in the 2007/08 season

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Type and dates of application</th>
<th>Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fluffy unbonded artificial fibre x 1</td>
<td>Trunk band; new bands – 18 Dec 07; 28 Feb 08</td>
<td>-</td>
</tr>
<tr>
<td>Fluffy unbonded artificial fibre x 2</td>
<td>Trunk band; new bands – 18 Dec 07; 28 Feb 08</td>
<td>-</td>
</tr>
<tr>
<td>Fluffy unbonded artificial fibre x 3</td>
<td>Trunk band; new bands – 18 Dec 07; 28 Feb 08</td>
<td>-</td>
</tr>
<tr>
<td>*Fluon</td>
<td>On black plastic band on trunk – 18 Dec 07; 21 Feb; 13 Mar 08</td>
<td>50 mm wide band</td>
</tr>
<tr>
<td>Ultra Wax (WAX 5F)</td>
<td>Drench on unbonded fibre trunk band – 18 Dec 07; 28 Feb 08</td>
<td>5 mL/L</td>
</tr>
<tr>
<td>Ultra Wax (WAX 10F)</td>
<td>Drench on unbonded fibre trunk band – 18 Dec 2007; 28 Feb 08</td>
<td>10 mL/L</td>
</tr>
<tr>
<td># Ultra Wax (WAX 10T); (WAX 5F)</td>
<td>Drench on trunk – 18 Dec 07; # 21 Feb 08</td>
<td>10 mL/L; # 5 mL/L</td>
</tr>
<tr>
<td>‘Vegie’ chilli (VEG10)</td>
<td>Drench on unbonded fibre trunk band – 18 Dec 2007; 28 Feb 08</td>
<td>10 mL/L</td>
</tr>
</tbody>
</table>

*Fluon: Z RM Teflon Resin TE3893-N from Nutech Paint P/L, Seaford, Victoria.; # This treatment changed to ‘Vegie’ chilli at 5 mL/L on unbonded trunk band on 21 Feb 2008; VEG5 (see text for explanation).

An assessment of weevil damage to olive trees was made on 7 April 2008. Fifteen tips were examined on each tree of the growth in the 2007/08 season. This avoided assessment of leaf damage caused by apple weevil in previous seasons to older foliage. Each tip was assessed according to the following visual damage rating score: 0 = none; 1 = minor; 2 = moderate; 3 = severe; 4 = extreme.

Treatments in this trial using unbonded fibre trunk bands and Fluon were judged to have given poor protection from apple weevil (see Figure 28). They were replaced with other exclusion methods for assessment during the remainder of the 2007/08 season (see Table 15 for details).

The trees previously receiving these treatments were treated with Pyganic® or a lower rate of ‘Vegie’ chilli at 5 mL/L sprayed onto an unbonded fibre trunk band. The details for Pyganic® are provided in Witchcliffe in the 2007/08 season. An old batch (more than 12 months since purchase) and a new batch of Pyganic® were compared, to determine possible effects of shelf life on efficacy. The trial design was a randomised complete block with five replications per treatment. Individual plots consisted of a single olive tree.

A second trial was conducted in the 2007/08 season, located adjacent to the trial described above. The treatment details are given in Table 16. The attractant mixed with Azamax® was supplied by Organic Crop Protectants P/L. Trees that initially were untreated with no protection from apple weevil adults subsequently had unbonded fibre bands attached to the trunks because it was considered that the number of adults at this trial site warranted some form of protection for olive trees that would have otherwise been assigned to an ‘untreated’ check treatment.
Table 15  Details of treatments superimposed on treatments in the same trial area and season for treatments in Table 14 that had not controlled apple weevil Kendenup, WA, in the 2007/08 season.

New treatments applied 8 April 2008

<table>
<thead>
<tr>
<th>Original treatment</th>
<th>New treatment</th>
<th>Type of application</th>
<th>Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>#Fluffy unbonded fibre 1</td>
<td>Same</td>
<td>Trunk band</td>
<td>-</td>
</tr>
<tr>
<td>#Fluffy unbonded fibre 2</td>
<td>Old batch Pyganic®</td>
<td>Drench on unbonded fibre trunk band</td>
<td>12 mL/L</td>
</tr>
<tr>
<td>#Fluffy unbonded fibre 3</td>
<td>New batch Pyganic®</td>
<td>Drench on unbonded fibre trunk band</td>
<td>12 mL/L</td>
</tr>
<tr>
<td>#Fluos</td>
<td>Vegie chilli VEG5</td>
<td>Drench on unbonded fibre trunk band</td>
<td>5 mL/L</td>
</tr>
<tr>
<td>Ultra Wax (WAX 5F)</td>
<td>Same</td>
<td>Drench on unbonded fibre trunk band</td>
<td>5 mL/L</td>
</tr>
<tr>
<td>Ultra Wax (WAX 10F)</td>
<td>Same</td>
<td>Drench on unbonded fibre trunk band</td>
<td>10 mL/L</td>
</tr>
<tr>
<td>VEG5</td>
<td>Same</td>
<td>Not retreated</td>
<td>5 mL/L</td>
</tr>
<tr>
<td>VEG10</td>
<td>Same</td>
<td>Not retreated</td>
<td>10 mL/L</td>
</tr>
</tbody>
</table>

As at Witchcliffe, a demonstration to determine whether control of apple weevil in one season could lead to reduced insect abundance the following season was undertaken at Kendenup. This demonstration did not commence until April, after which some egg laying would likely have commenced. Trees with unbonded fibre trunk bands were either left untreated or treated with ‘Vegie’ chilli at 5 mL/L and approximately 1 L spray solution per band applied on 7 April 2008. For the untreated and one of the sprayed trunk band areas, the central nine trees were monitored in an area five trees wide and five trees long. In the other area where bands were sprayed, the central eight trees of a four by six tree grid were monitored. Data from this demonstration were not designed for statistical analysis.

Table 16  Details of treatments applied on 11 December 2007 to different trunk fibre bands on olive trees to prevent apple weevil adults accessing the tree canopy, Kendenup, WA, 2007/08

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Rate</th>
<th>Second application</th>
<th>Third application</th>
</tr>
</thead>
<tbody>
<tr>
<td>21 Dec 07</td>
<td>Third application</td>
<td>28 Feb 08</td>
<td></td>
</tr>
<tr>
<td>Untreated then to unbonded fibre on 21 Dec 07</td>
<td>-</td>
<td>Banded</td>
<td>New band</td>
</tr>
<tr>
<td>Bonded fibre (BF)</td>
<td>-</td>
<td>-</td>
<td>New band</td>
</tr>
<tr>
<td>Unbonded fibre (Fluffy, FF)</td>
<td>-</td>
<td>-</td>
<td>New band</td>
</tr>
<tr>
<td>FF + Azamax® (neem) (FFAza)</td>
<td>12 mL/L</td>
<td>Re-treated</td>
<td>Re-treated</td>
</tr>
<tr>
<td>FF + Azamax® + Attractant (FFAzaAtt)</td>
<td>12 mL/L</td>
<td>Re-treated</td>
<td>Re-treated</td>
</tr>
<tr>
<td>FF + Abrade® (FFAbd)</td>
<td>100 mL/L</td>
<td>Re-treated</td>
<td>Re-treated</td>
</tr>
<tr>
<td>FF + Pyganic® (FFPyg)</td>
<td>12 mL/L</td>
<td>Re-treated</td>
<td>Re-treated</td>
</tr>
<tr>
<td>FF + Azamax® + Pyganic® (FFAzPyg)</td>
<td>12 + 12 mL/L</td>
<td>Re-treated</td>
<td>Re-treated</td>
</tr>
</tbody>
</table>
Results and discussion

2006/07 season

In the 2006/07 season, the only treatment that consistently reduced weevil numbers in the canopy was unbonded fibre (fluffy) bands on trunks (Figure 26). The Barrier Glue reduced numbers at times, but the integrity of the band was compromised by the black plastic substrate moving, and allowing a channel of unprotected area along which weevils could move up the trunk. Constant maintenance was required to maintain the complete circumference of glue on the plastic. The baked fibre band was only partially successful in keeping weevils from entering the tree canopy. The application of Azidol® (neem) to the baked fibre band did not improve their effectiveness to weevil movement.

Figure 26. Abundance of apple weevil adults (square root transformation) in monitoring bands in olive trees where untreated bonded (baked) and unbonded (fluffy) artificial fibre bands were placed on the main trunk. Other treatments included bonded fibre bands sprayed with Azidol® (neem), or trunks and canopies treated with other products (see Table 13 for details), Kendenup, WA.

Results are separated into two graphs for clarity. Arrows indicate the dates of application of products (see text for details). Bars on graphs are LSD=0.05 and levels of statistical significance: * = P<0.1; ** = P<0.01; *** = P<0.001.
2007/08 season

All bands failed to prevent weevils accessing the olive tree canopy in the early part of the 2007/08 season (Figure 27). This included artificial fibre bands, bonded and unbonded, old bands deployed the previous season, and new bands applied to trees at the start of the 2007/08 season.

Figure 27. Adult apple weevil abundance in monitoring bands in olive trees where untreated bonded and unbonded (fluffy) artificial fibre bands from the previous season (‘Old’) were compared with weevil numbers in trees where ‘New’ bands were placed.

The results of treatments applied to trees in the same area are given in Figure 28. Treatments most successful in excluding apple weevil from the tree canopy were those that contained the chilli extract—‘Vegie’ and Wax (Figure 28).

Figure 28. Adult apple weevil abundance (square root transformation) in monitoring bands in olive trees where a range of exclusion bands were applied to trunks (see Table 14 for details). Arrows indicate the dates of application of products. Bars on graphs are LSD=0.05 and levels of statistical significance: ns = not significant; * = P<0.1; ** = P<0.01; *** = P<0.001.

When applied directly to the tree trunk, chilli was less effective than when applied to the artificial fibre trunk band. Using the higher rate of wax on the trunk band resulted in a lower number of weevils in the monitoring band, compared to the lower rate of chilli, though this result was not statistically significant. The placement of one, two or three fibre trunk bands to olive trees resulted in the same
number of weevils in the monitoring bands. This apparent poor control was unexpected and at variance to results at Witchcliffe.

The only possible reason for poor control was the extent of weevil pressure. When compared to the result for untreated and chilli treated unbonded fibre trunk bands, Fluon on the black plastic trunk bands was not effective in preventing weevils accessing the tree canopy. As mentioned above, some of the treatments in this area were changed and monitoring of bands continued. The decision to do this was based on the poor exclusion afforded by the unbonded fibre trunk bands. This was probably the result of extreme weevil pressure. The bands had been trapping and causing weevil mortality through desiccation with the average number of dead weevils counted being 1918 (±722) during the period 18 December 2007 to 28 February 2008.

The level of weevil damage to tips of olive trees is given in Figure 29. The statistical analysis of the tip data was based on the average leaf damage score per tree following square root transformation.

![Figure 29. The frequency distribution of leaf damage score (see text for details) and average tip damage score (data square root transformed) for apple weevil damage to tips of olive trees where different weevil exclusion treatments were applied (see Table 14 for details) at Kendenup, WA.](image)

The bars on graph are the LSD=0.05, levels of statistical significance ** = P<0.01.

The three treatments containing chilli as ‘Vegie’ or Wax formulations resulted in the same level of damage to leaf tips from apple weevil, whilst the treatments Vegie and Wax at 10 mL/L resulted in significantly less damage than the non-chilli treatments.

Results of continued monitoring of weevil numbers in the same trial site, but where new treatments replaced those judged to have given poor control are given in Figure 30.
Treatments are divided into two graphs for clarity of presentation. Arrow indicates the date of application of products. Bars on graphs are LSD=0.05 and levels of statistical significance: ns = not significant; * = P<0.1; ** = P<0.01.

The only significant effect among these treatments for the remainder of the season was the reduction in weevil numbers on unbonded fibre bands treated with the more recent application of ‘Vegie’ chilli. It was apparent that the previous application of chilli had lost its effect on apple weevil adults, presumably due to exposure to air. The application of Pyganic® both as stored and new product, while reducing weevil numbers, gave results that were not significantly lower than numbers on the untreated unbonded fibre trunk band.

Results of exclusion treatments applied to a new trial site adjacent to the site used for the above trial are given in Figure 31. The only treatments that resulted in a significant reduction in weevil abundance compared to fibre bands were those that included an application of Pyganic®—either alone or with Azamax®.
Figure 31. Apple weevil adults abundance (square root transformed) in monitoring bands where a range of exclusion bands were applied to trunks (see Table 16 for details) at Kendenup, WA.

Arrows indicate the dates of application of products. Bars on graphs are LSD = 0.05 and levels of statistical significance: ns = not significant; * = P<0.1; ** = P<0.01; *** = P<0.001.

Apple weevil abundance on olive trees in the demonstration study to determine whether treatment one season can carry over into the next is given in Figure 32. The application of chilli resulted in reduced weevil abundance for the remainder of 2007/08 season, compared to trees with unsprayed fibre trunk bands. However, by the early part of the following season to mid-December there did not appear to be any carryover effect. The most likely reason for this non-effect was that application of treatments on 7 April 2008 commenced too late after the start of egg laying—see section below on timing of egg laying of apple weevil.
Figure 32. The abundance of apple weevil on olive trees where unbonded fibre trunk bands were placed and were either untreated or sprayed with ‘Vegie’ chilli extract during 2008 Kendenup, WA.

The arrow indicates the date of chilli application.

Site 3. Mumballup, WA (420104.34mE 6288149.95mN)

2006/07 season

The effectiveness of three treatments in preventing apple weevil adults gaining access to the canopy of trees was evaluated. Exclusion treatments were Barrier Glue and Fluon applied to black plastic trunk bands, and butt drenching with Surround®. Details of these products and how they were applied were the same as described for trials at Witchcliffe and Kendenup. Exclusion treatments were applied on 12 December 2006. Barrier Glue was reapplied on 14 March and 12 April 2007. Fluon was reapplied on 12 April 2007. The Surround® butt drench was reapplied on 8 January and 1 February 2007.

Weevil abundance was monitored by counting the number of weevils trapped in unbonded fibre trunk bands placed above each exclusion treatments, and just below the crotch of each tree. Weevil abundance was compared with that in unbonded fibre bands placed on trees with no trunk exclusion treatment. Prior to treatment application, fibre bands that had been placed on trees by the grower were removed, and the number of weevils trapped in the fibre bands counted. The number of apple weevil adults trapped in the fibre bands was either scored in the field if less than 50 weevils were present, or if >50 weevils present bands were returned to the laboratory for counting. Whenever bands were removed, they were replaced with a new unbonded fibre band in the field. Each treatment was replicated six times, with a single olive tree being one plot.
Results and discussion

The abundance of apple weevil adults in the unbonded fibre trunk bands is given in Figure 33.

![Figure 33. Apple weevil adults abundance (square root transformed) in unbonded fibre trunk bands where a range of exclusion bands were applied to trunks (see text for details) during the 2006/07 season, at Mumballup, WA.](image)

Arrows indicate the dates of application of products. Bars on graphs are LSD=0.05 and levels of statistical significance: ns = not significant; * = P<0.1; ** = P<0.01; *** = P<0.001.

There were significantly fewer adults able to cross the Barrier Glue and Fluon-treated bands to reach the unbonded fibre trunk bands. While the Barrier Glue performed well in preventing many weevils from climbing over it, the bands had to be checked regularly to ensure no material such as dried leaves had blown against it to create a bridge over which the weevils could walk. The application of Surround® to the trunk had no effect on the number of apple weevil adults gaining access to the unbonded fibre trunk band.

Site 4. Frankland, WA (506390.18mE 6199943.12mN)

2009/10 season

A new insecticide from DuPont P/L, Cyazypyr™ (cyantraniliprole), with some reported activity against weevils was included in a trial to compare its efficacy with indoxacarb (the active ingredient in Avatar®). Because so little was known of the mode of action of Cyazypyr™ on weevils, the trial included day and night spraying and a range of application rates. The details of treatments tested are given in Table 17.

The trial design was a randomised complete block with five replications. Plots were single adjacent olive trees. Insecticides were applied by hand lance to the canopies of olive trees to run-off. Night spraying commenced about three hours after sunset, by which time it was considered that most apple weevil adults would have entered the tree canopy to feed. The abundance of apple weevil adults was monitored with cardboard bands placed on a leader of each tree. Because neither the new insecticide nor Avatar® was registered for use on olives, no olives from the treated trees were included in the harvest from the grove.
Table 17  Details of treatments applied on 3 and 4 March 2010 to the canopy of olive trees to compare the efficacy of a new insecticide for control of apple weevil at Frankland, WA

<table>
<thead>
<tr>
<th>Product</th>
<th>Active ingredient</th>
<th>*Rate/100 L</th>
<th>Time applied</th>
</tr>
</thead>
<tbody>
<tr>
<td>Untreated</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Avatar®</td>
<td>indoxacarb</td>
<td>17 g</td>
<td>Night</td>
</tr>
<tr>
<td></td>
<td></td>
<td>12.5 g</td>
<td>Day</td>
</tr>
<tr>
<td></td>
<td></td>
<td>17 g</td>
<td>Day</td>
</tr>
<tr>
<td>New product</td>
<td>Cyazypyr™</td>
<td>17 mL</td>
<td>Night</td>
</tr>
<tr>
<td></td>
<td></td>
<td>12.5 mL</td>
<td>Day</td>
</tr>
<tr>
<td></td>
<td></td>
<td>17 mL</td>
<td>Day</td>
</tr>
<tr>
<td></td>
<td></td>
<td>34 mL</td>
<td>Day</td>
</tr>
</tbody>
</table>

* Agral spreader added to all insecticide sprays at 25 mL/100 L.

Results and discussion

The abundance of apple weevil adults, expressed as square root transformed data, is given in Figure 34.

Figure 34. Apple weevil adult abundance (square root transformed) in cardboard monitoring bands comparing foliar applications of indoxacarb and Cyazypyr™ insecticides and day- or night-spraying (see Table 17 for details) at Frankland, WA.

The arrow indicates the date of application. Bars on graphs are LSD=0.05 and levels of statistical significance: ns = not significant; ** = P<0.01; *** = P<0.001.

The abundance of apple weevil adults was not as high in this trial as was the case for other trials, but the activity of the new insecticide was demonstrated. Cyazypyr™ performed as well as Avatar®, with the only significant difference between the two insecticides occurring on the first sampling occasion after application. At this time Cyazypyr™applied at 17 and 34 mL per 100 L reduced numbers more than Avatar® applied at 17 g per 100 L. There was no significant difference between the levels of control achieved with Cyazypyr™applied at the range of rates used, although the highest rate resulted in the lowest number of weevils in the monitoring bands. There was no significant difference between day and night spraying and level of weevil control.
Timing of egg laying

Materials and methods

The fertility and fecundity of apple weevil was investigated in commercial groves at various locations in Western Australia where experiments on control methods were conducted. Adult weevils were collected from the period of emergence in December up to population decline around April. Twenty-five weevils were collected every two to four weeks and dissected in the laboratory under a dissecting binocular microscope. The presence of eggs was noted and the number of eggs of a size that indicated they were near maturity was counted.

Results and discussion

The results of the dissections to determine timing of onset of egg laying and fecundity are given in Figure 35 for olive groves in the localities of Kendenup, Mumballup and Witchcliffe respectively in Western Australia. Also shown on these figures is the abundance of weevil adults in the groves indicated by the numbers of weevils recorded in monitoring bands on the trunks of olive trees.

The abundance of apple weevil at all three locations increased from early December, declining in early summer to increase again during summer and autumn. This decline in number after the surge in emergence of the new season’s generation of weevils in early summer has been reported by Andrewartha (1933), who suggested that the decline was a reduction in activity or quiescence during the hot time of the year. Weevils burrow into the soil and cease feeding. As temperatures decline during summer towards autumn, the weevils re-emerge to continue feeding and also, as the figures indicate, to lay eggs. Numbers of weevils declined as winter approached.

The duration from the main emergence to the commencement of egg laying is quite protracted—at around 10 weeks. The average number of late-stage or near-mature eggs per weevil was not high on any one sampling occasion, but it would appear that they lay eggs over a reasonably long period. Eggs are laid singly and not in batches like other weevils. Andrewartha (1933) stated that each weevil lays around 55 eggs between March and late May to early June. This number of eggs per adult supports the observations here.

This relatively long duration between weevil emergence and commencement of egg laying has implications for intervention to reduce the number of weevils in olive groves. The main time for damage by apple weevil is December when the newly emerged weevils actively feed and when control actions are usually employed. However, the weevils that either escape this control or emerge after the control is applied are free to mature to lay eggs that provide the next generation of weevils to continue damaging the trees. If control was also implemented from late February, the ability for apple weevil to build up to damage trees the following season would be diminished, with the possibility that control would not be required every season.
Figure 35  The abundance of apple weevil adults in trunk bands on olive trees and the percentage of weevils with eggs and the average number of eggs per female at (a) Kendenup, (b) Mumballup and (c) Witchcliffe, during the period December 2006 to June 2007

Diurnal movement of apple weevil adults

Introduction

It is thought that apple weevil adults move diurnally between the soil where they spend the day and the canopy of their food tree, in this case olives. There are three main weevil pest species that occur in orchards in Western Australia—as well as apple weevil, they include Fuller’s rose weevil and garden weevil. All have a soil-borne larval stage and all feed on plant tissue within the tree canopy. Adults of Fuller’s rose weevil and garden weevil appear to remain in the tree canopy once they commence feeding after emerging from the soil. Garden weevil, like apple weevil, feed nocturnally and Fuller’s rose weevil feed at any time. However, of these, only apple weevil has an association with soil.

As mentioned earlier in this report, apple weevil adults enter a quiescent phase in the hotter period of the year around January to February when their apparent abundance declines. These weevils in fact burrow into soil to re-emerge later and enter the tree canopy to commence feeding and as shown in the previous section, commence egg laying.

To confirm the diurnal movement of apple weevil a short-term experiment was conducted in the same olive grove at Frankland (Site 4 above) where the insecticide trial was undertaken.
Methodology

Ten adjacent olive trees that were known to be infested with apple weevil were used for this study. Five of the trees had two bands of Barrier Glue applied to black plastic bands around the trunks. These exclusion bands were approximately 30 cm apart, with the lower band approximately 30 cm above the ground. The alternating and adjacent trees were left untreated.

On the five trees receiving the two bands of glue, three cardboard weevil monitoring bands were placed on the trunk—below, between and above the glue bands. A fourth monitoring band was placed on a leader branch in the tree canopy. In untreated trees, one monitoring band only was placed on the tree trunk. This band was located near the same height above ground as the central monitoring band of the trees receiving the glue. A second monitoring band was also placed on a leader branch within the canopy of the untreated trees.

Weevil monitoring bands had been placed on the leaders only of all trees used in this study prior to the application of glue. These bands were checked and the number of weevils recorded for about two weeks before the glue was applied. All trunk bands were placed on the trees the day the glue was applied. All monitoring bands were check the day after the glue was applied and then approximately one and three weeks after this.

Results and discussion

The number of apple weevil adults in the monitoring bands is given in Table 18. The number of weevils in the trunk bands of untreated trees was much higher than on trees receiving the Barrier Glue trunk bands. Initially there was a moderate number of weevils in the lower monitoring band of the Barrier Glue-treated trees. Presumably, by not gaining access to food, these weevils dispersed away from the trees with the glue bands. The fact that there were only very low numbers of apple weevil adults in the upper trunk band the day after the glue was applied indicates that very few weevils were in the tree canopy when the glue was being applied. Therefore, given the exclusion properties of the glue, apple weevil adults that had left the tree the morning of the day when the glue was applied were unable to access the tree canopy that night.

<table>
<thead>
<tr>
<th>Application Date</th>
<th>Treatment</th>
<th>Trunk bands</th>
<th>Canopy band</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Upper</td>
<td>Middle</td>
</tr>
<tr>
<td>8 Mar 10</td>
<td>Untreated</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Glue</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>12 Mar 10</td>
<td>Untreated</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Glue</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>23 Mar 10</td>
<td>Untreated</td>
<td>-</td>
<td>59.8</td>
</tr>
<tr>
<td></td>
<td>Glue</td>
<td>2.2</td>
<td>3.0</td>
</tr>
<tr>
<td>29 Mar 10</td>
<td>Untreated</td>
<td>-</td>
<td>51.6</td>
</tr>
<tr>
<td></td>
<td>Glue</td>
<td>0.4</td>
<td>0.2</td>
</tr>
<tr>
<td>14 Apr 10</td>
<td>Untreated</td>
<td>-</td>
<td>79.6</td>
</tr>
<tr>
<td></td>
<td>Glue</td>
<td>0.2</td>
<td>0.2</td>
</tr>
</tbody>
</table>

While this was a very limited study, it indicates the diurnal movement of apple weevil adults in olive trees—into the canopy from sunset onwards and out of the canopy back to the ground around sunrise. How far the weevils move away from the base of trees is not known, but would probably depend on the availability of shelter and whether the soil is soft enough to burrow into. The distribution of adult
weevils during the day is of relevance to the success of the control method that relies on trunk drenching with insecticide running off the trunk and soaking into plant debris and soil around the base of the tree.

**General discussion**

This project sought to evaluate a range of treatments for the control of apple weevil in olive groves. Studies were also conducted related to the time of egg laying of adults and the diurnal movement of apple weevil adults on and off olive trees. The treatments assessed for their potential to control apple weevil included synthetic insecticides and products acceptable for use in certified organic olive groves both as a trunk drench and foliar application.

**Chemical control**

Trunk drenching with the synthetic active ingredients α-cypermethrin, bifenthrin and fipronil showed good activity against apple weevil. While bifenthrin was the most effective, the other active ingredients gave near equivalent control. The duration of activity of the trunk drenches was not sufficient to control apple weevil present after the re-emergence of adults after their summer quiescence, although the treatment plots for most experiments were single trees only. Where entire groves are treated, it may be possible that a greater proportion of weevils are controlled in early summer. As indicated by the study on the timing of egg laying, weevils controlled in early summer have not matured to the stage of laying eggs. This may lead to the possibility that the breeding potential of the population is so reduced that use of insecticides may not be required the following season. This was partially demonstrated at one field site using larger treatment plots.

When different rates of the synthetic pyrethroid insecticides as a butt drench were compared, higher rates of α-cypermethrin and to a lesser extent fipronil improved the level of control of apple weevil. There did not appear to be a rate effect with bifenthrin. When bifenthrin was applied to unbonded fibre trunk bands, the number of apple weevil adults entering the tree canopy was significantly reduced compared to the numbers for untreated bands.

α-Cypermethrin is the only synthetic insecticide registered for use against apple weevil in olives, and even this insecticide is available only under an Australian Pesticides and Veterinary Medicines Authority (APVMA) minor-use permit, requiring periodic renewal. α-Cypermethrin has been used for many years in deciduous fruit tree orchards without any sign of insecticide resistance, but considering that apple weevil adults are parthenogenic and flightless, the chance of resistance development cannot be dismissed. From this point of view, there is an incentive to apply for registration for use of fipronil as a trunk drench because this insecticide is in a class with a different mode of action to bifenthrin and α-cypermethrin. Application for full registration of α-cypermethrin for control of apple weevil in olives should also be pursued.

Foliar application of indoxacarb (Avatar®) provided good control of apple weevil at all rates tested. The lowest tested rate (12.5 g per 100 L) is rate registered to control apple weevil in deciduous fruit tree crops. In one trial where day and night spraying were compared, there was no significant difference in the level of apple weevil control achieved. A second and new insecticide, cyantraniliprole (Cyazypyr™), was assessed for its efficacy as a foliar application. Although it was examined in only one trial, it performed as well as indoxacarb. The highest rate at which this new active ingredient was applied resulted in the greatest reduction in weevil numbers, but not significantly different to lower rates. There was no difference between day and night spraying. More trials with this insecticide against apple weevil are warranted.

The availability of an insecticide for foliar application to olives provides flexibility for conventional growers with problems with apple weevil, compared to the more time consuming method of trunk drenching. Indoxacarb is registered as Avatar® for use against apple weevil, Fuller’s rose weevil and garden weevil in deciduous fruit tree crops. A successful application has been made to Horticulture Australia Ltd as a voluntary contribution with financial support from the Australian Olive Growers’
Association and Du Pont Australia P/L to fund residue testing for indoxacarb in olives. If the results of the residue test indicate acceptable residue levels, an application will be made to APVMA for a minor-use permit to allow for the application of indoxacarb on olives.

**Products acceptable for use in certified organic olive groves**

A wide range of treatments acceptable for use in organic olive groves was assessed for their efficacy against apple weevil adults. These included trunk exclusion bands based on artificial fibre, both as bonded (baked to form sheets of fibres) or unbonded (as loose or ‘fluffy’ masses of fibre). In addition, products acceptable in organic agriculture were applied to these bands or alone to trunks and foliage of olive trees.

As a stand-alone treatment, the unbonded fibre was superior to the bonded fibre in trapping weevils. When the population of weevils was high, these bands, although trapping and killing many weevils, appear to lose their trapping properties with exposure in the field allowing enough weevils access to the tree canopy to cause leaf scalloping and be able to build up numbers to be a problem each season. Growers’ reaction to this has been to replace bands during the season or simply put more bands on the trunk (see right image in Figure 36).

![Figure 36.](image)

**Figure 36.** Left image, Trunk of an olive tree after a season where a black plastic band had been attached. Right image, Olive trees with multiple artificial fibre bands attached successively during a season; exposure to field conditions seemed to reduce the band’s ability to trap and exclude apple weevils from entering the tree canopy.

The application of chilli products ‘Vegie’ and ‘Wax’ to the artificial fibre trunk exclusion bands enhanced their ability to either kill or repel apple weevil adults from entering the tree canopy. The effect of the chilli degrades during a season and reapplication in mid-summer could be an advantage. This positive result has been reported to industry in a media release (Learmonth 2010). As well as hot chilli, the organic insecticide Pyganic® (natural pyrethrin) provided consistent activity when applied to artificial fibre trunk bands to enhance the exclusion effect of the bands. Both chilli and Pyganic® are worth consideration by olive growers who use the fibre trunk bands to enhance the level of exclusion these products provide. Exclusion bands that incorporate insecticides and other products have been shown to be effective in excluding garden weevil (vine snoutbeetle) adults from entering the canopy of deciduous fruit trees and grapevines in South Africa (Barnes et al. 1994, 1996).

Variable results were achieved with other control methods—trunk exclusion with Barrier Glue and Fluon or Teflon; Azamax® applied to fibre bands; and foliar application of Surround®. These
treatments performed well in some trials, but not in others. Therefore, their reliability is questionable as they seemed to break down more quickly after exposure in the field or required more maintenance than other exclusion treatments. Where black plastic substrate is required to protect the trunk and enhance the activity of Barrier Glue and Fluon, placing an impervious material like this on the trunk for an extended period of time may create other problems (see left image Figure 36). An attractant provided by the company that also supplied the Azamax®, did not improve the level of exclusion of bands when the combination of Azamax® and attractant was tested.

Multiple artificial fibre bands were attached to olive trees successively during a season because exposure to field conditions seems to reduce their ability to trap and exclude apple weevils from entering the tree canopy.

No marked effect on apple weevil control was apparent with the use of Surround®, chilli or neem as a trunk drench, the fungal preparation Myco-Force™ applied as a foliar spray or Abrade® (amorphous silica) when applied to artificial fibre trunk bands.

When conducting the trials on control of apple weevil, one aspect that was to be investigated was the pest status of the weevil—in both newly planted groves where plant death could be expected if weevil numbers were sufficiently high, and in mature groves to record leaf damage and possible yield loss should damage be severe enough.

As stated above, the one site where olives were being planted that was selected for studying the pest status of apple weevil in young olives had an infestation level too low to justify continuing the study. Apple weevil adults survive at low population levels in the pastures of the south-west of Western Australia. When olive groves are established in such areas, apple weevil can build up in numbers relatively quickly to become a threat to the survival of small olive plants. The habit of adults of girdling the soft stem tissue near the growing tip and feeding on the green bark near growing tips (see Figure 16) will if left unchecked, lead to reduced vigour of trees and possibly kill them. This has been reported by growers in areas from Margaret River on the west coast to an inland location at Kendenup in Western Australia. To avoid such adverse effects, growers need to consult farmers in the region for their experience and pay close attention to trees for the first few years after planting. The scalloping of leaves by adult weevils is a very characteristic sign of weevil presence and observation at night will confirm the identity of the pest.

In the mature groves at Witchcliffe and Kendenup where apple weevil control trials were undertaken, assessments of weevil damage were made.

In the Witchcliffe grove assessments of both leaf and fruit damage were planned, but fruit damage by girdling of the pedicel (see Figure 16) was found to be minor. This type of feeding by apple weevil adults also occurs in apple orchards and can lead to fruit of reduced size and if the feeding is severe enough, fruit will fall before harvest. Such damage to fruit in the Witchcliffe olive grove was so minor this category of damage was not recorded. Also feeding by apple weevil adults on pedicels to the extent of fruit fall in olive groves, is not reported as a concern. It is more likely related to the extent of tip girdling and general leaf function loss by scalloping. At the Witchcliffe grove, while significant differences in leaf damage using a scoring system were recorded among treatments, the level of leaf damage on untreated trees would have been unlikely to have affected yield.

The infestation level of apple weevil at the Kendenup grove was very high, with around 2000 apple weevil adults per tree trapped in the unbonded fibre trunk bands during the summer emergence period. Consequently, more severe damage was observed to tips by girdling and leaves from scalloping. This was reflected in the scoring system to compare treatments, where an ‘extreme’ category was included. Tree size was very variable at the Kendenup grove and it was considered unlikely that a significant yield difference among treatments would have been found, even though tip damage was high in the unsuccessful control treatments.
In terms of the level of apple weevil abundance at which control methods need to be applied, experience in one season will be an important determinant. Tree age must also be taken into account. Given the ability for small numbers of weevils to kill growing tips, the threshold for taking action in newly planted groves will be fewer weevils than for established groves. Mature olive trees will be able to tolerate moderate levels of weevils before action will be required. Organic olive growers will need to plan well to apply weevil control measures as they have fewer options in being reactive to a weevil infestation. For them, careful observation in one season will be required to be able to plan for action against apple weevil in the following season to prevent damage from occurring.

The study of the timing of egg laying of apple weevil has clarified the importance of good control of weevils early in the season before they have commenced laying eggs. For both conventional and organic producers of olives, planning their control with this objective should allow for more effective control of weevils and possibly control not being required each season.

The small study on weevil movement indicated that at the time of year it was undertaken, adults move into and out of olive trees on a daily basis. This has important implications for control of apple weevil with the different methods available. This is especially the case involving exclusion or prevention of weevil attack. This may be achieved by trunk barriers or trunk drenches of appropriate products. A repetition of this study at different times of the year may yield slightly different results. This study was undertaken in Frankland, WA, when weevils would have been laying eggs. Repeating the observation in early summer when weevils are actively feeding may result in a different pattern of movement.

**Recommendations for apple weevil control**

- Confirm on a semi-commercial scale that by controlling apple weevil in early summer, use of insecticides may not be required the following season.
- Pursue application for full registration of α-cypermethrin as a butt drench for control of apple weevil in olives. Confirm whether higher rates of the active ingredient than recommended on the current minor use permit improve the level of weevil control.
- Seek registration for use of either or both bifenthrin and fipronil to supplement and complement the use of α-cypermethrin for improved efficacy and resistance management.
- Encourage olive growers to spray fibre trunk bands with synthetic or natural pyrethroids or chilli products to enhance the exclusion effect of the fibre bands. Unbonded bands were generally more effective than baked artificial fibre bands for weevil exclusion.
- Pending results of residue testing of indoxacarb in olives, apply for a minor use permit for foliar application to control apple weevil.
- Confirm the efficacy of different rates of Cyazypyr™. Undertake further residue testing and if appropriate, apply for a minor use permit for foliar application to control apple weevil.
- Undertake further measurements to clarify the pest status and action threshold for controlling apple weevil in both newly planted and mature olive groves.
- Further studies in apple weevil movement between the soil and olive trees may lead to more efficient and less insecticide dependent methods of protecting olive trees from this pest.
- Apple weevil has a restricted global distribution with few researchers involved with studying management methods. Establish and maintain contact with the olive industry especially in the area thought to be its centre of origin—the Mediterranean region.
Appendices

Appendix A: List of biocontrol agents released for control of black scale in Australia (adapted from Waterhouse and Sands 2001)

Appendix B: 2005 Survey of Western Australian olive groves for black scale parasitoids and predators

Appendix C: Publications/Communication
## Appendix A: List of biocontrol agents released for control of black scale in Australia (adapted from Waterhouse and Sands 2001)

<table>
<thead>
<tr>
<th>Biological control agent</th>
<th>Host stage</th>
<th>Origin of agent</th>
<th>Year liberated and location</th>
<th>Established</th>
<th>Effectiveness</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>COLEOPTERA: COCCINELLIDAE</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>unidentified sp.</td>
<td></td>
<td>USA</td>
<td>1907 WA</td>
<td>?</td>
<td>Wilson 1960</td>
<td></td>
</tr>
<tr>
<td><strong>HYMENOPTERA</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>unidentified 3 spp.</td>
<td></td>
<td>China</td>
<td>1903 WA</td>
<td></td>
<td>Wilson 1960</td>
<td></td>
</tr>
<tr>
<td>unidentified</td>
<td></td>
<td>USA</td>
<td>1904 WA</td>
<td>?</td>
<td>Wilson 1960</td>
<td></td>
</tr>
<tr>
<td><strong>HYMENOPTERA: APHELINIDAE</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coccophagus capensis Compere</td>
<td>I</td>
<td>China</td>
<td></td>
<td></td>
<td></td>
<td>Noyes 1998</td>
</tr>
<tr>
<td>Coccophagus ceroplastae (Howard)(#)</td>
<td>I,A</td>
<td>Japan via Hawaii</td>
<td>1901 NSW</td>
<td>+</td>
<td>++</td>
<td>Wilson 1960; Noyes 1998</td>
</tr>
<tr>
<td>Coccophagus lycimnia (Walker) (#)</td>
<td>I</td>
<td>USA</td>
<td>1907 WA</td>
<td>+</td>
<td>+</td>
<td>Wilson 1960; Malipatil et al. 2000</td>
</tr>
<tr>
<td>Coccophagus semicircularis (Förster)(#)</td>
<td>I</td>
<td>?Europe</td>
<td></td>
<td>+</td>
<td>+</td>
<td>Smith et al. 1997; Malipatil et al. 2000</td>
</tr>
<tr>
<td><strong>HYMENOPTERA: ENCYRTIDAE</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baeoanusia minor (Silvestri)</td>
<td>I,A</td>
<td>South Africa</td>
<td>1903 WA</td>
<td>+</td>
<td>Wilson 1960</td>
<td></td>
</tr>
<tr>
<td>Diversinervis elegans Silvestri (#)</td>
<td>A</td>
<td>unknown</td>
<td></td>
<td>+</td>
<td>+++</td>
<td>Wilson 1960; Malipatil et al. 2000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Uganda, Kenya</td>
<td>1935–38 NSW</td>
<td>?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Encyrtus auranti (Geoffroy) (#)</td>
<td></td>
<td>?Europe</td>
<td></td>
<td>+</td>
<td>+</td>
<td>Noyes 1998</td>
</tr>
<tr>
<td>Encyrtus infelix (Embleton) (#)</td>
<td>I,A</td>
<td>USA</td>
<td></td>
<td>?</td>
<td>+</td>
<td>Noyes 1998</td>
</tr>
<tr>
<td>Metaphycus anneckei Guerrieri &amp; Noyes</td>
<td>A</td>
<td>South Africa</td>
<td>1902 WA</td>
<td>+</td>
<td>+++</td>
<td>Malipatil et al. 2000</td>
</tr>
<tr>
<td>Metaphycus helvolus (Compere)</td>
<td>I</td>
<td>USA</td>
<td>1943–47 NSW</td>
<td>+</td>
<td>++</td>
<td>Wilson 1960</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Qld, SA</td>
<td></td>
<td>+</td>
<td>+</td>
<td>Malipatil et al. 2000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>USA</td>
<td>1907</td>
<td>?</td>
<td>+</td>
<td>Noyes 1998</td>
</tr>
<tr>
<td>Biological control agent</td>
<td>Host stage</td>
<td>Origin of agent</td>
<td>Liberated location</td>
<td>Established</td>
<td>Effectiveness</td>
<td>References</td>
</tr>
<tr>
<td>--------------------------</td>
<td>------------</td>
<td>-----------------</td>
<td>--------------------</td>
<td>-------------</td>
<td>--------------</td>
<td>------------</td>
</tr>
<tr>
<td><strong>HYMENOPTERA: ENCYRTIDAE (continued from previous page)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Microterys nietneri</em> Motschulsky (? = <em>Microterys</em> sp.)(#)</td>
<td>I, A</td>
<td>South Africa</td>
<td>1902</td>
<td>WA</td>
<td>+</td>
<td>+</td>
</tr>
</tbody>
</table>

**HYMENOPTERA: EUPELMIDAE**

| *Lecaniobius utilis* Compere | Brazil | 1904 | WA | ? | Wilson 1960 |

**HYMENOPTERA: PTEROMALIDAE**

<table>
<thead>
<tr>
<th><em>Scutellista caerulea</em> (Fonscolombe)</th>
<th>E</th>
<th>South Africa</th>
<th>1902–03</th>
<th>WA</th>
<th>–</th>
<th>Jenkins 1946</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Sri Lanka ca 1903</td>
<td>WA</td>
<td>–</td>
<td>Wilson 1960</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Brazil</td>
<td>1904</td>
<td>WA</td>
<td>–</td>
<td>Jenkins 1946</td>
</tr>
<tr>
<td></td>
<td></td>
<td>USA</td>
<td>1903–04</td>
<td>WA</td>
<td>+</td>
<td>++</td>
</tr>
<tr>
<td><em>Scutellista sp.</em></td>
<td>China</td>
<td>1905</td>
<td>WA</td>
<td>–</td>
<td>Wilson 1960</td>
<td></td>
</tr>
<tr>
<td><em>Scutellista sp.</em></td>
<td>Timor</td>
<td>1905</td>
<td>WA</td>
<td>–</td>
<td>Wilson 1960</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>1905</td>
<td>WA</td>
<td>–</td>
<td>Wilson 1960</td>
<td></td>
</tr>
<tr>
<td><em>Moranilla californica</em> (Howard)</td>
<td>E</td>
<td>USA</td>
<td>1902</td>
<td></td>
<td></td>
<td>Bartlett 1978</td>
</tr>
</tbody>
</table>

**Key:**

(#) introduced primarily against another target pest species such as soft brown scale (*Coccus hesperidum* Linnaeus) in citrus.

I = immature stages of black scale, A = adult, E = egg predator
### Appendix B: 2005 Survey of Western Australian olive groves for black scale parasitoids and predators

<table>
<thead>
<tr>
<th>Site number</th>
<th>Collection date</th>
<th>Location</th>
<th>Description</th>
<th>Beneficials found</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>13/4/05</td>
<td>Gingin</td>
<td>Small area of grove infested with black scale. Has used treated scale. Crawlers present.</td>
<td>Cryptolaemus larvae and adults present on scale.</td>
</tr>
<tr>
<td>2</td>
<td>13/4/05</td>
<td>Gingin</td>
<td>Small area of grove infested with black scale.</td>
<td>Cryptolaemus larvae.</td>
</tr>
<tr>
<td>3</td>
<td>13/4/05</td>
<td>Gingin</td>
<td>Small area of grove infested with black scale. Spot spraying to control scale. Eggs + crawlers present.</td>
<td>No parasites emerged from sample.</td>
</tr>
<tr>
<td>4</td>
<td>13/4/05</td>
<td>Dandaragan</td>
<td>Most scale dead. Previously large infestation.</td>
<td>Converse ladybird (<em>Coccinella transversalis</em>) adults present.</td>
</tr>
<tr>
<td>5</td>
<td>13/4/05</td>
<td>Gingin</td>
<td>Most black scales dead; eggs. Previously large infestation. Treated with oil.</td>
<td>No parasites emerged from sample.</td>
</tr>
<tr>
<td>6</td>
<td>13/4/05</td>
<td>Gingin</td>
<td>Previous heavy infestation, scale now only present on few trees near packing shed. Scales not treated since.</td>
<td><em>Scutellista caerulea</em> larvae present.</td>
</tr>
<tr>
<td>7</td>
<td>6/4/05</td>
<td>Serpentine</td>
<td>Small grove. Few black scale present.</td>
<td>No parasites emerged from sample.</td>
</tr>
<tr>
<td>8</td>
<td>6/4/05</td>
<td>North Dandalup</td>
<td>Large grove. Previous large infestation. Few trees present with black scale.</td>
<td>No parasites emerged from sample.</td>
</tr>
<tr>
<td>10</td>
<td>6/4/05</td>
<td>Bolinda</td>
<td>Olives growing at side of road</td>
<td><em>Scutellista</em></td>
</tr>
<tr>
<td>11</td>
<td>6/4/05</td>
<td>Donnybrook</td>
<td>Previous large infestation. Few trees with black scale.</td>
<td>No parasites emerged from sample.</td>
</tr>
<tr>
<td>12</td>
<td>6/4/05</td>
<td>Mumballup</td>
<td>Large grove. Garden weevil. Young trees with black scale.</td>
<td>No parasites emerged from sample.</td>
</tr>
<tr>
<td>14</td>
<td>6/4/05</td>
<td>Boyup Brook</td>
<td>Large grove. Heavy infestation of black scale. Crawlers present.</td>
<td>Transverse ladybird (<em>Coccinella transversalis</em>) &amp; common spotted ladybird (<em>Harmonia conformis</em>).</td>
</tr>
<tr>
<td>15</td>
<td>7/4/05</td>
<td>Busselton</td>
<td>Previous heavy infestation of black scale.</td>
<td>Scale-eating caterpillar present.</td>
</tr>
<tr>
<td>Site number</td>
<td>Collection date</td>
<td>Location</td>
<td>Description</td>
<td>Beneficials found</td>
</tr>
<tr>
<td>-------------</td>
<td>-----------------</td>
<td>----------</td>
<td>-------------</td>
<td>-------------------</td>
</tr>
<tr>
<td>16</td>
<td>7/4/05</td>
<td>Busselton</td>
<td>Small grove. Trees near shop infested with black scale.</td>
<td>Scale-eating caterpillar present. <em>Euryischomyia</em> sp. 1 (Aphelinidae)</td>
</tr>
<tr>
<td>17</td>
<td>7/4/05</td>
<td>Busselton</td>
<td>Parapriasus australiasiae. Scutellista, Euryischomyia sp. 1 (Aphelinidae)</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>7/4/05</td>
<td>Margaret River</td>
<td>Previous heavy infestation of black scale. Few black scale present.</td>
<td><em>Parapriasus australiasiae</em> present. <em>Aphytis</em> sp. (Aphelinidae, normally parasite of Diaspididae)</td>
</tr>
<tr>
<td>19</td>
<td>7/4/05</td>
<td>Yallingup</td>
<td>Small number of trees infested. Latania and circular black (?) scale present.</td>
<td>Scale-eating caterpillar present. <em>Metaphycus annekei</em> (Encyrtidae)</td>
</tr>
<tr>
<td>20</td>
<td>7/4/05</td>
<td>Lake Clifton</td>
<td>Large grove. Heavy infestation of black scale. Have sprayed with oils.</td>
<td>Scale eating caterpillar present. <em>Scutellista</em>.</td>
</tr>
<tr>
<td>21</td>
<td></td>
<td>Manjimup</td>
<td>1200 trees. No scale in old grove. Minor scale in younger area on trees near dam, low s/mould, meat ants.</td>
<td>No parasites emerged from sample.</td>
</tr>
<tr>
<td>22</td>
<td>12/4/05</td>
<td>Manjimup</td>
<td>Very old trees beyond winery low scale; young trees near entrance high scale, s/mould, ants.</td>
<td><em>Moranila</em> sp. (Pteromalidae)</td>
</tr>
<tr>
<td>23</td>
<td>12/4/05</td>
<td>Northcliffe</td>
<td>6-YO trees; one with very low scale. No spray.</td>
<td>No parasites emerged from sample.</td>
</tr>
<tr>
<td>24</td>
<td>12/4/05</td>
<td>Northcliffe</td>
<td>Approx 1000 trees, 8 YO. Heavy scale, has used malathion, s/mould, ants.</td>
<td>No parasites emerged from sample.</td>
</tr>
<tr>
<td>25</td>
<td>12/4/05</td>
<td>Northcliffe</td>
<td>Unmanaged trees. V old trees some with old scale, s/mould. Young trees – low scale, ants.</td>
<td>No parasites emerged from sample.</td>
</tr>
<tr>
<td>26</td>
<td>12/4/05</td>
<td>Pemberton</td>
<td>About 50 5-YO trees. Some with high scale, s/mould, ants. Has used white oil. Much apple weevil damage.</td>
<td><em>Euryischomyia</em> sp. 2 (Aphelinidae)</td>
</tr>
</tbody>
</table>
Appendix C: Publications/communication


**Learmonth, SE 2010**, Chilli solution to olive pest. Media release by Department of Agriculture and Food. [www.agric.wa.gov.au](http://www.agric.wa.gov.au)."

**Field days/workshops**


# Glossary

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eclosion</td>
<td>The emergence of an insect from its pupa case, or of a larva from its egg</td>
</tr>
<tr>
<td>Hyperparasitoid</td>
<td>An organism that parasitises and develops on a primary parasitoid</td>
</tr>
<tr>
<td>Moulting</td>
<td>Shedding of the skin</td>
</tr>
<tr>
<td>Parasitoid</td>
<td>Organism which spends much of its life cycle attached to or within the body of its host, ultimately killing it</td>
</tr>
<tr>
<td>Univoltine</td>
<td>Population with one generation per year</td>
</tr>
</tbody>
</table>
References


Altmann, JA & Baker GJ 2009, Biological control of black scale, Saissetia oleae (Olivier) (Hemiptera:Coccidae), in olives, Final report to Horticulture Australia, Project FR05017.


Crop Data Management Systems 2010, Labels, [http://www.cdms.net/LabelsMsds/LMDefault.aspx](http://www.cdms.net/LabelsMsds/LMDefault.aspx)


EFSA (European Food Safety Authority) 2010, ‘Reasoned opinion of EFSA: Consumer safety assessment of the EU MRLs established for methidathion’, *EFSA Journal*, vol. 8, no. 6, 1639 [49 pp.].


Grafton-Cardwell, EE, Godfrey, LD, Chaney, WE & Bentley, WJ 2005, ‘Various novel insecticides are less toxic to humans, more specific to key pests’, *California Agriculture*, vol. 59, p. 29, [http://repositories.cdlib.org/anrcs/californiaagriculture/v59/n1/p29](http://repositories.cdlib.org/anrcs/californiaagriculture/v59/n1/p29)


Grout TG & Richards, GI 1991, ‘Effect of Buprofezin applications at different phenological times on California red scale (Homoptera: Diaspididae)’, *Journal of Economic Entomology*, vol. 84, no. 6, pp. 1802–1805.


Jenkins, CFH 1946, ‘Biological control in Western Australia’, *Journal of the Royal Society of Western Australia*, vol. 32, pp. 1–17.


Learmonth, SE 2010, ‘Chilli solution to olive pest’, Media release by the Western Australia Department of Agriculture and Food, [www.agric.wa.gov.au](http://www.agric.wa.gov.au)


Majer, JD & Koch, LE 1982, ‘Seasonal activity of hexapods in woodland and forest leaf litter in the south-west of Western Australia’, *Journal of the Royal Society of Western Australia*, vol. 65, no. 2, pp. 37–45.


Morillo, C 1977, ‘Morfología y biología de *Saissetia oleae* (Homoptera Coccidae)’, *Boletín de la Real Sociedad Española de Historia Natural Sección Biológica*, vol. 75, pp. 87–108.


Orphanides, GM 1993, ‘Control of *Saissetia oleae* (Hom.: Coccidae) in Cyprus through establishment of *Metaphycus barletti* and *M. helvolus* (Hym.: Encyrtidae)’, *Entomophaga*, vol. 38, pp. 235–239.

Peleg, BA 1983, ‘Effect of a new phenoxy juvenile hormone analog on California red scale (Homoptera: Diaspididae)– Florida wax scale (Homoptera: Coccidae) and the ectoparasite *Aphytis holoxanthus* DeBache (Hymenoptera: Aphelinidae)’, *Journal of Economic Entomology*, vol. 81, no. 1, pp. 88–92.


Yarom, I, Blumberg, D & Ishaaya, I 1988, ‘Effects of buprofezin on California red scale (Homoptera: Diaspididae) and Mediterranean black scale (Homoptera: Coccidae)’, *Journal of Economic Entomology*, vol. 81, no. 6, pp. 1581-1585.

Management of Black Scale and Apple Weevil in Olives

By Sonya Broughton and Stewart Learmonth

Pub. No. 12/019

This report provides olive growers with monitoring, and organic and conventional control methods for black scale and apple weevil. The information generated by this project also provides new methods to improve control of apple weevil.

This report is targeted at Australian olive growers who are having problems controlling black scale and/or apple weevil.

RIRDC is a partnership between government and industry to invest in R&D for more productive and sustainable rural industries. We invest in new and emerging rural industries, a suite of established rural industries and national rural issues.

Most of the information we produce can be downloaded for free or purchased from our website <www.rirdc.gov.au>.

RIRDC books can also be purchased by phoning 1300 634 313 for a local call fee.