Centre for Environmental Stress and Adaptation Research
Department of Zoology

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Total System Approach to Sustainable Pest and Weed Management in Grapevines: Research and Demonstration Project



FINAL REPORT to

GRAPE AND WINE RESEARCH & DEVELOPMENT CORPORATION

Project Number: **MU LTU 04/01**

Chief Investigator: **Dr. Martina Bernard**

Research Organisation: **CESAR - Department of Zoology**
The University of Melbourne
31 October 2007

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by Dr Martina Bernard [1]

Chief investigator

Project N°: LTU 02/01: July 2002 - Feb 2005 LaTrobe University
MU LTU 04/01: Mar 2005 - Oct 2007 University of Melbourne

Academic advisor/ project supervisor: Prof Ary Hoffmann[2]
Academic advisors: Dr Paul Horne[3]
Dr Alan Yen[4]
Prof Steve Wratten[5]
and others (pg 4)

[1] CESAR-Dpt. of Zoology, University of Melbourne, Parkville, Victoria 3010
[2] CESAR-Dpt. of Genetics, University of Melbourne, Parkville, Victoria 3010
[3] IPM Technologies, Pty Ltd, PO Box 560 Hurstbridge, Victoria 3099
[4] DPI, Primary Industries Research Victoria, Knoxfield
[5] National Centre for Advanced Bio-Protection Technologies, PO Box 84, Lincoln University, Canterbury, New Zealand

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1.1 ABSTRACT

This research and demonstration project of Total System Approach/Integrated Pest Management (IPM) in wine grapes was conducted along the model of fully integrating its research and extension aspects. This approach has been advocated by many leading universities in the field, including the University of California, and is now required by the USDA (US Department of Agriculture) for research grants, to maximise practical relevance of research outcomes and their uptake in grower communities. The key aims of this project were to collect baseline data required to advance IPM and sustainable management of pests in Australian viticulture in order to reduce pesticide use in wine grapes in the long term, and facilitate greater reliance on biological control.

To this effect, (1) field data on naturally present biological control providers in vineyards and their seasonal population changes and succession in abundance were collected from vineyards practicing IPM for at least 3 years. (2) Effects of a large number of viticultural pesticides on a key species of biological control providers (predatory mites) were investigated through rigorous laboratory methods that met international standards required for designating pesticides as safe to beneficial organisms. (3) Effects of selected insecticides on green lacewings, brown lacewing, and damsel bugs were also investigated to indicate which of the novel insecticides recently registered in wine grapes could be damaging natural biological control services in vineyards. (4) Comprehensive guidelines for sustainable grapevine production: IPM were devised in a user friendly form, ready for use by growers as a self assessment guide of their progress towards sustainable pest management, and allowing them to easily identify the next most feasible adoption step they may undertake. An interim final report (31 October 2006) was produced. This final report (31 October 2007) including additional publications and pesticide testing was also produced.

1. 2 AKNOWLEDGEMENTS

This research into vineyard insect ecology encompassed handling and identification of many invertebrate species, and thus called on the expertise and generosity of many senior insect ecologists and systematic taxonomists specialized in various invertebrate groups in Australia. Their input, beyond simply the input of staff employed and funded by this project was necessary for the success of this project, and represents standard practice in entomology. I wish to express my thanks and gratitude to these people for advancing my knowledge and understanding in the complex field of conservation bio-control and systematics, and to growers and wine companies who participated in this research.

Many thanks to the GWRDC and its officers for funding, and for their assistance and understanding in modifying this project during its cause, to best respond to new emerging pest issues and growers' needs, and for allowing for delays for medical reasons and untimely pesticide laboratory development. Many thanks to DPI-Primary Industries Research Victoria, Knoxfield for providing access to their pesticide testing laboratory, insectary, CTR rooms and glasshouses for testing pesticides, rearing predatory mite colonies and plants in the first and final years of this project, and for collaborative work, and to IPM Technologies for ongoing expertise sharing, for rearing predatory insect colonies and for testing collaboration in the final year 2007. Many thanks to Dr Paul Horne (IPM Technologies), Drs Alan Yen and John Wainer (DPI, PIRVIC, Knoxfield) for guidance in applied insect ecology and systematics, and for making pesticide testing at DPI Knoxfield possible for me. Many thanks to Peter Cole (IPM Technologies) and Drs Amanda Kobelt and Alan Yen (DPI) for collaboration on pesticide bioassays in the final year of the project, to Dr Mali Malipatil (DPI PIRVIC Knoxfield-Taxonomy Collection) for providing me with access to high resolution microscopes required for species identification, and for teaching in nabid and mealybug systematics. Many thanks to Prof Steve Wratten (National Centre for Advanced Bio-Protection Technologies, Lincoln University, New Zealand) for post doctoral advice and guidance and for his contribution to joint publications and extension, to Prof Ary Hoffmann (Cesar, Melbourne Uni) for guidance in research design and statistical analysis, to Prof Tim New (La Trobe University) for guidance in all lacewing matters, to Dr Adam Slipinski (CSIRO) for some ladybird beetle species identification, to Dr Cate Paull and Prof Andrew Austin (University of Adelaide) for identifying LBAM parasitoid wasps to species.

Many thanks also to Ms Vicki Carter for outstanding technical assistance in the field over two years, to Linda Semeraro (DPI, PIRVIC, Knoxfield-Taxonomy Collection) for a refresher course in insect mounting at the start of the project, and for her wonderful insect photography in joint publications. Many thanks also to Dr Cate Paull, Peter Oatwright Kelly, and to IPM experts James Altmann and Rob Weppler (Biological Services Ltd. Loxton), Dan Papacek (Bugs for Bugs Ltd.), and Richard Llewellyn for valuable comments on various publication manuscripts, and for advice in field collecting and rearing and for supply of predatory mites. Many thanks to Prof. David Evans Walter and Dr. Jennifer J. Beard (University of Queensland) for their generosity in teaching predatory mite systematics, to Janyce Truett (DPI PIRVIC Knoxfield), Ms Cindy Edward (University of Melbourne-Cesar) and William Bigand (ENSAT, Toulouse, France) for excellent technical support during laboratory bioassays, to Dr. Swarna Hewa-Kapuge (La Trobe University-Cesar) for carrying out a green lacewing bioassay in 2002, and to Dr. Angela Corrie (La Trobe University-Cesar) for carrying out a bioassay with predatory mites in 2002. Last but not least, many thanks to the growers and wine companies who helped initiate this research, and who participated by providing valuable feedback and access to vineyards, generously accommodating my research in busy vineyard schedules. To mention but a few, whose vineyards were used extensively in my research over a two year period, Craig Callec, Ray Guerin and Alex Sass (Hardy Wine Company), Drs. Neil and Elisabeth Roberts (Rising Vineyard Ltd.), Stuart Sissins and Michael Brocksopp (Tarrawarra Wines Ltd); this work could not have been possible without their generous contribution.

Martina Bernard, 31 October 2007

2. EXECUTIVE SUMMARY

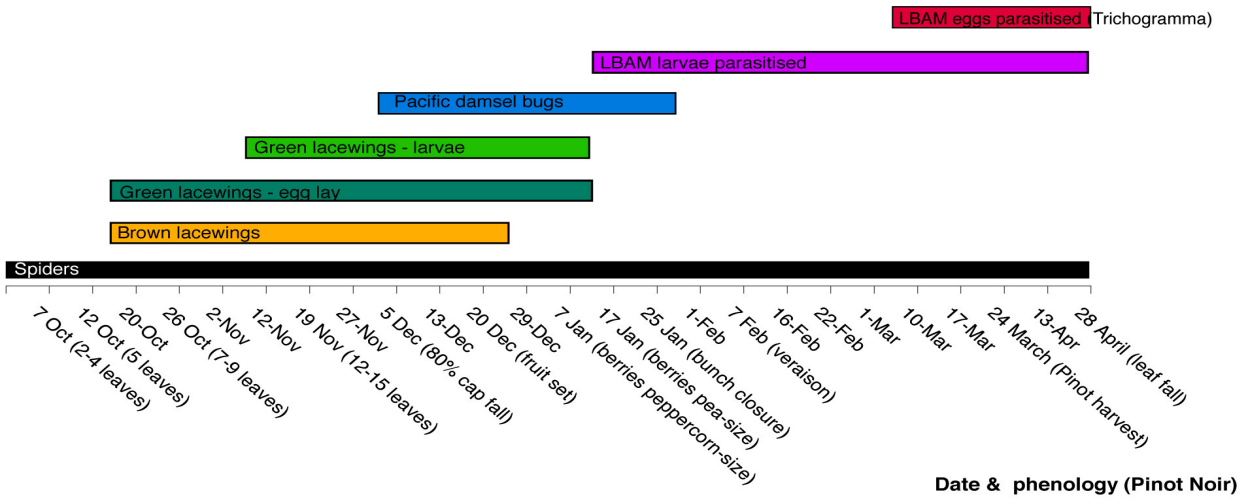
Beneficial insects in IPM vineyards

Project publications represent the first published seasonality data on lacewings *Micromus tasmaniae* (brown lacewing), *Mallada signatus* (green lacewings) and other predatory species such as *Nabis kinbergii* (Pacific damsel bug) from Australian vineyards. These species contribute to biological control of light brown apple moth (LBAM), mealybugs, and other pests. A summary of seasonal succession of these and other species comprising the beneficial species complexes associated with LBAM and mealybugs was produced based on data over two growing seasons 2003-2005 from the Yarra Valley and surrounding areas (Fig.1).

Project publications also represent the first published seasonality records of the parasitoid species complex of LBAM from Victoria, complementing a recently published 1st record of the LBAM parasitoid species complex from Limestone Coast, SA by Adelaide University [1]. Together these data jointly establish the most abundant species parasitising LBAM larvae in Australian vineyards to date: *Dolichogenidea tasmanica*, allowing linkages to important research conducted on this species overseas, and allowing these benefits to also flow Australia growers.

Research findings indicate that beneficial species undergo changes in abundance over the growing season (Fig. 1), each contributing to a greater or lesser degree to overall pest control, and that the beneficial species complex as a whole delivers pest control (rather than one key 'stand alone' species), thus de-emphasizes *Trichogramma* sp. which was until recently presented to growers as the main, key LBAM bio-control agent in vineyards. *Trichogramma* wasp parasitized LBAM eggs late in the season, and other wasp parasitoids of LBAM larvae were abundant from mid-late season (Fig. 1). In early spring and summer, insect predators and spiders were more abundant. Periods of high abundance are of practical interest, because they indicate when each species is likely to contribute the most to pest control, and when use of pesticides toxic to beneficial species will be especially detrimental. New high label rates of wettable sulphur (6 kg/ha) against powdery mildew are used early in the season, and novel insecticides against LBAM are registered up to *c.* fruit set; a time of high green and brown lacewing and damsel bug abundance. Therefore any off-target toxicity is well-positioned in time, to affect these beneficials and their contribution to pest control.

Fig. 1 Approximate periods of high abundance of beneficials in the study sites; 2003-05 growing seasons (no data collected before 7 October & after 28 April).



Findings on high abundance of LBAM larval parasitoid wasp *D. tasmanica* were highly practically significant, because they allowed linkage with published research from New Zealand, where *D. tasmanica* is naturalized and abundant after introductions from Australia. 12 years of New Zealand research established how to enhance this wasp and its biological control of LBAM in vineyards, by providing a very specifically selected, high quality nectar resource [2-5], by using agronomically suitable, drought tolerant, fast flowering plants, with characteristics that do not lead to LBAM increase in vineyards. Vineyard application of this research in New Zealand has significantly improved LBAM larval parasitism, and reduced LBAM below the economic threshold without the need to spray. This approach is consistent with the Total System Approach [6], the basis of this project. Research collaboration was thus sought as part of this project, with Prof Steve Wratten (National Centre for Advanced Bio-Protection Technologies, Lincoln University, New Zealand) who conducted this research.

Economic benefits. Project findings and New Zealand research findings were extended to Australian growers in joint publications with Prof Wratten, and in extension seminars 2006- 07. As a result, one innovative industry leader in SA piloted buckwheat nectar source over 12 ha of Chardonnay in 2006-07. His agronomic assessment and cost benefit analysis were extended to growers across SA and Victoria in a linkage project (RITA 13th AWITC Regional Forum), and more industry leaders are piloting nectar plants in 2007-08. This is important given that *D. tasmanica* life-span, egg-load, and LBAM parasitism can be significantly increased by access to nectar, important after fruit set when no sprays (except expensive Bt) are registered against LBAM, and when LBAM often reaches high numbers in cooler summers. It is also highly relevant to tight-bunch varieties, and may lead to reduced need for expensive botryticide sprays, by improved LBAM control. The seasonal cost of nectar resources is very low and is returned within a one spray saving. Economic benefits to growers in Australia from nectar plants could be very significant, since parasitoids of mealybug, scales, and predators whose adult life stages feed on nectar (e.g. green lacewings, hover flies) are also expected to be enhanced by this important ecological mechanism, and since buckwheat nectar supply to hoverflies is already successfully enhancing biological control in commercial organic lettuce production in California.

A new predator of grape rust mite. A new predator has been found in vineyards by this project: predatory thrips, *Haplothrips victoriensis* (Fig. 3) is here reported from vineyards and feeding on rust mite in feeding tests for the first time.The species is a known TSM (two-spotted mite) predator in lucerne.

Pesticide effects on natural enemies of pests

Economic benefits from enhanced biological control above cannot be realized unless pesticides use in vineyards is carefully adjusted to cause minimum damage to *D. tasmanica,* and other beneficial species. Pesticide testing was thus a major part of the project. A comprehensive Australian eco-toxicological testing standard for predatory mites was developed and used to test effects on a key native predatory mite (*Euseius victoriensis)* significant to viticulture, evaluating 7 d mortality and effects on egglay and meeting IOBC (International Organisation for Biological Control) standards for evaluating pesticide effects, required to accurately designate pesticide safety. A total of 35 pesticides were tested (Table 1) using *E. victoriensis* as indicator species for effects on vineyard bio-control as a whole. Selected insecticides and wettable sulphur were further tested on young life stages of three key predators *Micromus tasmaniae* (brown lacewing), *Nabis kinbergii* (damsel bug), and *Mallada signatus (*green lacewing) in collaboration with Peter Cole (IPM Technologies) and Amanda Kobelt (DPI Knoxfield), and Polyram®, Delan®, and Stroby® were also tested on *M. signatus.* A full interpretation of all results in the context of world-wide research on pesticide effects (to Dec 2006) on beneficials was completed in scientific publications (Targets 3.3.1 and 4.1), giving recommendations for safe pesticide use for the Australian wine industry per each target pest and disease. List of 'safe' pesticides was presented in grower seminars and published on line e.g.: http://www.phylloxera.com.au/board/meetings/view.asp?region=Riverland Results overall, complemented by a world-literature review, indicate substitution of pesticides safer to beneficials in Australian viticulture is easily possible.

Pesticides safe/low toxicity to predatory mites. Pesticides Amistar, Anvil, Barrak, Captan, Delan, Filan, Fungi-fos, Kocide, Mycloss, Ridomil Gold Plus (metalaxyl & copper hydroxide), Rubigan, Stroby, Topaz, Avatar, Delphin, Mimic, adjuvants (Agral, Bond), and herbicide glyphosate, caused no significant 7 day mortality or egglay effects compared to controls, and are designated 'safe' to predatory mites in Australian vineyards (Tables 2-3). Canola oil (2%), the highest recommended rate against rust mite at wooly bud was only moderately toxic, resulting in 56.6% mortality and surviving females reproduced at *c*.50% capacity compared to controls. Canola oil was safer than wettable sulphur (600g/100L) and is the 'softer' option available to treat rust mite at wooly bud. Wettable sulphur toxicity was dose related. Wettable sulphur (200g/100L) was significantly less toxic than higher rates of wettable sulphur, causing 81.7% 7-day mortality, but surviving females reproduced at *c*.50% capacity, ensuring survival into the next generation. Another common species (*Typhlodromus doreenae)* is reported to have some tolerance to wettable sulphur, and so results here may overstate the toxic effect of wettable sulphur on the predatory mite species complex as a whole, but rates of c. ≤ 2 kg/ha (tank mix concentration ≤ 400g/100L) are recommended to conserve predatory mites in vineyards. Shorter, 48hrs testing of Teldor, Peratec, Domark, and Applaud indicated no significant 48h mortality to predatory mites compared to controls. These pesticides are likely to be 'safe' to predatory mites, but 7 d testing need be completed before these can be unequivocally designated as 'safe'. Indoxacarb was also safe to predatory mites. However, indoxacarb was toxic to other beneficial species (Table 4), and these toxic effects preclude a general conclusion on its safety to beneficials.

Pesticides toxic to predatory mites. Predatory mites suffered the highest mortality after exposure to mancozeb (93-100%), and the few surviving females laid no eggs. Metiram was less toxic than mancozeb, with cumulative 7 day mortality after exposure not significantly different to controls, but high sub-lethal toxicity, causing 93.4% reduction in egglay compared to controls. Carbandezin, benomyl, and wettable sulphur (600g and 1200g /100L) were highly toxic, resulting in 7 day mortalities of 78.6-100%, and no egglay. Spinosad and emamectin were highly toxic, resulting in 95.5% and 77.9 % mortality at 48 hrs, and 100% mortality 7 days after exposure. Spinosad fresh dry residues were also highly toxic, resulting in 85.5% mortality 7 days after exposure, and in significantly reduced egglay compared to controls. Shorter, 48h testing resulted in Switch (77.8% mortality) and Scala (100% mortality) indicating these botryticides are not safe to predatory mites, but the results are preliminary, and tests will be repeated in testing under CX 2295 to confirm results in 7 d duration testing. In lieu of this short test, additional tests below on brown lacewings and damsel bugs were completed instead.

Pesticides effects on *Mallada signatus* (green lacewing), *Micromus tasmaniae* (brown lacewing), and *Nabis kinbergii* (damsel bug). Bt (*Bacillus thuringiensis* subsp. *kurstaki),* wettable sulphur (200g/100L) direct overspray and fresh dry residue caused no significant 3 day mortality to *M. signatus, M. tasmaniae, or N. kinbergii* 1st instar juveniles compared to controls. Higher wettable sulphur concentration (600g/100L) as direct overspray was significantly more toxic compared to the controls, causing moderate 3 d mortality (33.3 %) to *M. signatus* larvae, but not to *M. tasmaniae.* Polyram, Delan, and Stroby caused no significant 48hr mortality, or effects on egg-lay or egg hatchability over a 4-day period compared to the controls, following direct overspray of young larvae, and their initial food supply.

Avatar, Success, Proclaim. Results on these novel insecticides indicate a patchwork of toxicity across these beneficial species, suggesting none can be considered 'safe' in general to biological control providers in Australian vineyards. Success direct overspray and residue caused no significant mortality to *M. signatus* 1st instar larvae, but direct overspray was moderately toxic (26.1% mortality) to *M. tasmaniae* larvae. These results are consistent with generally low Success toxicity to predators, but spinosad is highly toxic to many parasitoid wasp species [109], including the key Australian LBAM parasitoid *D. tasmanica* [7]. Avatar direct overspray and residue caused significantly higher 3 day mortality to *M. signatus* compared to the controls (77.8% and 58.3% respectively), representing a level of mortality of c.75% that of highly toxic chlorpyrifos (Lorsban), and toxicity to *D. tasmanica* is also reported [7]. However, Avatar was not toxic to *M. tasmaniae* and *N kinbergii* in 3 day-duration testing. Proclaim was

safe to both *M. signatus* and *M. tasmaniae* 1st instar larvae; 3 day mortality following exposure to direct overspray and residues did not differ significantly from the controls, except for a minor (15.8%) mortality recorded for *M. tasmaniae*. However, proclaim direct overspray and residues were highly toxic to *N. kinbergii* 1st instar juveniles, resulting in a significantly higher 3 day mortality (100% and 96.3% respectively) compared to the control.

Project publications

Refereed by scientists prior to publication in ANZGGW- Bernard M., Horne P. A., Papacek D., Jacometti M. A., Wratten S. D., Evans K. J., Herbert K. S., Powell K. S., Rakimov A., Weppler R., Kourmouzis T., Yen A. L., **2007**. Guidelines for Environmentally Sustainable Wine Grape Production in Australia: IPM adoption self-assessment guide for growers, The Australian and New Zealand Grapegrower and Winemaker, 518 (March), p. 26-36

Over and above project targets - Bernard M., and S. D. Wratten, **2007**. AgNote: Enhancing beneficial insects and mites in vineyards: providing nectar, pollen, and shelter in vine rows. The Australian and New Zealand Grapegrower and Winemaker, 519 (April), p. 33-34

Bernard M., Carter V., Semeraro L., Wratten S. D., **2006**. Beneficial insects in vineyards: Parasitoids of LBAM and grapevine moth in South-East Australia. The Australian and New Zealand Grapegrower and Winemaker, 513 (October): p. 19-26

Bernard M., Wainer J., Carter V., Semeraro L., Yen A. L., Wratten S. D, **2006**. Beneficial insects and spiders in vineyards: Predators in South-East Australia. The Australian and New Zealand Grapegrower and Winemaker, 512 (September): p. 37-48

Refereed scientific paper - Bernard, M.B., P.A. Horne, and A.A. Hoffmann, **2005**, Eriophyoid mite damage in *Vitis vinifera* (grapevine) in Australia: *Calepitrimerus vitis* and *Colomerus vitis* (Acarina: Eriophyidae) as the common cause of the widespread 'Restricted spring growth' syndrome (RSG). Experimental and Applied Acarology, 35(1-2): p. 83-109.

Refereed scientific paper - Bernard, M.B., Horne P.A., Hoffmann A.A., **2004**, Developing Eco-toxicological Testing Standard for Predatory Mites in Australia: Acute and Sub-lethal Effects of Fungicides on *Euseius victoriensis* and *Galendromus occidentalis* (Acari: Phytoseiidae). Journal of Economic Entomology, 97(3):p891-899

Bernard, M., P. Horne, and A. Hoffmann, **2004**, Ecological Pest Management: The effect of viticultural fungicides on beneficial predatory mites. The Australian and New Zealand Grapegrower and Winemaker, 485a: p 7-12

Manuscripts – due for submission

Refereed scientific paper- completed - submission Jan 2008 to include CX 2295 tests currently in progress Mortality and sub-lethal fecundity effects of pesticides on the predatory mite *Euseius victoriensis* (Acari: Phytoseiidae): a study to maximise conservation biological control in Australian vineyards. Bernard, M., Horne P., Cole P., Kobelt A., Hoffmann A., Journal of Economic Entomology

Refereed scientific paper - 70% completed, submission March 2008
Martina B. Bernard, John Wainer, Ary. A. Hoffmann, Paul A. Horne, Alan L. Yen, Stephen D. Wratten, Functional biodiversity for Integrated Pest Management (IPM) in vineyards of South-East Australia: seasonal abundance of polyphagous predators and parasitoids of leafrollers (Lepidoptera: Tortricidae), Australian Journal of Entomology

Over and above project targets - Refereed scientific paper- 95% completed - submission Dec 2007 Bernard M. B., Horne P. A., Papacek D., Jacometti M. A., Wratten S. D., Evans K. J., Herbert K. S., Powell K. S., Rakimov A., Weppler R., Kourmouzis T., Yen A. L., Guidelines for Environmentally Sustainable Wine Grape Production in Australia: IPM adoption assessment, Australian Journal of Entomology

Funding other than GWRDC and 'in-kind'

A very substantial in-kind support in the form of expertise by IPM Technologies Ltd. and many other scientists from Australia and overseas (National Centre for Advanced Bio-Protection Technologies, Lincoln University) was provided to this project. Access to research facilities was provided by DPI

PIRVIC Knoxfield. IPM Technologies further provided expertise and rearing of insect colonies used in collaborative testing in 2007. A very substantial input, supervision, and guidance in specialized species level identification (not available at CESAR) was provided to the CI by various Australian systematic entomology experts, without any remuneration from GWRDC (Acknowledgements p. 4). Moreover, $52,589 was raised by the CI towards this project over and above GWRDC funds: $32,589 from commercial contract bioassays for pesticide manufacturers carried out by CI and $12,500 carried out by other staff; $7,500 from licensing CI's PhD data on canola oil efficacy against grape rust mite to Agrichem Ltd., for registration against rust mite in grapes in Australia (as per contract between GWRDC, LaTrobe Uni, Agrichem). The funds were used to extend the project beyond its original closing date and to enhance its scope.

Recommendations for future communication strategy

(1) That project findings and technical publications 2006-2007, as well as selected publications from other authors, be incorporated into a single volume publication updating IPM publications for growers, Crop Protection Series Number 1-Pests and Diseases, and the IPM Research to Practice Manual.

(2) That project findings and technical publications 2006-2007, and selected publications by other authors be presented in the form of grower seminars in regions where these seminars were not delivered to date by this project.

(3) That a list of pesticides safe to beneficials/ pesticide effects on natural enemies produced by this project be listed in the AWRI guide to viticulture pesticides, AND/OR be linked as a pdf to on-line winery spray diaries, allowing growers easy access to up-to-date information on pesticide safety to natural enemies, and a choice of sustainable pesticide use.

(4) That the publication: "Bernard M., et al **2007**. Guidelines for Environmentally Sustainable Wine Grape Production in Australia: IPM adoption self-assessment guide for growers, The Australian and New Zealand Grapegrower and Winemaker, 518 (March), p. 26-36" be used as the technical document on which pest management in any future potential accreditation scheme for sustainable wine grape production in Australia is based. This would match efforts of other wine exporting countries who already have sustainable accreditation schemes (see this publication for www. links to these schemes). That IPM specialists with proven practical record in Australia be involved in developing the pest management aspect of any future potential Australian accreditation scheme, so that the scheme is technically sound and allows for practical growth towards greater sustainability into the future.

(5) Interim report recommendation: "That grower seminars in this project, and new seminars on a successful sustainable wine grape production certification scheme in the USA be extended to interested regions and associations in Australia" was in fact fulfilled in July - August 2007, under GWRDC RITA Project: 13th AWITC Regional Forum. The CI was the co-coordinator and one of the presenters of this extension forum.

(6) 3. BACKGROUND

3.1 Summary of background provided in the original application

Pest, disease and weed control strategies since WW II focused mainly on approaches that kill pests by chemical means. There is a growing realization that these approaches are crude, expensive, and capable of disrupting ecological systems and diminishing their life-sustaining services that are essential to human well being and survival. A shift away from killing target pests alone, to integrative understanding of the beneficial species complexes available for natural pest control, their role and interactions and their optimal harnessing, backed up by selective 'soft' insecticides that play a supportive rather than major role in pest management, has been gaining momentum since late 1970's. This approach (Total System Approach)[6] focuses on pest control as a component integrated with optimal managing the entire agroecosystem, and includes many strategies. For example, cover crops to reduce soil erosion, improving soil structure, providing nectar, pollen, and refugia for natural enemies, increasing natural enemy fitness and parasitism/ predation rates.

There is overwhelming evidence that Total System Approach/or IPM leads to major pesticide reductions in all crops where it has been diligently implemented. For example in glasshouse crops in the EU and in Australian IPM-citrus production, where IPM adoption resulted in up to 90% pesticide reduction and major annual savings [8]. There is also evidence that Total System/IPM protects cropping systems and growers' economic gains from damage by pests induced via broad-spectrum pesticide use; for example from two-spotted mite and other mite pests [9, 10]. The 'induced pest' concept is well established and documented. Local examples include: induced pests mite outbreaks in Queensland citrus orchards via mancozeb, methidathion and mancozeb suppressing predatory mites [11]; mancozeb effect on grape rust mite and widespread RSG symptoms in wine grapes (GWRDC Project DAV 98/1); broad-spectrum insecticide effect on mealybugs (*Pseudococcus* sp.) in table grapes (Horticulture Australia FR00036) and in wine grapes in Western Australia due to widespread use of broad-spectrum pesticides against weevils. The first step in implementing the Total System/ IPM is thus research off-target effects of pesticides on vineyard natural biological control providers. The second step is to document naturally present biological control providers in Australian vineyards, and to 'fill-in' current gaps in knowledge that limit IPM implementation.

This project emerged from IPM PhD research on grapevine rust mite and bud mite by Martina Bernard (supervised by Prof A. Hoffmann and Dr P. Horne; DAV 98/1). Through many discussions with growers and viticulturists during implementation of IPM strategies for rust and bud mite, we became keenly aware of the need to develop integrated chemical and non-chemical strategies that consider/integrate all beneficial organisms, pests and diseases, rather than just mites. This was impossible at the time, because little information on: (1) beneficials impacting most on key vineyard pests; (2) toxicity of fungicides and insecticides to these beneficials. In the absence of such information it was difficult to advise growers on safer chemical alternatives, and on overall control programs that maximize utilization of beneficials and minimise pesticide use and environmental impacts. For example, some control measures implemented for one pest or disease cancelled out the effect of controls implemented for another target organism, and induced pests by killing its natural bio-control agents. This in turn led to unnecessary and ineffective post-damage spraying in an attempt to clean up induced problems. For example, the use of mancozeb to control phomopsis and downy mildew, led to industry-wide rust mite outbreaks, widespread RSG symptoms in vines due to rust mite and bud mite (DAV 98/1). There was thus a clear need to test key pesticides currently in use, and to assess the IPM-compatibility of new pesticides, in order to provide growers with information that would allow them to make informed choices about pesticide use, and give them a genuine option to conserve and enhance beneficial arthropods and biological control potential in their vineyards, use resources more effectively, and realize substantial savings in the short and long-term.

3.2 Other relevant background

3.2.1 Pesticide effects on beneficial invertebrates: how to best evaluate effects of pesticides

Most data available on pesticide safety to beneficial invertebrates are not generated on Australian beneficial species. Unlike in the EU, the Australian regulator (APVMA) requires no data on beneficial invertebrate safety (except for honeybees) for pesticide registration, and sets no minimum testing standards, despite increasing awareness among growers of advantages in conserving naturally present biological control potential of their vineyards. Data on Australian beneficials are therefore scant, and are obtained from tests of varying methodology and rigor. Moreover, data generated by pesticide manufacturers have often been marketed without the disclosure of testing methods. This makes such data difficult to evaluate, because it is a well-established fact that the testing method influences the result. Differences in concentration, dose, strain, length of test, developmental stadium tested, residue vs. topical spray application, and acute vs. sub-lethal testing. To solve this problem, near 'worst-case scenario' laboratory pesticide testing standards, and standardized field tests, were established in the EU [13, 14], and are required for EU pesticide registration. This testing is done on *c.* 8-9 beneficial species that collectively indicate the likely effects on beneficial groups across cropping systems in the EU. But EU results do not transfer easily into the Australian context. pesticide effects on beneficials can be species-specific and can vary widely even within the same invertebrate family or genus. A local example established by Thomson and Hoffmann (DAV 98/1) [12] is the negative impact of wettable sulphur on a native species of *Trichogramma* (egg parasitoid of LBAM), not apparent from tests on equivalent European *Trichogramma* species.

In Australia, there was little research on pesticides off-target effects on key Australian beneficial species, (including for novel LBAM insecticides registered since the conception of this project) to the 'worst case scenario' rigor. Few standardized testing protocols have been proposed for Australian species, such as for *Trichogramma sp*. Westwood [12] and the brown lacewing *Micromus tasmaniae* [15], and relatively few results were published [16]. Procedures have not been standardized, and pesticides were sometimes classed 'safe', based only on 48 h mortality results [17, 18], disregarding internationally established sub-lethal and worst-case exposure methods. Moreover, claims about pesticide safety to beneficials have been made in Australia by pesticide promotional material with no reference to testing methods, even though different results can be obtained depending on methodology. This led to extensive use of some cheap, generic fungicides, compatible with most other sprays, such as Mancozeb in Australian viticulture, a subsequent disruption of predatory mites, and major outbreaks of grapevine rust mite cross regions in the 1990's.

3.2.2 IPM field research and demonstration: beneficial invertebrates in Australian vineyards

This project was designed to elucidate the role of beneficial invertebrates in Australian vineyards in relation to natural pest control. Naturally occurring biological control of crop pests is an important ecosystem service, sustaining human life and well-being [19-21]. It is responsible for the control of the majority of all potential pests even in highly modified horticultural and agricultural landscapes, particularly where IPM or organic methods are used [22-24]. This ecosystem function is underpinned by biological diversity. Preventing its damage, and enhancing ecosystem services provision of agricultural fields generally, are key aims of sustainable crop production, recognized as crucial to maintaining high-productivity agriculture into the future [25-27]. Generalist predators constitute an important functional group which provides biological control services in vineyards. Most studies of these groups to date investigated aphid-feeding guilds in cereal crops, corn, or cotton. Studies of generalist predators from vineyards or orchards are relatively few, and are mainly from Europe, North America, or New Zealand; for example [28-33], with so far only two Australian exceptions [34, 35].

A literature review at the start of the project revealed there was no published Australian work on seasonality of generalist insect predators in vineyards, their role, interactions, or functional relationships, or their relative contributions to vineyard pest control of LBAM (*E. postvittana)* and longtail mealybug (*P. longispinus)*. Generalist predators found in Australian vineyards were documented only by anecdotal or unpublished records. Except for [34-40] and current work by Paull and Austin (unpublished data) there was no research evaluating feeding preferences and feeding rates, other than anecdotal or unpublished records [41, 42]. The only extensively studied beneficials were LBAM egg-parasitoid wasps *Trichogramma* sp. (some 25 studies published), but even these studies (except for [43]) were for the most part not concerned with seasonality and natural occurrence of these wasps in vineyards, concentrating instead on their biology, rearing, or on releasing in vineyards [44-46]. It is economically and ecologically paramount, that prior to expensive releases of any beneficial control agent, the vineyard ecosystem be studied to evaluate naturally present bio-control providers, and to maximize their pest control potential by inexpensive means. Some of these means are available to growers now, but are not yet extensively used in Australia. Maximizing natural present bio-control potential, can in turn maximise the success of bio-control releases, should they be required.

In the absence of almost all information relevant to IPM, and conservation bio-control in Australian vineyards, this project faced having to select the most strategic first data to collect, to best contribute baseline, IPM-relevant information on key beneficial species and their changes over the season. These seasonal data are standard key criteria that help establish which predators are most important to pest control. To obtain such information, I opted to (i) sample the entire generalist predatory species guilds (except phytoseiid predatory mites -specialist sampling required), and (ii) LBAM parasitoids, on a weekly basis over two entire growing seasons, and (iii) concurrently sample all pests (except pest mites -specialist sampling is required). Given the importance of lacewings in many other crops, and unpublished data from grapes (Horne and Altmann, unpublished data), I placed my research emphasis on this group. Lacewing predation in crop environments is well established in other parts of the world [47, 48], and key Australian green lacewing species have been recorded throughout Australia [49-51], and as key predators in citrus and many other crops [16, 52, 53](Horne unpublished data). Similarly for example, several brown lacewing species commonly occur throughout Australia [40, 54, 55] including in vegetable crops and cotton [36, 56, 57]. This meant that of the many possible available sampling methods, I selected methods which optimized collection of lacewings. To this effect a literature review of sampling methods was also undertaken.

4. AIMS AND PERFORMANCE TARGETS

4.1 Aims

1. **To develop an itemized benchmarking map that documents all aspects of the total system/IPM approach in grapevines for use by growers for self assessment to evaluate the level of IPM-adoption in their vineyard; and that can be used as a starting point for a future IPM accreditation and marketing scheme.**
2. **To investigate the pest control potential of key beneficial insects, naturally present, and with a potential for establishment after release.**
3. **To investigate lethal and sub-lethal effects of key fungicides and insecticides used in wine grapes and table grapes, on key beneficials beneficial invertebrates, identify effective substitute compounds, and/or improve timing and applications, and compile the chemical window within which sustainable viticulture can be practiced.** (Change: testing of pesticides specific to table grapes was not done, as Horticulture Australia funds were not secured).
4. **To undertake a pilot implementation, demonstration and cost benefit analysis of integrated total system pest management in wine grapes**. (Change approved: cost benefit analysis of IPM in table grapes was not done- Horticulture Australia funds not secured; cost benefit analysis of wine grapes was not done due to the major shift in the wine market (over-supply, then drought/frost/fire) during the project's life, making such analysis difficult at the time. However, publication (output 4) provides an accurate baseline for cost benefit analysis in the future.

4.2 Outputs and performance targets

Several changes to completion dates for performance targets were approved by the GWRDC in line with project the extension until October 2007. Some changes to Output 2 were also approved; for reasons see previous progress reports.

Outputs	**Performance Targets as per final project application (25 June 2002) and approved changes**
1. Testing of fungicides, insecticides and herbicides on beneficials	1.1 Grower article on work published by Jan 04 **(completed- published Mar 04)** 1.2 Scientific papers submitted by Jan 2005 **(completed - published 2005)** 1.3 On line & hard copy of results for easy use by growers by Jan 2006 **(completed)** 1.4 Five extension workshops help by Jan 2006, at least 500 growers participating **(completed and exceeded by grower demand)** 1.5 Bioassays with lacewings and predatory mites **(90% completed Oct 2006)** 1.5 Bioassays with lacewings (*M. signatus*) **(completed Oct '07)** and a repeat of D. Bennett's testing on predatory mites **(48 h test completed Oct '07; additional tests on new species completed Oct '07):** repeat of Bennett's test concluded at 48 hr mortality (instead of 7 d) due to temporary problems with predatory mite culture causing control mortality > 25%. In lieu of this, 2 new bioassays with 2 other beneficial species (*M. tasmaniae* and *N. kinbergii*- due in CX 2295) were completed Oct 2007 ahead of time, to fulfill Target 1.5. A further repeat of Bennett's test will now be completed as soon as mite culture is restored, as part of CX 2295 in tandem with other CX 2295 testing on that culture (as per p.18-19).

2. Feeding trials on beneficial completed, interaction between key parasitoids and key predators investigated. (Feeding trials with predatory thrips on grape rust mite were completed.) Change approved: After completing feeding trials with a predatory thrips, substitute: (i) field trials to improve efficacy of BT via improved application, (ii) expanded field assessments of beneficials, and (iii) a review and extension seminars development on a newly merged pest (mealybug) for the original output 2 above.	2.1 Grower article on work published by Jan 2005 - **approved to be completed as a 2nd grower article - new target 3.2.2 (Output 3) below**. 2.2 Scientific paper submitted by Jan 2006. Change approved: field trail on BT application, and predatory thrips feeding results **to be incorporated into scientific paper (Target 3.3) below.** 2.3 Additional target approved due to grower demand: a review and preparation of extension material for grower seminars on mealybug biology, control options and beneficials of mealybug pests and their management; and additional extension seminars conducted on this topic in winter/spring 2005 **(completed/exceeded by demand)**
3. Totals system approach in vineyards set up, implemented and maintained, and cost benefit analysis of demonstration project completed.	3.1 Report on cost-benefit analysis completed by Jan 2006. **(not completed/ change approved)** due to the major shift in the wine and grape market during the life of the project (over-supply, then drought/frost/fire). Publication (output 4) documents the full spectrum of pest management options in wine grapes, and is now the firm basis for a future cost benefit analysis along the sustainable- unsustainable spectrum.) 3.2.1 Grower article (a) on results published by Jan 2006 (completed by approved revised date June 2006) **(completed – published Sept 2006)** 3.2.2 Grower article (b) on results published by Jan 2006 (completed by approved revised date June 2006) **(completed –published Oct 2006)** 3.3 Scientific paper submitted by Jan 2006. Change approved: submission by a revised date Dec 2006 (**completed as below; exceeded by 2 additional papers):** 3.3.1 Scientific paper: Mortality and sub-lethal fecundity effects of pesticides on the predatory mite *Euseius victoriensis* (Acari: Phytoseiidae): a study to maximise conservation biological control in Australian vineyards, Journal of Economic Entomology **(completed - submission Jan 08 to include tests on same species due in CX 2295)** 3.3.2 Scientific paper: Functional biodiversity for Integrated Pest Management (IPM): seasonal abundance of polyphagous predators and parasitoids of leafrollers (Lepidoptera: Tortricidae) in vineyards of South-East Australia, Australian Journal of Entomology **(80% completed - submission Mar 2008)** 3.4 Five extension workshops held by Jan 2006, at least 500 growers participating **(completed in winter 2006, and exceeded by grower demand)**
4. Total system benchmarking map itemized per each pest and draft accreditation criteria developed.	4.1 Report on total system benchmarking and draft accreditation criteria on web site and completed for publishing in technical literature by a revised date 30 Oct 2006. **(Completed - published - March 2007 in an expanded form: 'Guidelines for sustainable wine grape production in Australia: IPM', including a fully integrated disease management overview)**
5. Final report	5.1 Final report completed and sent to GWRDC by Feb 2006- changes approved: 5.1 Revised due date for interim final report 31 Oct 2006, incorporating all performance targets except Targets 1.5 and 3.3 **(completed Oct 2006)** 5.2 Final report incorporating Targets 1.5 and 3.3 due 30 Oct 2007. **(completed 9 Nov 2007)**

5. METHODS

5.1 OVERALL METHODOLOGY APPROACH

This project used the latest model for integrated agricultural research and extension advocated by leading universities, including the University of California, and now required by USDA (US Department of Agriculture) for all federally funded agricultural research projects, to ensure high impact, practical research outcomes and rapid adoption into practice. This project fully integrated research and extension components throughout its duration, departing from the model usually used in Australian agricultural research, where the two components are carried out by different personnel and projects, dedicated to either research or extension, and where the extension component of research at best consist of only a few presentations and a technical article. By contrast, in the research here each research component had an equivalent extension component, and where applicable and advantageous, these were carried out concurrently. As research results unfolded, they were allowed to strategically drive the direction of the project, changing some project outcomes and performance targets, while adhering to overall original aims. Inherent to strategic research, is that new data drive the direction of research. Growers' response to topical research structured in this way was phenomenal, and was demonstrated by their high demand for seminars on research topics throughout the life of the project. In response to this demand, many more face-to-face, audience-tailored seminars were conducted than were originally listed in the final project application. The project consisted of five key methodological components:

Integrating laboratory research and extension:

(1) Laboratory bioassays testing pesticides for effects on key vineyard beneficial species used as indicators of effects on the rest of the, then unknown, beneficial species complex

(2) Communication of results (1) supplemented by a comprehensive review of international literature. Firstly, to growers participating in the field research the following year, who immediately adopted the findings into practice. Secondly, to other growers in the research region, and in other regions by demand. In this way laboratory results were immediately put into practice.

Integrating field research and extension:

(3) Intensive field data collections over 2 years documented seasonality of beneficial and pest invertebrates in research sites. For most beneficials we sampled (except for *Trichogramma* sp.) this data were collected for the first time from Australian vineyards. This data collection was independently corroborated by a concurrent project in another region (Limestone Coast, SA).

(4) Communication on weekly basis throughout the season of pest and beneficial monitoring results to growers participating in the research. In this way IPM was jointly implemented at the research sites by growers and researchers, alongside research data collection on pest and beneficial numbers (Section 9). This is the way all successful IPM/Bio-control implementation has occurred in Australia; i.e. research was used as a problem solving tool in 'bottom up' IPM implementation. It is the reverse of the 'top-down' IPM implementation approach in which an attempt is made to gather all possible entomological data prior to any implementation, and which leads to slow, low levels of uptake.

(5) Communication of field results to other growers in the region who already knew on ongoing basis about adoption in research vineyards in their region, and extension to other regions by demand. This way local grower experience figured strongly in extension; a proven key factor for new technology uptake.

5.2 METHODS- LAB RESEARCH

For all pesticides tested by this project and the type of each test see (Table 1).

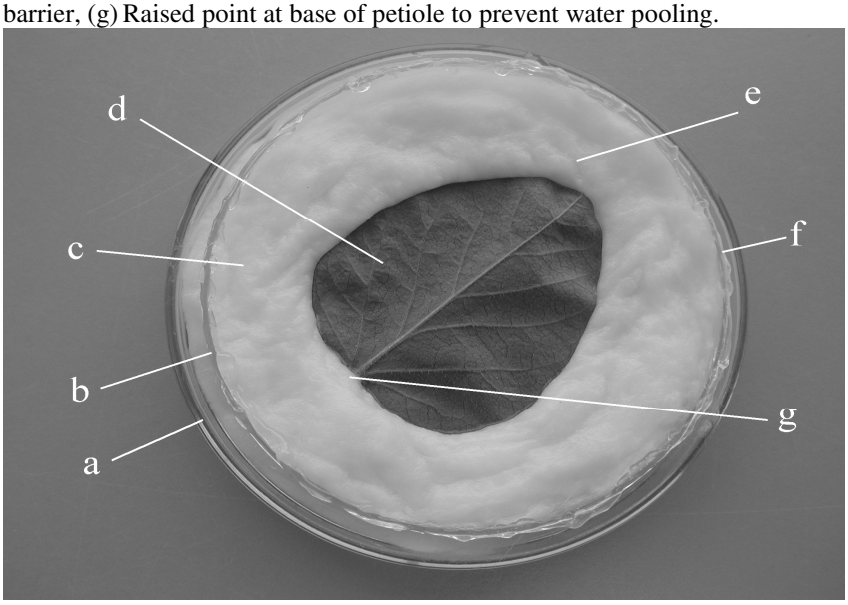
5.2.1 Selection of predatory mite testing species

Due to limited funds and resources, it was impossible to test all beneficials, and so a careful strategic choice of the 1st test species was made based on literature. A key predatory mite species was selected *(Euseius victoriensis)*, which is more sensitive to pesticides than some other predatory mites. To establish this, a literature review was conducted on suitable testing species based on two key selection criteria: (i) sensitivity to pesticides/ ability to show pesticide effects; (ii) the significance of the species to commercial crop production in Australia. The selection of an indicator test species of predatory mites was complicated by limited data. Historically, the introduction of exotic predatory mites to Australia, such as *Anystis sp.*, *T. pyri*, *Galendromus occidentalis*, and *P. persimilis,* moved research away from indigenous species. I selected two commercially significant phytoseiid predatory mites for developing testing procedures: a widespread indigenous generalist predator *Euseius victoriensis*, and naturalized organophosphate resistant *G. occidentalis*; TSM (*T. urticae*) predator, feeding also on rust mites and other pest mites [60] introduced to Australia in 1972 [61-64], and adapted to hot, dry Australian conditions, and an excellent control agent in pome and stone fruit, grapes and outdoor vegetables [16]. *E. victoriensis* was selected for testing because of its wide distribution, presence on a wide range of plants [11, 65, 66] and generalist feeding on pollen [11, 53], that can allow early season pollen-sustained releases and build up, to enhance bio-control potential. *E. victoriensis* is widespread in inland and sub-coastal citrus crops, controlling citrus eriophyoids, as well as *Polyphagotarsonemus latus* (broad mite) and *Eutetranychus orientalis* (oriental spider mite) [11, 63]}[11, 53, 63, 67, 68] reported from inland stone fruit and grapes in association with TSM and eriophyoids mite pests [65] [69].

5.2.2 Australian testing standard for evaluating acute and sub-lethal effects of pesticides on predatory mites

A comprehensive 'worst case scenario' testing method was developed, that sets the standard for all future testing of predatory mites in Australia, and is ready for use by other researchers in testing in many other crops. The laboratory bioassay for testing the effect of pesticides on *Euseius victoriensis* (Womersley) and *Galendromus occidentalis* (Nesbitt) on detached leaves of *Glycine max* (L.) (soybean) and *Phaseolus vulgaris* L. (French bean) was developed and validated in initial testing. The method was then used to test 35 pesticides and other agrochemicals. The tests allowed standardized comparisons between different mite species and leaf substrates, under 'worst case scenario' exposure, comparable to commercial pesticide application. Young juveniles, along with their initial food and the entire water supply, were sprayed runoff point using precision spraying equipment (Potter Spray Tower). The highest registered field rate concentration used on French bean, was adjusted to deliver the same pesticide dose per higher runoff point volume on hairy soybean. Cumulative mortality was assessed at 48 hrs, 4 days and 7 days after spray application. Sub-lethal effects of pesticides were also assessed: fecundity of freshly matured adult females was assessed (for 7 days from the onset of oviposition) after they were exposed to pesticides as young juveniles. Test standardization on various leaf substrates provides an alternative approach to standardization via residue on glass used by IOBC/WPRS regulatory testing in the EU. For full description of methods see [70]. Bayfidan, Rovral, and Accord were tested in 2007, but the assay was terminated at 48 hrs due to high mortality in controls from predatory mite cannibalism. This technical difficulty with predatory mite culture will be rectified within 4-6 weeks. In the mean time, insecticide tests on other key predators *M. tasmaniae* (brown lacewing) and *N. kinbergii* (damsel bug) due in PART B - 2008 were completed ahead of time and are reported here in lieu of the above termination. For all pesticides tested by this project and the type of each test see (Table 1).

Figure 2: *E. victoriensis* bioassay: detached leaf test unit (soybean).
(a) Glass Petri-dish (100-mm diameter), (b) Plastic Petri-dish (90-mm diameter), with a base drilled centrally (10-mm diameter) and 10-mm-diameter cotton dental wick inserted (not visible), (c) Cotton wool lining, (d) Upturned leaf embedded in cotton wool (petiole intact), (e) Cotton wool barrier around each leaf (2-4 mm high), (f) Sticky barrier, (g) Raised point at base of petiole to prevent water pooling.



5.2.3 Bioassay methods with green lacewings and other suitable testing species

Compounds found safe to *Euseius victoriensis* were not tested further. Key compounds found harmful were tested further, and data from a world wide literature review were combined to prepare a comprehensive 'safe' pesticide profile for the wine industry. Green and brown lacewings species (*Mallada signatus*, *Micromus tasmaniae)*, and the predatory damsel bug (*Nabis kinbergii*) were selected as other suitable testing species based on (i) very high abundance during field seasons 2003-2005 in all vineyards studied and wide-ranging distribution across Australia [40, 54, 55], including in vegetable crops and cotton [36, 49-51, 56, 57], and based on (ii) a literature review indicating feeding on LBAM larvae and mealybugs [16, 34, 41, 42, 52, 53, 71](Horne & Altmann unpublished data). A testing method for *M. signatus* was developed and trialed with four fungicides: Polyram, Delan, Stroby and Mancozeb (toxic reference*). M. signatus* 1st and 2nd instar larvae, their food supply, and the testing unit surface were over-sprayed with highest label rate concentrations. Mortality of larvae was assessed regularly until pupation. Egglay of emerged adults and egg hatchability were assessed for a 4 day period.

A modification of this method (Cole, Kobelt, Horne, unpublished) was used in collaboration with Cole and Kobelt (IPM Technologies & DPI) to test the effect of insecticides on *M. signatus, M. tasmaniae*, and *N. kinbergii* juveniles, separating mortality effects for direct overspray, exposure to fresh resides, and ingestion of pesticide-treated prey. Newly hatched larvae (<48h old) of each species were sprayed to runoff on absorbent paper using hand-held atomizer, controls with distilled water. A non-ionic surfactant 0.1 ml/L Wetter® 600 (600g/L nonyl phenol ethoxylate, Gulf Ag) was added to all treatments. 16 larvae were sprayed per replicate, and each treatment replicated 6x. Larvae were transferred after spraying to 70 ml ventilated plastic containers, each containing an oversupply of prey (turnip aphids, *Lipaphis erysimi*) on a 40mm diameter cabbage leaf disc. Containers were incubated at 24 ± 1.0°C, 14L: 10D photoperiod, for 72 h and mortality assessed. Death was defined as inability to walk when prodded with a fine brush. In residue testing, the above method was followed, except that the cabbage leaf disks were sprayed to runoff, air dried at 24°C before incubating predatory larvae as above. Data were angle transformed and analysed using the Bonferroni test, comparing each treatment to pooled control values.

Table 1: Pesticides tested: common name, product formulation, and beneficial species tested (Tests completed since the Interim final report Oct 2006 - green).

Common name of active constituent	Product formulation	*G. occidentalis (predatory mite)*	*E. victor. (pred. mite)*	*M. signatus (green lacewing)*
Downy mildew, Phomopsis, Black spot				
boscalid	Filan® 500 WG	**yes**	**yes**	**-**
dithianon	Delan® 700 WG	**yes**	**yes**	**yes**
kresoxim-methyl	Stroby® 500 WG	**yes**	**yes**	**yes**
mancozeb	Mancozeb® 750 WG	**yes**	**yes**	**yes**
metiram	Polyram® 700 WG	**yes**	**yes**	**yes**
phosphonic acid	Fungi-fos® 400	-	**yes**	-
chlorothalonil	Barrak®	-	**yes**	-
metalaxyl, copper hydroxide	Ridomil® Gold Plus	-	**yes**	-
captan	Captan®	-	**yes**	-
azoxystrobin	Amistar®	-	**yes**	-
dimethomorph	Acrobat®	-	-	-
copper hydroxide/ copper oxycholride	Kocide®	-	**yes**	-
fenarimol	Rubigan®	-	**yes**	-
pyraclostrobin	Cabrio®	Not registered 2002-03 at time of testing, due in CX 2295.		
trifloxystrobin	Flint®	Further testing due in CX 2295.		
Powdery mildew				
wettable sulphur: 200g/100L	Thiovit®	-	**yes**	**yes**
wettable sulphur: 600g/100L	Thiovit®	-	**yes**	**yes**
wettable sulphur: 1200g/100L	Thiovit®	-	**yes**	-
triadimefon	Accord®	Tested Oct 07. Test terminated at 48 h, re-testing due in CX 2295.		
triadimenol	Bayfidan®	Tests on brown lacewing and damsel bug completed in lieu of this in collaboration with P Cole & A Kobelt (DPI & IPM Tech.)		
azoxystrobin	Amistar®	-	**yes**	-
hexaconazole	Anvil®	-	**yes**	-
pyraclostrobin	Cabrio®			
trifloxystrobin	Flint®			
tebuconazole	Folicur®			
quinoxyfen	Legend®	Not registered 2002-03 at time of testing. Due in CX 2295.		
spiroxamine	Prosper®			
potassium bicarbonate/ 2ml canola oil	Ecocarb/Synertrol oil			
flusilazol	Nustar®	-	-	-
myclobutanil	Mycloss®	-	**yes**	-
fenarimol	Rubigan®	-	**yes**	-
pemcozole	Topaz®	-	**yes**	-
Botrytis				
azoxystrobin	Amistar®	-	**yes**	-
chlorothalonil	Barrak®	-	**yes**	-
carbandezin	Bavistin®	-	**yes**	-
captan	Captan®	-	**yes**	-
boscalid	Filan®	**yes**	**yes**	-
benomyl	Marvel®	-	**yes**	-
cyprodinil + fludioxonil	Switch®		**yes***	-
fenhexamid	Teldor®		**yes***	-
pyrimethanil	Scala® 400 EC		**yes***	-
hydrogen peroxide, peroxyacetic acid	Peratec®		**yes***	-
iprodione	Rovral Aquaflo	Tested Oct 07. Test terminated at 48 h, re-testing due in CX 2295. Tests on brown lacewing & damsel bug completed in lieu of this, in collaboration with P Cole & A Kobelt (DPI & IPM Tech. Ltd)		
procymidone	Sumisclex®	Not tested: re-classified S7 poison (teratogenic effects)		
tetraconazole	Domark® 40ME	-	**yes***	-
		Not registered 2002-03 at time of testing. Due in CX 2295. Tested Oct '07, further testing due in CX 2295.		

Common name of active constituent	Product formulation	*G. occidentalis (predatory mite)*	*E. vic. (predatory mite)*	*M. signatus (green lacewing)*	*M. tasmaniae (brown lacewing)*	*N. kinbergii (damsel bug)*
indoxacarb	Avatar®	-	**yes**	**yes**	**yes**	**yes**
Bt	Delphin®	-	**yes**	**yes**	**yes**	**yes**
tebufenozide	Mimic®	-	**yes**	**yes**	-	-
emamectin	Proclaim®	-	**yes**	**yes**	**yes**	**yes**
Spinosad (overspray)	Success Naturalyte	-	**yes**	**yes**	**yes**	**-**
spinosad (fresh residue)	Success Naturalyte	-	**yes**	**yes**	**yes**	**-**
canola oil	Supastik®	-	**yes**	-	-	
buprofezin	Applaud®	-	**yes***	-	-	-
imidacloprid	Confidor®	Confidor and Applaud not registered 2002-03 at time of testing, due in CX 2295. Applaud tested Oct '07, further testing due in CX 2295.				
	Agral®	-	**yes**	-	-	
	Bond®	-	**yes**	-	-	
glyphosate	Roundup®	-	**yes**	-	-	

*** 48 hrs mortality data only; tests on brown lacewings and damsel bugs completed in lieu of this shortening.**
Pesticides were tested at the highest rate registered in wine grapes in Australia, and applied to runoff on bean leaf test units, with proportionate dilutions in *E. victoriensis* assays to compensate for higher runoff point and higher spray deposit on soy bean.
G. occidentalis assay: 4.46 ± 0.06 mg/cm^2, *E. victoriensis* assay: 7.51 ± 0.09 mg/cm^2 wet spray deposit.

5.2.4 Laboratory feeding tests with predatory thrips - *Haplothrips victoriensis*

Winter feeding on *C. vitis* was tested in a preliminary no-choice feeding test over 4.6 days (100 h). *H. victoriensis* 1st and 2nd instar larvae, and over-wintering rust mite deutogynes were obtained from field-collected dormant canes and cordon sections in winter. Test units were sterile Petri-dishes (Gelman®, 50mm diameter) containing agar substrate, with the base taped on the outside with black tape for rust mite detection. Test units were set up, kept and scored inside a CT room (14°C, 60% RH, 12h d), to prevent condensation due to temperature changes. Agar was made per[72]. Petri-dish bases were partially filled with autoclaved water agar (4g/100ml) dyed with 0.4% charcoal, and 0.01% Polymyxin B Sulphate (Sigma, Australia) was added after autoclaving. Unlike for *Aceria tosichella* Keifer (wheat curl mite) [72] high rust mite and *H. victoriensis* mortality resulted due to drowning in condensation. Thus agar substrate was reduced to one half of the surface area, and predators and prey were not placed on it, when transferred to the dish. In total, 6 units were set up, each initially with seven to eight rust mite deutogynes transferred with a single-hair brush, and one *H. victoriensis*. Feeding units were paired with controls containing rust mite alone. Four test units and four controls were set up initially, the rest were set up as *H. victoriensis* larvae were obtained from dissected canes. Feeding was assessed at 24 h intervals for first 3 d, and at 28 h interval on the last 4th d; eaten rust mite remnants and drowned rust mites were counted and removed, live and intact-dead rust mite were counted, and new live rust mites were added to have 6-12 live rust mites per test unit at the start of each new 24 h assessment period. Larger numbers of rust mites were added by placing them on a glass cover-slip, and placing the cover-slip inside the petri-dish. Rust mites were deemed dead when no movement in response to gentle prodding occurred, and they had glassy, hydrated appearance. A dissecting microscope (10-45 magnification) and a cold light source were used.

5.3 METHODS- FIELD RESEARCH

5.3.1 Study sites and pesticide use

Four large commercial vineyards were studied over two years. **Sites I-II**: were in higher altitude in ranges 10-15 km from Hoddles Creek (145°35'E, 37°50'S) and were selected due to a history of high LBAM infestations compared to the Yarra Valley (Horne, unpublished data). Sites III-IV were in Yarra Valley. **SITE III** (45 ha), 12 km East of Yarra Glen (145° 22'E, 37°39'), **Site IV** (33 ha) 8 km West, was added in the 2nd year in lieu of Site III, which abandoned IPM in spring '04, using chlorpyrifos when *P. longispinus* was first found. Vine blocks studied ranged from 2-3.6 ha (Sites I, II, IV), 5 -8.1 ha (Site III). Vines were VSP trained, pruned to 2-bud spurs, spaced at 1.5-1.8 m, with row spacing of 2.2-2.5 m. All sites were in close proximity to remnant native vegetation near at least one border, and were chosen for this for study; to (a) provide a high source of LBAM, allowing IPM study and demonstration under high LBAM pest pressure, and because (b) native remnant vegetation is a source of beneficial invertebrates as demonstrated by many European studies. This aided my aim to demonstrate IPM/Totals System potential in vineyards with regional-landscape conditions that optimise natural bio-control ecosystem service. Sites I-II were close to tall wet sclerophyll forest of *Eucalyptus regnans* F. Muell. (mountain ash) with dense multi-layered understoreys consisting of species typical for South Eastern Australia, with more open stands of *E. obliqua* L'Herit. (messmate) and *E. radiata* Sieb. ex DC. (Peppermint Gum) on drier slopes [73]. Site III bordered grazed Yarra River flood plains, containing a mixture of exotic pasture grasses and semi-cleared native vegetation including native grasses *Themeda triandra* Forsk. (kangaroo grass) rushes, sedges, and stands of *Eucalyptus camaldulensis* Dehnh. (river red gum) and *E. viminalis* Labill. (manna gum) near the river, *c*. 600 m away. Site IV bordered open dry sclerophyll forest of *E. goniocalyx* F. Muell. ex Miq. (long-leaved box), *E. macrorhyncha* F. Muell. (red stringybark), and *E. polyanthemos* Schau. (red box) typical of Silurian-derived sedimentary hills North-East of Melbourne, with 2-layered understorey of typical species. Alternate row mowing was practiced in all study blocks in 2004-05. Grasses and forbs were flowered before mowing alternate rows *c.* 3 times per growing season. Mid-rows contained exotic perennial grasses, infrequently interspersed with weeds such as; *Trifolium repens* L. (white Dutch clover), *Plantago lanceolata* L. (plantain), *Taraxacum officinale* Web. (dandelion), *Acetosella vulgaris* (sorrel), *Medicago sativa* L. (alfalfa), *Sonchus oleacerus* (milk thistle), *Malva* sp., and *Rumex crispus* (curled dock).

All sites used IPM for at least three consecutive years, implemented with the aid of IPM consultants (IPM Technologies Ltd., Hurstbride, Victoria). The IPM scheme was broadly consistent with IOBC Guidelines for Integrated Grape Production '99 [74]. Broad-spectrum insecticides and fungicides toxic to phytoseiid predatory mites [70, 75] and to other beneficials were not used. Wettable sulphur use in study blocks did not exceed 300g/100L (3kg/ha). Tebufenozide (Mimic 700WP) and BT (Dipel, Delfin), and one spinosad (Success) spray per season in one site (2004) were used, except for an accidental indoxacarb (Avatar) spray ('02) in one site prior to this research. Monitoring of pests and beneficials was used to decide when to spray and when not to spray, and the data was provided to the grower each week.

5.3.2 Sampling of pests and beneficials

Field sampling was frequent enough to ascertain seasonal changes and phenology of all key beneficials, and show any changes in their seasonal abundance. Such data were not available until this project, yet are crucial to ascertaining the beneficial species complexes of key vineyard pests and the relative contribution to pest control made by each beneficial species within the complex. Given the central importance of these data, extensive weekly sampling was the most time consuming performance target of the project, requiring 4 days full time work per week during the entire growing season (2 days per week per 2 staff: chief investigator and technical assistant). Sorting beneficials and identification to species were additional tasks over and above the four days per week sampling commitment.

Concurrent sampling of all life stages of key pests LBAM (*E. postvittana),* longtail mealybug (*P. longispinus)*, citrophilous mealybug *(P. calceorariae*), grapevine moth (*Phalaenoides glycinae*) and all macro-invertebrate natural enemies was done. Vineyards were sampled weekly over two growing seasons 2003-04 and 04-05, using direct observation of vine canes (fortnightly for spiders, and when re-entry periods applied). Weekly pheromone trap counts were used to monitor male LBAM flights. Chardonnay and one other vine variety (Cabernet Sauvignon, Pinot Gris, Pinot Noir, or Merlot) were sampled at each site. In the 2nd year, sampling was further complemented by fortnightly suction sampling of alternately-mowed vine midrow vegetation. Given no single sampling method is ideal to accurately sample all relevant species, funding constrains, and a dearth of data on generalist predators, the study was weighted towards investigating the most promising insect predators: green and brown lacewings (Chrysopidae and Hemerobiidae). Direct observation was thus chosen for its singular capacity to accurately sample stalked chrysopid eggs [33, 76-78], and for its proven capacity to sample most relevant macro-invertebrates in commercial IPM monitoring (Altmann, Horne, Papacek, unpublished). Direct observation of vine canopy was deficient in collecting 1st instar lacewing larvae compared to beating [33, 78], and it is so deficient in sampling spiders [79]. Only daytime sampling was done, which can underestimate insect and spider numbers [80], but multiple-methods canopy sampling was beyond the scope of this project.

Four well-established sampling methods were used concurrently:
(a) Direct observation of vine canopy (whole shoots):
100 randomly selected shoots (replicated 3-6x; n=3-6) were examined from tips, both leaf sides, one fruit cluster, to 10 cm cordon sections below each shoot. 300-600 shoots were checked weekly at each site (7 October-28 April), in four vineyards 2003-05. The shoot was the basic sampling unit, as shoots grew in spring, the sampling effort increased accordingly. Pest infestation and damage on fruit clusters (100 bunches; n=3-4) was recorded separately from infestation on the rest of the shoots, to allow for later comparisons. In the case of green lacewings, only freshly-laid green or gray eggs were counted (no emerged eggs), therefore numbers recorded are an underestimate of eggs laid each week. Larval parasitism of LBAM was estimated only by direct observation field counts, rather than by larval dissections or rearing of collected larvae, which was beyond the scope of this project. Field counts of parasitoid pupae were made by direct observation of the vine canopy. Parasitoid pupae and abnormal LBAM larvae were collected, reared to adult emergence in the lab, and identified to species. Scoring larval parasitism in the field is fast and well-suited to routine IPM-monitoring, but underestimates parasitism [81], as only parasitoid cocoons are scored (parasitized larvae show no superficially visible symptoms). This was compensated by weekly sampling frequency, to sufficiently indicate peak seasonal parasitoid activity. The alternative (collecting large numbers of LBAM larvae, rearing these to adult emergence, and scoring % parasitism), and the study of mealybug and scale parasitoids were beyond the scope of this project. % LBAM egg parasitism was scored by weekly counts of all LBAM egg-masses (emerged, freshly laid, and parasitised). All parasitised egg-masses were collected, reared to emergence, and wasps identified to genus. Very high LBAM numbers were recorded in the cooler 2004-05 season.

(b) Additional direct observation of vine canopy (leaves only)-longtail and citrophilous mealybug. Sampling of mealybugs was undertaken in the above transacts. Each week 25 vines per transact (n = 6) were randomly selected. Four crown leaves were randomly selected per each vine (total of 100 leaves; n = 6). Both sides of leaves were examined with a hand-lens in the field at 10x magnification. Crown leaves were chosen due to *P. longispinus* preference for these sheltered sites [71]. Ants associated with mealybugs were collected from feeding columns tending mealybugs and harvesting honeydew, and stored in 75% ethanol until identification. Late instar larvae and adult female mealybugs were collected, stored in 75% ethanol until identification to species in the lab. (Vines with mealybugs were tagged and further examined sampling 20 crown leaves per vine per week until the end of April).

(c) Vacuum suction sampling of long inter-row grass: 8-11 randomly chosen ($1m^2$) long grass quadrats were vacuumed for 60 s every 14 days (20 Oct-28 April 2004-05), using a suction sampler. Each catch

was captured in a nylon bag attached to the suction tube, killed immediately by ethyl acetate vapor for 24 hrs, and sorted for 5-7 days until sorting. Quadrant locations were marked to prevent re-sampling. In the lab, each sample was placed in a white plastic tray (grid markings over the base) and examined by two independent assessors over a total time of 30-60 minutes, depending on plant debris. Plant debris was slowly removed at 10x magnification, removing and counting taxa and sorting to Family/morpho-species. Sorted specimens were stored in 70% ethanol until species identification. Suction sampling was chosen for greater efficiency compared to pitfall traps or sweeping, in collecting winged adults and 3rd instar brown lacewing larvae; but was limited by underestimating 1-2nd instar larvae [82, 83].

(d) Pheromone traps: DeltaTraps (AgriSense-BSC Ltd, Mid Glamorgan,UK; Lures-CSIRO, Australia) four per site, hung at cordon level *c.* 1-1.3 m above ground, were used to weekly sample flights of LBAM males, October-April, removing males after counting. Lures were replaced every five weeks.

5.3.3 Sampling end-points and damage to fruit clusters at harvest

The relevance of seasonal pest population data to crop quality at harvest was also evaluated to determine the significance of seasonal pest and beneficial monitoring data. 100 bunches (n = 3) one per vine, were randomly selected 2-5 days prior to harvest from randomly chosen vines sampled during the season. The number of LBAM larvae, severity of feeding damage, and the number of berries per bunch with dry, and wet botrytis rot were scored for two varieties, in two sites, over two years. Feeding damage was scored according to four categories: no, minor, moderate, severe. The damage differences between vine varieties at each site were compared using Chi square analysis. Parasitoid pupae, spiders and other predators found inside bunches were recorded.

5.3.4 Species identification

Sorting and species ID of specimens were the most time consuming part of the project, apart from field sampling. Partly due to the fact, that new ID skills had to be acquired by the CI and supervision and guidance was not available at CESAR, but came from various systematic entomology experts specializing in key taxa. An informal skills exchange was also organized between the CI and Dr M. Malipatil (DPI PIRVIC Knoxfield-Invertebrate Taxonomy Unit); curating of Knox mite collection by CI was exchanged for guidance and teaching from expert taxonomists at the unit.

Hemerobiidae (brown lacewings) and Chrysopidae (green lacewings) larvae were identified to species [84-87]. Hemerobiid eggs [88] were incubated in the lab, and larvae identified to species when 1st found, in spring. Adults were identified to species using wing venation and other characters, dissecting abdomens, clearing in KOH, and examining genital characters [50, 54, 89, 90]. Voucher specimens of dry-mounted adults and wet specimens of larvae were prepared. Nabidae larvae and adults were identified [91-93], and voucher specimens confirmed by Dr Malipatil (DPI Knoxfield).Coccinellidae were identified [94-98]; voucher specimens of *Hypodamia sp.* and *Harmonia sp.* confirmed by Dr. P. Horne, vouchers of *Diomus sp*. and *Schymus sp.* were identified to species by Dr A. Slipinski (CSIRO Canberra). *Stethorus sp.* specimens were only identified to genus. Mealybug specimens were dissected, cleared in KOH and clover oil, slide-mounted in euparal, and identified to species [99, 100]; voucher specimens confirmed by Dr Malipatil. Ants were identified [101-104], and identification confirmed by Dr. Wainer (DPI Knoxfield). All hymenopteran and dipteran parasitoids of *E. postvittana* reared from field collected cocoons were sorted to morpho-species and dry-mounted; voucher specimens (Hymenoptera) were identified to species by Dr. Paull (Adelaide University) [1], voucher specimens (Diptera) were only identified to genus. Coleoptera: Staphylinidae (rove beetles), Diptera: Syrphidae (hoverflies) and Asilidae (robber flies) were identified [105] to family only; vouches confirmed by Dr. J Wainer. Araneae (spiders) were sorted to identify most common morpho-species; voucher specimens were identified to species by Dr. J Wainer. All voucher specimens will be lodged in DPI PIRVIC Knoxfield Insect Collection.

5.3.4 Field trial optimizing BT application to improve effectiveness against LBAM

BT insecticides are an important pest control tool, because they are the safest insecticides to beneficials, and also the only insecticides registered after fruit set - harvest. At this time of year, in cooler seasons LBAM numbers and subsequent larvae canopy infestations can be very high. During extension seminars over some years, we constantly came across the attitude among growers that BT does not control LBAM larval infestations sufficiently. Yet very few growers were aware of optimal BT application procedures (developed by Dr. Paul Horne, IPM Technologies). Output 3 (Beneficial feeding trials) was thus amended in agreement with GWRDC to carry out a controlled, replicated field trial on optimal BT application in late summer '04, when high LBAM infestations occurred. A trail using the following applications (i-iv) was conducted in Merlot on 23 Feb 04; treatment was replicated 6x, controls 3x, and randomly allocated to vine rows: **(i)** High spray volume 1000 L/ha; **(ii)** 2kg/ha Delphin®; **(iii)** night spray application (18:00 to 1:00) to reduce BT degradation by solar radiation; **iv)** addition of a feeding inducant (Mobait®). Assessments were carried out 6.5-7.5 days after spray application (1-2 March), allowing enough time for large larvae to die. The spray was applied by the grower via commercial spray equipment. An extension report on the trial was provided to participating growers immediately after the trial in 2004 (Appendix V).

6. RESULTS

6.1 LAB RESEARCH

Results with predatory mites indicate that growers can substitute many safe pesticides per each pest/ pathogen in place of pesticides highly toxic predatory mites and other beneficial species (see 6.1.1-2). Results with predatory mites on wettable sulphur and novel insecticides need be interpreted jointly with result on other beneficial species (see 6.1.3), given that testing of insecticides indicated a patchwork of both toxicity and safety across different species, which is not consistent for each pesticide.

6.1.1 Pesticide effects on predatory mites:
Results of tests used to develop eco-toxicological testing standard for predatory mites in Australia

G. occidentalis. There was a significant difference in 7 d mortality effects of fungicides on *G. occidentalis* (Bioassay 1 (32-80 h old), $F = 60.40$; $df = 3, 16$; $P<0.001$; Bioas. 2 (41-89 h old), $F = 32.09$; $df = 4, 16$; $P<0.001$). Mortality was highest following exposure to mancozeb and metiram. Controls differed from mancozeb and metiram but not from dithianon, boscalid, or kresoxim-methyl (Table 2). Sub-lethal effects followed a similar pattern. Fungicides differed significantly in their effect on female fecundity (Bioas. I, $F =117.43$; $df =3, 16$; $P<0.001$; Bioas. 2, $F = 79.93$; $df =4, 16$; $P<0.001$). The greatest reduction in fecundity was due to mancozeb, which caused an almost complete cessation of oviposition; controls differed from mancozeb and metiram, but not from dithianon, boscalid, or kresoxim-methyl, and fecundity in metiram treatments was significantly higher than in mancozeb treatments (Table 2). Toxicity of metiram in the two bioassay tests was similar. Toxicity of mancozeb in the two bioassay tests was also similar (Table 2), suggesting that minor juvenile age differences did not influence the results. Metiram and mancozeb toxicity was not evident immediately after spraying. In both bioassays, mortalities for metiram and mancozeb were not significantly different from controls or other treatments at 48 h (Bioas I, $F = 1.79$; $df = 3, 16$; $P = 0.19$; Bioas. 2, $F = 0.72$, $df = 4, 16$: $P = 0.59$). At 4 d, mortalities for metiram were not significantly different from controls or other treatments, but mortalities for mancozeb were significantly higher (Table 2; Bioas. I, $F = 11.16$; $df =3, 16$;$P<0.001$; Bioas. 2, $F=3.15$; $df =4, 16$;$P< 0.05$).

E.victoriensis. There was a significant difference in 7 d mortality of fungicides to *E. victoriensis* (Bioassay 3 (10-58 h old), $F = 46.80$; $df = 2, 9$; $P<0.001$; Bioassay 4 (22-70h old), $F = 23.49$; $df = 4, 14$; $P<0.001$). In both bioassays, mancozeb exposure caused the highest mortality. Posthoc tests indicated control mortality differed from mancozeb but not from metiram, dithianon, boscalid, or kresoxim-methyl (Table 2). Fungicides also differed in their sub-lethal effect on fecundity (Bioassay 3, $F = 447.75$; $df = 1, 6$; $P<0.001$; Bioassay 4, $F = 17.63$; $df = 4, 13$; $P<0.001$). Posthoc tests indicated that controls differed from metiram and from mancozeb, but not from dithianon, boscalid, or kresoxim-methyl (Table 2). Mancozeb and metiram substantially reduced fecundity. Fecundity in adult females exposed to mancozeb in Bioassay 3 was not analyzed as 4 d mortality had reached 97.7%. Unlike for *G. occidentalis*, mancozeb toxicity to *E. victoriensis* was evident early on. Mortality for mancozeb was significantly higher than for controls at 48 h and 4 d after spraying (Bioassay 3, $F= 97.39$; $df = 2, 9$; $P<0.001$; $F = 61.17$; $df = 2, 9$; $P<0.001$; Bioassay 4, $F = 28.80$; $df = 4, 14$; $P<0.001$, $F = 14.88$; $df =4, 14$; $P<0.001$). Metiram toxicity to *E. victoriensis* was therefore due to a sub-lethal effect on fecundity, while the effect of mancozeb on *E. victoriensis* was due to both direct mortality and a sub-lethal effect. Observations of *E. victoriensis* tendency to disperse from the test units suggest that both these chemicals have a repellant effect.

Results indicate the need for 7-day duration testing and egg lay testing to correctly evaluate toxicity of pesticides to predatory mites. For full discussion of these results including the relationship of laboratory results to field effects see [70].

Table 2. Cumulative mean mortality (95% C.I.), and fecundity (mean ± S.E.), after juveniles, their initial food and water supply were sprayed to runoff on a leaf substrate (based on 3-5 replicates)

Treatment	Percent mortality 48 h (95% C.I.)	Percent mortality 4 d (95% C.I.)	Percent mortality 7 days (95% C.I.)	Mean egg lay per female per day for days 3 - 9 after spraying	Percent fecundity reduction
			***G. occidentalis* - Bioassay 1**		
control	5.44[a]	14.8[a]	26.9[a]	19.5 ± 0.65[a]	-
	(0.04, 10.7)	(9.67, 19.9)	(20.6, 33.3)		
Dithianon	1.82[a]	6.62[a]	22.0[a]	20.6 ± 0.48[a]	0
Delan	(0.00, 3.53)	(3.87, 9.38)	(15.4, 28.7)		
Metiram	4.47[a]	6.17[a]	76.9[b]	9.19 ± 1.36[b]	52.9
Polyram	(0.82, 8.00)	(1.17, 11.0)	(66.3, 87.7)		
Mancozeb	15.6[a]	29.5[b]	82.1[b]	2.16 ± 0.34[c]	88.9
Dithane	(1.26, 29.6)	(19.5, 39.4)	(79.1, 85.2)		
			***G. occidentalis* – Bioassay 2 ***		
control	1.74[a]	3.74[a]	18.6[a]	13.6 ± 0.37[a]	-
	(0.00, 3.11)	(0.06, 7.29)	(8.63, 28.5)		
boscalid	2.57[a]	4.65[a]	9.96[a]	13.7 ± 0.51[a]	0
Filan	(0.00, 5.00)	(0.08, 9.04)	(1.58, 18.0)		
kresoxim-methyl	1.82[a]	4.73[a]	12.7[a]	12.4 ± 0.53[a]	9.06
Stroby	(0.00, 3.25)	(0.04, 9.29)	(2.23, 22.7)		
Metiram	1.67[a]	13.9[a]	77.8[b]	8.61 ± 0.67[a]	36.8
Polyram	(0.00, 4.87)	(12.5, 15.4)	(65.2, 89.1)		
Mancozeb	8.25[a]	20.7[b]	93.8[b]	0.95 ± 0.78[c]	93.0
Dithane	(0.00, 22.2)	(4.94, 39.8)	(91.4, 96.0)		
			***E. victoriensis* – Bioassay 3**		
control	2.27[a]	5.48[a]	12.6[a]	10.8 ± 0.41[a]	-
	(0.00, 5.15)	(0.00, 12.6)	(0.48, 26.5)		
metiram	9.05[a]	15.2 [a]	20.8[a]	0.71 ± 0.23[b]	93.4
Polyram	(3.60, 14.9)	(3.51, 28.1)	(5.84, 36.8)		
mancozeb	82.3[b]	97.7[b]	98.9[b]	-	-
Dithane	(74.3, 89.9)	(95.0, 99.5)	(97.5, 99.7)		
			***E. victoriensis* – Bioassay 4**		
control	3.47[a]	7.16[a]	14.4[a]	13.1 ± 0.30[a]	-
	(0.00, 7.06)	(0.00, 11.4)	(6.53, 22.8)		
Boscalid	1.39[a]	11.7[a]	22.0[a]	10.8 ± 1.18[a]	17.7
Filan	(0.00, 3.07)	(0.45, 24.7)	(15.0, 29.2)		
Dithianon	1.19[a]	10.0[a]	14.0[a]	12.4 ± 1.42[a]	5.91
Delan	(0.00, 2.63)	(0.63, 20.6)	(1.16, 28.1)		
kresoxim-methyl	1.04[a]	6.24[a]	17.5[a]	11.4 ± 0.57[a]	13.3
Stroby	(0.00, 2.30)	(4.62, 7.90)	(9.78, 25.5)		
Mancozeb	50.9[b]	75.0[b]	92.7[b]	0.33 ± 0.27[b]	97.5
Dithane	(41.0-76.6)	(56.6, 91.4)	(81.1, 100)		

Mean egg-lay per adult female per day ± S.E. for days 3-7 after exposure as freshly hatched juveniles. Means within the same bioassay and column, followed by a different letter, are significantly different (P< 0.001; * P< 0.05; Tukey b test).

6.1.2 Pesticide effects on predatory mites: testing per the above method on *Euseius victoriensis*

Bioassay 5- downy mildew fungicides. There was a significant difference (P<0.001) in 48h, 4d and 7-d cumulative mortality effects of fungicides on *E. victoriensis* juveniles (F = 25.80, 21.66, and 23.82 respectively; df = 6, 21 in each case). Post hoc tests indicate mortality was significantly higher after exposure to mancozeb; 87.3% of mites died within 48 h, 98.5% by 7 d of exposure, and no eggs were laid by surviving females (Table 3). By contrast, captan, chlorothalonil, copper hydroxide, metalaxyl/copper

hydroxide, and phosphorous acid did not reduce female fecundity compared to the control (F = 0.821; df = 5, 18; P = 0.55), and did not differ significantly from the control in mortality effects (Tukey b; Table 3).

Bioassay 6 - powdery mildew fungicides. There was a significant difference (P<0.001) in 48h, 4d and 7-d cumulative mortality effects of fungicides on *E. victoriensis* (F = 45.18, 86.50, and 90.05 respectively; df = 9, 28 in each case). Post hoc tests indicate wettable sulphur (all concentrations studied), benomyl, and carbendazim resulted in significantly higher cumulative mortality compared to the control at all time intervals, with 7 d mortalities of 81.7- 100%, 78.6%, and 97.4% respectively (Table 3). Wettable sulphur (≥ 600/100L), benomyl, and carbendazim also resulted in complete fecundity suppression. Post hoc tests indicate wettable sulphur (200g/100L) was significantly less toxic than the above compounds (7 d mortality of 81.7%), and resulted in significantly lower fecundity compared to the control (F = 5.856; df = 5, 18; P= 0.002), but the 51.7% reduction was only moderate (Tukey b; Table 3). Azoxystrobin, hexaconazole, myclobutanil and penconazole did not differ significantly from the control in mortality or fecundity effects, except for a minor 32.0% fecundity reduction due to penconazole (Tukey b; Table 3). Toxic effects of wettable sulphur, benomyl, and carbendazim were not fully expressed at 48 h or 4 d, indicating the need for 7 d mortality and fecundity testing to accurately evaluate pesticide safety to phytoseiid predatory mites..

Bioassay 7 - botrytis fungicides and buprofezin. There was a significant difference in 48 h mortality effects of treatments on *E. victoriensis* (P< 0.05; Table 3). Post hoc tests indicate that Scala, Switch and mancozeb were significantly more toxic than the control, resulting in 100%, 77.8% and 91.5% mortality respectively. Teldor, Domark, Peratec, and the insecticide Applaud caused no significant mortality at 48 h compared to controls. The test clearly indicates high toxicity to *E. victoriensis* of Scala and Mancozeb, but the exact toxicity of Switch cannot be inferred due to mortality in controls exceeding the internationally acceptable limit of 25%. The results are thus only preliminary. The high control mortality occurred due to predatory mite cannibalism resulting from a change in diet supplied to the mite colony prior to testing, and will be rectified ASAP, and Bioassay 7 will be repeated under GWRDC CX 2295. To complete Performance Target 1.5, additional testing not required by this project, on brown lacewings and damsel bugs was completed in lieu of this bioassay (see 6.1.4).

Bioassay 8- insecticides and other compounds. There was a significant difference in 48 h, 4 d, and 7d cumulative mortality effects of treatments on *E. victoriensis* (F = 51.72; df = 9, 29; P<0.001), (F = 33.47; df = 8, 27; P<0.001), and (F = 4.576; df = 6, 21; P<0.01) respectively. Post hoc tests indicate mancozeb and the insecticides spinosad and emamectin benzoate were significantly more toxic compared to the control, resulting in 48 h mortality of 100%, 95.5%, and 77.9% respectively, and 100% mortality at 4 d, making fecundity assessments redundant (Tukey b; Table 3). Post hoc tests indicate canola oil (2L/100L), an acaricide effective against *Calepitrimerus vitis* {Bernard, 2005 #23}, was significantly more toxic at 48 h, 4 d, and 7 d compared to the control, but the mortality effects were moderate (35.7%, 50.1%, and 56.6% respectively), and fecundity was slightly (30.1%), but not significantly reduced (F = 1.6285; df = 6, 20; P = 0.191; Table 3). Glyphosate, the insecticides indoxacarb, *Bacillus thuringiensis* subsp. *kurstaki*, tebufenozide, and the fungicide fenarimol had no significant effect on female fecundity compared to the control (F = 1.6285;df = 6, 20; P = 0.191;Table 3), and no significant mortality effects (Tukey b; Table 3).

Bioassay 9- surfactants and spinosad residue. There was a significant difference (P<0.001) in 48 h, 4 d, and 7d cumulative mortality effects of treatments on *E. victoriensis* (F = 29.98; df = 4, 12), (F = 31.55; df = 4,12;), and (F = 28.07; df = 3,10) respectively. Post hoc tests indicate that spray surfactants, nonyl phenol ethylene oxide and the synthetic latex formulation were not significantly toxic compared to the control and caused no detrimental effect on fecundity. Mancozeb and spinosad fresh dry residue resulted in significantly higher mortality compared to the control (Tukey b, Table 3). Cumulative 48h, 4d and 7d mortality due to spinosad fresh dry residue reached 33.9%, 63.6%, and 85.5 % respectively (Table 3), and surviving females reproduced at a significantly reduced rate compared to the control and surfactants (F = 25.99; df = 3, 10; P<0.001; Table 3), resulting in only 1.57 ± 1.03 eggs per female per the 7 d-period immediately following maturity; representing an 83.3% reduction (Table 3).

Table 3. Cumulative mean mortality (95% C.I.) and fecundity (± S.E.) of *Euseius victoriensis* after direct overspray of juveniles, their initial food and water supply to runoff on soybean (based on 4 replicates)

Treatment	% Mortality 48 h (95% C.I.)	% Mortality 4 d (95% C.I.)	% Mortality 7 d (95% C.I.)	Reproduction (*R*) per female for 7 d after maturity ± SE	% Fecundity reduction
Bioassay 5 - downy mildew fungicides					
control	4.55 [a]	8.76 [a]	10.95 [a]	9.85 ± 0.58 [a]	-
captan **Captan**	6.15[a]	8.26[a]	13.9[a]	10.8 ± 1.08[a]	0.00
chlorothalonil **Barrack**	12.4 [a]	17.7 [a]	22.1 [a]	9.79 ± 1.40 [a]	0.55
copper hydroxide **Kocide**	10.5 [a]	25.0 [a]	29.4 [a]	10.6 ± 0.64 [a]	0.00
metalaxyl/ copper hydroxide **Ridomil Gold Plus**	6.03 [a]	11.4 [a]	12.7 [a]	9.81 ± 0.73 [a]	0.36
phosphorous acid **Fungi-fos**	5.00 [a]	9.03 [a]	9.92 [a]	12.0 ± 0.95 [a]	0.00
Toxic reference: mancozeb **Mancozeb 750 WG**	87.3 [b]	95.6 [b]	98.5 [b]	0.00 ± 0.00 [b]	100
Bioassay 6 - powdery mildew fungicides					
control	0.00[a]	1.32[a]	2.95[a]	*11.5 ± 0.70[a]	-
azoxystrobin **Amistar**	0.00[a]	3.03[a]	6.37[a]	*11.3 ± 0.67[a]	2.32
hexaconazole **Anvil**	2.78[ab]	4.25[a]	4.90[a]	*9.93 ± 0.76 [a]	14.0
myclobutanil **Mycloss**	0.00[a]	0.00[a]	2.94[a]	*10.8 ± 0.89[a]	6.37
penconazole **Topaz**	1.39[ab]	2.78[a]	4.51[a]	*7.85 ± 1.00[ab]	32.0
wettable sulphur **Thiovit** (200g/100L)	49.7[cd]	72.2[b]	81.7[b]	*5.58 ± 1.52[b]	51.7
wettable sulphur **Thiovit** (600g/100L)	61.2[d]	98.7[c]	100.0[c]	-	-
wettable sulphur **Thiovit** (1200g/100L)	81.8[e]	100.0[c]	100.0[c]	-	-
benomyl**- Marvel**	28.8[c]	58.7[b]	78.6[b]	0.00 ± 0.00[c]	100
toxic ref: carbendazim **Bavistin**	12.7[b]	57.0[b]	97.4[c]	0.00 ± 0.00[c]	100
Bioassay 7– botrytis fungicides and buprofezin (Preliminary results due to mortality in the control > 25%)					
control	40.7 ± 4.05 [a]	-	-	-	-
cyprodinil/ fludioxonil **Switch**	77.8 ± 6.39 [b]	-	-	-	-
fenhexamid **Teldor 500 SC**	38.9 ± 2.22 [a]	-	-	-	-
pyrimethanil **Scala 400 SC**	100 ± 0.00 [c]	-	-	-	-
tetraconazole **Domark 40 ME**	45.0 ± 2.10 [a]	-	-	-	-
hydrogen peroxide/ peroxy acetic acid **Peratec**	39.2 ± 7.90 [a]	-	-	-	-
Buprofezin **Applaud**	51.5 ± 1.47 [a]	-	-	-	-
toxic ref: mancozeb	91.5 ± 0.25 [c]	-	-	-	-

Bioassay 8 - insecticides and other compounds					
control	5.95[a]	9.00[a]	14.2[a]	9.56 ± 0.16[a]	-
Bacillus thuringiensis subsp. *kurstaki* **Bt**	0.00[a]	1.47[a]	3.41[a]	9.87 ± 0.56[a]	0.00
canola oil **Supastik Oil**	35.7[b]	50.1[b]	56.6[b]	6.68 ± 2.77[a]	30.1
emamectin benzoate **Proclaim**	77.9[c]	100.0[c]	-	-	-
fenarimol	3.63[a]	5.26[a]	17.00[a]	11.0 ± 0.40[a]	0.00
glyphosate **Roundup**	2.00[a]	2.17[a]	3.25[a]	8.08 ± 0.34[a]	
Indoxacarb **Avatar**	4.84[a]	6.62[a]	6.89[a]	10.1 ± 1.29[a]	15.5
spinosad **Success Naturalyte**	95.5[cd]	100.0[c]	-	-	-
Tebufenozide **Mimic**	1.04[a]	2.17[a]	7.14[a]	10.0 ± 0.10[a]	0.00
toxic ref: mancozeb	100.0[d]	-	-	-	-
Bioassay 9 - surfactants and spinosad residue test					
control	1.04[a]	5.31[a]	14.1[a]	9.39 ± 0.72[a]	-
nonyl phenol ethylene oxide- **Agral**	2.56[a]	7.07[a]	24.2[a]	9.47 ± 1.03[a]	0.00
synthetic latex/ non-ionic surfactant - **Bond**	6.63[a]	8.86[a]	18.5[a]	10.2 ± 0.32[a]	0.00
spinosad- **Success** fresh dry residue	33.9[b]	63.6[b]	85.5[b]	1.57 ± 1.03[b]	83.3
toxic ref: mancozeb	81.6[c]	100.0[c]	-	-	-

Means within the same assay and column followed by different letters are significantly different (P< 0.001; *P< 0.01), Tukey b test. Reproduction (*R*) was measured for 7 d from the onset of oviposition (6 to 13 d after spraying), excluding a pre-oviposition period.

6.1.3 Pesticide effects on green lacewings, brown lacewings, and damsel bugs 2007 in collaboration with P. Cole and A. Kobelt (IPM Technologies and DPI Knoxfield)

Results indicate a patchwork of toxicity of the novel insecticides (Avatar®, Success®, and Proclaim®) across the beneficial species tested, suggesting that none of these insecticides can be considered 'safe' to biological control providers in vineyards in general. A full interpretation of these results and results on *E. victoriensis* (p. 24-28) has been made in the context of world-wide research on pesticide toxicity to beneficial species in publication mansucript Target 3.3.1, giving recommendations for safe pesticide use for the Australian wine industry per each target pest/ disease, and in publication Target 4.1 (Appendix VII).

Bt (*Bacillus thuringiensis* subsp. *kurstaki),* wettable sulphur (200g/100L) direct overspray and fresh dry residue caused no significant 3 d cumulative mortality to *M. signatus* (green lacewing) *Micromus tasmaniae* (brown lacewing) *, or N. kinbergii* (damsel bug) 1st instar larvae compared to the controls (Table 4). Higher wettable sulphur concentration (600g/100L) as direct overspray was significantly more toxic compared to the controls, causing moderate 3 d mortality (33.3 %) to *M. signatus* 1st instar larvae but not to *M. tasmaniae.*

Spinosad (Success®) direct overspray and residue caused no significant mortality to *M. signatus* juveniles, but direct overspray was moderately toxic (26.1% mortality) to *M. tasmaniae* 1st instar larvae P< 0.0001 (Table 4). These result are consistent with generally low toxicity of spinosad to predators, however spinosad is highly toxic to many different parasitoid wasp species [109], including a key Australian LBAM parasitoid wasp, *Dolichogenidea tasmanica* [7].

Indoxacarb (Avatar®) direct overspray and fresh dry residue caused significantly higher 3 d cumulative mortality to *M. signatus* compared to the controls, 77.8% and 58.3 % mortality respectively P < 0.0001. This represents a level of mortality which is c. 75% that of the highly toxic chlorpyrifos (Lorsban®), and high toxicity to parasitoid wasps is also reported. However, indoxacarb was not significantly more toxic to the control to *M. tasmaniae* and *N kinbergii* (Table 4).

Emamectin (Proclaim®) was safe to both *M. signatus* and *M. tasmaniae* 1st instar larvae 3 d cumulative mortality following exposure to direct overspray and residue did not differ significantly from the controls except for minor mortality (15.8%; P< 0.05) recorded for *M. tasmaniae* after exposure to residue. However, surprisingly emamectin direct overspray and residues were very highly toxic to *N. kinbergii,* resulting in a significantly higher 3 d cumulative mortality (100% and 96.3% respectively) compared to the control (P< 0.0001; Table 4).

Table 4: Cumulative mean mortality (± S.E.) of *M. signatus, M. tasmaniae, and N. kinbergii* after direct overspray of juveniles with insecticides and wettable sulphur to runoff, and 3 d exposure to fresh dry residues (based on 6 replicates)

Treatment	Application rate (g or ml/ 100L)	Direct overspray % Mortality 3 d ± S.E.	Residue % Mortality 3 d ± S.E.	Direct overspray Statistic F (df)	Residue Statistic F (df)
Mallada signatus (green lacewing) - Bioassays 10 – 11					
control	-	6.25 ± 2.14	3.75 ± 2.43		
Bt	100	0.00 ± 0.00	0.00 ± 0.00	2.479 (5,15)	0.691 (5,15)
Proclaim	50	11.0 ± 3.92	8.0 ± 3.31	1.210 (9,15)	0.975 (9,15)
Avatar	25	77.8 ± 10.2*	58.3 ± 14.8*	98.72 (5,15)*	31.32 (5,15)*
Success	160	10.3 ± 4.93	10.0 ± 4.52	0.685 (5,15)	1.435 (5,15)
wettable sulphur	200	0.0 ± 0.00	-	2.479 (5,15)	-
wettable sulphur	600	33.3 ± 7.43*	-	21.36 (5,15)*	-
toxic ref: Lorsban		100.0 ± 0.00*	100.0 ± 0.00*		
Micromus tasmaniae (brown lacewing) - Bioassays 12 – 13					
control	-	0.83 ± 0.83	3.63 ± 1.57		
Bt	100	0.00 ± 0.00	0.00 ± 0.00	0.147 (5,39)	0.787 (5,39)
Proclaim	50	2.94 ± 2.82	15.8 ± 7.32**	1.164 (9,39)	6.642 (9,39) **
Avatar	25	3.30 ± 3.30	10.0 ± 7.14	1.152 (9,39)	1.860 (9,39)
Success	160	26.1 ± 7.80*	-	27.16 (5,39)*	-
wettable sulphur	200	5.6 ± 3.51	0.00 ± 0.00	3.521 (5,39)	0.787 (5,39)
wettable sulphur	600	0.83 ± 0.83	3.63 ± 1.57	0.147 (5,39)	0.787 (5,39)
toxic ref: Lorsban		100.0 ± 0.00*	100.0 ± 0.00*		
Nabis kinbergii (Pacific damsel bug) - Bioassays 14 -15					
control		3.33 ± 0.33	6.67 ± 4.44		
Bt	100	0.00 ± 0.00	0.00 ± 0.00	0.583 (5,9)	1.313 (5,9)
Proclaim	50	100.0 ± 0.00*	96.3 ± 2.34*	490.6 (5,9)*	311.8 (9,9)*
Avatar	25	10.0 ± 5.1	-	1.200 (9,9)	
toxic ref: Lorsban		100.0 ± 0.00*	100.0 ± 0.00*	490.6 (5,9) *	490.6 (5,9) *

Testing completed in collaboration with P. Cole (IPM Technologies Ltd.) and A. Kobelt (DPI Knoxfield)
* Significantly different from the control < P 0.001, ** significantly different from control < P 0.05; Bonferroni test.

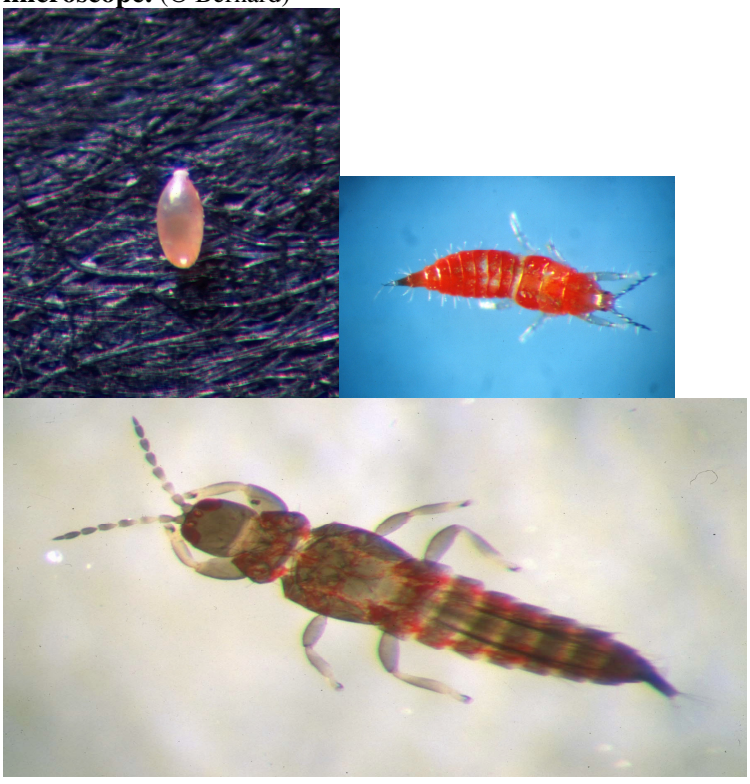
6.1.4 Pesticide effects on green lacewings initial testing 2003 (S. Hewa Kapuge). Tests conducted so far on *M. signatus* after direct overspray of young larvae, their food supply and the test unit substrate with metiram, dithianon, kresoxim-methyl indicated no significant mortality P<0.01 at 48h and through to pupation, compared to controls, and no significant effect on adult egg lay, or egg hatchability compared to the controls.

6.1.5 Feeding tests with predatory thrips *Haplothrips victoriensis* on grape rust mite

Haplothrips victoriensis Bagnall (Thysanoptera: Phlaeothripidae) was recorded for the first time as a predator of grapevine rust mite, commonly over-wintering in association with rust mite, and feeding on rust mite in a preliminary 'no choice' tests in the laboratory. *H. victoriensis* is a tiny predator (2-3 mm) whose adults and larvae feed on grape rust mite as established by this project, and they also feed on (two posted mite (TSM), and on lucerne pollen [106]. *H. victoriensis* over-winters in bark fissures on vine canes, and under the bark of older wood. Eggs are often laid under the outer scales of dormant buds, where young larvae feed on rust mite. It complements phytoseiid predatory mites tested in bioassays as part of this project, in controlling grapevine rust mite. In this project, *H. victoriensis* was also found in IPM vineyards during the growing season, and observed feeding on thrips in shoot tips, but due to limited resources, sampling methods were not specific for optimally collecting these micro-predators, and these data are therefore not quantitative.

First instar *H. victoriensis* larvae consumed two *C. vitis* deutogynes (n=2) over a 100 h period at 14°C, while second instar larvae each consumed a mean of 7.3 ± 1.12 deutogynes (n=6). Larvae fed within the first 24-h period in 14°C, after being collected from dormant winter canes, indicating *H. victoriensis* does not undergo complete dormancy. This is a high feeding rate considering the low temperature in which tests were done, and the fact that it is a result with field collected over-wintering predators. The result is the first ever account on predation on grapevine mite, but the feeding tests are preliminary due to the low number of predators tested. Assessments of predatory capacity at 25°C, with ≥ 20 individuals of each life-stage over the entire developmental period, and prey preference tests, are required to further evaluate this predator on grapevine rust mite. However, given that grapevine rust mite has not yet been successfully reared in the laboratory in high numbers anywhere in the world, and given the highly time consuming task of collecting rust mites for feeding tests, this would be extremely difficult to accomplish. *H. victoriensis* is a key TSM (two spotted mite) predator in lucerne in Australia, completing development on TSM eggs or lucerne pollen [106], and of *Thrips palmi* Karny (melon thrips) in eggplant in Queensland [107].

Fig. 3 Predatory thrips (*Haplothrips victoriensis*) **(a) egg, (b) larva, (c) adult photographed through a microscope.** (© Bernard)



6.2 RESULTS
FIELD RESEARCH

6.2.1 Optimising BT application for improved efficacy against LBAM

Optimized BT application as developed by IPM Technologies Ltd.: high spray volume 1000 L/ha, 2kg/ha Delphin®, night spray application (18:00 to 1:00) to reduce BT degradation by solar radiation, addition of a feeding inducant (Mobait®) resulted in a significant ($P< 0.05$) mean 71.9% reduction in bunch infestation by LBAM larvae, and mean 53.8% reduction in leaf canopy infestation by LBAM larvae (Table 5). The greatest mortality effect was due to mortality of 1-3thinstar larvae. This result was obtained even at sub-optimal timing of the spray, when considerable proportion of LBAM larvae reached 4-6th instar stage, some two weeks after the spray application was first recommended to the grower (i.e. when *c.* 90% of all larvae were 1-2nd instars). The improved BT spray application will benefit growers in regions and seasons when near veraison/ harvest applications are required. A report on trial results was provided to participating growers in summer 2004 (Appendix V).

Table 5. Mean *E. postvittana* (LBAM) larvae (instars 1-6) in bunches and on leaves of canes in the control and high volume (1000 l/ha) Bt treatment . Means based on control n = 3; treatment n = 6).

	Average LBAM larvae (Instar 1-6) per 72 bunches	Average LBAM larvae (Instar 1-6) per 72 vine canes (leaf canopy only)
Control	5.3a	40.0a
Bt- **Dipel** (2kg/ha) + feeding inducant -**Mobait®**	1.5b	18.5b

Means in same column followed by a different letter are significantly different from each other, Tukey b, $P< 0.05$.

6.2.2 Pest and beneficial populations and their seasonal changes in IPM vineyards

Graphs showing trends found in four IPM-managed vineyards two growing seasons 2003-05 in/ near the Yarra Valley situated in close proximity to large blocks of remnant native vegetation, were published in detailed, easy to follow summary articles in the Australian and New Zealand Grapegrower and Winemaker in September and October 2006 (Appendix VII). Photographs of all key beneficial insects have been made and prepared as a PowerPoint presentation, for teaching/extension use by the wine industry, and widely extended already.

- Bernard M., Wainer J., Carter V., Semeraro L., Yen A. L., Wratten S. D, **2006**, Beneficial insects and spiders in vineyards: Predators in South-East Australia. The Australian and New Zealand Grapegrower and Winemaker, 511(September): p. 37-48
- Bernard M., Carter V., Semeraro L., Wratten S. D., **2006**, Beneficial insects in vineyards: Parasitoids of LBAM and grapevine moth in South-East Australia. The Australian and New Zealand Grapegrower and Winemaker, 511 (October): p. 19-26

A scientific paper with the above data has been prepared, and will be submitted for publication ASAP. The published copy will be supplied to GWRDC for inclusion in Appendix VII. This paper is the 5th scientific paper produced by this project; target of 3 scientific papers was required by the project (see Executive summary):

- Martina B. Bernard, John Wainer, Ary. A. Hoffmann, Paul A. Horne, Alan L. Yen, Stephen D. Wratten, (**submission March 2008**) Functional biodiversity for Integrated Pest Management

(IPM) in vineyards of South-East Australia: seasonal abundance of polyphagous predators and parasitoids of leafrollers (Lepidoptera: Tortricidae), Australian Journal of Entomology

6.2.3 IPM benchmarking map

Guidelines for Sustainable Wine Grape Production in Australia: IPM adoption self assessment guide for growers

A comprehensive reference publication was completed by CI in collaboration with many expert co-authors from Australia and New Zealand, specializing in topics covered by the paper. The paper was refereed prior to publication by two overseas scientists with a very high standing in IPM and biological control in wine grapes [Dr John Charles (HortResearch, Auckland, New Zealand), Dr Cliff Ohmart (Lodi Woodridge Wine Commission, California, USA)], and by two Australian IPM experts [James Altmann (Biological Services and Fruit Doctors, Loxton, SA), Richard Llewellyn (BioResources, Samford, Qld)]. It was also widely circulated for comment to viticulturists and wine industry personnel within the Australian wine industry, to ensure maximum relevance to the industry. A scientific paper version of this guide has since also been prepared for publication in the Australian Journal of Entomology, and is due for submission ASAP. The IPM guidelines outline all chronological steps required to fully implement Total System/IPM. Tables per each pest contain summaries of all control methods available, and make a clear distinction (in different color) of IPM-compatible, IPM-transition, and IPM-incompatible practices. This guide is intended as an easy to follow, yet comprehensive reference for growers, viticulturists, and wineries to use, when evaluating the level of their IPM adoption, and to easily identify the next most feasible step they may wish to undertake towards greater sustainability. It is also the technical document that can underpin the pest and disease management module, in a future sustainable wine grape production accreditation scheme in Australia. As such, it is fully referenced and outlines in detail what constitutes Total System/Integrated Pest Management (IPM) for long-term conservation and enhancement of naturally present biological control in vineyards, preventative pest control strategies, and precise use of pesticide as support tools (not the mainstay) of pest and disease management, causing minimal damage to natural biological control (Appendix VII):

- Bernard M., Horne P. A., Papacek D., Jacometti M. A., Wratten S. D., Evans K. J., Herbert K. S., Powell K. S., Rakimov A., Weppler R., Kourmouzis T., Yen A. L., **2007**. Guidelines for Environmentally Sustainable Wine Grape Production in Australia: IPM adoption self-assessment guide for growers, The Australian and New Zealand Grapegrower and Winemaker, 518 (March), p. 26-36

An additional, over and above project target, publication was produced in collaboration with Prof Steve Wratten, to give growers information on how to use nectar plants in vineyards, giving more details than could be included in the reference guide above. This extended findings from New Zealand research on nectar use in vineyards, for the control of LBAM without the need for pesticides, to Australian growers (Appendix VII):

- Bernard M., and S. D. Wratten, **2007**. AgNote: Enhancing beneficial insects and mites in vineyards: providing nectar, pollen, and shelter in vine rows. The Australian and New Zealand Grapegrower and Winemaker, 519 (April), p. 33-34

Grower workshops in the Eastern states flowed in 2006 and 2007, and many growers are now piloting these practices. This demonstrates the effectiveness of a fully integrated research- extension model in the speed of new technology adoption.

7. OUTCOMES/ CONCLUSION

OUTPUT 1: Testing of fungicides, insecticides and herbicides on beneficials

An eco-toxicological testing standard for evaluating pesticide effects on Australian species of predatory mites was developed, and used to evaluate most viticultural pesticides registered in wine grape in and frequently used. Pesticides were tested for their effect on phytoseiid predatory mites: key predators of grape rust mite *Calepitrimerus vitis* and grape bud mite *Colomerus vitis*, which prevent outbreaks of these confirmed causal agents of RSG (Restricted Spring Growth Syndrome) in Australian vineyards [108]. The methodology and the results of the first bioassay conducted were published in the US, Journal of Economic Entomology in 2004 [70] (Performance target 1.2). Subsequent bioassay results were published in the Australian and New Zealand Grapegrower and Winemaker [75] (Performance target 1.1). These results, together with our unpublished bioassay results were supplemented by information from a world-wide literature review of pesticide effects on beneficial invertebrates were: immediately used to inform the seasonal spray diary for IPM-demonstration sites in seasons 2003-04 and 2004-05 (Performance target 1.4), and were progressively extended in grower seminars conducted in winters 2003, 2004, 2005, 2006 exceeding in seminar delivery target 1.4 many times over. The information was collated into an easy to follow guide of pesticides safe to natural enemies, extended in winter 2006, and posted on line as part of seminar summaries: e.g. http://www.phylloxera.com.au/board/meetings/view.asp?region=Riverland (Performance targets 1.3 and 1.4). Over and above these targets, the 'safe pesticides list' was provided to grower associations (Mclaren Vale, Riverland, Limestone Coast, and King Valley) and has been used by 21 vineyards across in these regions participating in RITA project on predatory mites (GWRDC: MU 05/01) in 2005-06, 2007-08. It was also provided to King Valley Vignerons for use by interested growers and in RITA study vineyards in the King Valley. Further bioassays were completed in 2007 (Table 1- green) (Performance target 1.5), and a manuscript of refereed scientific paper completed (Performance target 3.3- 3.3.1). This paper is due for submission to the US Journal of Economic Entomology in Jan 2008, when results of CX 2295 testing currently in progress (Table 1- blue) will be included.

(Performance target 1.1): Bernard, M.B., P.A. Horne, and A.A. Hoffmann, Developing Eco-toxicological Testing Standard for Predatory Mites in Australia: Acute and Sub-lethal Effects of Fungicides on *Euseius victoriensis* and *Galendromus occidentalis (Acarina: Phytoseiidae).* Journal of Economic Entomology, 2004. 97(3): p. 891-899.

(Performance target 1.2): Bernard, M., P.A. Horne, and A.A. Hoffmann, 2004, Ecological Pest Management: The effect of viticultural fungicides on beneficial predatory mites. The Australian and New Zealand Grapegrower and Winemaker, 485a: p. 7-12.

(Performance target 3.3 – manuscript for publication 3.3.1)
Mortality and sub-lethal fecundity effects of pesticides on the predatory mite *Euseius victoriensis* (Acari: Phytoseiidae): a study to maximise conservation biological control in Australian vineyards. Bernard, M., Horne P., Cole P., Kobelt A., Hoffmann A., Journal of Economic Entomology - completed

OUTPUT 2: Feeding trials on beneficials, field trial to improve Bt efficacy via optimal application, and control of a newly emerging pest in wine grapes - mealybugs

(Performance target 2.1 approved as a new target 3.2.2): grower article on beneficials in vineyards was published Oct 2006 (p. 34). Laboratory feeding tests with a newly recorded predator of rust mite *(H. victoriensis*) were conducted, and results prepared for publication (Results p. 30 - Performance target 2.2). A field trial to test improved application of Bt was conducted (Results p. 31- Performance target 2.2). Both results were approved by GWRDC to be included in a refereed scientific publication under Target 3.3 below. (Performance target 2.3): grower seminars on mealybug pests in vineyards were prepared and conducted in winters 2004-2006, exceeded by grower demand, and the presentation pdf posted on line http://www.phylloxera.com.au/board/meetings/view.asp?region=Barossa%20Valley

OUTPUT 3

(Performance target 3.1) Cost benefit analysis of IPM, was not completed. The rigor and requirements of meeting and exceeding other performance targets did not allow sufficient time, and this target was abandoned due to the changing economic climate in the wine industry during the cause of this project (oversupply, drought, frost). This target (beyond simple per hectare costing already known to growers) needs to involve an agricultural economist, an exercise beyond the scope of this project. However, economic advantages of IPM were briefly addressed in publications Output 4. Publications giving a comprehensive overview of beneficial insects in Australian vineyards and their seasonality were published (Performance targets 3.2.1 and 3.2.2). The scientific version of these publications (Performance Target 3.3 - manuscript publication 3.3.2) is still in preparation. (Performance target 3.4) grower seminars extending output 3, was greatly exceeded by grower demand (see Appendix I).

(Performance target 3.2.1) Bernard M., Wainer J., Carter V., Semeraro L., Yen A. L., Wratten S. D, **2006**, Beneficial insects and spiders in vineyards: Predators in South-East Australia. The Australian and New Zealand Grapegrower and Winemaker, 511(September): p. 37-48

(Performance target 3.2.2) Bernard M., Carter V., Semeraro L., Wratten S. D., **2006**, Beneficial insects in vineyards: Parasitoids of LBAM and grapevine moth in South-East Australia. The Australian and New Zealand Grapegrower and Winemaker, 511 (October): p. 19-26

(Performance Target 3.3 – manuscript for publication 3.3.2) Martina B. Bernard, John Wainer, Ary. A. Hoffmann, Paul A. Horne, Alan L. Yen, Stephen D. Wratten, Functional biodiversity for Integrated Pest Management (IPM) in vineyards of South-East Australia: seasonal abundance of polyphagous predators and parasitoids of leafrollers (Lepidoptera: Tortricidae), Australian Journal of Entomology; Refereed scientific paper - 70% completed, submission March 2008

(Performance Target over and above project requirements) Bernard M. B., Horne P. A., Papacek D., Jacometti M. A., Wratten S. D., Evans K. J., Herbert K. S., Powell K. S., Rakimov A., Weppler R., Kourmouzis T., Yen A. L., Guidelines for Environmentally Sustainable Wine Grape Production in Australia: IPM adoption assessment, Aust Journal of Entomology; 95% completed - submission Dec 2007

OUTPUT 4

(Performance target 4.1): - refereed by scientists prior to publication in ANZGGW: Bernard M., Horne P. A., Papacek D., Jacometti M. A., Wratten S. D., Evans K. J., Herbert K. S., Powell K. S., Rakimov A., Weppler R., Kourmouzis T., Yen A. L., **2007.** Guidelines for Environmentally Sustainable Wine Grape Production in Australia: IPM adoption self-assessment guide for growers, The Australian and New Zealand Grapegrower and Winemaker, 518 (March), p. 26-36

(Performance output over and above project targets) - Bernard M., and S. D. Wratten, **2007.** AgNote: Enhancing beneficial insects and mites in vineyards: providing nectar, pollen, and shelter in vine rows. The Australian and New Zealand Grapegrower and Winemaker, 519 (April), p. 33-34

OUTPUT 5: An Interim Final Report was completed 31 October 2006 and approved by the GWRDC. This Final Report, due 31 October 2007 is now complete.

CONCLUSION:

This project has met its overall aims and objectives, and has far exceeded research extension performance targets. The project enjoyed massive grower involvement and support throughout its life, indicating the importance of sustainable wine grape production to Australian growers, and adoption benefits that can be gained by fully integrating research and extension components of projects.

8. RECOMMENDATIONS

Future research, extension and potential policy direction arising from this research

- That project findings, beneficial images, and Output 4- IPM adoption grower self-assessment guide be incorporated into an updated IPM Research to Practice Manual.
- That grower seminars conducted in this project be extended to other interested regions and associations. In particular, the seminar: 'Natural Vineyard Defences against Mealybugs & Other Pests', summarizing knowledge to date on relevant mealybug species, their biology, control options, and beneficials) be extended to interested grower groups across Australia. The seminars were extremely well received by growers and pest control advisers, and are available for delivery in a power-point format. A half-day IPM update module is suggested as a package incorporating also the latest pesticide effects on beneficials, information on how to pilot midrow cover crops with nectar resources, and IPM adoption grower self-assessment.
- That an assessment of key known nectar resources in vineyards from New Zealand research (buckwheat, phacelia, alyssum) on mealybug parasitism (and LBAM parasitism) in Australia be done, via RITA partnership with interested innovative growers keen to pilot these cover crops.
- This research project ascertained key beneficials present in vineyards, and their seasonal changes in abundance. To build on this research, the next step is to: quantify predation contributions by each of these species. Until very recently this would have been a mammoth task requiring expensive, lenghty methods such as filed caging and exclusion experiments. However, new technology is revolutionizing field predation analysis. Infra red video-analysis of predation is fast, effective, inexpensive, and it can quantify contributions from various beneficials at the same time. Assessments of LBAM and mealybug predation are recommended in an Australian collaboration with the world-pioneers of these techniques in agricultural research such as Prof Steve Wratten.
- Non-native nectar resources of just three plants (buckwheat, phacelia, alyssum) have resulted in major improvements in beneficial longevity, egglay and pest parasitism. But the potential of Australian native plants to deliver nectar resources to vineyards is unknown. Its benefit is potentially far reaching, especially in eventual long-term linkages with Landcare and re-vegetation. It is recommended GWRDC seeks policy linkages in joint funding with federal sources assigned to Landcare, to fund such research. For best results, the screening of nectar suitability of Australian native plants to key beneficials need be done in collaboration with Australian LBAM and mealybug parasitoid specialists and leading overseas scientists already far ahead in the field of nectar chemical analysis and beneficial assessment, and interested grower associations in Australia already wishing to facilitate such work at present.
- Pesticide effects on beneficials: It is clear that as new pesticides are registered, ongoing strategic, highly prioritized, independent testing of these for effects on key beneficial biological control providers, and the speedy dissemination of results to growers are required. At present such testing is done on a piecemeal basis, industry by industry. Savings can be made if linkages between funding bodies were sought to undertake this work across agricultural and horticultural commodities. This is entirely possible because:
  (1) Key generalist predators are the same species across many crops.
  (2) For specialist parasitoids, several key species can be carefully chosen as indicators.
  (3) Differences in highest registered label rates across crops can be overcome simply by testing the highest dose registered in Australia. If safe, testing of lower label rates is redundant.
  (4) A single-testing-system such as this is successfully implemented not only across a single country, but across Europe. However, for accurate grower information, designating safe pesticides in the most economic way, the lab testing must test worst-case scenario exposure.

Appendix I: COMMUNICATION

1.1 Publications

Bernard, M.B., P.A. Horne, and A.A. Hoffmann, **2004**, Developing Eco-toxicological Testing Standard for Predatory Mites in Australia: Acute and Sub-lethal Effects of Fungicides on *Euseius victoriensis* and *Galendromus occidentalis* (Acarina: Phytoseiidae). Journal of Economic Entomology, 97(3): p. 891-899

Bernard, M., P. Horne, and A. Hoffmann, **2004**, Ecological Pest Management: The effect of viticultural fungicides on beneficial predatory mites. The Australian and New Zealand Grapegrower and Winemaker, 485a: p 7-12

Bernard, M. B., P. A. Horne, and A. A. Hoffmann, **2005**, Eriophyoid mite damage in *Vitis vinifera* (grapevine) in Australia: *Calepitrimerus vitis* and *Colomerus vitis* (Acarina: Eriophyidae) as the common cause of the widespread 'Restricted Spring Growth' syndrome. Experimental and Applied Acarology 35: 83-109

Bernard M., Wainer J., Carter V., Semeraro L., Yen A. L., Wratten S. D, **2006**, Beneficial insects and spiders in vineyards: Predators in South-East Australia. The Australian and New Zealand Grapegrower and Winemaker, 511(September): p. 37-48

Bernard M., Carter V., Semeraro L., Wratten S. D., **2006**, Beneficial insects in vineyards: Parasitoids of LBAM and grapevine moth in South-East Australia. The Australian and New Zealand Grapegrower and Winemaker, 511 (October): p. 19-26

Bernard M., Horne P. A., Papacek D., Jacometti M. A., Wratten S. D., Evans K. J., Herbert K. S., Powell K. S., Rakimov A., Weppler R., Kourmouzis T., Yen A. L., **2007.** Guidelines for Environmentally Sustainable Wine Grape Production in Australia: IPM adoption self-assessment guide for growers, The Australian and New Zealand Grapegrower and Winemaker, 518 (March), p. 26-36

Bernard M., and S. D. Wratten, **2007.** AgNote: Enhancing beneficial insects and mites in vineyards: providing nectar, pollen, and shelter in vine rows. The Australian and New Zealand Grapegrower and Winemaker, 519 (April), p. 33-34

1.2 Manuscripts for publication

Mortality and sub-lethal fecundity effects of pesticides on the predatory mite *Euseius victoriensis* (Acari: Phytoseiidae): a study to maximise conservation biological control in Australian vineyards. Bernard, M., Horne P., Cole P., Kobelt A., Hoffmann A., Journal of Economic Entomology

Martina B. Bernard, John Wainer, Ary. A. Hoffmann, Paul A. Horne, Alan L. Yen, Stephen D. Wratten, Functional biodiversity for Integrated Pest Management (IPM) in vineyards of South-East Australia: seasonal abundance of polyphagous predators and parasitoids of leafrollers (Lepidoptera: Tortricidae), Australian Journal of Entomology

Bernard M. B., Horne P. A., Papacek D., Jacometti M. A., Wratten S. D., Evans K. J., Herbert K. S., Powell K. S., Rakimov A., Weppler R., Kourmouzis T., Yen A. L., Guidelines for Environmentally Sustainable Wine Grape Production in Australia: IPM adoption assessment, Australian Journal of Entomology

1.3 GROWER SEMINARS

Winter/spring 2003

These were conducted on demand and by invitation from grower associations, one year ahead of output requirements. First pesticide safety information from testing conducted 2002/03 was disseminated to growers ahead of due date Jan '04, via all major chemical resellers through BASF communication channels. Results reached wine grape, table grape, and fruit growers in a very efficient way. This method was used, because it proved extremely effective in achieving dissemination and adoption of rust mite IPM (DAV 1/98) via Agrichem Ltd. communication channels. Extension seminars & consultations were also carried out by the CI:

1. August 2003- Landgorne Creek , SA: attendance 100+ (grower seminar)
2. Sept 2003 - Young, NSW: attendance 100+ (grower seminar)
3. Nov 2003 - Hardy Wine company, SA (1 day extended seminar/consultation)

Winter/spring 2004

Nine in depth grower seminars were conducted due to popular demand, far exceeding the required output, and one presentation at the International Congress of entomology, Brisbane.

1-2. July 2004 - 12th Wine Industry Tech. Conference, Melbourne, Vic: attendance 57 (2 workshops)
3. August 2004 - Manjimup, WA: attendance 30+ (grower seminar)
4. August 2004 - Margaret River, WA: attendance 80+ "
5. August 2004 - Mt Barker, WA: attendance 80+ "
6. Sept 2004 - Coonawarra, SA: attendance 50+ "
7. Sept 2004 - Riverland, SA: attendance 120+ "
8. Sept 2004 - King Valley: attendance 40+ "
9. Sept 2004 - Alpine Valley: attendance 30+ "
10. August 2004 - International Congress of Entomology (ICE) (scientific conference presentation)

.

Winter/spring 2005

Nine new seminars were conducted in response to grower demand, extending new data on beneficials with many photographs, up to date overview of pesticide effects, targeting most requested information: mealybug pests, their biology, beneficials feeding on mealybug,, and available control options. Seminars led to the change in practices. Many growers (for example in Riverland) started using alternate row mowing, and many decided to further limit the use of pesticides that have the potential to disrupt naturally present beneficials in their vineyard. This year pilot training/professional development for vineyard staff in practical beneficial insect recognition and monitoring methods was also done; the first such offered by wine companies to their staff and growers, far beyond the industry RTP IPM seminars.

1. August 2005 - Yarra Valley, Vic: attendance 30 (grower seminar)
2. August 2005 - McLaren Vale (Grape, Wine &Tourism Council): 50+ "
3. Sept 2005 - Riverland: attendance 100+ "
4-5. Oct 2005 -Clare Valley, McLaren Vale, SA (Hardy Wine Company): 70+ "
6- 7. Nov 2005 - King Valley, Vic: (KVV): attendance 50, 20+ "
8-9. Nov 2005 - King Valley, Vic (Brown Bros Ltd): attendance 15+ (staff training)
10. March 2005 - Oregon Wine Industry Symposium, Oregon State University, Corvallis, Oregon,
Dr. Martina Bernard - invited speaker (conference presentation)

Fully funded by the Oregon Wine Industry Council, USA; Topic: Biology, detection, and control of grapevine rust mite, bud mite, and RSG (Restricted Spring Growth): successful RSG prevention in Australia. Also promoting Australian wine industry and research, and making links with researchers and IPM implementation experts in the USA.

Winter/spring 2006 - additional seminars over and above required quota

Conducted on demand and by invitation of Grape Industry and Phylloxera Board of SA), and in conjunction with presenting (in some regions) new data for project MU04/01. Seminars extended: a finalized list of pesticides safe to beneficials; natural vineyard defenses against mealybugs and other pests; New Zealand research and practical application on supplying nectar to beneficials via cover crops.

1. August 2006, Limestone Coast: attendance 50+ (grower seminar)
2. Sept 2006 - Riverland, SA: attendance 150+ "
http://www.phylloxera.com.au/board/meetings/view.asp?region=Riverland
3. Sept 2006 - Adelaide Hills, SA: attendance 25+ "
http://www.phylloxera.com.au/board/meetings/view.asp?region=Adelaide%20Hills
4. Sept 2006- Barossa, SA: attendance 100+
http://www.phylloxera.com.au/board/meetings/view.asp?region=Barossa%20Valley
5. Sept 2006 – McLaren Vale: attendance 50+ "
6. October 2006 Barossa, SA: attendance 25+ ; Sustainable wine grape production half-day seminar jointly with other researchers (Adelaide University, Lincoln University, New Zealand) on IPM and biological control to key wine industry leaders in SA.

1.4. Other extension activities
Phone and face to face enquiries by growers, wine company personnel, and chemical re-sellers were processed on one-to-one basis by the chief investigator throughout the project (ongoing assistance with IPM of rust mite & bud mite, and demand for information on pesticide effects on beneficials, and options for integrated controls, monitoring, and mealybugs. At least 40 enquiries were handled each year. Weekly reports on pest and beneficial numbers, regular discussions and assistance with all pest control matters in their vineyards, were provided to growers participating in our research in 2003/04 and 2004/05 (see Appendix V).

1.5 Further communication activities: See sections 2. Executive Summary, and 8. Recommendations.

Appendix II: INTELLECTUAL PROPERTY

Intellectually pottery sharing arrangement between GWRDC and La Trobe University is was arranged to be 50% each. The subsequent intellectually pottery sharing arrangement between GWRDC and the University of Melbourne is also arranged to be 50% each.

Appendix III: STAFF

Chief investigator: Dr. Martina B. Bernard
Project supervisor/ academic advisor: Prof. Ary A. Hoffmann
Academic advisors: Dr. Paul A. Horne (IPM Technologies Pty. Ltd.) was remunerated to the value of $7,500 (as per final project application). The majority, of his contribution was on in-kind basis.
Dr Alan L. Yen (DPI, Primary Industries Research Victoria, Knoxfield)
Prof Steve Wratten (National Centre for Advanced Bio-Protection Technologies, Lincoln University, NZ)

Research collaborators – bioassays 2007
Mr Peter Cole (IPM Technologies Pty. Ltd.)
Dr Amanda Kobelt (DPI, Primary Industries Research Victoria, Knoxfield)

Other expert academic advisors and assistance - in-kind basis
Dr John Wainer (DPI, PIRVIC, Knoxfield-Taxonomy Collection)
Dr Mali Malipatil, (DPI PIRVIC Knoxfield-Taxonomy Collection)
Ms Linda Semeraro (DPI, PIRVIC, Knoxfield-Taxonomy Collection)
Mr James Altmann (Biological Services Ltd. Loxton)
Ms Cate Paull (University of Adelaide)
Prof Tim New (LaTrobe University)
Prof David Evans Walter (University of Queensland)
Dr Jennifer J. Beard (University of Queensland)
Prof Andrew Austin (University of Adelaide)
Dr Adam Slipinski (CSIRO)

Research Fellow: lacewing bioassay - 2003
Dr. Swarna Hewa-Kapuge (LaTrobe University-Cesar)

Technical assistance
Ms Vicki Carter (University of Melbourne-Cesar)
Ms Cindy Edward (University of Melbourne-Cesar)
Ms Angela Corrie (LaTrobe University-Cesar) - bioassay 8
Mr David Bennett (LaTrobe University-Cesar) - bioassays 3, 9
Ms Janyce Truett (DPI PIRVIC Knoxfield) - in kind
Mr William Bigand (ENSAT, Toulouse, France) - in kind

Appendix IV:

1. Paull, C. and A.D. Austin, *The hymenopteran parasitoids of light brown apple moth, Epiphyas postvittana (Walker) (Lepidoptera: Tortricidae) in Australia.* Australian Journal of Entomology, 2006. **45**: p. 142-156.
2. Berndt, L.A., S.D. Wratten, and S.L. Scarratt, *The influence of floral resource subsidies on parasitism rates of leafrollers (Lepidoptera:Torticidae) in New Zealand vineyards. Biological Control. 37: 50-55.* 2006.
3. Irvin, N.A., et al., *The effects of floral understoreys on parasitism of leafrollers (Lepidoptera: Tortricidae) on apples in New Zealand.* Agricultural and Forest Entomology, 2006. **8**(1): p. 25-34.
4. Irvin, N.A., S.D. Wratten, and C.M. Frampton, *Understorey management for the enhancement of the leafroller parasitoid Dolichogenidea tasmanica (Cameron) in orchards at Canterbury, New Zealand*, in *Hymenoptera: evolution, biodiversity and biological control*. 2000. p. 396-403.
5. Irvin, N.A., et al., *Effects of floral resources on fitness of the leafroller parasitoid (Dolichogenidea tasmanica) in apples.* Proceedings of the Fifty Second New Zealand Plant Protection Conference, Auckland Airport Centra, Auckland, New Zealand, 10-12 August, 1999, 1999: p. 84-88.
6. Lewis, W.J., et al., *A total system approach to sustainable pest management.* Proceedings of the National Academy of Scineces USA, 1997. **94**: p. 12243-12248.
7. Newman, I.C., J.T.S. Walker, and D.J. Rogers, *Mortality of the leafroller parasitoid Dolichogenidea tasmanica (Hym: Braconidae) exposed to orchard pesticide residues.* New Zealand Plant Protection, Volume 57, 2004. Proceedings of a conference, Hamilton, New Zealand, 10-12 August 2004, 2004: p.8-12.
8. Hardman, J.R., D. Papacek, and D. Smith. *The use of Integrated Pest Management in citrus orchards in Queensland- An economic perspective*. in *37th Annual Conference of the Australian Agricultural Economics Society, 9-11 February*. 1993. University of Sydney.
9. Hardman, J.M., et al., *Performance of a pyrethroid-resistant strain of the predator mite Typhlodromus pyri (Acari: Phytoseiidae) under different insecticide regimes.* Journal of Economic Entomology, 2000. **93**(3): p. 590-604.
10. Hardman, J.M., et al., *Insectary rearing and initial testing in Canada of an organophosphate/pyrethroid-resistant strain of the predator mite Typhlodromus pyri (Acari: Phytoseiidae) from New Zealand.* Environmental Entomology, 1997. **26**(6): p. 1424-1436.
11. Smith, D. and D.F. Papacek, *Studies of the predatory mite Amblyseius victoriensis (Acarina: Phytoseiidae) in citrus orchards in south-east Queensland: Control of Tegolophus australis and Phyllocoptruta oleivora (Acarina: Eriophyidae), effect of pesticides, alternative host plants and augmentative release.* Experimental & Applied Acarology 1991. **12**: p. 195-218.
12. Thomson, L.J., D.C. Glenn, and A.A. Hoffmann, *Effects of sulfur on Trichogramma egg parasitoids in vineyards: measuring toxic effects and establishing release windows.* Australian Journal of Experimental Agriculture, 2000. **40**(8): p. 1165-1171.
13. Candolfi, M.P., et al., eds. *Guidelines to evaluate side effects of plant protection products to non target arthropods.* 2000, Iobc/Wprs: Gent; Belgium.
14. Samsoe-Petersen, L., *Sequences of standard methods to test effects of chemicals on terrestrial arthropods.* Ecotoxicology and Environmental Safety, 1990. **19**: p. 310-319.
15. Rumpf, S., C. Frampton, and D. Reto Dietrich, *Effects of conventional insecticides and insect growth regulators on fecundity and other life-table parameters of Micromus tasmaniae (Neuroptera:Hemerobiidae).* Journal of Economic Entomology, 1998. **91**(1): p. 34-40.
16. Llewellyn, R., ed. *The Good Bug Book*. 2 ed. 2002, Integrated Pest Management Pty. Ltd.: Mundubbera, Australia. 110.
17. Goodwin, S., *Laboratory evaluation of pesticides on an Australian strain of the Chilean predatory mite, Phytoseiulus persimilis Athias-Henriot*, in *Acarology VI, Volume 2*, D.A. Griffiths and C.E. Bowman, Editors. 1984, Ellis Horwood Limited: Chichester, UK. p. 647-654.
18. James, D.G. and M. Rayner, *Toxicity of viticultural pesticides to the predatory mites Amblyseius victoriensis and Typhlodromus doreenae.* Plant Protection Quarterly, 1995. **10**(3): p. 99-102.
19. Myers, N., *Environmental services of biodiversity.* Proceedings of the National Academy of Sciences of the United States of America, 1996. **93**(7): p. 2764-2769.
20. Daily, C.G., *Introduction: What are ecosystem services?*, in *Nature's services: societal dependence on natural ecosystems.* 1997, Island Press, Washington D.C. p. 1-10.
21. Naylor, R.L. and P.R. Ehrlich, *Natural pest control services and agriculture*, in *Nature's services: societal dependence on natural ecosystems.*, G.C. Daily, Editor. 1997, Island Press, Washington D.C. p. 151-174.
22. de Bach, P., *Biological control of natural enemies*. 1974: Cambridge University Press, London.

23. Cullen, R., et al., *Ecosystem services on New Zealand arable farms.* AERU Discussion Paper, 2004(No.151): p. 84-91.
24. Takatsuka, Y., et al. *Values of ecosystem services on arable land and the role of organic farming*. in *New Zealand Agricultural Resource Economics Society (NZARES) 11th annual conference*. 2005. Nelson, New Zealand.
25. Tilman, D., et al., *Agricultural sustainability and intensive production practices.* Nature (London), 2002. **418**(6898): p. 671-677.
26. Matson, P.A., et al., *Agricultural intensification and ecosystem properties.* Science (Washington), 1997. **277**(5325): p. 504-509.
27. Robertson, G.P. and S.M. Swinton, *Reconciling agricultural productivity and environmental integrity: a grand challenge for agriculture.* Frontiers in Ecology and the Environment, 2005. **3**(1): p. 38-46.
28. Szentkiralyi, F., *Brown lacewing (Neuropteroidea, Hemerobiidae) assemblages in Hungarian apple orchards.* Acta Phytopathologica et Entomologica Hungarica, 1992. **27**(1-4): p. 601-604.
29. Szentkiralyi, F. and F. Kozar, *How many species are there in apple insect communities?: testing the resource diversity and intermediate disturbance hypotheses.* Ecological Entomology,1991.**16**(4):p.491-503.
30. Costello, M.J. and K.M. Daane, *Spider (Araneae) species composition and seasonal abundance in San Joaquin Valley grape vineyards.* Environmental Entomology, 1995. **24**(4): p. 823-831.
31. Costello, M.J. and K.M. Daane, *Influence of ground cover on spider populations in a table grape vineyard.* Ecological Entomology, 1998. **23**(1): p. 33-40.
32. Costello, M.J. and K.M. Daane, *Abundance of spiders and insect predators on grapes in central California.* Journal of Arachnology, 1999. **27**(2): p. 531-538.
33. MacLellan, C.R., *Populations of some major pests and their natural enemies on young and semidwarf apple trees in Nova Scotia*
Canadian Entomologist, 1977. **109**: p. 709-806.
34. MacLellan, C.R., *Natural enemies of the light brown apple moth, Epiphyas postvittana, in the Australian Capital Territory.* Canadian Entomologist, 1973. **105**(5): p. 681-700.
35. Cordingley, C.L., *Factors causing mortality of the grape vine moth, Phalaenoides glycine Lewin (Lepidoptera: Agaristidae).* Journal of the Australian Entomological Society, 1981. **20**: p. 33-38.
36. Samson, P.R. and P.R.B. Blood, *Voracity and searching ability of Chrysopa signata (Neuroptera: Chrysopidae), Micromus tasmaniae (Neuroptera: Hemerobiidae), and Tropiconabis capsiformis (Hemiptera: Nabidae).* Australian Journal of Zoology, 1980. **28**(4): p. 575-580.
37. Pearce, S., et al., *Spider fauna of soybean crops in south-east Queensland and their potential as predators of Helicoverpa spp. (Lepidoptera: Noctuidae).* Australian Journal of Entomology, 2004. **43**(1): p. 57-65.
38. Jun Ma, et al., *Functional response and predation on of Nabis kinbergii (Hemiptera: Nabidae) to Plutella xylostella (Lepidoptera: Plutellidae).* Insect Scince, 2005. **12**: p. 281-286.
39. New, T.R., *Aspects of the biology of Chrysopa edwardsi Banks (Neuroptera, Chrysopidae) near Melbourne, Australia.* Neuroptera International, 1981. **1**(4): p. 165-174.
40. New, T.R., *Comparative biology of some Australian Hemerobiidae*, in *Progress in World's Neuropterology*, J. Gepp, H. Aspock, and H. Holzel, Editors. 1984: Graz. p. 153-165.
41. Furness, G.O., *The dispersal, age-structure and natural enemies of the long-tailed mealybug, Pseudococcus longispinus (Targioni-Tozzetti) in relation to sampling and control.* Australian Journal of Zoology, 1976. **24**: p. 237-47.
42. Furness, G.O., *Chemical and integrated control of the long-tailed mealybug, Pseudococcus longispinus (Targioni-Tozzetti) (Hemiptera: Coccidae) in the Riverland of South Australia.* Australian Journal of Agricultural Research, 1977. **28**(2): p. 319-332.
43. Danthanarayana, W., *Occurrence of Trichogramma funiculatum, an egg parasitoid of the light brown apple moth, Epiphyas postvittana.* Entomologia Experimentalis et Applicata, 1980. **28**(3): p. 287-294.
44. Glenn, D.C. and A.A. Hoffmann, *Developing a commercially viable system for biological control of light brown apple moth (Lepidoptera: Tortricidae) in grapes using endemic Trichogramma (Hymenoptera: Trichogrammatidae).* Journal of Economic Entomology, 1997. **90**(2): p. 370-382.
45. Glenn, D.C., M.J. Hercus, and A.A. Hoffmann, *Characterizing Trichogramma (Hymenoptera: Trichogrammatidae) species for biocontrol of light brown apple moth (Lepidoptera: Tortricidae) in grapevines in Australia.* Annals of the Entomological Society of America, 1997. **90**(2): p. 128-137.
46. Bennett, D.M. and A.A. Hoffmann, *Effects of size and fluctuating asymmetry on field fitness of the parasitoid Trichogramma carverae (Hymenoptera: Trichogrammatidae).* Journal of Animal Ecology, 1998. **67**(4): p. 580-591.

47. McEwen, P.K., T.R. New, and A.E. Whittington, *Lacewings in the crop environment*, in *Lacewings in the crop environment*. 2001. p. xviii + 546 pp.
48. New, T.R., *The biology of Chrysopidae and Hemerobiidae (Neuroptera), with reference to their usage as biocontrol agents: a review.* Transactions of the Royal Entomological Society, 1975. **127**(2): p. 115-140.
49. New, T.R., *Zoogeography of the Australian Chrysopidae (Neuroptera).* Neuroptera International, 1983. **2**(3): p. 145-155.
50. New, T.R., *A revision of the Australian Chrysopidae (Insecta: Neuroptera)*, in *Australian Journal of Zoology, Supplementary Series*. 1980. p. 143pp.
51. Smithers, C.N., *New distribution records for Australian Chrysopidae (Neuroptera).* Australian Entomological Magazine, 1988. **15**(1): p. 35-38.
52. Horne, P.A., T.R. New, and D. Papacek, *Preliminary notes on Mallada signatus (Chrysopidae) as a predator in field crops*, in *Lacewings in the Crop Environment*, P.K. McEwen, T.R. New, and A.E. Whittington, Editors. 2001, Cambridge University Press: Cambridge. p. 395-397.
53. Smith, D., G.A.C. Beattie, and R. Broadley, eds. *Citrus pests and their natural enemies: Integrated pest management in Australia*. Q197030. 1997, Department of Primary Industries Queensland, Horticultural Research and Development Corporation: Australia.
54. New, T.R., *A revision of the Australian Hemerobiidae (Insecta: Neuroptera).* Invertebrate Taxonomy, 1988. **2**(3): p. 339-411.
55. Smithers, C.N., *New records of Australian Hemerobiidae (Neuroptera).* Australian Entomological Magazine, 1991. **18**(4): p. 139-141.
56. Horne, P.A., P.M. Ridland, and T.R. New, *Micromus tasmaniae: a key predator on aphids on field crops in Australasia?*, in *Lacewings in the Crop Environment*, P.K. McEwen, T.R. New, and A.E. Whittington, Editors. 2001, Cambridge University Press: Cambridge. p. 388-394.
57. Bishop, A.L. and P.R.B. Blood, *A record of beneficial arthropods and insect diseases in southeast Queensland cotton.* PANS (Pest.Artic.News.Summ.), 1977. **23**(4): p. 384-386.
58. Bernard, M., et al., *Beneficial insects in vineyards: Parasitoids of LBAM and grapevine moth in South-East Australia, .* Australian and New Zealand Grapegrower and Winemaker, 2006. **511** (October): p. 19-26.
59. Bernard, M., et al., *Beneficial insects & spiders in vineyards: Predators in South-East Australia.* The Australian and New Zealand Grapegrower and Winemaker,, 2006. **511**(September): p. 37-48.
60. McMurtry, J.A. and B.A. Croft, *Life-styles of phytoseiid mites and their roles in biological control.* Annual Review of Entomology, 1997. **42**: p. 291-321.
61. Readshaw, J.L., *Biological control of orchard mites in Australia with an insecticide-resistant predator.* Journal of the Australian Institute of Agricultural Science, 1975. **41**(3): p. 213-214.
62. Field, R.P., *Control of the two-spotted mite in a Victorian peach orchard with an introduced insecticide-resistant strain of the predatory mite Typhlodromus occidentalis Nesbitt (Acarina: Phytoseiidae).* Australian Journal of Zoology, 1978. **26**(3): p. 519-527.
63. Schicha, E., *Phytoseiidae of Australia and neighboring areas*. 1987, Oak Park, Michigan,USA.: Indira Publishing House.
64. Whitney, J. and D.G. James, *The phytoseiid fauna of grapevines in Australia.* International Journal of Acarology, 1996. **22**(4): p. 279-284.
65. James, D.G., *Overwintering of Amblyseius victoriensis Womersley (Acarina: Phytoseiidae) in southern New South Wales.* General and Applied Entomology, 1989. **21**: p. 51-55.
66. James, D.G., *Effect of pesticides on survival of Amblyseius victoriensis (Womersley), an important predatory mite in southern New South Wales peach orchards.* Plant Protection Quarterly, 1989. **4**(4): p. 141-143.
67. Walter, D.E., *Review of Australian Asperoseius Chant, Euseius Wainstein, Okiseius Ehara and Phytoscutus Muma (Acari: Mesostigmata: Phytoseiidae) with a key to the genera of Australian Amblyseiinae and descriptions of two new species.* Australian Journal of Entomology, 1999. **38**(2): p. 85-95.
68. James, D.G., J. Whitney, and M. Rayner, *Phytoseiids (Acari: Phytoseiidae) dominate the mite fauna on grapevines in Canberra district vineyards.* Journal of the Australian Entomological Society, 1995. **34**(1): p. 79-82.
69. James, D.G., *Biological control of Tetranychus urticae (Koch) (Acari: Tetranychidae) in southern New South Wales peach orchards: the role of Amblyseius victoriensis (Acarina: Phytoseiidae).* Australian Journal of Zoology, 1990. **37**(6): p. 645-655.

70. Bernard, M.B., P.A. Horne, and A.A. Hoffmann, *Developing Eco-toxicological Testing Standard for Predatory Mites in Australia: Acute and Sub-lethal Effects of Fungicides on Euseius victoriensis and Galendromus occidentalis (Acari:Phytoseiidae).* Journal of Economic Entomology, 2004. **97**(3):p.891-899.
71. Charles, J.G., *Distribution and life history of the longtailed mealy bug, Pseudococcus longispinus (Homoptera: Pseudococcidae), in Auckland vineyards.* New Zealand Journal of Zoology, 1981. **8**(2): p. 285-293.
72. del Rosario, M.S.E. and W.H. Sill, *Additional biological and ecological characteristics of Aceria tulipae (Acarina: Eriophyidae).* Journal of Economic Entomology, 1964. **57**: p. 893-896.
73. Costermans, L., *Native trees and shrubs of South Eastern Australia*. 1992, Sydney: Weldon Publishing.
74. Malavolta, C. and E.F. Boller, eds., *Guidelines for integrated production of grapes.* IOBC wprs Bulletin, Bulletin OILB srop, 1999. **22**(8): p. 7-14.
75. Bernard, M., P.A. Horne, and A.A. Hoffmann, *Ecological Pest Management: The effect of viticultural fungicides on beneficial predatory mites, .* The Australian and New Zealand Grapegrower and Winemaker,, 2004. **485a**: p. 7-12.
76. New, T.R., *Sampling and studying lacewings in crops* in *Lacewings in the Crop Environment*, P.K. McEwen, T.R. New, A.E. Whittington, Editors. 2001, Cambridge University Press: Cambridge. p. 351-356.
77. Neuenschwander, P., *Sampling procedures for chrysopid populations*, in *Biology of Chrysopidae*, M. Canard, Y. Semeria, and T.R. New, Editors. 1984, Dr W. Junk: The Hague. p. 205-212.
78. Szabo, S. and F. Szentkiralyi, *Communities of Chrysopidae and Hemerobiidae (Neuroptera) in some apple-orchards.* Acta Phytopathologica Academiae Scientiarum Hungaricae, 1981. **16**(1/2): p. 157-169.
79. Costello, M.J. and K.M. Daane, *Comparison of sampling methods used to estimate spider (Araneae) species abundance and composition in vineyards.* Environmental Entomology, 1997. **26**(2): p. 142-149.
80. Leathwick, D.M. and M.J. Winterbourn, *Arthropod predation on aphids in a lucerne crop.* New Zealand Entomologist, 1984. **8**: p. 75-80.
81. Vickerman, G.P. and S.D. Wratten, *The biology and pest status of cereal aphids (Hemiptera: Aphididae) in Europe: a review.* Bulletin of Entomological Research, 1979. **69**(1): p. 1-32.
82. Leathwick, D.M. and D.R. Penman, *The efficiency of sampling for aphid predators from lucerne*, in *Proceedings of the Forty Second New Zealand Weed and Pest Control Conference, Taranki Country Lodge, New Plymouth, 8-10 August, 1989.* 1989. p. 81-85.
83. Leathwick, D.M., *Applied Ecology of the Tasmanian Lacewing Micromus tasmaniae Walker (Neuroptera: Hemerobiidae)*, in *Lincoln College*. 1989, University of Canterbury: New Zealand. p. 129.
84. New, T.R., *The immature stages of Drepanacra binocula (Neuroptera: Hemerobiidae), with notes on the relationships of the genus.* Journal of the Australian Entomological Society, 1975. **14**: p. 247-250.
85. New, T.R. and C. Boros, *The early stages of Micromus tasmaniae (Neuroptera: Hemerobiidae).* Neuroptera International, 1983. **2**(4): p. 213-217.
86. Monserrat, V.J., et al., *Recognition of larval Neuroptera*, in *Lacewings in the crop environment*, P.K. McEwen, T.R. New, and A.E. Whittington, Editors. 2001, Cambridge University Press. p. 43-81.
87. Boros, C., *Descriptions of the larvae of six Australian species of Chrysopa Leach, s.l. (Neuroptera: Chrysopidae).* Australian Journal of Zoology, 1984. **32**: p. 833-49.
88. Gepp, J. *An illustrated review of egg morphology in the families of Neuroptera (Insecta: Neuropteroidea).* in *Proceedings of the Third International Symposium on Neuropterology*. 1990. Berg en Dal, Kruger National Park, R.S.A. 131-149.
89. New, T.R., *Introduction to the systematics and distribution of Coniopterygidae, Hemerobiidae, and Chrysopidae used in pest management*, in *Lacewings in the crop environment*, P.K. McEwen, T.R. New, and A.E. Whittington, Editors. 2001, Cambridge University Press. p. 6-28.
90. New, T.R., *Handbook of Zoology, Volume IV: Arthropoda: Insecta - Planipennia: Lacewings*, ed. M. Fischer. 1989, Berlin, New York: de Gruyter.
91. Woodward, T.E. and N. Strommer, *Nabis kinbergii Reuter, the current name for Tropiconabis nigrolineatus (Distant), and its Australian distribution (Hemiptera: Nabidae).* Journal of the Australian Entomological Society, 1982. **21**(4): p. 306.
92. Woodward, T.E., *The identity of the species commonly known in Australia as Nabis capsiformis Germar (Hemiptera: Nabidae).* Journal of the Australian Entomological Society, 1982. **21**(2): p. 143-146.
93. Strommer, N.G., *Genera Nabis Latreille and Stenonabis Reuter (Hemiptera: Nabidae) in Australia.* Rec. S. Aust. Mus., 1988. **22**(2): p. 79-93.

94. Matthews, E.G., *A guide to the genera of beetles of South Australia. Part 6. Polyphaga: Lymextloidea, Cleroidea and Cucujoidea*, in *A guide to the genera of beetles of South Australia. Part 6. Polyphaga: Lymextloidea, Cleroidea and Cucujoidea.* 1992, South Australian Museum: Adelaide. p. 74 pp.
95. Houston, K.J., *A revision of the Australian species of Stethorus Weise (Coleoptera: Coccinellidae).* Journal of the Australian Entomological Society, 1980. **19**(2): p. 81-91.
96. Britton, E.B. and B. Lee, *Stethorus loxtoni sp. n. (Coleoptera: Coccinellidae) a newly-discovered predator of the two-spotted mite.* Journal of the Australian Entomological Society, 1972. **11**(1): p. 55-60.
97. Houston, K.J., *The New Zealand species of Stethorus Weise.* New Zealand Journal of Zoology, 1990. **17**: p. 271-278.
98. Kapur, A.P., *On the old world species of the genus Stethorus Weise (Coleoptera, Coccinellidae).* Bulletin of Entomological Research, 1948. **39**: p. 297-320.
99. Williams, D.J., *Australian mealybugs.* 1985, London: British Museum (Natural History).
100. Williams, D.J. and G.W. Watson, *Scale insects of the tropical South Pacific region. Part 2. Mealybugs (Pseudococcidae).* Scale insects of the tropical South Pacific region. Part 2. Mealybugs. 1988. 260 pp.
101. Andersen, A.N., *The ants of southern Australia: a guide to the Bassian fauna*. The ants of southern Australia: a guide to the Bassian fauna. 1991, Melbourne; Australia CSIRO Publications vii + 70 pp.
102. Andersen, A.N., *The ants of northern Australia*. The ants of northern Australia. 2000, Melbourne; Australia CSIRO Publishing;. 106 pp.
103. Shattuck, S.O. and N.J. Barnett, *Australian Ants - Their Biology and Identification, Monographs on Invertebrate Taxonomy Vol. 3*. 1999, Melbourne; Australia: CSIRO Publishing.
104. Shattuck, S.O. and N.J. Barnett. *Australian Ants online: http://www.ento.csiro.au/science/ants*. [cited; Available from: http://www.ento.csiro.au/science/ants.
105. Matthews, E.G., *A guide to the genera of beetles of South Australia. Part 2. Polyphaga: Staphylinoidea and Hydrophiloidea*, in *A guide to the genera of beetles of South Australia. Part 2. Polyphaga: Staphylinoidea and Hydrophiloidea*. 1982, South Australian Museum: Adelaide.
106. Bailey, P. and G. Caon, *Predation on twospotted mite, Tetranychus urticae Koch (Acarina: Tetranychidae) by Haplothrips victoriensis Bagnall (Thysanoptera: Phlaeothripidae) and Stethorus nigripes Kapur (Coleoptera: Coccinellidae) on seed lucerne crops in South Australia.* Australian Journal of Zoology, 1986. **34**(4): p. 515-525.
107. Young, G.R. and L. Zhang. *IPM of melon thrips, Thrips palmi Karny (Thysanoptera: Thripidae), on eggplant in the top end of the Northern Territory*. in *Proceedings of the Sixth Workshop for Tropical Agricultural Entomology, Darwin, Australia, 11 15 May 1998. Technical Bulletin Department of Primary Industry and Fisheries, Northern Territory of Australia. 2001, No. 288, 101 111; 18 ref.* 2001: Department of Primary Industries and Fisheries Northern Territory of Australia; Darwin; Australia.
108. Bernard, M.B., P.A. Horne, and A.A. Hoffmann, *Eriophyoid mite damage in Vitis vinifera (grapevine) in Australia: Calepitrimerus vitis and Colomerus vitis (Acarina: Eriophyidae) as the common cause of the widespread 'Restricted spring growth' syndrome (RSG).* Experimental and Applied Acarology, 2005. **35**(1-2): p. 83-109.
109. Williams T., Valle J., Vinuela E., 2003, Is naturally derived insecticide spinosad compatible with insect natural enemies ? , Biological science and Technology, Vol 13 (5), p. 459-475

APPENDIX V: OTHER RELEVANT MATERIAL

Pest & beneficial sampling- weekly grower report

Pest & beneficial sampling – IPM field monitoring sheet

Bt field trial report to participating growers

AgNote: Nectar, pollen, and shelter resources for beneficial insects and mites in vineyards

Pest & beneficial sampling- weekly grower report

PEST AND BENEFICIAL MONITORING
TOTAL SYSTEM MANAGEMENT/ IPM in Australian vineyards
Prepared by: Martina Bernard as part of GWRDC project LTU 02/01 CESAR, LaTrobe Uni & IPM Technologies

Date
Site
Vine stage **Variety 1** **Variety 2**

PESTS

LBAM
LBAM males (average per trap, based on 4-5 traps) ……....
LBAM egg masses (average per 100 canes, based on 3 reps) ……..……
LBAM larvae (average per 100 canes, based on 3 reps)……

Wine moth
Larvae (average per 100 canes, based on 3 reps) ……..

Mealybug
No. vines infested (4 crown leaves of 25 vines searched; 3 reps)……...…..……..……
No. of mealybugs (average per 100 leaves) ……...……
No. of new infested vines compared to last week……
Comments:

BENEFICIALS

CANOPY
(average per 100 canes, based on 3 reps) **Variety 1** **Variety 2**

GLW eggs ……...
GLW larvae ……...
BLW eggs ……...
BLW adults ……...
Spiders ……
LBAM egg-masses parasitized (*Trichogramma*)
……
LBAM larval parasitoids - cocoons……...
Other

INTER-ROW VEGETATION
(average per $1m^2$ of uncut inter-row grass: 60 sec suction, 8-10 reps)

BLW adults/larvae……..
Predatory damsel bugs adults/larvae ……
Spiders ……
Other

Action suggested

1.1 Pest & beneficial sampling – IPM field monitoring sheet

DIRECT OBS. MONITORING SHEET: Martina Bernard- Total System/IPM in grapevines - GWRDC Project LTU/02/01					
Season II: 2004-05	**Date**	**SITE**	**Vine stage**		
LBAM trap: No. males					
Sticky Trap collected					
Variety	**rep1**	**rep2**	**rep3**	**Total**	**Mean**
LBAM Egg mass/100 canes-fresh					
Egg mass/100 canes-fresh- emerged					
Parasitised egg mass					
LBAM larvae **1-2**					
LBAM **3-4**					
LBAM **5-6**					
LBAM larvae/ 100 bunches					
Mealybug /New vines infest.					
Vines total infest.					
No. vines ants					
M-bug **1**/100 crown leaves					
M-bug **2**					
M-bug **3**					
Vine moth /100 canes: **1-2**					
Vine moth **3-4**					
Vine moth **5-6**					
Heliotis larva/100 canes					
GLW egg green/gray					
GLW larvae					
Spiders adult/ spiderling					
egg sacks P/A					
BLW adult/100 canes					
BLW eggs/ (larvae)					
Coccinellid/100 canes larvae					
Harmonia c. adult					
Hippodamia v.					
Coccinella t.					
Near **Diomus spp.**					
Stethorus					
Rove beetles/100 canes					
Nabids/100 canes					

Predatory mites
anystids (o/red very fast)
stigmaeiid (bright/slow)
bdellids(orange snout.)
other

Beneficial-other
***D. tasmanica* cocoons**

***Goniosus* cocoons**

Thrips P/A (R= reproducing)

Aphids P/A

Hoppers

Pest bugs

Weevils

Pests-other

BT TRIAL 2003-2004 - MERLOT
SUMMARY FOR PARTICIPATING GROWERS

Prepared by Martina Bernard, CESAR, La Trobe University, GWRDC Project LTU/02, March 2004

Treatments
Control: 3 replicates
Delphin®: 6 replicates @ 2kg/ ha; plus feeding inducant (Mobate®) at recommended label rate
Spray volume: 500 L/ha
Spray date and time of day: 23 Feb 04; 6pm - 1am
Assessment dates: 1-2 March 04, 6 ½ days – 7 ½ days after spray application (time for large larvae to die)

Method of scoring LBAM
In each replicate larvae were counted in 72 canes selected randomly (6 canes per panel) across 15 panels, giving the total of 216 canes assessed for control, and 432 for BT treatment. Averages per each treatment were calculated. Larvae were scored in 1-2, 3, 4, and 5-6 instar categories, to assess BT effectiveness against different ages of larvae.

Results

	Average LBAM larvae (Instar 1-6) **per 72 bunches**	Percentage of infested bunches	**BT efficacy: reduction in bunch infestation**
Control	5.3 ± a	7.4 % (5.3/ 72)	
BT	1.5 ± b	2.1 % (1.5/72)	**71.7 %**

	Average LBAM larvae (Instar 1-6) **per 72 canes Leaf canopy only**	Percentage of infested canes	**BT efficacy: reduction in leaf canopy infestation**
Control	40.0 ± a	55.6% (40.0/72)	
BT	18.5 ± b	25.7 % (18.5/72)	**53.8 %**

Results in the same column followed by a different letter are significantly different ANOVA ($P< 0.05$).

Interpretation of results

Bunch vs. canopy infestation
Merlot bunches had low larvae infestation compared to the canopy infestation. Larvae did not automatically move into bunches, as is usually assumed. This means that the threshold for spraying late in the season can be higher than the 1-4% canopy infestation often used early in the season. Merlot bunches were open, and allowed for effective spray penetration. Lower spray efficacy in closed bunch varieties is likely.

BT efficacy
The majority of surviving larvae in the BT treatment were 4^{th}- 6^{th} instars. The 2kg/ha rate worked extremely well against 1^{st} – 2^{nd} instars, and moderately well against 3^{rd} instars. Higher kill would have been expected if spray was applied earlier, before larvae grew in size). Higher BT rate than 2kg/ha is needed to kill larger caterpillars (4^{th}-6^{th} instars). Results are comparable to BT efficacy found in vegetable crops (Horne, unpublished data).

Spray timing for optimal Bt success
The high efficacy against young larvae confirms that the best time to spray Bt was soon after large numbers of egg-masses first appeared (26 Jan-3 Feb '04), as detected by monitoring (3 Feb '04) when Bt spray was 1^{st} recommended to the grower. At that time >90% of all larvae were 1-2 instars, and majority of egg-masses hatched. The sudden large 'egg-lay-cue' found in the week of 26 Jan-3 Feb '04 was easy to detect, and can be used by growers to optimally time BT applications. To do so, careful weekly monitoring is critical from fruit set onwards, especially in cooler seasons.

Suggestions for LBAM control strategy
Given the cost of Bt sprays, repeated use late in the season (needed in the cool summer '04 in the study vineyard, when LBAM pressure became suddenly very high) is not economical. The following strategy is thus suggested: **(i) 1x optimally timed Bt spray** (after fruit set) if necessary based on monitoring; **(ii)** encouragement of naturally present **LBAM larval parasitoids**. To achieve LBAM larval parasitoids conservation certain novel insecticide sprays sprays may need to be avoided, and some cover crops can be used to improve parasitoid effectiveness by providing them with nectar (New Zealand Research).

AgNote: Providing NECTAR, POLLEN, and SHELTER to encourage BENEFICIALS INSECTS in vineyards

Prepared by: Dr Martina Bernard, Dpt. of Zoology- Cesar, University of Melbourne
Source of information: Prof Steve Wratten, National Centre for Advanced Bio-Protection Technologies, Lincoln University New Zealand; 30 September 2006

Alternate row mowing of grass inter-rows
provides pollen and shelter for beneficials. Common predators are aided by alternate row mowing; e.g. damsel bugs *(Nabis kinbergii)*, brown lacewings *(Micromus tasmaniae*), ground dwelling predatory beetles and spiders. Predatory mites feed on pollen as a supplementary food source. In addition, nectar resources can also be provided.

What makes a good nectar source for beneficials

- Nectar must be high in sugar
- The right nectar quality (sugar ratio)
- Confirmed in lab & in the field
- Flower shape must allow access
- Fast to flower
- Agronomy (compatible with vineyards)
- Low water requirement
- Low/no weed potential
- Low pest attractiveness
- This takes years to establish (!) … 10 years of research in New Zealand (Lincoln Uni) and recent work in Australia in collaboration with New Zealand so far established 3 plants:
- **Buckwheat**
- **Phacelia (*Phacelia tanacetifolia)…..*** both researched as nectar source for the most common LBAM larval parastoid *Dolichogenidea tasmanic* (Lincoln University).
- **white alyssum (*Lobularia maritima*)** researched as nectar source for *Trichogramma* (Charles Sturt University &Lincoln University)
- 1/10 vine inter-rows sown to these plants provide high quality nectar and pollen not only for these parasitoids, but also for predators whose adult life stages feed on nectar and pollen e.g. hoverflies, common Australian green lacewing (*Mallada signatus*), other parasitoids such as parasitoids of mealybugs, vine scale, and vine moth.
- In New Zealand vineyards the use of flowering buckwheat in one row in ten reduces leafroller populations to below economic thresholds. A whole wine region is adopting these and other practices, using native and non-native plants: www.waiparawine.co.nz/index.cfm/research/greening_waipara.html and www.lincoln.ac.nz/story13772.html

How to use buckwheat

- all cultivars ok
- sow only 1 in every 10 rows
- 15m either side of row = no decline in LBAM parasitism
- direct drilling (2cm deep) from November, then again at least 1x (Jan, Feb) in off-set rows
- time to flowering *c*. 5 weeks(Nov planting), c. 3 weeks (Jan/Feb plantings)
- 45kg seed/ha ….that means only about 0.5 kg per 100 m row
- seed cost: 67c/kg ..... that means 34c per 100m row !!
- water-in after drilling (again if very dry)
- New Zealand supplier
  Midland Seeds, 393-405 West Street, PO Box 65, Ashburton, NZ;
  Ph +64 3 308 1265, Fax +64 3 308 1266, email office@midlands.co.nz web www.midlands.co.nz
  Buckwheat is also available in Australia (restrictions on bringing seed in from New Zeland may apply)
- Buckwheat is an annual, so need be re-sown each year; this is necessary until research on nectar resource of Australian native plants is done.

The use of these strategies is intended only once IPM Step I (minimal use/ emimination of pesticides toxic to beneficials) is implemented, and in conjunction with regular monitoring of pests and beneficials.
Please contact us if using these practices in your vineyard, and for further info: martinab@unimelb.edu.au; mobile 0409 936 503.

APPENDIX VI:
BUDGET RECONCILIATION

Project financial reconciliation for **LaTrobe University (1 July 2002 - 28 February 2005)** was completed by LaTrobe University, as part of CESAR transfer to the University of Melbourne, and is on file at GWRDC.

Project financial reconciliation for **University of Melbourne (1 March 2005 – 31 October 2007)** is attached, see next page.

APPENDIX VII:
COPIES OF PUBLISHED PAPERS