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Sustainable viticulture 2010 and beyond: Vineyard management to maximize beneficial invertebrates to increase the bottom line

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Sustainable viticulture 2010 and beyond: Vineyard management to maximize beneficial invertebrates to increase the bottom line

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1 Abstract:

Pest control in vineyards is provided by natural enemies and chemicals, and an increase in the abundance of enemies can shift the balance towards sustainable pest control with economic and environmental rewards. Vineyard management practices, including selection of less toxic chemicals, establishing or maintaining vegetation within the vineyard, and to a lesser extent planting cover crops, all increase abundance and diversity of natural enemies. Each of these options carries costs but through improved pest control there is the potential for both economic and environmental benefit. The project makes specific recommendations for achieving these outcomes.

2 Executive summary:

The project provides ways of assessing impacts of chemical use, vegetation and cover crops with a view to supporting the industries' environmental image while enhancing economic outcomes. We have identified means to enhance invertebrate diversity, including those that contribute to pest control as predators and parasitoids and to soil health. We have examined options within the context of practices that are all part of normal vineyard management. This includes chemicals that are often a part of pest and disease management, non-crop vegetation that is increasingly managed or put in place to provide a variety of vineyard services, and inter row crops that are being considered in response to drier conditions within vineyards. The management practices targeted all have economic and environmental components. Reduced use of chemicals detrimental to beneficial invertebrates has the potential to enhance pest control and decrease the environmental impact of chemicals in the industry. Vegetation in vineyards, with a range of different primary functions, similarly increases natural enemies with potential to reduce chemical impacts, and confers the benefits of the vegetation and enhances the image of the industry both locally and globally. Reduced rainfall and temperature increases associated with changing climate conditions have spurred interest in cover crops which can grow in the more difficult conditions.

The project led to three main findings with direct practical implications. The first finding is that a simple chemical rating based on IOBC criteria across a season provides an effective tool for growers to broadly assess the likely impact of their spray programs on beneficials. Pesticide information on beneficials facilitates consideration of environmental impacts of chemical use with a view to supporting the industry's environmental image while maintaining all-important pest control and is available through the CESAR website at http://cesar.org.au/index.php?option=com_collateral_manage. This index was validated across regions and some of the key chemicals contributing to low ratings have been identified.

The second finding is that shelterbelts and remnant vegetation adjacent to vineyards can increase pest control within a vineyard and increase abundance of natural enemies. The vegetation has to be structurally complex but narrow shelterbelts appear to be as effective as entire blocks of remnant vegetation at least for many groups of natural enemies. This means that growers can influence beneficial invertebrates in vineyards by altering the nature of non-crop vegetation bordering vineyards.

The third finding is that some types of native vegetation used as cover crops within vineyards and relatively resistant to drought can increase the abundance of natural enemies within vineyards. Crop selection is critical but, when successful, cover crops have potential to confer benefits for pest control. Again an additional value of these can be the provision of resources for natural enemies with associated increase in abundance (without any increase in pests).

The project also contributed to an increased understanding of invertebrates within vineyards more generally. We catalogued the distribution of invertebrate groups across southeastern

Australia and collected information on the relative abundance of predators and parasitoids. This included new species of small local ladybirds that appear particularly abundant in vineyards and new information on ground dwelling invertebrates. We also collected the first comprehensive data set on ants in vineyards and showed that a diversity of native species were almost always the only ants found in commercial vineyards, typically with few detrimental effects on outbreaks of pest species.

Environment is important to growers, their families, the community and the industry. Outcomes from the project show that in making choices to increase its environmental position such as 'reinstating areas of native habitat in the landscape'[1] and attention to 'use of insecticides, herbicides and fungicides as a priority environmental issue' and 'maintaining & enhancing natural ecological systems & protecting biodiversity'[2] can have practical benefits. The research outcomes were completed across a wide range of vineyards, regions and vegetation types so are likely to be broadly applicable across the industry. Chemical impacts can be ameliorated, and the cost of softer chemicals, vegetation in real terms or in loss of crop land or sowing cover crops can in part be recouped with increases in natural enemies, all contributing to the aim of a profitable and sustainable future[3]. Overall practical implications are that management practices can lead to increased biodiversity of invertebrates with advantages in pest control, soil health and environmental footprint. Management practices can lead to less toxic chemicals applied, increased vegetation to provide additional protection, as well as increased native grasses, and environmentally there are benefits to the industry and to the broader community and possibly industry carbon footprint. Benefits may also include reduced soil compression from tractor runs with reduced chemical applications or reduced mowing, sowing with successful establishment of native grass cover crops and even possible future impacts on carbon accounting. At the moment only fuel is included as an input but possible future changes may see inclusion of costs of carbon input to chemicals applied and credits for vegetation and soil management options.

"There … a rapidly growing concern about ecological sustainability – factors which suit the 'clean and green' Australian wine industry." Australia's 'clean and green' image is a critical competitive advantage[4]. Identifying means to enhance natural enemies will provide a degree of protection in the future. If pest distributions change under conditions of altered temperature or water availability, attractive conditions for natural enemies can help in different ways: they will assist in the migration of existing natural enemies with their pests and also provide diversity to improve prospects for new relationships to develop. The extensive knowledge of pest and natural enemy distributions and range of relationships with grower groups developed in the course of this project will be applied in the future for input to modeling to predict potential impacts of climate change on distributions of pests and their natural enemies.

Our communication strategy led to information being imparted to growers, consultants and agronomists through diverse avenues. We now regularly provide responses to grower queries about increasing abundance and diversity of natural enemies, and their contribution to pest control, through information about chemical impacts and adjacent remnant and shelterbelt vegetation. We have also reached a wider audience of landholders with invitations to speak through Landcare, Greening Australia and Catchment Management Authorities. We have proposed a workshop at AWITC 2010, and initiated involvement with Wine Technology and Viticulture course at School of Land and Environment (University of Melbourne) where we will now have an on going role in provision of information on environmentally sustainable pest and disease management. We would like to see the

[1] From Winemakers Federation of Australia Policy Position *'Statements on Biodiversity'*
[2] *Sustaining Success* - in 2002
[3] GWRDC mission statement
[4] From WFA 10 year marketing strategy *'The Marketing Decade'*

database appear on a more grower accessible website and in the future, see the value in growers having easy access to pest and natural enemy images such as those provided by ' Insects Pests and Beneficials Guide' published by the Cotton CRC http://www.cottoncrc.org.au or Commonwealth government's 'Pest and Diseases Images Library' http://www.padil.gov.au or further development of http://www.winetitles.com.au/diagnosis.

Additional financial support for aspects of the project was provided by Fosters Group ($15000) for vegetation and chemical impacts sampling and analysis, Chris Penfold ($15000) for cover crop sampling and analysis**,** Holsworth Wildlife Research Endowment grants to Clare D'Alberto ($5000)(spiders) and Chee Seng Chong ($10000)(ants) and University of Melbourne travel scholarship to Clare D'Alberto ($3000)(spider gut content analysis and predation).

3 Background:

Invertebrates such as spiders, mites and insects underpin biodiversity in vineyards and perform important roles in vineyards as pests, natural enemies and soil conditioners. They include widespread and common pests such as light brown apple moth, scale, mealybugs, rust, bud and blister mites and those that are more local or regional problems such as weevils, Rutherglen bugs and leafhoppers. At the same time, control of pests is provided by a range of invertebrate natural enemies, predators and parasitoids, that provide important control. In an earlier GWRDC project we developed and validated simple methods for assessing invertebrate fauna in vineyards and used these to identify simple indicators - common and widely distributed groups which are significant in vineyard management, and gain a broad understanding of the complex interactions between aspects of vineyard management and key beneficial invertebrates in the vineyard.

The principal objective of the current project was the assessment of vineyard management practices specifically, chemical applications, adjacent vegetation and the use of cover crops, to identify those which enhance beneficial invertebrates (natural enemies and soil organisms) in vineyards. The aim was to provide essential and practical input into the effects of management practices relevant to vineyard performance, economic savings and environmental effects. Increasing natural enemies has multiple benefits – reduced costs in labour and chemicals, reduced environmental impacts, increased view of goodness of industry and enhancement of the industries 'clean and green' image.

4 Project aims and performance targets:

The aim of the project was to increase pest control provided by natural enemies of vineyard pests and thus improve the capacity of natural pest control with potential to both improve control of some of the more difficult pests and reduce input of chemicals with associated environmental and economic costs.

Three areas of vineyard management were targeted

1. chemical inputs to viticulture
2. the role of inter row vineyard plantings in providing resources for natural enemies and beneficial soil organisms (collaboration with Chris Penfold and Mike McCarthy)
3. the role of woody vegetation adjacent or within vineyards in providing resources for natural enemies

Table 1. Planned project outputs and performance targets as proposed in original application

Outputs	Performance Targets
Year 1: 2006-2007	
1. A list of vineyard chemicals affecting natural enemies and soil organisms. Identification of chemicals of critical importance.	1. Identification, analysis and tabulation of data for impact on key beneficials identification of key natural enemies for which laboratory chemical testing data is incomplete. Article in Australian & new Zealand Grapegrower and Winemaker Contribution to workshops to inform growers
2. A list of cover crop plants which encourage natural enemies	Identification, analysis and tabulation of plants with potential for a positive impact on key natural enemies.
3. 4. A list of cover crop plants which encourage soil organisms	3. Identification, analysis and tabulation of plants with potential for a positive impact on key natural enemies.
4. Characteristics of adjacent vegetation to maximise the presence of natural enemies.	4. Identification, analysis and tabulation of available data on noncrop habitats to increase key natural enemies. Identification, analysis and tabulation of available data on noncrop habitats to ameliorate off target chemical effects .
Year 2: 2007-2008	
1. Laboratory testing of chemical effects on key natural enemies where deficiencies in published literature are identified	1. Identification of effects of relevant chemicals on key natural enemies for which gaps in laboratory chemical testing data were identified Article in Australian Grapegrower and Winemaker Publication of results in peer-reviewed science article
2. Report results of targeted field survey of vineyards using chemicals of interest identified	2. Identification of chemicals that compromise natural enemies. Potential cost-benefit analysis of the possible savings in chemical use if spray program is sensitive to the effects on natural enemies, allowing increased natural enemies and decreased chemical application. Presentation of information regarding effects of chemicals on natural enemies at grower meetings Article in Australian Grapegrower and Winemaker Publication of results in peer-reviewed science article
3. Report from field studies on impacts of cover crop plants on natural enemies	3. Identification of cover crops that encourage natural enemies without a loss of production, including potential cost-benefit analysis (in collaboration with Mike McCarthy and Chris Penfold). Presentation on effects of cover crops on natural enemies at grower meetings and publication of results in peer-reviewed science article
4. Report from field studies on the responses of soil organisms to different cover crops	4. Identification of cover crops that potentially increase numbers of soil organisms and hence improve soil quality without a loss of production, including potential cost-benefit analysis (in collaboration with Mike McCarthy and Chris Penfold). Presentation on effects on soil organisms at grower meetings and publication of results in , peer-reviewed science article.
Year 3: 2008-2009	
1. A cost / benefit analysis of management practices (chemical use, within vineyard and adjacent vegetation plantings) on beneficial invertebrates	1. Article(s) in Grapegrower and Winemaker Presentations at grower meetings, conferences and workshops
2. Invertebrate indicators that growers can use to monitor their vineyard for maximum profit and sustainability	2. Provide recommendations to industry on sustainable vineyard management practices
3. Report to GWRDC	Final report submitted

5 Method:

5.1 Overview

The overall aim of the project was to identify the impacts of a range of vineyard management practices on invertebrates beneficial to grape production principally as predators and parasitoids, but also those that contribute to biodiversity and soil health. Enhancing abundance of natural enemies has potential to improve control of difficult pests and also to reduce chemical impacts with associated economic and environmental impacts by shifting the balance towards pest control by natural enemies and away from chemicals. The areas identified as critical to invertebrate abundance were chemical toxicities, adjacent vegetation and inter row vegetation. Outcomes were achieved with a 3 way attack:

1. Extensive literature surveys for available information from Australia and overseas for each of the 3 areas
2. Sampling invertebrates in many vineyards across 4 wine regions vineyards with a range of experiences in the 3 areas. We sampled a wide range of invertebrates from both the canopy (using sticky traps) and the ground (using pitfall traps) in over 90 vineyards across 4 regions in south eastern Australia - Yarra Valley, Wrattonbully, Padthaway and Barossa Valley.
3. To demonstrate that not only could vineyard practice enhance natural enemies, but that this was reflected in an increase in predation of the most important insect pest in most vineyards, we established a light brown apple moth colony and placed eggs in all vineyards to test the effectiveness of each management practice in actively promoting pest control

Sampling protocols for all studies We used 5 replicates (pitfall and yellow sticky traps) at 5 sampling points within each vineyard block (site) of each project. Two commonly used trapping methods for agriculture were utilised to census a diverse range of invertebrate fauna: pitfall traps targeting ground dwelling invertebrates and sticky traps targeting canopy dwelling arthropods (Thomson *et al.*, 2004). Pitfall traps were constructed from plastic sleeves, 22 mm diameter by 150 mm deep, sunk into the ground with a glass test tube 20 mm in diameter, containing 40 mm of ethylene glycol, inserted so that the top of the trap was flush with the soil surface as adapted from Majer (1978). Sticky traps were commercially available (Agrisense^{TM}) yellow sheets (240 mm by 100 mm) sticky on both sides. These were suspended from the lower wire of the vertical two-wire trellis system ensuring the lower margin was 1m above the ground. Repeated sampling over the growing season each year (Oct – March) was considered necessary to obtain the range of organism present in vineyard environments (Thomson *et al.*, 2004).Traps placed out for one week for the first week of the month across the grape growing season so 4 or 5 collections were made for each project.

All invertebrates collected were sorted and identified in the laboratory using a stereo-microscope (Leica M50) at a magnification of 6 to 40 times, yellow sticky traps *in situ* and pitfall trap contents tipped into a Petri dish. Invertebrate groups were first sorted to order (Harvey and Yen, 1997) then important predators and parasitoids including beetles, hymenopteran parasitoids, and spiders were subsequently taken to family (Mathews, 1980-1997; CSIRO, 1991; Hawkeswood, 2003; Stevens *et al.*, 2007). The beetles Carabidae, Coccinellidae and Staphylinidae and hymenopteran parasitoids, where possible, were then sorted to species using Matthews (1980, 1982, 1992) and Ślipiński (2007) and Glenn *et al*. (1997), Paull and Austin (2006) and Stevens *et al.* (2007). We also gratefully acknowledge taxonomic assistance from Dr Mali Malipatil (DPI), Prof Andrew Austin (University of Adelaide), Dr Cate Paull (SARDI), Dr John La Salle (CSIRO, Canberra) for parasitoids and Dr Adam Ślipiński (CSIRO, Canberra), Dr Ken Walker, Mr Peter Lillywhite (Museum of Victoria) and Dr Eric Matthews (South Australian Museum) for beetles.

For analysis, the mean numbers of each group collected per sampling point (mean of 5 replicate traps) within a vineyard across the season were used. Abundance data was log-transformed and normality confirmed with Kolmogorov – Smirnov tests prior to analysis.

Analysis of variance (ANOVA) was used to compare abundance of groups which occurred in reasonable numbers and across most of the vineyard sites for each study. All analyses were undertaken with SPSS for Windows version 15 (later v. 17), SPSS Inc., Chicago, Illinois.

In addition to investigating effects of management practices on abundance of natural enemies, we investigated natural predation and parasitism of LBAM eggs to directly assess the impact of management practice on pest control. LBAM eggs were obtained from our colony, originating in the Yarra Glen area. Emerged moths were placed for oviposition in plastic cups (Charnol, Australia) with horizontal ridges and following oviposition, cups were cut into strips with egg masses intact and stored at 4°C until placed in vineyards for predation/parasitism assessment in response to management practice.

There are 3 flights of LBAM each year (Danthanarayana, 1975). We placed eggs in the vineyards for five days and replaced with a second batch for a further five days to coincide with the predicted second flight (in February for each season). At each sampling point in the vineyard on each occasion, we place three egg cards (containing two egg masses of 20-70 eggs). LBAM egg masses form a raft which adheres to the cup and, although confirmation of predation as the cause of egg loss, and identification of the predator, would only be possible with direct observation, our previous experience suggests egg masses are not displaced by events such as rain or wind. On collection, cards were scored for missing egg masses lost due to predation, returned to the laboratory, placed at 25°C for a further five days, then assessed for parasitism (eggs turning black), and returned to 25°C until parasitoids emerged and were identified morphologically (Glenn *et al.*, 1997). Percentage egg masses lost to predation or parasitism was calculated for each sampling point. Analysis was carried out using arcsin transformed mean percentage egg masses lost to predation for each vineyard, pooling across the two repeat trials used each time. ANOVA was then used to compare treatment effects on predation at different sites.

Because of applications of chemicals for control of light brown apple moth, there were low numbers of all Lepidoptera and it was not possible to analyse naturally occurring light brown apple moth.

5.2 Chemical methods

5.2.1 Chemicals literature review

We completed a literature survey of information published in scientific journals and by the IOBC (International Organization for Biological Control of Pest Organisms) to create an extensive database and from this we produced a web based tool for grower information. An important aspect of the data base is that it is based solely on publications in the peer reviewed scientific literature and does not include information in unpublished and unrefereed reports.

5.2.2 Laboratory testing of chemicals

We assessed the acute toxicity of two insecticides and 3 fungicides to a rove or staphylinid beetle (*Dalotia* (previously *Atheta*) *coriaria* Kraatz Coleoptera: Staphylinidae) (supplied by Biological Services Loxton South Australia 5333) and a ladybird beetle *Cryptolaemus montrouzieri* Mulsant (Coleoptera: Coccinellidae) ('mealybug ladybird') (Bugs for Bugs *Mundubbera,* Queensland 4626) by measuring direct mortality.

Ladybird beetles are important predators of a range of vineyard pests. While best known for eating mealybugs, and the species selected here is commercially provided for mealybug control, other species are known to eat light brown apple moth, mites and scale. We also chose to look at effects on an Aleocharine staphylinid beetle. Relatives in Europe eat fungal spores and are known predators of phytophagous mites (Paoletti and Lorenzoni, 1989). Our research was the first time that these tiny beetles had been recorded from vineyards.

The insecticides tested were chlorantraniliprole and indoxacarb, both are nominally 'soft' chemicals for control of Lepidoptera such as light brown apple moth or grapevine moth, with some concerns regarding their impacts on non-target beneficials. Indoxacarb toxicity (IOBC) varies from 1 ('harmless') to a predatory mite and a predatory fly but 4 ('very harmful') to a parasitoid. Published tests with indoxacarb also indicate that it ranges from being harmless to moderately harmful to several parasitoids (Hewa-Kapuge *et al.*, 2003; Newman *et al.*, 2004) and moderately harmful to coccinellids and predatory bugs (Agnello *et al.*, 2003; Studebaker and Kring, 2003; Galvan *et al.*, 2005). There are as yet no published toxicities for chlorantraniliprole, although the manufacturers label indicates 'concerns with adverse effects on foliage dwelling predators'. Chlorantraniliprole is not currently registered for use on vines. Chlorantraniliprole was tested as [Alticor® (DuPont)] (concentration of active ingredient chlorantraniliprole 350 g/kg) with the manufacturer's recommended rates for application ('label rate'), 9g/100 L. Indoxacarb was tested as [AVATAR® (DuPont)], concentration of active ingredient indoxacarb 300 g/kg, and recommended application rate ('label rate'), 17 g/100L.

Fungicides tested were potassium bicarbonate [Eco-Rose® (Organic Crop Protectants)], concentration of active ingredient potassium bicarbonate 940g/kg, 'label rate' 400 g/100L; trifloxystrobin [Flint® (Bayer)],concentration of active ingredient (500 g/kg) 'label rate' 400 g/100L and pyraclostrobin [Cabrio® (NuFarm)] concentration of active ingredient (200 g/kg) 'label rate' 50g/100L, all low toxicity.

In the laboratory, chemicals were applied to adult rove and ladybird beetles using a Potter tower (Potter, 1952) at a range of rates (0.125-2 X label rate). Each replicate, consisting of about 10 animals (rove or ladybird beetles), was placed in a 90-mm plastic Petri dish, there were 5 treatment concentrations for each chemical and a water control, and 5 replicates for each treatment: chlorantraniliprole, indoxacarb, potassium bicarbonate, trifloxystrobin and pyraclostrobin.

After spraying the Petri dishes were placed in ventilated containers (11 cm diameter with 7-cm mesh inserts in lids). The containers with treated beetles were kept at 24ºC and 14L: 10D photoperiod for 48 hours. Mortality was scored after 6, 12, 24 and 48 hours.

5.2.3 In vineyard assessment of chemical impact

Previous work (Thomson and Hoffmann, 2006b) from a survey of 19 vineyards in the Yarra Valley indicated that natural enemy abundance and diversity is affected by chemical applications and further, that the overall impact of a season long spray program can be predicted from the toxicities of the chemicals applied. Responses of valuable natural enemies to chemicals then are such that consideration of chemical toxicities enhances abundance and diversity (Thomson and Hoffmann, 2007). We completed a survey of 61 vineyards in three regions of South Australia to validate and extend this work and with particular interest in the effects of sulphur and indoxacarb. As mentioned above, indoxacarb is possibly a chemical of low toxicity to beneficials, but there are many references in the scientific literature suggesting otherwise and we received comments from grower observations that also suggested harmful effects. Sulphur is known to influence a range of natural enemies including parasitoids, predatory mites, spiders and beetles (Mansour and Whitecomb, 1986; Mansour, 1987; Thomson *et al.*, 2000; Martinson *et al.*, 2001; Prischmann *et al.*, 2005; Gent *et al.*, 2009) among many others and is known to be more toxic at higher concentrations (Thomson *et al.*, 2000). In addition, we were interested in testing if there is the potential for repeated applications of chemicals, even at lower levels, to have a negative impact on natural enemies.

Spray records were kindly provided by vineyard managers and chemical toxicities from our database (generated from IOBC toxicity information and scientific publications) were used to calculate overall toxicity ratings for each of the 61 vineyards. Chemicals used had toxicity ratings from 1, 'harmless' < 25% reduction in control capacity, through to 4, 'very harmful' > 75% reduction in control capacity, on a 4 point scale. To compute a season-long estimate of chemical effects, a modified rating involved changing the IOBC scale of 1-4 to 0-3 (see Thomson and Hoffmann (2006a). The rate of sulphur usage varied; hence applications were assigned ratings based on concentration. Water rates vary when applying sulphur, but generally 1000 L/ha is used to provide full coverage, hence assumptions for toxicity rating for sulphur are: < 1600 g active compound / ha (a.c./ha) = 1, 25% to 50% reduction in control capacity; less than 3200 g a.c./ha = 2, 50% to 75% reduction in control capacity; greater than 3200g a.c./ha = 3, > 75% reduction in control capacity (Thomson and Hoffmann, 2006a).Two ratings were used for indoxacarb (applied as Avatar®); to reflect the diverse responses reported from natural enemies tested. Both ratings of 1 and 4 were used, but only the former is presented as probabilities from statistical tests were only minimally affected and conclusions were identical. Season long scores (pesticide metric) for each site were calculated by multiplying modified IOBC toxicity ratings for each pesticide used at a site by the number of times it was applied and summing across pesticides applied for that season.

We then surveyed the invertebrate fauna for 5 months at each of the 61 vineyards with 5 pitfall traps and 5 yellow sticky traps (5 m apart) each month in one row 50 m from the vineyard edge (1525 pitfall traps and 1525 yellow sticky traps).

The mean abundance of each invertebrate group collected per trap within site across the season was used in the statistical analyses to compare group and abundances and community response to total chemical impact for the season. For analysis of the effects of chemical impact on natural enemies we used non-metric multidimensional scaling (NMS) to analyse the structure of the invertebrate communities detected in the canopy and on the ground at each site and compared this to the likely chemical impact calculated from the toxicity rating of all chemicals used for the season. NMS is an effective method for analyzing ecological data sets because it does not assume linear relationships and can be performed with data that are non-normally distributed, arbitrary, discontinuous or contain numerous samples with a value of zero (McCune and Grace, 2002). This ordination procedure was completed with PC-ORD version 5.0 (McCune and Mefford, 1999). Analysis of community structure produced axes indicating that there was structure in the communities and we determined whether this community structure was influenced by chemicals in vineyards by investigating correlations between the pesticide metric and derived axis scores from NMS. Multiple regressions were run to test the contribution of ratings from the two most commonly used pesticides (indoxacarb, sulphur – see below) on the NMS axes associated with pesticides, in an exploratory analysis to ascertain whether these chemicals contributed independently to community structure. Spearman's rank (r_s) correlations were computed to describe associations between ground or canopy invertebrate guilds and NMS axes. Finally rank correlations were computed to explore directly associations between the specific guilds and the pesticide metric.

We investigated predation and parasitism of light brown apple moth eggs at 30 of the vineyards to directly assess the impact of overall chemical impact on pest control. In 2007, eggs were placed outside on 1 February for five days and a second batch placed outside on 6 February for five days On each occasion, we placed three LBAM egg cards (containing two egg masses of 20-70 eggs) at the 5 replicated sampling points at 30 vineyard sites (50 m from the vineyard edge). Correlation between arcsine transformed percentage predation and overall toxicity rating was then calculated.

5.3 Cover crops methods

Site selection and establishment of cover crops was provided by Chris Penfold. We assessed invertebrate responses and predation/parasitism of light brown apple moth.

Using endemic plants as cover crops in contrast to the typical exotics used in most vineyards has diverse potential advantages. It increases floral biodiversity, and potentially the plants will grow without impacting on vineyard water use, do not need mowing or reestablishment annually. A literature review made clear a significant issue with cover crop use: attention to the requirements of the proposed cover crop is essential to in field success. Hence native cover crops were trialled in the field. In August 2006, three native perennial cover crops, and one introduced annual cover crop, were sown in a randomised block design consisting of 4 mid-rows per treatment (with length 150 m), 4 treatments per block with each cover crop treatment applied to the entire row and blocks replicated four times. Native treatments were wallaby grass, *Austrodanthonia richardsonii* Cashmore (Poaceae), seeded at a rate of 10 kg/ha; windmill grass, *Chloris truncata* (Poaceae) (2 kg/ha), and a mix of creeping *Atriplex semibaccata* and lagoon *A. suberecta* saltbushes (Chenopodiaceae) (3.3 kg/ha). No maintenance was carried out on the native species after they were sown. The control, sown in May 2007 and again in May 2008, was the introduced annual cereal oats *Avena sativa* L. var Ogle (Poaceae), seeded at a rate of 100 kg/ha. This was rolled to the ground in September 2007 and 2008, which is common practice for this annual cover crop to minimise competition for water during summer whilst still allowing for soil cover and stability. Native cover crops selected were endemic to the region and chosen to fulfil a range of local and agronomic requirements, such as ease of establishment, low maintenance, ability to compete with weeds and seed availability. The saltbush treatment consisted of a mix of two species to ensure establishment and survival of the cover crop. The control was a commonly-used cover crop of vineyards in the region.

In the 2007-2008 and again 2008-2009 seasons, we sampled invertebrates in the canopy and on the ground. There were 4 replicates for each of the 4 treatments with 5 traps in each replicate traps placed in the middle row of each replicate (400 pitfall traps and 400 yellow sticky traps each season). To assess if treatment influenced predation of light brown apple moth eggs, sentinel egg cards were placed in the vineyard at each trap point in the 4 replicated blocks (20 points for each treatment). LBAM egg cards were stapled onto the vine leaves approximately 1 m above the ground, for 3 days and replaced with new egg cards for a further 3 days.

To assess the effects of cover crop treatments on invertebrate groups and the consistency of these effects over time, we analysed the collections over two seasons separately. Mean numbers from both pitfall and yellow sticky traps (pooled over traps within a mid-row) were used in analyses. To determine the effect of cover crops on invertebrates in the canopy and on the ground, multivariate analysis of variance (MANOVA) was first used to compare responses of all common parasitoid genera in the canopy and on the ground as well as on the 4 potential pests collected (Rutherglen bugs and leafhoppers from the canopy and weevils and burrowing bugs from the ground). Effects on individual taxa where then tested with ANOVAs followed by post hoc (Tukey's b) to identify single species and order level responses. Initially, block effects were included in MANOVAs and ANOVAs, but as significant effects of block were not detected, these are not presented.

ANOVAs were also used to assess whether predation levels of sentinel egg masses were affected by cover crop treatment, using mean percentage predation of eggs placed above each cover crop treatment (arcsine transformed prior to analyses).

5.4 Adjacent vegetation methods

We examined the effects of woody vegetation adjacent to the vineyard. The other point of interest with respect to woody vegetation within grape growing regions is the type. Vineyards may have a range of woody vegetation types adjacent and we considered two broadly different categories: shelterbelts and larger blocks which were either remnant or had been replanted. To examine the potential impact of adjacent vegetation, sampling was undertaken at 61 sites in commercial vineyards in South Australia: 21 in the Barossa Valley, 30 at Wrattonbully and 10 at Padthaway. Padthaway and Wrattonbully are 300 km and 400 km south east of Barossa. The regions were selected to have a range of the percentage of woody vegetation forming the landscape. 28 sites were selected with woody vegetation on one boundary of the vineyard and 33 without woody vegetation (minimum distance from nearest vegetation 200 m). For the sites with adjacent vegetation, we selected vineyards with linear complex shelterbelts (long narrow strips with widths ranging from 4.0-9.1 m) and blocks of remnant vegetation or replanted vegetation, areas ranging in size from 3.2-25.4 ha. At Barossa 8 sites with adjacent vegetation (5 remnant and 3 shelterbelts), 13 without, Wrattonbully 13 with adjacent vegetation (8, 5) and 17 without and Padthaway, 7 with adjacent vegetation (4, 3) and 3 without.

Each site consisted of a vineyard block with 3 m between rows, and rows consisting of vines 2 m apart planted to trellis with poles 5 m apart and of similar size (5-8 ha). Vine size and vigour were similar throughout the blocks. Undervine and inter row management practices were similar: soil under the vines was bare earth following application of herbicides, and between the vines was mown grass (mainly perennial rye grass *Lolium perenne* and phalaris *Phalaris* sp., with varying amounts of capeweed *Arctotheca calendula* and clover *Trifolium repens*). Only chemicals of low toxicity to beneficials (based on IOBC ratings - http://www.koppert.nl – and related data – see Thomson and Hoffmann, (2006a) were used, including sulphur (Thiovit®) (at 200 g/100L) and tebufenozide (Mimic®).

We sampled with yellow sticky traps and pitfall traps in the vegetation and in the vineyard 20 m and 50 m from the vineyard edge over 5 months of the 2006-2007 season, again with 5 replicates for each sampling point (4575 pitfall traps and 4575 yellow sticky traps).

The mean numbers of each group collected per sampling point (mean of 5 replicate traps) within a vineyard across the season were used in the analyses. Analysis of variance (ANOVA) was used to compare abundance of groups which occurred in reasonable numbers and across most of the vineyard sites, in vineyards with adjacent remnant and shelterbelt vegetation and those without adjacent woody vegetation. ANOVA was also used to compare abundances of these groups across the 3 regions.

We investigated predation and parasitism of light brown apple moth eggs at 30 of the vineyards to directly assess the impact of vegetation on pest control. In 2007, eggs were placed outside on 1 February for five days and a second batch placed outside on 6 February for five days On each occasion, we placed three LBAM egg cards (containing two egg masses of 20-70 eggs) at the 5 replicated sampling points at 30 vineyard sites (50 m from the vineyard edge).

5.5 New methodologies that may benefit other related or unrelated research

Our proposal involved a simple metric for sustainable chemical use, effectively estimating the cumulative impact of chemical inputs across an entire season on beneficial groups and the complex communities of invertebrates found in vineyards. Such a metric can assist growers in developing targets for sustainable chemical use and enhancing natural enemies that can provide effective pest control.

First developed under a previous project (Thomson *et al*. 2004), we have continued to develop sampling strategies for invertebrates in vineyards. Rapid sampling is essential for success in achieving our aims and publishing our results, and for determining effects of management practices on a diverse range of vineyard invertebrates. The sampling methods are both sufficiently accurate to reliably detect differences between treatments and inform on outcomes and economic effects. Development and validation of such techniques is critical for determining chemical effects.

Success is evident from both the number of peer reviewed and industry publications generated in the course of the current project and evidence for utilization by growers. While communicating information to the industry is a critical outcome, peer reviewed publications are also essential in that they ensure the scientific validity of the methods and also that results are in the wider sphere for communication. Such publications increase the accessibility of information and in the long run has potential to save funding $$ in that research is more easily shared among researchers and other parties both within Australia and internationally.

6 Results/Discussion:

6.1 Invertebrates collected from vineyards

Although the focus of the project is on natural enemies, diversity is also important as a measure of environmental sustainability. Invertebrates not only contribute to many other essential services including nutrient cycling, soil health and pollination, but diversity and abundance of invertebrates also underpins diversity and abundance of visible and desirable vertebrates. We go into some detail of the diversity of the collections made to demonstrate the importance of invertebrates in vineyard ecosystems, and the range of invertebrates that contribute to each desirable ecosystem service. We collected, sorted and assessed several hundred thousand invertebrates from the canopy and the ground. Traps collected an abundant and diverse community of ants, spiders, beetles, parasitoids, mites, flies, bugs earwigs, thrips, lacewings, slaters, springtails, millipedes and centipedes. For some groups sorting to order level may be adequate with some exceptions (see comments following). Slaters (Isopoda), millipedes (Julida) and springtails (Collembola) all contribute to nutrient turnover. Dragonflies (Odonata), lacewings (Neuroptera), earwigs (Dermaptera) and centipedes (Chilopoda) can largely be considered predators. Many orders though include families with diverse roles, some also contribute to soil health, many others include natural enemies which contribute to control of the pests through parasitism or predation (Buchanan and Amos, 1992; Thomson *et al.*, 2007) and yet others are pests. We sorted our collections from each study to the most informative level practical.

Spiders (Araneae) are generally considered as contributing to pest control in agriculture (Nyffeler *et al.*, 1994 Marc *et al.*, 1999; Greenstone, 1999) and have been shown to be important predators in vineyards (Costello and Daane, 1999), eating LBAM caterpillars (Buchanan and Amos, 1992) and scale (Mansour and Whitecomb, 1986). A diverse range of spider families was present in all vineyards sampled including Agelenidae, Amaurobiidae, Clubionidae, Ctenidae, Dictynidae, Gnaphosidae, Heteropodidae, Linyphiidae, Lycosidae, Metidae, Micropholcommatidae, Miturgidae, Nemesiidae, Nicodamidae, Oxyopidae, Salticidae, Theridiidae and Zoridae. Such diversity is important as the different families employ diverse hunting strategies: large and small ground hunters, vagrant and mobile hunters roaming the canopy and web builders, allowing them to impact on a range of pests. Their specific role in biocontrol however remains unclear. This dearth of knowledge is attributed to the difficulty of studying small, cryptic, liquid feeding animals. Gut Content Analysis (GCA) (Symondson, 2002) is a commonly used technique in predation studies, whereby gut content is examined for identifiable prey fragments. As spiders are liquid feeders, the prey fragments available for identification through GCA are molecular in nature.

This project demonstrated that spiders not only exist in large numbers in vineyards but that they do actually prey upon light brown apple moth. In a PhD project established in this project, Clare D'Alberto developed LBAM primers and through feeding trails demonstrated that LBAM as prey an be detected in spiders following predation (D'Alberto *et al.*, 2007). Currently analysis of vineyard collected spiders is documenting the importance of spiders in light brown predation in the field.

Bugs (Hemiptera) do include pests like scale and mealybugs but also several important families of predatory bugs: Reduviidae, Nabidae, Anthocoridae, Pentatomidae and Lygaeidae. For example, the shield bug *Oechalia schellenbergii* Guérin-Méneville (Hemiptera: Pentatomidae) attacks LBAM caterpillars. Other bugs of interest include Rutherglen bug *Nysius vinitor* Bergroth, a native bug which occurs in all states of Australia and can reach pest status in hot, dry areas when their need for moisture drives them into the crop to suck fluid from the shoots, stems and berries of the vine, causing extensive damage (Buchanan and Amos 1992). And leafhoppers such as common brown leafhopper *Orosius argentatus* (Evans) Hemiptera Cicadellidae which may be involved in transmission of viruses like grapevine yellows. Flies (Diptera) also include predatory and parasitic families which contribute to pest control including Empididae, Tachinidae, Dolichopodidae, Syrphidae and Cecidomyiidae. The predatory cecidomyiid *Diadiplosis koebelei* (Koebele) can cause considerable mortality of mealybugs (Furness, 1976) and at least one fly. *Voriela uniseta* (Diptera: Tachinidae) is a larval parasitoid of LBAM (Buchanan and Amos, 1992).

Beetles (Coleoptera) perform diverse roles in vineyards: saprophytic beetles contribute to nutrient turnover, fungi or mould feeding eaters reduce fungal spores, predators eat a range of pests and of course there are pests. Many beetle families were collected: Anthicidae, Byrrhidae, Bostrichidae, Carabidae, Cerambycidae, Coccinellidae, Corylophidae, Cryptophagidae, Chrysomelidae, Curculionidae, Elateridae, Histeridae, Lathrididae, Laemophloeidae, Mordellidae, Nitulidae, Pselaphidae, Scarabaeidae, Staphylinidae, Scraptiidae and Tenebrionidae. A few families include pests, the most common being weevils (Curculionidae) but there are also several other wood boring beetles like fig longicorn *Acalolepta vastator* (Newman) (Coleoptera: Cerambycidae), the auger beetle *Bostrychopsis jesuita* (Fabricius) (Coleoptera: Bostrichidae) and African black beetle *Heteronychus arator* (Fabricius) (Coleoptera: Scarabaeidae) which can be a pest of vines in young vines. Other families (eg Chrysomelidae) include pests that while they can cause damage to adjacent vegetation such as Eucalypts, are not considered damaging in vineyards. Coleoptera (together with Hymenoptera) include the most important contributors to pest control as predators and parasitoids in all agricultutural systems and vineyards are no exception. Three of the beetle families, Carabidae, Staphylinidae and Coccinellidae are considered especially important predators and were well represented at all sites, with many different species collected. For example, ladybird beetles were far more diverse than expected. Our collections included not only the well-known orange and black but about 15 species: a *Stethorus* sp., *Cryptolaemus montrouzieri* Mulsant, four species of Scymninae *Diomus sydneyensis* (Blackburn), *D. notescens* (Blackburn) and two currently undescribed species of *Diomus* (A. Ślipiński pers.com.), (here called *Diomus* n. sp. 1 and *Diomus* n. sp. 2), four species of Coccinellinae (*Coccinella transversalis* (Fabricius), *C. septempunctata* L. and *Micraspis frenata* (Erichson) and a *Harmonia* sp., This diverse range includes predators of a range of pests including aphids, psyllids, leafhoppers, chrysomelids, mites, mealybugs, scale and white flies (Ślipiński, 2007). Some eat Lepidoptera (Evans, 2009) including light brown apple moth (MacLellan, 1973) other genera prey on scale (Hodek and Honěk, 2009), *Stethorus* spp. specialize in mite predation (Biddinger *et al.*, 2009). We collected about 19 species of staphylinid beetles from five genera (*Blediotrogus*, *Tachinus*, *Leptacinus* and two Aleocharinae genera *Ocalea* and *Aleochara*, all predators (CSIRO, 1991) especially the Aleocharines which are known to be mite predators in vineyards, and discovered one previously unknown (*Ischyrodyodoys thomsonae*). Our collections of carabids included more than 25 different species. Although less is known about the specific activities of Australian carabids, all carabids are predators and probably include the full range of vineyard pests in their diets.

Although many wasps, ants and bees (Hymenoptera) are very small, these play key roles in the functioning of ecosystems. Wasps regulate insect populations though predation and parasitism, bees are among the most important pollinators of flowering plants, and ants dominate many terrestrial landscapes, including vineyards, where they are involved with vital ecological processes such as predation, seed dispersal and soil health. Due to the huge diversity, small size and sexual dimorphism within the hymenopteran parasitoids, identification to taxonomic levels lower than family is difficult (La Salle and Gauld, 1993). Families of Hymenoptera collected included: Formicidae, Bethylidae, Eulophidae, Pteromalidae, Braconidae, Ichneumonidae, Chalcididae, Encyrtidae, Aphelinidae, Mymaridae, Scelionidae and Trichogrammatidae. These and other parasitoids may contribute to control of a range of vineyard pests including light brown apple moth, scale and mealybugs (Thomson *et al.*, 2007). Scelionidae and Eulophidae are genera that contain important biocontrol agents of pest Lepidoptera, Hemiptera and Thysanoptera; Scelionidae are a large family of endoparasitoids of eggs of a wide range of insects, potentially encompassing both predators and pests as well as spiders (Austin *et al.* 2005) and Eulophidae are another large and biologically diverse family with range of hosts and biology (Gauthier *et al*. 2000). Of the identified scelionid taxa, *Trimorus* sp. is known to parasitise eggs of Carabidae (Austin *et al*. 2005) but the host group of the *Dyscritobaeus* species is at present unknown (A. Austin pers. comm.) though other members of the subfamily parasitise crickets, grasshoppers and bugs. A number of species of Mymaridae are also important natural enemies of pests, parasitising insect eggs, especially those concealed in plant tissue or in soil including weevils and bugs such as leafhoppers. Some species of Mymaridae are used successfully in biological control, for example *Anaphes nitens* Girault against *Gonipterus scutellatus* (Gyllenhal) (Coleoptera: Curculionidae), a pest of Eucalyptus (Stevens *et al.*, 2007). Tiphiidae or flower wasps are generally reported to be ectoparasitic on subterranean coleopteran (beetle) larvae, but very few host records are available. Pteromalidae are parasitoids of range including lepidopteran eggs and pupae and include at least one parasitoid *Lissopimpla semipunctata* (Kirby) of grapevine moth *Phalaenoides glycinae* Lewin. There are several well known *Trichogramma* egg parasitoids of light brown apple moth (Glenn *et al.*, 1997), other known interactions include the aphelinid and encyrtid parasitoids of mealybugs and scale , *Coccophagous gurneyi* Compere, *C. lymnia*, *Euxanthellus phillippiae* Silvestri, *Tetracnemoidea brevicornis* Girault, *T. sydneyensis*, *Alamella mira* Noyes, *Anagyrus fusciventris* (Girault), *Crisatithotrax* sp*., Leptomastix* spp*., Metaphycus* spp. (esp *M. lounsbury* Howard) and *Ophelosia* spp. (Pteromalidae), chalcids *Brachymeria phya* Walker and *B. teuta* Walker are pupal parasitoids of LBAM, *Euplectrus agaristae* Crawford (Eulophidae), a *Eurytoma* sp*.* (Eurytomidae) and *Echthromorpha intricatoria* Fabricius (Ichneumonidae) parasitise grapevine moth.

So hymenopteran parasitoids are known to contribute to control of many vineyard pests and their importance in biological control is underscored by the existence of commercial suppliers. New roles for parasitoids are constantly being uncovered. Paull and Austin (2006) recorded 7 previously unknown parasitoids of light brown apple moth in a recent study (increasing to about 27 the number of known parasitoids of LBAM eggs, larvae and pupae) and a braconid has recently been identified as a possible parasitoid of elephant weevil. *Orthorhinus cylindrirostris* (Fabricius).

We make special mention of ants (Formicidae) due to their abundance and the clear need for improved understanding their role in vineyards. The prior lack of information about diversity and roles of ants in vineyards led to the establishment of a PhD project focussing on ants in vineyards. Some ants do provide indirect protection for scale insects and mealybug colonies in vineyards by removing excreted sugars (called honeydew) for food, causing ants in general to be viewed as a pest by many growers. This may overshadow numerous ecologically beneficial roles that ants undertake, but often go unnoticed. Ants perform many valuable ecosystem services and are among the most important soil engineers, in addition to earthworms and micro-organisms, enhancing soil conditions and enrichment by moving and redistributing soil during nest building and maintenance (Lobry de Bryn, 1999). They are also involved in the pollination, protection and seed dispersal of many native plants. Ants have a broad diet that ranges from being highly specialised predators to generalist scavengers. This allows them to exert a considerable influence on the arthropod communities present in vineyards. Ants are probably the most conspicuous insects in vineyards and were the most abundant invertebrate collected from the ground in all studies. We collected 21452 ants from more than 140 native species, with members of the genera *Iridomyrmex, Pheidole* and *Rhytidoponera* being the most widespread. A single vineyard often housed more than 20 species (Chong, 2008; Chong *et al.*, in review). Of interest also is the low frequency of collection of the highly invasive Argentine ant, *Linepithema humile* (Mayr), which has been found to enhance mealybug densities in Californian and South African vineyards (Addison and Samways, 2000; Daane *et al.*, 2007). Other studies in Australia have explored the use of native ants as indicators of management practices, including pesticide applications (Chong *et al.*, 2007) and tillage (Sharley *et al.*, 2008), but little is known of the ecology of native ants in vineyards and their interactions with other organisms (Chong *et al.*, in review). We did not find any increase in scale with ant abundance and in fact observed at least one species eating LBAM eggs (Chong *et al.*, in review). Perhaps this is not surprising as there are many records of ants eating a range of lepidopteran eggs (Gravena and Pazetto, 1987), *Heliothis virescens* F. (McDaniel and Sterling, 1979; Agnew and Sterling, 1982), *Helicoverpa armigera* (Hübner) (Mansfield *et al.*, 2003) and *Opisina arenosella* Walker (Way *et al.*, 1989). Our study found native ant communities did not increase the survival of scale insects nor suppress various beneficial arthropods (Chong *et al.*, in review), suggesting that management practices targeting native ant species in vineyards are unnecessary. The roles of native ants in vineyards have long been overlooked and merit further exploration through more long-term and in-depth studies, given their ecological importance and potential to augment pest suppression.

Lacewings (Neuroptera) were predominantly brown *Micromus tasmaniae* (Walker) (Neuroptera: Hemerobiidae) with a few green lacewings, *Mallada signata* (Schneider) (Neuroptera Chrysopidae). Both are voracious consumers of LBAM eggs and young caterpillars. Many thrips (Thysanoptera) are pests but are not generally considered a problem in grapes. An interesting finding in our collection was a large number of *Desmothrips* sp. (Aeolothripidae), a facultative predator usually of larvae of other thrips but potentially of eggs of LBAM (L. Thomson, unpub. obs.). Mites (Acarina) are diverse and sometimes abundant in vineyards where they can cause serious problems including bud, blister, bunch and rust mite. Pest mites are extremely small and require specialized sampling techniques not employed here. However, we collected predatory mites (including Phytoseiidae), effective natural enemies that limit populations of phytophagous mites in many crops including vineyards (Duso, 1992; McMurtry and Croft, 1997). According to some sources (eg James, 1989), the predatory mites *Typhlodromus doreenae* (Schicha) and *Amblyseius victoriensis* (Womersly) have proved successful in providing control against mite pests of grapevines in some parts of Australia. These are generalist predators that feed on a wide range of food including pollen, so large populations of these predators may be present even when prey is scarce (Nicholas *et al.*, 1998). *A. victoriensis* is the major predator of blister and rust mites while *T. doreenae* is considered the key biological control agent for bunch mite.

Earwigs (Dermaptera) were abundant and we collected the introduced European earwig *Forficula auricularia* Linnaeus (Dermaptera: Forficulidae) and several native earwigs including the native common brown earwig, *Labidura truncata* Kirby (Dermaptera: Labiduridae). Earwigs are also carnivorous and prey on a wide range of other insects and mites that occur in the vineyard. They are known to be important predators of light brown apple moth (Frank *et al.*, 2007). Although there are suggestions that European earwigs eat new vine foliage and can therefore be nuisance pests, the role of all earwigs as potentially useful predators should be considered before control measures are used.

Dragonflies (Odonata) are highly visible reminders of biodiversity within vineyards. These often brightly coloured, fast flying insects are well known and easily recognised. Dragonflies are medium to large insects with body lengths ranging from 15-120 millimetres. They are often seen flying rapidly through vineyards especially at dusk, following regular flight paths every day. Adults and nymphs are both predators, although nymphs are generally aquatic.

6.2 Chemical results and discussion

6.2.1 Literature review chemicals

Results of literature survey collated and presented with references to scientific papers are provided in the database on the CESAR website at http://cesar.org.au/index.php?option=com_collateral_manage

6.2.2 Laboratory testing chemicals

The fungicides potassium bicarbonate and trifloxystrobin and the insecticide indoxacarb had no detrimental effects on either beetle at up to 2 times the label rate 48 hours after spray application. The insecticide chlorantraniliprole had no effect on either beetle up to the label rate, but some indication of a negative impact on *Cryptolaemus* when applied at the highest rate (Table 2).

Table 2. Effects of 5 chemicals on two beneficials (*Dalotia coriaria* and *Cryptolaemus montrouzieri*). Mortalities are presented as % survival relative to the control for the highest concentration tested. Probabilities represent results of Mann-Whitney tests to determine which chemical treatments are different from controls. NS = non significant.

Beetle	Time (hours)	Potassium bicarbonate		pyraclostrobin		trifloxystrobin		indoxacarb		chlorantraniliprole	
		% survival	*P*	% survival	*P*	% survival	*P*	% survival	*P*	% survival	*P*
Dalotia	6	98	NS	96	NS	100	NS	100	NS	100	NS
	12	100	NS	98	NS	97	NS	100	NS	100	NS
	24	100	NS	95	NS	97	NS	100	NS	98	NS
	48	100	NS	91	NS	90	NS	100	NS	98	NS
Cryptolaemus	6	93	NS	94	NS	92	NS	100	NS	85	**0.014**
	12	97	NS	96	NS	98	NS	100	NS	91	NS
	24	100	NS	100	NS	98	NS	100	NS	98	NS
	48	100	NS	98	NS	100	NS	100	NS	88	**0.041**

6.2.3 In vineyard assessment of chemicals

A summary of the total chemicals applied at the 61 vineyard blocks in 2006-2007 and their toxicities is provided in Table 3. Spray records indicated a range of pesticide usage on these blocks from bud burst (July) to harvest (Feb – March), both in terms of active ingredients and application frequency. Although broad-spectrum pesticides were not applied in the blocks, pesticides nevertheless had a range of IOBC toxicity ratings from 1, harmless < 25% reduction in control capacity, through to 4, > 75% reduction in control capacity, on a 4 point scale. Insecticides were applied in 44 of the 61 vineyard blocks, with only two active compounds used; 75 applications of indoxacarb (as Avatar®) (rated 1 or 4 through IOBC) and 61 applications of *Bacillus thuringiensis* (Dipel DF) (rated 1). Both active constituents targeted control of light brown apple moth. Insecticides accounted for 13% of total chemical applications, and were always applied with fungicides. Fungicides comprised 64% of all chemical applications; the most common fungicide was sulphur, accounting for 35% of all fungicidal applications. With sulphur having the highest damage rating and being the most frequently applied, this chemical contributed substantially to ratings overall. Pesticides were applied in combination with other active constituents (1380 in total) in 509 applications. The most common combination was a mixture of sulphur with another fungicide and perhaps an insecticide when invertebrate pests were evident. Commercially available mixtures (eg Ridomil Gold Plus - copper hydroxide & metalaxyl-M) were rarely used.

Chemical impacts on non-target invertebrates might also be influenced by the addition of adjuvants to 74% of "tank mixes". Adjuvants were included in most sprays but there is almost no information on their impact on non-target hosts and the few available reports show variable toxicity effects (Thomson *et al.*, 2000; Hewa-Kapuge *et al.*, 2003; Acheampong and Stark, 2004; Cocco and Hoy, 2008; Evans *et al.*, 2008) so the impacts of adjuvants on invertebrates were not considered. Additionally, herbicide usage accounted for 23% of applications but again, herbicides could not be considered further due to limited information on toxicity in the literature or IOBC ratings.

33806 organisms were collected from the canopy and 95036 from the ground. Ordination analysis of the canopy trap data indicated a two-dimensional solution (P = 0.004) for which the lowest stress was 7.8 requiring 67 iterations to reach the default instability of 10^{-4}. These two axes accounted for 95% of the variance. Ordination analysis of the pitfall data, excluding ants, indicated a three-dimensional solution (P = 0.004) for which the lowest stress was 11.4 requiring 98 iterations to reach the default instability of 10^{-4}. These three axes accounted for 84% of the variance.

Table 3. Pesticide information for sites. Ratings of the toxicity of pesticides are based on their likely impact on beneficial invertebrates based on IOBC criteria (see text for details). The total number of applications number for each product applied over the 61 vineyard blocks is given for the 2005 / 06 growing season.

Active compound	*Product (example)*	*Range of applications*	*Toxicity (IOBC)*	*Number of applications*
Insecticides				
Bacillus thuringiensis	DiPel	1-5	1	61
Indoxacarb	Avatar	1-3	1 or 4	81
Fungicides				
Captan	Captan	1	1	18
Chlorothalonil	Bravo	1-2	1	41
Copper hydroxide	Kocide Blue	1	1	23
Copper hydroxide & metalaxyl-M	Ridomil Gold Plus	1	3[a]	5
Copper oxychloride	Oxydul	5-6	1	23
Copper sulphate	Tri-Base Blue	1-5	1	87
Cyprodinil & fludioxonil	Switch	1	2[a]	7
Dithianon	Delan	1-3	1	33
Fenarimol	Rubigan	1-3	1	36
Fenhexamid	Teldor	1	2	6
Iprodione	Rovral	1	1	2
Mancozeb	Dithane	2	2	12
Penconazole	Topas	1	1	12
Pyrimethanil	Scala	1-2	1	28

Quinoxyfen	Legend	1	1	2
Sulphur	Kumulus DF	2-5	2-4	222
Trifloxystrobin	Flint	1-3	1	75

[a]rating calculated on the highest score for the two active constituents

When chemical applications (toxicity metrics) were compared to community structure, chemical applications were found to influence both the canopy and ground dwelling communities. For the canopy data, analyses indicated that the ordination axis 1 from the NMS analysis associated with the chemical metric (r = 0.386, *P* = 0.002) but axis 2 was not associated (r = 0.096, *P* = 0.467). In a multiple regression analysis on axis 1 scores, forward selection resulted in a model that only included indoxacarb (b = 0.055 ± 0.017, *P* = 0.002); the contribution from sulphur was not significant once indoxacarb was included the model (*P* = 0.465). Indoxacarb applications therefore seemed to make a larger contribution to changes in community structure, although this result needs to be treated cautiously, because chemicals were often applied with other actives (see chemical use summary above). Using a modified toxicity rating of 3 for indoxacarb (i.e., IOBC rating 4, > 75% mortality) yielded almost identical results. For the pitfall data, there was a significant correlation between the chemical metric and axis 1 (r = 0.609, *P* < 0.001) as well as with axis 3 (r = -0.348, *P* = 0.006) but not axis 2 (r = -0.067, *P* = 0.610). Multiple regression indicated that axis 1 scores were linked to both sulphur (b = 0.067 ± 0.023, *P* = 0.005) and indoxacarb (b = 0.088 ± 0.020, *P* < 0.001). Using the higher toxicity rating for indoxacarb did not affect these conclusions. Further investigation of which groups might be associated with specific invertebrate guilds was achieved by correlating guild numbers with both axis scores and the pesticide metric. This analysis should be regarded as exploratory because patterns of interactions among guilds might obscure patterns for individual groups. For the canopy data, three parasitoid groups and Neuroptera associated significantly positively with axis 1 while three other parasitoid groups as well as two groups of predatory Coleoptera (Coccinellidae and Staphylinidae) associated negatively (Table 4). Because high values for axis 1 were associated with high metric scores (Fig. 1), groups showing negative associations with axis 1 were expected to potentially correlate negatively with the pesticide metric. Coccinellidae, Staphylinidae, predatory Diptera and two families of parasitoids, Bethylidae and Ichneumonidae, were all adversely affected by the chemical treatments across the season.
For the ground dwelling organisms, a number of groups were negatively associated with axis 1, indicating they were reduced with increased toxicity loading, including some spider and beetle groups (including carabids), as well as earwigs, Hemiptera and slaters, while there were also positive associations for Anthicidae and in particular millipedes (Julidae) (Table 4). There were negative associations with axis 3 for the millipedes, anthicids and staphylinids. Because axis 3 was negatively associated (Fig. 1), we expected the millipedes and anthicids to show an increase in abundance with increasing chemical scores, which was the case (Table 5).

Table 4. Canopy dwelling invertebrates sampled in 06/07 season from 59 South Australian vineyard blocks. Spearman correlations (r_s) are used to test guild/family associations with axis scores derived from NMS ordination of the community data and with season-long chemical impact score.

Guild	*Taxon*	*Sites present*	*Abundance*	*r_s (NMS axis score)* axis 1	axis 2	*r_s (chemical impact score)*
Parasitoid Hymenoptera	Trichogrammatidae	35	719	0.462**	-	-
	Eulophidae	18	225	0.281*	-	-
	Mymaridae	29	1480	0.432**	-	-
	Figitidae	40	1012	-0.442**	-	-
	Bethylidae	56	3568	-0.760**	-	-0.369**
	Ichneumonidae	51	871	-0.534**	-0.425**	-0.450***

	Other small < 1.5mm	36	19444	-0.336**	-0.996**	-
Predatory Diptera	Asilidae Syrphidae	42	3416	-	-	-0.338**
Predatory Thysanoptera	Aeolothripidae	59	1788	-	-	-
Neuroptera	Chrysopidae Hemerobiidae	53	21422	0.257*	-	-
Araneae[a]		59	1153	-	-	-
Predatory Coleoptera	Coccinellidae	57	675	-0.366**	-0.377**	-0.378**
	Staphylinidae	53	212	-0.320*	-	-0.329*
Fungi / Mould Feeding Coleoptera	Corylophidae	44	157	-	-	-
	Cryptophagidae	10	26			
	Laemophloeidae	7	14			
	Lathrididae	58	500			
	Others	3	3			
Saprohytic Coleoptera	Anthicidae	27	77	-	-0.465**	-
	Mordellidae	16	75			
	Scarabaeidae	12	61			
	Scraptiidae	9	40			
	Others	11	11			
Pest Coleoptera	Chrysomelidae	22	141	-	-	-
	Curculionoidae	17	23			
	Others	6	7			

P < 0.05; ** *P* < 0.01; *** *P* < 0.001.

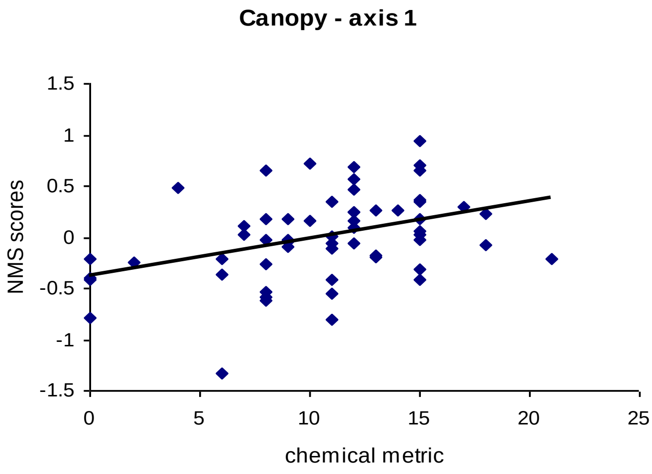
Table 5. Ground dwelling invertebrates sampled in 06/07 season from 61 South Australian vineyard blocks. Spearman correlations (r_s) are used to test guild/family associations with axis scores derived from NMS ordination of the community data and with season-long chemical impact score.

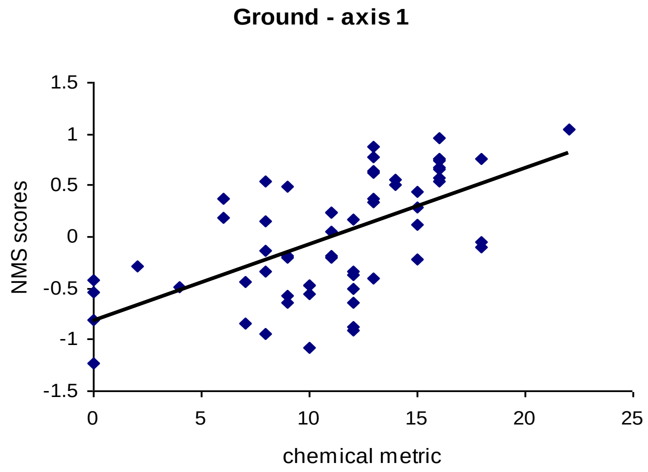
Guild	*Taxon*	*Sites present*	*Abundance*	*r_s (NMS axis score)* axis 1	axis 2/3	*r_s (chemical impact score)*
All spiders	Araneae	61	2075	NI	NI	-0.327**
Large ground hunters	Lycosidae Miturgidae	61	926	-0.283*	-	-
Medium ground hunters	Clubionidae Corinnidae Gnaphosidae Prodidomidae	54	249	-	-0.379(2)**	-
Vagrant hunters	Zodariidae	27	104	-0.391**	-	-
Mobile hunters	Salticidae	22	42	-0.453**	-	-
Web builders	Araneidae Linyphiidae	44	168	-	0.276(3)*	-
Centipedes	Lithobiidae	42	169	-	-	-
Millipedes	Julidae	54	6041	0.774**	-0.803(3)**	0.606***
Anthicidae	Anthicidae	55	1179	0.468**	-0.316(3)*	0.291*
Carabidae	Carabidae	57	444	-0.430**	-	-0.295*
Staphylinidae	Staphylinidae	60	375	-	-0.271(3)*	-
	Pselaphidae	14	30			
Tenebrionidae	Tenebrionidae	61	1616	-0.280*	0.476(2)**	

Saprophytic Coleoptera	Byrrhidae	37	150			
	Elateridae	22	36			
	Histeridae	13	23			
	Laemophloeidae	18	57	-0.358**	-	-
	Lathridiidae	11	14			
	Nitidulidae	18	57			
	Scarabidae	40	105			
Pest Coleoptera	Bostrichidae	8	9			
	Chrysomelidae	5	8	-0.307*	-	-
	Curculionidae	37	134			
Earwigs	Dermaptera	55	1391	-0.280*	0.476(2)**	-
Predatory Hemiptera	Lygaeidae Miridae Nabidae Reduviidae	33	85	-	0.282(2)*	-
Hemiptera	Cydnidae	32	139	-0.279*	-	-
Lacewings	Neuroptera	33	223	-	-	-
Slaters	Isopoda	29	3886	-0.373**	-0.692(2)**	-

NI=not included in NMS analysis.
* *P* < 0.05; ** *P* < 0.01; *** *P* < 0.001.

Fig. 1. Plot of NMS axis scores of invertebrate communities against season-long chemical application metric for vineyard blocks. Only NMS axes associated with the metric were plotted.





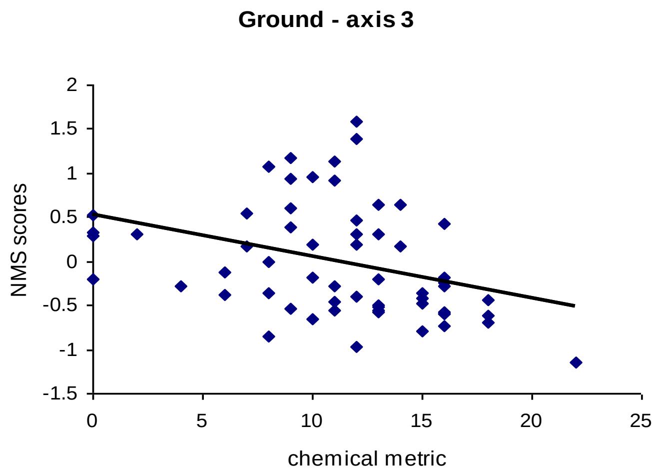


Table 6. Invertebrates sampled in 06/07 season from 61 South Australian vineyard blocks which declined in abundance with higher chemical ‘scores the vineyard

Guild	Examples	Sites present	Abundance	Pest attacked
Parasitoids	Trichogramma	61	27799	Can be extremely abundant and diverse. Many tiny and difficult to see. Attack almost the entire range of potential pests lay their eggs inside eggs, larvae or pupae of LBAM, scale, mealybugs and even weevils or other pest beetles.
Canopy spiders	Web builders like Linyphids and orb weavers (Araneidae) and active hunters like Jumping spiders (Salticidae)	59	1153	Range of hunting strategies employed enables them to assist in control of a whole range of vineyard pests feeding on LBAM and vine moths as caterpillars and adults, on scale and mealybug and even tiny prey like mites.
Ground spiders	Active hunters and ‘lie in wait’ burrow builders like Zodariidae and wolf spiders	61	2075	
Predatory beetles	Ladybirds (Coccinellidae)	57	675	Mealybugs, scale, mites and LBAM
	Staphylinidae	53	212	Generalist predators, include mite prey
	Carabidae	57	444	Generalist predators
Predatory flies	For example robber flies (Asilidae) and hover flies (Syrphidae)	56	3416	LBAM and mealybugs
Earwigs	Mainly European earwig with some native earwigs	55	1391	LBAM
Abundance increased				
Invasive millipede	Portuguese millipede	**54**	**6041**	Reduced nutrient cycling and potentially feeding on new vine growth

Negative effects were detected on two groups of parasitoids that include species important in controlling light brown apple moth (Paull and Austin, 2006). They also included predatory beetle groups known to feed on mealybug, likely to prey on aphids and the immature stages of moth pests including eggs. On the ground, a direct negative effect was suggested for carabid beetles, which are known predators of potential pest species like weevils (Zaller *et al.*, 2009) (Table 6).Our results also indicate that applications of indoxacarb can have a negative impact on invertebrates and alter community structure. We also detected independent effects of sulphur on invertebrates. The associations detected between the pesticide toxicity metric and invertebrate community structure suggests that this metric might provide an overall way of assessing chemical impacts. Pesticides are currently rated for toxicity to non-target organisms on the basis of individual applications, but this does not take into account cumulative effects across a season or even across multiple seasons. We have previously emphasised the need to consider metrics or models that include all chemicals and applications (Thomson and Hoffmann, 2007) and here results from a broadly based study substantiate this- a simple metric provided clear assessment of actual community impacts. The only invertebrates that may be resistant to chemical effects are ants (Chong *et al.*, 2007) presumably because a substantial fraction of ant populations occurs below ground (Shattuck, 1999).

Another interesting observation from the chemical impacts was the beneficial effect on millipedes, demonstrated by a large increase in abundance. This was a single species, the Portuguese millipede *Ommatoiulus moreleti*, which is an introduced nuisance pest species in southeastern Australia where it has invaded houses and damages household vegetable gardens (Baker, 1985). These millipedes are not regarded as beneficial within vineyards and may have a negative impact on native millipede species. This finding is consistent with the notion that invasive species might be favoured by increased toxicity of chemicals applied on farms, either directly as a consequence of increased tolerance levels (Hoffmann *et al.*, 2008; Toepfer *et al.*, 2009) or indirectly through a reduction in predators of the invasive species (Hoddle, 2004). The Portuguese millipede arrived in Australia 50 years ago, and released from its natural control agents, it is considered an invasive species causing nuisance and potential environmental problems. Unlike endemic millipedes (of which there are up to 2000 species), which are important detritivores in the Australian landscape (Black, 1997), it is herbivorous and may threaten native flora or new growth in agricultural crops (Paoletti *et al.*, 2007). Further, a change in function of communities dominated by *O. moreleti* is expected due to a reduction in the turnover of dead plant material.

6.3 Cover crops results and discussion

Yellow sticky traps collected 10105 individuals in the canopy and pitfall traps collected 4063 from the ground. Cover crop treatments had a significant effect on natural enemy abundance both in the canopy and on the ground. In the MANOVA on canopy parasitoid taxa there was a significant effect in season 1 ($F_{(12, 24)} = 2.60$, $P = 0.023$) and season 2 ($F_{(15, 23)} = 2.74$, $P = 0.048$), and ANOVAs showed significant responses of the 3 Eulophidae species and Scelionidae sp. 2 in season 1 (all more abundant with windmill grass) and only Scelionidae sp. 1 in season 2 (more abundant with salt bush) (Table 7 and Fig. 2). The predatory thrips were significantly more abundant in both seasons on the native saltbush and windmill grass. Responses of total parasitoids, spiders and lacewings were not significant (Table 7). On the ground, total parasitoid abundance was significantly influenced by cover crop treatment and a MANOVA on the parasitoid genera indicated significant effects both in season 1 ($F_{(15, 23)} = 3.34$, $P = 0.005$) and season 2 ($F_{(12, 24)} = 2.88$, $P = 0.013$). ANOVAs showed significant responses of Scelionidae sp. 3, Pteromalidae and Tiphiidae in season 1 and only Tiphiidae in season 2 (Table 7), with an increased abundance on all native cover crops in the first season and salt bush in the second season (Fig. 3). ANOVAs on the 3 predatory taxa (Araneae, Carabidae and Dermaptera) showed significant responses only for Dermaptera in season 1 (Table 7), with an increased abundance associated with salt bush and windmill grass.

A MANOVA on the 4 potential pests (Rutherglen bugs, leafhoppers, weevils and burrowing bugs) was significant in both seasons (season 1, $F_{(12, 24)} = 4.46$, $P = 0.001$; season 2, $F_{(12, 24)} = 2.77$, $P = 0.016$). Rutherglen bugs, significant in both seasons (Table 7), increased in abundance with salt bush (Fig. 4). Burrowing bugs were more abundant in all 3 native cover crop treatments in both seasons (Fig. 4) although significant only season 1 (Table 7). Weevils were more abundant with most cover crop treatments compared to the control in both seasons (Fig. 4), although this was only significant in season 2 (Table 7). Leafhopper numbers were not significantly affected by cover crop treatment (Table 7).

Table 7. ANOVAs testing the influence of cover crop treatment on arthropod abundance found in the canopy (yellow sticky traps) and on the ground (pitfall traps) for 5 months across 2 seasons. Mean squares (MS) are presented along with F ratios and *P* values. Bold values show significant effects of treatment.

		Season 1			Season 2		
	N	$F_{(3,12)}$	MS	*P*	$F_{(3,12)}$	MS	*P*
potential natural enemies							
canopy							
Total parasitoids	8429	3.12	0.054	0.406	1.76	0.089	0.209
Araneae	122	0.23	0.005	0.874	0.29	0.006	0.833
Desmothrips sp.	1100	5.54	0.091	**0.013**	5.52	0.600	**0.013**
Lacewings [a]	206	-	-	-	2.09	0.161	0.154
Eulophidae sp.1	654	6.49	0.128	**0.007**	5.9	0.134	0.109
Eulophidae sp.2	282	6.07	0.044	**0.009**	1.03	0.092	0.413
Eulophidae sp. 3[b]	114	5.25	0.092	**0.015**	-	-	-
Scelionidae sp. 1	1961	1.37	0.020	0.299	5.90	0.343	**0.010**
Scelionidae sp. 2	63	3.48	0.014	**0.049**	2.37	0.007	0.122
Bethylidae [a]	124	-	-	-	2.70	0.076	0.092
Mymaridae	220	-	-	-	0.67	0.044	0.586
Trichogramma	70	1.79	0.019	0.204	5.09	0.028	**0.017**
ground							
Dermaptera	212	6.47	0.119	**0.007**	1.19	0.183	0.353
Araneae	654	1.94	0.031	0.177	1.59	0.331	0.243
Carabidae	87	1.77	0.024	0.206	1.01	0.070	0.423
Combined parasitoids	1800	4.13	1.147	**0.032**	9.24	4.938	**0.002**
Scelionidae unknown	581	11.53	1.238	**0.001**	1.78	0.298	0.204
Dyscritobaeus sp.	433	2.64	0.530	0.097	1.92	0.351	0.181
Trimorus sp.	33	3.58	0.300	0.055	0.41	0.009	0.746
Tiphiidae	393	11.62	1.150	**0.001**	4.08	0.016	**0.033**
Pteromalidae[b]	360	11.24	1.233	**0.001**	-	-	-
potential pests							
Rutherglen bugs	82	6.36	0.049	**0.008**	4.61	0.018	**0.023**
Leafhoppers	166	0.34	0.004	0.795	0.55	0.017	0.658
Weevils	129	1.79	0.087	0.204	7.46	0.105	**0.004**
Burrowing bugs	1181	15.54	1.254	**<0.001**	3.27	0.340	0.059

[a] detected in season 2 only
[b] detected in season 1 only

Fig. 2. Mean number (log transformed) of parasitoid genera collected per trap in the canopy with yellow sticky traps in season 1 (season 2 not presented). Different letters above the bars reflect significant differences in abundance between the cover crop treatments in posthoc tests. Error bars represent standard errors.

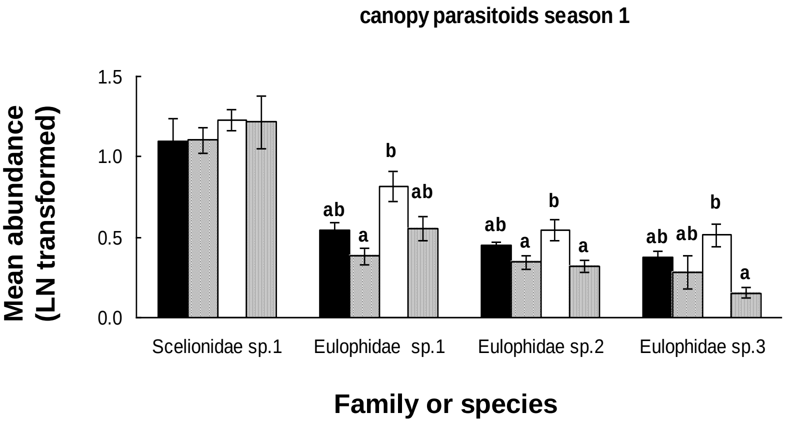


Fig. 3. Mean number (log transformed) of parasitoid genera collected per trap on the ground with pitfall traps in season 1 (season 2 not presented). Different letters above the bars reflect significant differences in abundance between the cover crop treatments in posthoc tests. Error bars represent standard errors.

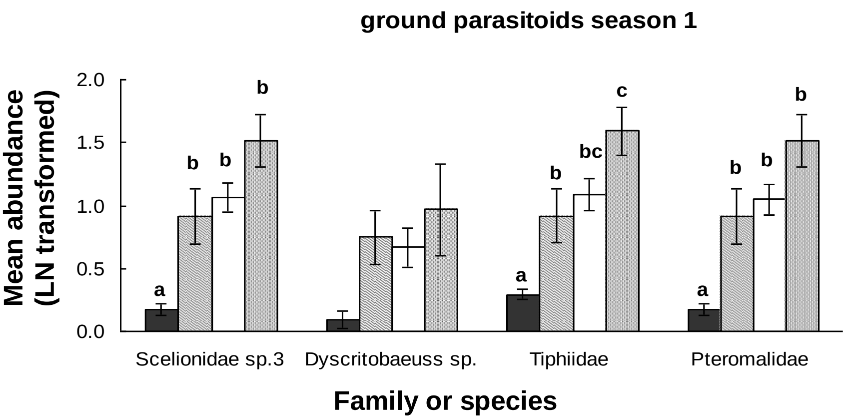
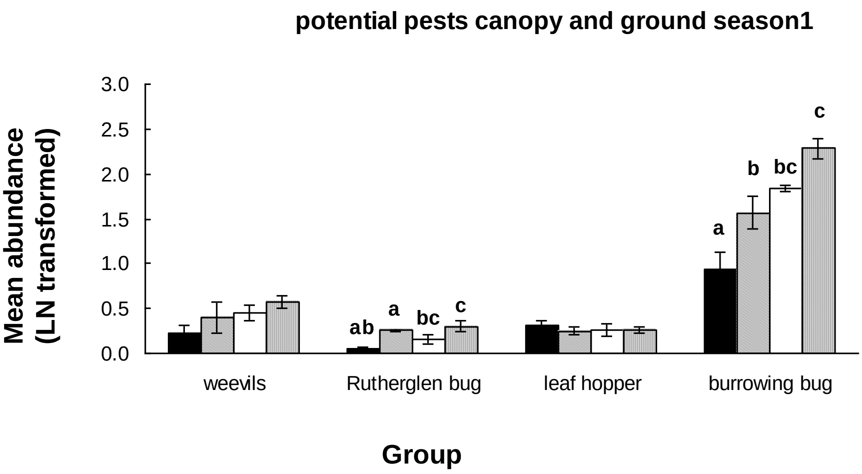


Fig. 4. Mean number (log transformed) of potential pests collected per trap in the canopy with yellow sticky traps (Rutherglen bugs and leafhoppers) and on the ground with pitfall traps (weevils and burrowing bugs) in season 1 (season 2 not presented). Different letters above the bars reflect significant differences in abundance between the cover crop treatments in posthoc tests. Error bars represent standard errors



The native cover crops grew successfully over 2 seasons without any maintenance although the influence of cover crop treatment on invertebrate abundance appeared to be greater in the first season. Abundance of a range of parasitoids, earwigs and predatory thrips, natural enemies which may assist in pest control in vineyards, was increased with the native cover crops, especially windmill grass and saltbush, although there was also an increase in some potential pests.

These positive effects need to be counterbalanced by an increase in some potential pest species including Rutherglen bugs and weevils in the native cover crops. The role of the burrowing bug detected here (*Adrissa* sp.) is unclear. While knowledge of the biology of the family is limited (Henry and Froeschner, 1988) they may be beneficial to soil overall due to their burrowing activity, but relatives are known to feed on the roots of plants and may act as pests, although other Cydnidae are seed eaters (Filippi *et al.*, 2009).

What characteristics of the cover crops may confer this benefit of natural enemies? Oats are favoured as a cover crop, they grow rapidly and increase soil nitrogen and add organic matter to the vineyards (Ludvigsen, 2008). They may also provide shelter and pollen for beneficials but oats flower only in spring, in contrast to the native cover crops trialled here which flower during the grape growing seasons in which we sampled, ranging from November to June (windmill grass) to throughout the year (saltbush) (George, 1984), thus they may provide greater resources and more complex structure. Perennial cover crops may also provide shelter throughout the year, without the disruption caused by resowing required by an annual such as oats.

Native species as inter row cover crops did establish successfully and also have potential to increase abundance of several potentially important natural enemies of vine pests but they might also increase local pest problems. The increase in natural enemies may provide an economic benefit and potentially reduce the need for chemical applications to control pests, as well as increasing the economic and environmental sustainability of the wine industry. However more information is required on the role of different taxa in vineyards, as well as the potential negative impact of native hosts on pest species.

6.4 Adjacent vegetation results and discussion

We collected 127529 organisms in the canopy and 191250 from the ground. Numbers of parasitoid families Figitidae, Trichogrammatidae, Eulophidae, Mymaridae and the beetle families Coccinellidae and Staphylinidae showed significant changes in response to the presence of adjacent vegetation (Table 8). Numbers of Bethylidae, Braconidae, Ichneumonidae, other small parasitoids, spiders, and lacewings were not affected by vegetation (Table 8). Where significant effects were found, the abundance of all taxa except Mymaridae was increased with the presence of adjacent vegetation (Fig. 5) whether this consisted of remnant forest or planted shelterbelts. Mymaridae were more abundant in vineyards without adjacent vegetation. While overall ladybird beetles and one species (*Diomus* n. sp. 1) were significantly more abundant with adjacent vegetation, the abundance of two other species (*D. notescens* and *Diomus* n. sp. 2) was not affected by vegetation (Table 8). The type of vegetation present generally had no effect on taxon abundance in vineyards; post hoc (Tukey b) analysis on the taxa which showed significantly increased abundance with adjacent vegetation found no impact of vegetation type, with the exception of the Figitidae (Fig. 5).

There was an effect of collecting region on the abundance of Bethylidae, Braconidae, Ichneumonidae, Mymaridae, other small parasitoids, spiders, Staphylinidae, ladybird beetles overall and *D. notescens* and *Diomus* n. sp. 2 in particular (Table 8). In general natural enemies were more abundant in the Padthaway region compared to Barossa and Wrattonbully (Fig. 6). The taxa that showed a significant response to region tended to be those that did not show a response to local vegetation, with the exception of Coccinellidae and Staphylinidae when considered at the family level, (but not at the level of genus for the ladybird beetles).

Table 8. ANOVAs on effect of presence of local adjacent vegetation on abundance of natural enemy groups with (28 sites) and without (33 sites) vegetation. For the vegetated sites, 17 had remnant vegetation and 11 had shelterbelt vegetation. Species in bold are known parasitoids of LBAM (Danthanarayana, 1980; Glenn *et al.*, 1997; Paull and Austin, 2006). Significant probabilities are also indicated in bold.

Group	Family	Species	Woody vegetation			Region			Interaction
			$F_{(2,61)}$	MS	*P*	$F_{(2, 61)}$	MS	*P*	
Parasitoids	Figitidae (2608)	*Anarchis* sp.	4.09	0.581	**0.022**	3.11	0.441	0.053	0.008
	Bethylidae (8408)	***Goniozus*** **sp.**	1.52	0.341	0.228	9.64	2.154	**<0.001**	0.167
	Braconidae (1400)	*Ascogaster* sp. ***Dolichogenidea tasmanica*** **Cameron**	0.89	0.075	0.419	12.70	0.706	**<0.001**	0.736
	Ichneumonidae (1389)	***Australoglypta latrobei*** **Gauld** ***Eriborus epiphyas*** **sp. n.** ***Phytodietus celsissimus*** **Turner**	1.95	2.271	0.071	1.79	0.451	**0.013**	0.452
	Trichogrammatidae (736)	***Trichogramma*** **spp.**	9.86	10.070	**<0.001**	1.24	0.530	0.297	0.683
	Eulophidae (226)	Eulophidae sp.	23.78	14.702	**<0.001**	0.26	0.181	0.772	0.601
	Mymaridae (1508)	*Mymar* sp. Mymaridae spp.	4.59	0.240	**0.015**	8.89	0.465	**<0.001**	0.064
	Other small parasitoids (19925)	See text	0.87	1.464	0.241	8.11	4.862	**0.001**	0.191
Spiders	Various (2629)	See text	1.24	0.057	0.298	7.16	0.334	**0.002**	0.632
Beetles	Coccinellidae[a] (2011)	combined	4.22	0.164	**0.025**	14.29	0.416	**<0.001**	0.482
	(429)	*D. notescens*	2.33	0.028	0.108	9.17	0.123	**<0.001**	0.120
	(629)	*Diomus* n. sp.1[b]	1.35	0.009	0.269	8.75	0.570	**<0.001**	0.357
	(398)	*Diomus* n. sp. 2[b]	4.32	0.006	**0.018**	1.11	**0.002**	0.337	0.189
	Staphylinidae[c] (753)		6.15	0.054	**0.004**	5.21	0.500	**0.009**	0.034
Lacewings	Hemerobiidae (683)	*M. tasmaniae*	1.93	0.056	0.156	1.53	0.045	0.227	0.078

[a] 10 genera of Coccinellidae: a *Stethorus* sp.; five species of Scymninae *Cryptolaemus montrouzieri* Mulsant, *Diomus sydneyensis* (Blackburn), *D. notescens* (Blackburn), *Diomus* n. sp.1 and *Diomus* n. sp. 2;four species of Coccinellinae: *Coccinella transversalis* (Fabricius), *C. septempunctata* L. and *Micraspis frenata* (Erichson) and a *Harmonia* sp.

[b] 2 currently undescribed species both from the genus *Diomus* (*Diomus* n. sp.1 and *Diomus* n. sp. 2) (A. Ślipiński pers.com.).

[c] 19 genera including 220 of the 2 most common species *Aleochara* and *Leptacinus* and lower numbers of *Dalotia, Ocalea*, *Leptacinus*, *Tachinus*, *Pseudoplandria*, *Aleochara* and *Oligota* spp.

Fig. 5. Mean number (log transformed) of families or species, collected per trap with sticky traps 50 m into the vineyard adjacent to the vegetated (shelterbelt or remnant) or unvegetated edge, with significant response to the presence of adjacent vegetation. Letters above the bars show differences in abundance between the vegetation treatments in post hoc (Tukey b) tests. Error bars represent standard errors.

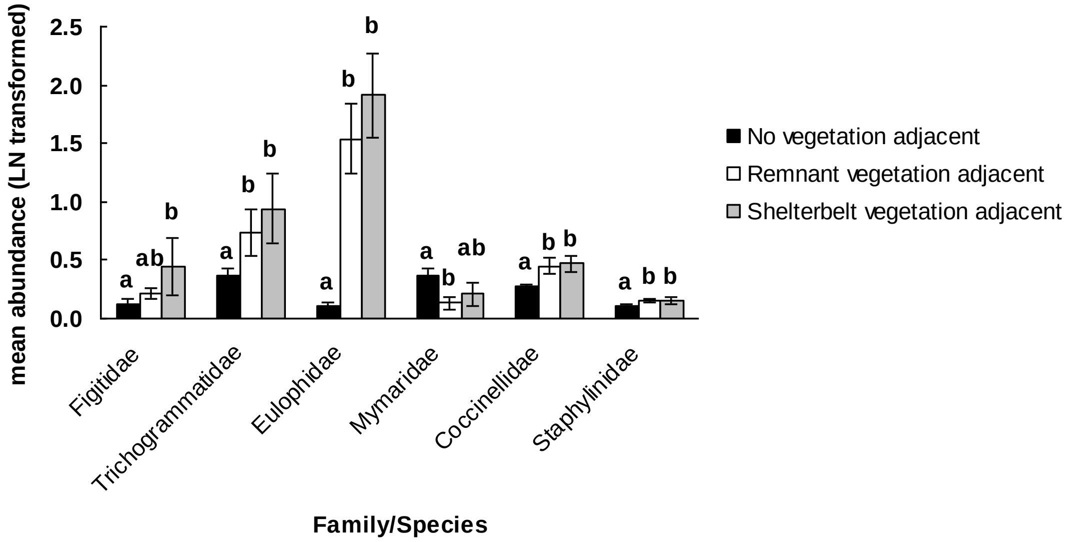
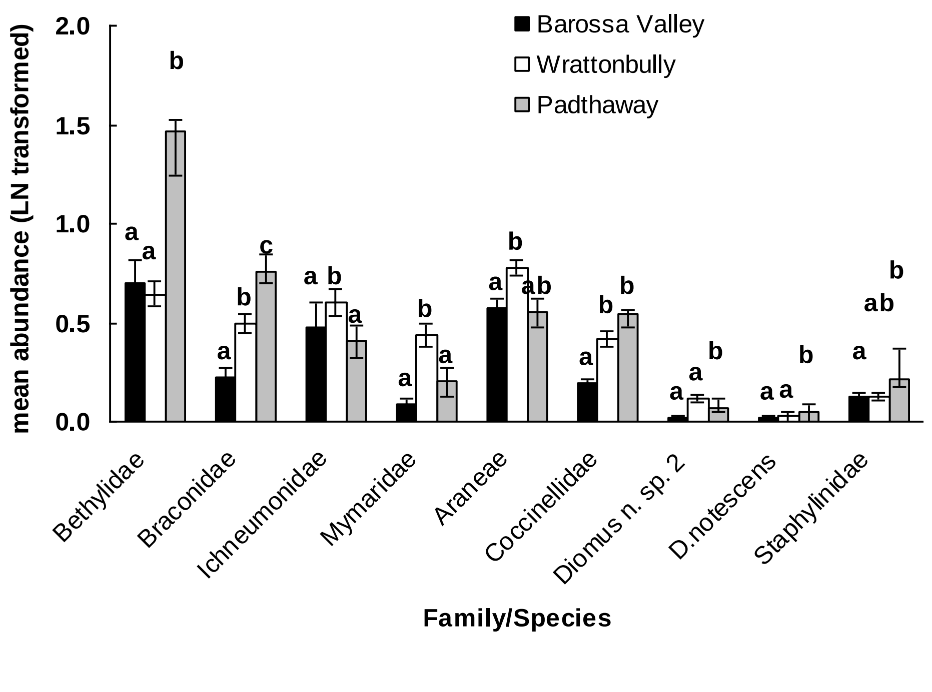


Fig. 6. Mean number (log transformed) of families or species, collected per trap with sticky traps 50 m into the vineyard adjacent to the vegetated (shelterbelt or remnant) or unvegetated edge, with significant variation in abundance with region in post hoc tests. Letters above the bars show differences in abundance between the regions. Error bars represent standard errors.



If adjacent vegetation can provide resources for natural enemies and contribute to pest control this may help in grower decisions to maintain or establish vegetation as an adjunct to crop. In 3 vineyard regions, we found that local woody vegetation tended to enhance numbers of a range of natural enemies, although not all enemies were affected by vegetation. This may be at least partly related to the size of the beneficials, with the smaller parasitoids from Eulophidae and Trichogrammatidae increased in vineyards along with Figitidae, Coccinellidae and Staphylinidae, but the larger parasitoids Bethylidae, Braconidae and Ichneumonidae, as well as spiders and lacewings not affected. Some groups of enemies may only respond to vegetation at a wider scale. The spatial scales of natural enemy responses may be related to their foraging range and dispersal distances (Schmidt *et al.*, 2008) and it has previously been suggested that parasitoid response depends on size (Roland and Taylor, 1997; Gathmann and Tscharnkte, 2002; Van Nouhuys and Hanski, 2002). With the exception of Figitidae, the parasitoids and ladybird beetles which were here positively influenced by vegetation at a local scale tended to be smaller for these respective groups. Of the 3 individual genera of ladybird beetles, the smallest *Diomus* n. sp. 1 (at around 1.2 mm in length) was positively associated with adjacent vegetation, whereas *Diomus* n. sp. 2 and *D. notescens* (both around 2.5 mm) were not. Although adjacent vegetation may influence the abundance of ground spiders, landscape scales of 500 m radius and more have been identified as relevant for many spiders (Clough *et al.*, 2005; Schmidt *et al.*, 2005; Schmidt and Tscharnkte, 2005).

This study showed some predators and parasitoids were not affected by local vegetation and many of these showed a difference at the regional scale. These natural enemies may respond to wider features of the surrounding landscape. For some natural enemies, availability of regional species pools may be more important than local resources (Schweiger *et al.*, 2005). For instance, larger undisturbed areas may be necessary to preserve abundant populations of larger parasitoids (Kruess and Tscharntke, 2000; Kruess, 2003).

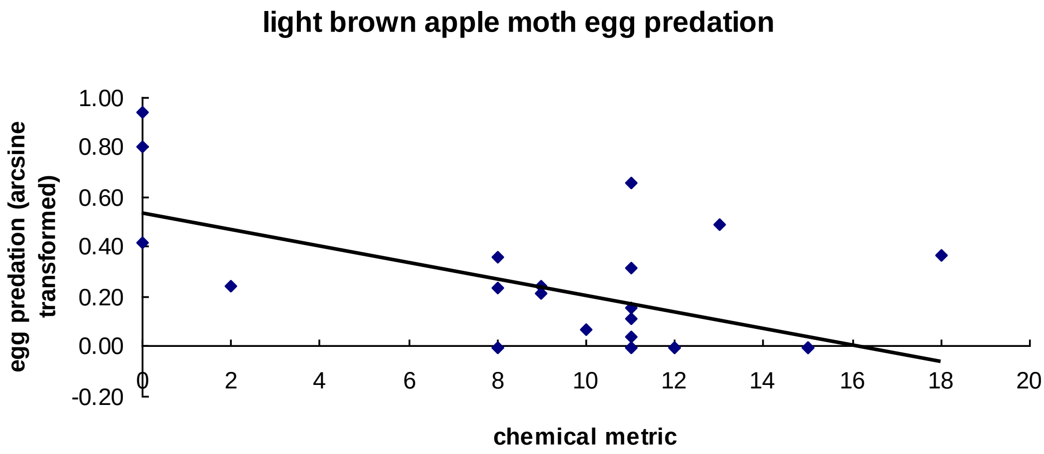
These results indicate that vegetation can have an implied economic value in terms of the value of natural control services. Putting a value on improved ecosystem services provided by different agricultural management practices can alter their value (Thomson and Hoffmann, 2007; Zhang and Swinton, 2009) with both environmental and economic advantages to growers important in encouraging establishment or maintenance of non-crop vegetation (Bianchi *et al.*, 2006). An important outcome of these results is that shelterbelts performed as well as remnant or revegetated blocks in promoting pest control. We selected complex shelterbelts with robust understoreys, not subject to chemical sprays or grazing as we had previously identified these as important in increasing natural enemies (Tsitsilas *et al.*, 2006) in Australian shelterbelts.

6.5 Effect on light brown apple moth control results and discussion

All three studies indicated that abundance and diversity of natural enemies responds to management practices. What happened to predation and parasitism of light brown apple moth? Does increase in natural enemies translate to greater pest control? The answer is an unequivocal yes to increased predation but a surprising result for parasitism. With reduced chemical impact in the vineyard, with presence of adjacent vegetation and with introduction of native grass cover crops in the inter row, increased predation of light brown eggs was seen. Although several species of *Trichogramma* were found at the different sites, an extremely low level of egg parasitism was recorded. We put thousands of egg cards in vineyards and despite the presence of known egg parasitoids *Trichogramma* spp very little parasitism was observed so further analysis of parasitism was not possible. This result is surprising, as in previous years high levels of parasitism of both sentinel and naturally occurring

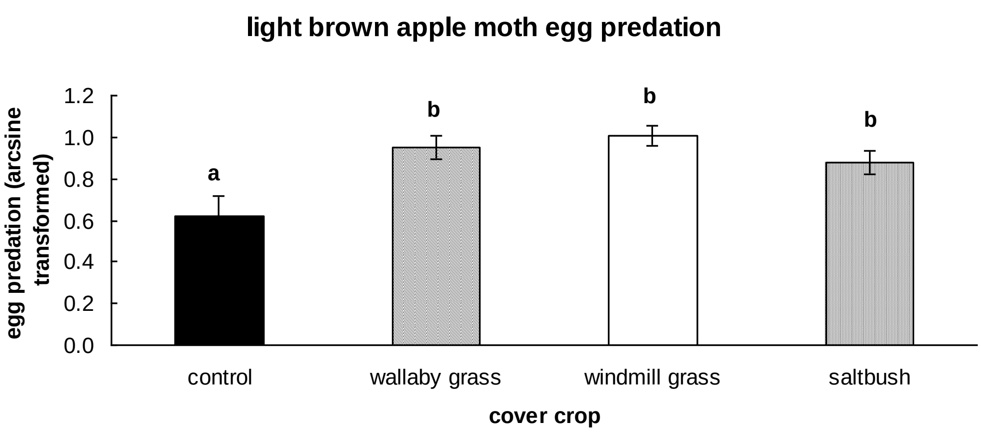
egg masses have been reported over a long period of time (for example 57% sentinel eggs in Thomson and Hoffmann (2009) and 43% of naturally occurring eggs in Dantharayana (1983)). This interesting result will be further investigated.
With chemicals, predation was significantly affected by overall chemical loading for the season (r_s = -0.0430, P = 0.022), with a significant decline in egg predation with increased toxicity as assessed by the pesticide metric (Fig. 7). Predation of the 2500 egg cards placed in 30 of the 61 vineyards was significantly correlated to overall chemical input as assessed by the chemical metric.

Fig. 7 Correlation of (arcsine transformed) predation of light brown apple moth (LBAM) eggs with chemical metrics at 30 of the 61 sites where overall chemical toxicities (chemical metric) were calculated.



Predation was increased with native cover crops compared to the exotic, oats. A total of 560 LBAM egg cards were placed at 80 sampling points within the study site to assess predation of LBAM eggs. Predation levels of LBAM eggs were significantly affected by cover crop treatment ($F_{(3,12)}$ = 6.79, P = 0.006), with predation higher in all three native treatments compared to the control (Fig. 8).

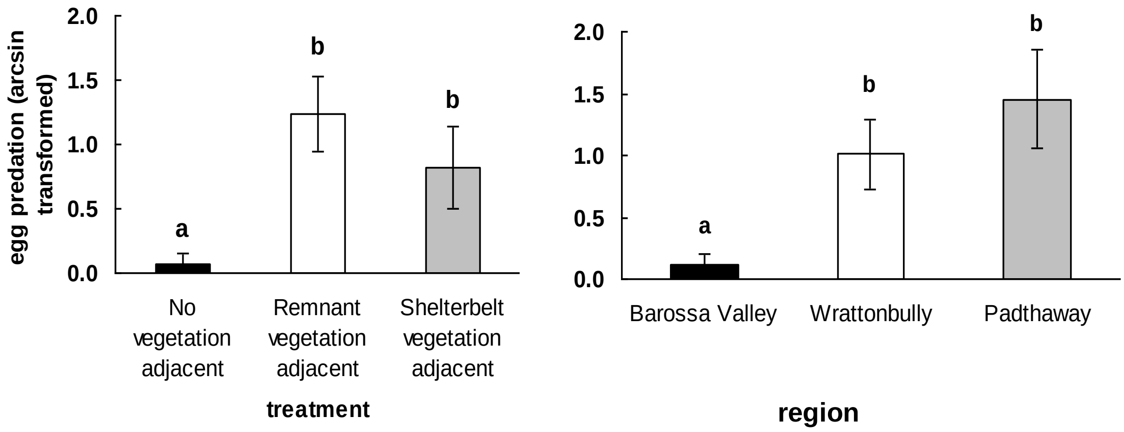
Fig. 8. Mean of percentage of light brown apple moth eggs eaten with cover crop treatment over 3 months (arcsine transformed) in season 1. Letters above the bars show differences in abundance between the cover crop treatments. Error bars represent standard errors.



This is direct evidence of beneficial effects of the native cover crops because predation of light brown apple moth eggs increased when these crops were present. This increase in predation may be related to increased abundance of earwigs (Dermaptera) and the predatory thrips. Earwigs are generalist predators and are known predators of light brown apple moth in vineyards, especially in the case of the common European earwig (Danthanararayana, 1983; Frank *et al.*, 2007), and while the predatory thrip *Desmothrips* sp. collected here is known to be a facultative predator of larvae of other thrips but potentially also of LBAM eggs (L. Thomson unpub. obs.).

Finally, predation was increased in vineyards with adjacent vegetation, whether shelterbelt or remnant, compared to vineyards without adjacent vegetation. In total 2396 egg cards (consisting of 2 or 3 egg masses of 20-70 eggs each) were placed in 30 vineyards with average predation of 16.38 (±12.54)%. Significantly more predation of eggs occurred in vineyards with adjacent vegetation ($F_{(2, 30)} = 4.12$, $P = 0.032$). Post hoc analysis showed the number of eggs eaten in vineyards with remnant and roadside vegetation did not differ (Fig. 9). There was a significant difference in egg predation between region ($F_{(2, 30)} = 4.57$, $P = 0.020$) (Fig. 9) with less predation at Barossa compared to the other regions.

Fig. 9. Mean percentage (arcsine transformed) of light brown apple moth eggs predated 50 m into the vineyard adjacent to the vegetated (shelterbelt or remnant) or unvegetated edge, (a) response to presence of vegetation (b) response to region in post hoc tests. Letters above the bars show differences in abundance between the regions. Error bars represent standard errors



It is not known which predators were responsible for the increased predation of *E. postvittana* eggs in vineyards with adjacent vegetation. This might include some of the coccinellids that were increased by adjacent vegetation, or perhaps other known predators such as ants (Hymenoptera: Formicidae) and earwigs (Dermaptera) that were not assessed here

7 Outcome/Conclusion:

The aim of the project was to provide recommendations to increase pest control provided by natural enemies of vineyard pests and thus improve the capacity of natural pest control to deal with some of the more difficult pests. We were interested in developing recommendations for reducing the input of toxic chemicals with associated environmental and economic benefits. We successfully identified the impact of each management practice on a diverse range of invertebrates. Changes to management practices led to increase diversity and abundance of natural enemies in vineyards. It is obvious that increased abundance of natural enemies can increase pest control but less so that increased diversity will also provide better pest control as has been shown elsewhere (Cardinale *et al.*, 2006; Tscharntke *et al.*, 2007; Straub and Snyder, 2008). For example, a range of natural enemies have been shown to be effective at reducing populations of light brown apple moth (MacLellan, 1973; Danthanarararayana, 1983; Buchanan and Amos, 1992; Thomson and Hoffmann, 2009). Our demonstration that the increase in diversity and abundance of natural enemies is reflected in improved control of light brown apple moth confirms the usefulness of this approach.

7.1 Performance against planned outputs and performance targets

Planned output/performance target: 'Identification of critical chemicals, laboratory testing where deficiencies are identified'. We have provided readily accessible chemical information for growers when seeking information on specific chemicals and the potential impact of an overall spray program via the database. We have also demonstrated from field data that decreased toxicity as assessed from the database leads to increased diversity and abundance of natural enemies. High toxicity loads in vineyards adversely affected specific invertebrate groups and suggest that high toxicity ratings will decrease the activity of predatory and parasitoid groups in vineyards. Interestingly, there some indication of disruption to invertebrate communities even when broad-spectrum sprays were avoided and that fungicides as well as insecticides can be harmful to the communities. This is likely to decrease ecosystem services provided by beneficial invertebrates including pest control. Consideration of the overall impact of a chemical spray program for a growing season can result in increased diversity and abundance of natural enemies and increased pest control. This important outcome adds value to the frequently more expensive 'softer' chemicals, has potential to decrease necessity for chemical application for pest control and to increase sustainability/decrease environmental footprint of the industry with reduced chemical loading impacting on the environment.

Planned output/performance target *'Cover crop plants which encourage natural enemies and soil organisms and field study impacts of cover crops on natural enemies'*

We have provided information on cover crop plants which encourage natural enemies and reported on field studies on impacts of cover crops on natural enemies. The vineyard mid-row constitutes some two thirds of the vineyard floor, and as growers move toward improving ecological sustainability through adopting best management practices, the use of native

rather than exotic ground cover species in the mid-row has potential with less maintenance, improved soil health and increased natural enemies.There are many reports of positive impacts on natural enemies with a range of cover crops, but it is also apparent that choice of cover crop for the region with particular attention to rainfall and temperature is critical to success. Further, while this work demonstrated that cover crops can increase a range of potential natural enemies and increased predation of light brown apple moth, there was also potential for some pests to be increased with native grasses as cover crops. The native species planted as inter row cover crops established successfully and increased abundance of several potentially important natural enemies of vine pests but we add a note of caution to their use as they might also increase local pest problems. The increase in natural enemies may provide an economic benefit and potentially reduce the need for chemical applications to control pests, as well as increasing the economic and environmental sustainability of the wine industry. However more information is required on the role of different taxa in vineyards, as well as the potential negative impact of native hosts on pest species.

Planned output/performance target '*Characteristics of adjacent vegetation to maximize presence of natural enemies*' We have shown in extensive field studies across a range of grape growing regions that a diverse range of woody vegetation can be beneficial. This is important as it means that for pest control it is not necessary to be prescriptive about the vegetation in place or the form it needs to take; it will increase diversity and abundance of natural enemies regardless. The variety of ways vegetation coexists with grape vines – shelterbelts may be planted to provide protection of the crop from wind or the surroundings from spray drift, areas unsuited to vines may be planted to vegetation, areas of remnant vegetation may be left for environmental or other considerations – all of these will potentially contribute to enhance natural enemy populations and increased pest control. We do however recommend a structurally complex vegetation with understory plants.

Planned output/performance target 'A cost / benefit analysis of management practices (chemical use, within vineyard and adjacent vegetation plantings) on beneficial invertebrates'
Here we give a detailed analysis on the potential value of the increased natural enemies compared to the cost of establishing vegetation.

Benefit-cost analysis for pest control benefit provided by natural enemies increased by vegetation associated with vineyards and cost of establishing vegetation

Many vineyards in south eastern Australia are established on land relatively recently cleared and thus exist in a mosaic of pasture, crops and woody vegetation. This normally consists of planted shelterbelts (trees with an understory of shrubs and grasses), though occasionally there are stands of original forested remnant vegetation. Remnant vegetation may pre-date the establishment of viticulture or may be regrowth following clearing and thus may be representative of the original landscape. In our experience, shelterbelts lie in the range 4 m-9 m width and remnant in blocks ranging from about 5-25 ha. The analysis is based on establishment of shelterbelt vegetation, although we mention regeneration or assisted regeneration in remnant blocks, costs associated with a decision to support remnant or revegetation of a disused vineyard block especially the introduction of fencing, such costs would be variable. Here we provide a benefit cost analysis, estimating costs likely to be incurred and estimating the potential benefit in natural enemies provided by the vegetation as measured from our monitoring of natural enemies at 71 sites in four regions of south eastern Australia over 3 years. We have measured abundance of a diverse range of natural enemies 50 m into vineyard blocks where the vineyard is either bordered by a shelterbelt or by more vineyard blocks or pasture to assess the benefit to production in contributing to pest control within the vineyard.

We estimate the benefit provided by these natural enemies and compare to the cost of establishment of new vegetation such as shelterbelts or assisted natural regeneration of remnant including the potential land lost for productivity. We account only for the benefits and costs of the project to the grower –effects of establishment/increase of vegetation may be broader – through social, environmental and employment effects. In establishing benefit-cost of vegetation around vineyards there are different aspects to be considered, some of which can be measured and others which are more difficult to infer. The latter includes social or environmental benefits such as those flowing from the existence on the vegetation on the local amenity. Social and environmental benefits which will enhance the position of the industry or limit potential negative effects on local community are difficult to measure. This may simply take the form of it being easier to continue to farm within an increasingly concerned population or even a direct advantage in terms of distance from a boundary that the activity is permitted to be carried out. This might arise from concrete attributes such as protection from spray drift, noise or visual impact of farm sheds or processing plants to more esoteric attributes such as visual amenity of the area, contribution to tourism in increased attractiveness encouraging visitors, cellar door sales and so on. While these are outside the scope of our project, it is important to note that such effects nevertheless can be large and add to the benefit side of the ledger. This is important because the growers incur all the costs (unless they have access to volunteer labour through a community contribution or access community funding for revegetation) though they do not necessarily receive all the benefits. Similarly, consideration of the other use to which labour or machinery used in creating the vegetation compared to the resulting vegetation is not considered. It also excludes the benefits or costs of currently non-marketed commodities such as potential for future carbon accounting or contribution to pollution remediation, as there is no inclusion of agriculture in the proposed emissions trading scheme at this time but potentially this does provide 'banking' for the future.

We also do not consider the value of the land. There are two aspects to this, imputed lost value and imputed gained value. If the land given over to revegetation could otherwise be used for grape growing, there is potential income lost. However, revegetation is generally designed to be integrated with block boundaries to allow maximum production to continue - eg plantings along fence boundaries, and small block planting in gully and waterlogged areas - or is put in place for another purpose which ameliorates this cost. There are also possibilities for tax deductions with introduction of vegetation. If land is either retained as remnant or revegetated, if a covenant is placed on the land so that future development is not possible, a tax deduction for the value of the land is allowable. Some municipalities provide rate exemption for this portion of the land. For example say a property is 1000 ha and 100 ha remnant is to be retained and protected. Say the value of the land is $4000/ha and putting in vines increases value to $10000/ha. The loss in value of the retained land can be claimed as a loss. However, there is too much variation in both these factors for us to include them in cost/benefit calculations.

Estimation of benefit of natural enemies provided by presence of vegetation adjacent to a vineyard.

We estimate the value of vegetation to pest control by calculating the value of the natural enemies provided if these animals were purchased from commercial suppliers. There is a limited number of species available for purchase; we use the value of these in our calculation. With the exception of *Trichogramma*, these are used as examples as there is an amazingly diverse range of natural enemies present in vineyards, far beyond the one or two species that are commercially available. The commercially available natural enemies include: two parasitoids *Trichogramma* for light brown apple moth control and *Aphytis* for scale control, several ladybird beetles, including *Chilocorus* for scale control and *Cryptolaemus* ('mealybug destroyer') for mealybug control, a staphylinid or rove beetle (*Dalotia coriaria* Kraatz*)*, and several predatory mites and generalist predator green lacewings (*Mallada signata*). Note that not all of these are identified as relevant to vineyard pest control. The existence of vegetation adjacent to a vineyard increased the abundance of a range of natural enemies (Table 9).The value of adjacent vegetation to the grower is at least $516-696 per year (per 4-9 m wide x 100 m long stand of native vegetation as shelterbelt). It is also important to again emphasise that in this we have only considered a small number of the diverse range of natural enemies enhanced by vegetation; if a value could be put on all these, the overall value would be higher.

Table 9. Natural enemies increased by adjacent vegetation in vineyards in Victoria and South Australia and the value of these calculated from price from commercial suppliers.

Natural enemy	Examples from what is commercially available	Price/unit ($/unit)	Increase in abundance/ha	Value/100 m shelterbelt
parasitoids	*Trichogramma* *Aphytis*	0. 0009 0.0044	5673	$5.00
Ladybird beetles	eg *Chilocorus,* *Cryptolaemus*	0.40 0.28	1200	$480-660
Staphylinid beetles	*Eg Dalotia*	0.06	520	$31.00
Total value for 100 m vegetation				**$516-696**

A further source of increased value comes from potential effects at the wider or landscape scale, where growers would share benefits. While our data indicate vegetation increases abundance of natural enemies in the vineyard immediately adjacent to it and we can put a value on this to the grower who maintains/establishes the vegetation, it also true that there are benefits of vegetation at the wider or landscape scale and there will be benefits to all growers in a given area. For example, adjacent vegetation increases *Trichogramma*, the most important egg parasitoid of light brown apple moth. However, lightbrown will also exist as caterpillars and pupae, and control at these stages will be important for overall control of populations of this pest. Several larval parasitoids including *Eriborus epiphyas* sp. n. (Paull and Austin, 2006), *Australoglypta latrobei* Gauld, *Phytodietus celsissimus* Turner and the well known *Dolichogenidea tasmanica* Cameron as well as the Bethylidae pupal parasitoids *Goniozus* species are enhanced at the wider scale. This is also true of ladybird beetles. The smaller species are enhanced at the local level, and these are included in the calculation, but the larger species at the landscape level are not. This is important as the range of ladybirds encouraged contribute to control of a range of pests including lightbrown apple moth (MacLellan, 1973), scale (Hodek and Honěk, 2009) and mites (Biddinger et al., 2009). We have not included these benefits, shared by all growers in a district.

Estimating the costs associated with establishing vegetation adjacent to a vineyard

Revegetation is most commonly carried out by the grower on land identified as requiring restoration such as riparian zones along waterways, or potentially subject to erosion, or on land unsuitable for productive grape growing. The main factors influencing costs are whether the grower undertakes the revegetation or contracts the work to an outside agency, and the length of associated fencing. There are many variables in the establishment of vegetation and we mention some of these and present two examples that cover grower compared to contractor established vegetation.

Three primary methods of revegetation are commonly used and all three are relevant to vineyard settings though we do not discuss regeneration further:
1. *Assisted natural regeneration* in which no seed or seedlings are added to the site, but seed stores from remnant trees and shrubs and/or seed stores already present in the soil are encouraged to germinate instead. Assisted natural regeneration relies on having adequate seed stores available either in remaining trees, shrubs and grasses in the area, or in the soil of the area being regenerated (Casey and Chalmers, 1993). The primary factor affecting success of assisted natural regeneration is the preparation of an adequate receptive seedbed around existing remnant vegetation in which seeds can germinate and grow, and the exclusion of grazing (usually by constructing fencing) which might otherwise destroy new growth)
2. *Revegetation by direct seeding*, in which sites are seeded and fenced to achieve revegetation; and
3. *Revegetation using seedlings*, in which seedlings are first grown in nurseries and then transplanted to the revegetation site.

Common costs incurred in revegetation projects include project planning and management, transport costs for machinery/seeds/seedlings/personnel and so on, mechanical and chemical site preparation, fencing, weed control, seed and direct seeding costs or seedlings and seedling establishment costs and tree guards/stakes. Several types of costs decrease on a per hectare basis as the size of the revegetation project increases. These include fencing, site preparation, line/boom spraying of herbicides and direct seeding, most of which can be attributed to a fixed cost per project for mobilisation and transport of equipment used. Other cost components, including seedlings, seed and tree guards are more likely to be independent of the size of the project, ie their cost per hectare does not change with project size except for bulk buying of components.

We have not considered other costs which may be incurred such as site specific costs due to slope, rocks, fertilizer application or watering, erosion control matting, the use of mulch or straw to suppress weeds, reduce water loss or further spraying of weeds to continue weed control. We do not discuss these as there is variation in individual cases. We also do not consider the costs of machinery which may be employed either in purchase or costs of use (depreciation) as there is too much variation - ie if a ripper is available or needs to be purchased and depreciated - but these need to be considered by each individual when considering costs of revegetation.

We outline below some common factors to consider in estimating costs (Schirmer and Field, 2001, Greening Australia, Landcare) and then calculate costs of establishing vegetation in two extreme ways –with contracting the entire scheme and alternatively with the grower providing all possible resources – labour, machinery and management (see Table 10).

Table 10**.** Example of cost of establishment of shelterbelt by contractor or grower using seedlings, with and without the most economical fence (5 stranded wire). As fencing makes a significant contribution to the overall cost, we first calculate the cost of a square ha and then those for costs of 4 m and 9 m wide shelterbelt.

Contractor					Grower				
Cost description	**Cost/ha for 1ha project ($)** ie square of 100 m side		**Cost/ha for typical vineyard shelterbelt 4^a (9)^b m** ^{a} 4 x 2500m ^{b} 10 x 1000 m		**Cost description**	**Cost/ha for 1ha project($)** i e square of 100 m side		**Cost/ha for typical vineyard shelterbelt 4^a (9)^b m** ^{a} 4 x 2500m ^{b} 10 x 1000 m	
	With fencing	**Without fencing**	**With fencing**	**Without fencing**		**With fencing**	**Without fencing**	**With fencing**	**Without fencing**
Site preparation using contractor deep ripping	60	60	60	60	Site preparation deep ripping . No machinery cost, in-kind labour at $15/hr	15	15	15	15
Fencing materials @ $1100 per kilometer (plain wire)	440		a 5508 b 2461		Fencing materials @ $1100 per kilometre	440		a 5508 b 2461	
Fencing labour @ 44 hours labour/km = $1500/km. Labour cost estimated at $34/hr	600		a 7512 b 3357		Fencing labour, in-kind, labour cost estimated at $15/hr $660/km	264		a 3305 b 1477	
Boom spraying 3 times @ $89/ha/application	267	267	267	267	Boom spraying 3 times chemical cost only	90	90	90	90
Seedings $0.60/seedling	600	600	600	600	Seedlings $0.60/seedling	600	600	600	600
Guards/stakes plastic and stake	1000	1000	1000	1000	Guards/stakes milk carton or similar grower	170	170	170	170

					supplied and stake				
Mechanised planting@$0.50/plant labour and planter hire	500	500	500	500	Mechanised planting hire planter @ $100/hr	100	100	100	100
Total cost per ha contractor	**3467**	**2407**	**a 15510 b 8245**	**2407**	**Total cost per ha grower**	**1679**	**975**	**a 9792 b 4913**	**975**

Labour
While contractors commonly cost labour at $25-$35 per hour, Landcare certainly values this form of labour much less. In-kind labour is then contributed by growers (or indeed by volunteers).

Project management costs
These are commercially quoted at $28/hr or $500 per established hectare

Site preparation
Site preparation usually involves two elements: weed control and soil disturbance. Both aim to allow seed or seedlings to grow more easily. A range of mechanical site preparation techniques is available, commonly deep ripping alone or associated with cultivation. The average cost/ha by contractor is $60 for deep ripping only (tractor and ripper) or $140 for deep ripping and cultivation. Costs will be reduced for projects undertaken with a large in-kind contribution by growers, or are undertaken using machinery owned by organisations such as Landcare groups or Greening Australia. For a grower using their own ripper and tractor, it is estimated that deep ripping would cost 1.2 hours labour per hectare plus set-up time of 0.5 to 1.5 hours labour.

Preplanting weed control
Weed control methods used in weed and pasture control is commonly undertaken with boom spraying, and spot spraying is used for post-establishment weed control;

Weed control is needed before establishment of new plants can occur as weed species compete for nutrients, water and light on the site. Weed control usually uses a knockdown herbicide only, most commonly glyphosate, or less commonly a combination of knockdown and residual herbicide, with simazine the most commonly used residual herbicide. With labour, equipment hire and herbicides, the cost of boomline spraying in preparation to planting by a contractor is estimated at about $90 per application and 3 applications are common.

However if the grower has access to machinery (as most growers have) the cost will clearly be reduced. Chemical costs at $15 to $30 using glyphosate or other knockdown chemicals applied at between 1 litre (L) to 2L per hectare cost will depend on number of applications required to achieve control. Again we have not considered machinery costs as there are too variable – does the grower have access to tractor, boomline sprayer either on site or through local Landcare organization? Machinery owned by grower or local organisation will clearly significantly reduce costs compared to either hire of machinery or contracting this part of the operation.

Fencing costs
In regeneration projects, fencing animals out of an area of remnant vegetation improves regeneration by ensuring germinating seedlings will not be eaten. Fencing in direct seeded areas is recommended and in areas where seedlings are planted out, fencing alone is not likely to be entirely effective unless tree guards are also used to prevent seedlings from being eaten by animals such as rabbits which can get through most conventional fences. A range of fencing is used with the extremes being a plain wire fence materials (cost $1100/km) and rabbit proof fence (1 barbed, 4 plain wire, rabbit mesh, 90cm high plus 15 cm buried (105 cm total) (cost $3550) and then there are additional labour costs.

Fencing is generally included as an establishment cost for revegetation to exclude livestock and native/feral animal species but may not be considered essential for vineyards where generally there no presence of grazing animals and the cost of rabbit proof fencing may be difficult to justify. We calculate costs with a single type of fence plain wire 5 stranded and compare this to no fencing.

Vegetation costs

Vegetation may be put in place by direct seeding or planting seedlings of various sizes. For direct drilling and planting seeds, the major variable is whether the grower is undertaking the revegetation or employing a contractor. Seed is available for $250/ha compared to the rate charged by a contractor at about $400/ha plus labour costs. Costs of hire of a direct seeder will contribute to grower costs although direct seeders are the sort of equipment made available by interested commercial enterprises such as Alcoa (the Alcoa Machinery Loan Scheme), at about $30 per day (Greening Australia, 2009).

If seedlings are used rather than direct seeding the recommended rate of planting is 1000/ha and the cost of these depends on the size of the seedlings and the size of the order, with larger plants more expensive and larger orders of course being cheaper per plant. We estimate costs using smaller seedlings bought in quantity ($0.60/seedling for purchases of >1000) but more advanced seedlings will cost up to $6.00 each (200-300 mm pots). Seedlings may be planted by hand or by mechanized planter. There will be greater labour cost with the former (contractor 50 cents/plant labour and hire of hand planter) and greater machinery costs with the latter (commercial hire of mechanized planter may be $100/hr, although again some are available through community organizations or similar for $20/hr or even free). The labour costs vary widely with the skill of the planters with 3-4 labour hours per 100 seedlings quoted for contractors but 6-20 for experienced farmer/volunteer, and up to 20-96 labour hours per 100 seedlings for inexperienced volunteers!

Tree guards and stakes are often put in place when planting seedlings to protect from rabbits and other small fauna browsing or enhance growth due to ‘greenhouse effect’. There is range of practices here; they may be made ‘at home’ eg for from milk cartons or cut down plastic bottles to cost as little as $0.17 but if purchased with the seedling may add as much as $1.00 to the cost of each plant.

While costs are calculated per ha (Table 10), the more common configuration seen in vineyards is lineal, along roads, between blocks, along water ways, around sheds. The cost of fencing is greatly increased for lineal configurations. A ‘square’ ha requires 400 m of fencing but a ha of shelterbelt 4 m wide would require 5 km of fencing if fenced on all sides. We calculate the cost of establishing one ha of revegetation by a contractor and a grower, with and without fencing and compare this to the cost of establishing shelterbelts 4-9 m wide, the range of widths of shelterbelts found in vineyards (Table 11).

Table 11. Cost per 100 m of establishing shelterbelts of commonly observed widths in vineyards in Victoria and South Australia

Established by	With fencing		Without fencing	
	Cost/ha a. 4 x 2500 m b. 9 x 1000 m	Cost/100 m for a. 4 and b. 9 m shelterbelt	Cost/ha	Cost/100m for a. 4 and b.9 m shelterbelt
Contractor	a 15510	a 620	2407	96
	b 7677	b 768		216
Grower	a 9792	a 389	975	39
	b 4913	b 490		88

We discuss the cost of revegetation with seedlings as this appears to be the most common in vineyards (pers obs, Greening Australia), although in general, direct seeding is a cheaper method of revegetation than establishing seedlings, while assisted natural regeneration costs less than either of the above methods. However, there is little hard data on the relative success of the different methods in regions and on different sites. Without a better understanding of the success of different methods, it is not possible to assess whether a method that is cheaper at the establishment phase is really the most cost effective revegetation method available.

Conclusion
The cost of establishing a typical 4 (9) m wide shelterbelt, as commonly found associated with vineyards in Victoria and South Australia, ranges from $620 (768) per 100 m for of fenced shelterbelt put in place by a contractor to $39 (88) for an unfenced shelterbelt put in place entirely at grower expense. The minimum benefit derived from 100 m of shelterbelt is $516-596. Based on the costs and benefits estimated here, there will be a net gain of every year except the first year for a fenced shelterbelt installed by a contractor. For a shelterbelt lifetime of say 20 years, with benefit in terms of natural enemies being derived from say conservatively from the 5th year, this represents a net gain ranging from $7482 for the most expensive option, fenced 9 m shelterbelt installed by a contractor to $8211 for an unfenced 4 m shelterbelt installed by the grower (Summarized in Table 12).

Finally, I again emphasise that this benefit comes from consideration only of five natural enemies with commercial value. If you consider that at least 20 different natural enemies are found at each site whose value cannot be imputed because of lack of commercial data, the benefits are even greater.

Table 12. Summary of overall benefit cost for 100 m of vegetation 4 or 9 m wide with a lifetime of 20 years.

Established by	Fenced/unfenced	Width (m)	Cost ($)	Benefit derived/year ($)[1]	Net gain first productive year[1]	Net gain over 20 years[2]
Contractor	Fenced	4	620	550	-70	7630
		9	768	550	-218	7482
	Unfenced	4	96	550	454	8154
		9	216	550	334	8034
Grower	Fenced	4	389	550	161	7861
		9	490	550	60	7760
	Unfenced	4	39	550	511	8211
		9	88	550	412	8112

[1] Mean value from our measurements in vineyards with shelterbelt widths 4-9 m. It is possible that within this, natural enemy abundance will vary with width.

[2] Assuming production of natural enemies at the rate assessed in our studies for from 5 years-20 years post establishment, with single establishment cost.

All specific performance targets pertaining to publication/communication of results were met with 11 peer reviewed and 6 industry (*Australian Viticulture* and *Australian & New Zealand Grapegrower and Winemaker*) publications (See Appendix 1) in addition to presentation at 23 conferences/field days/workshops.

7.2 Practical implications of the research
Practical implications for the industry are diverse with outcomes showing that selecting from the 'normal' range of vineyard management practices can have both economic and environmental benefits. When there is an interest in enhancing natural enemies, first and foremost the nature of chemical use has to be considered. Chemicals are essential for disease and pest control but choices can be made about the chemicals used and

consideration of toxicities will allow growers to increase abundance and diversity of natural enemies and increase their contribution to pest control. Adjacent vegetation can be easy to provide and planted in areas identified as unsuitable for vines or to provide shelter. Such vegetation is good for natural enemies while providing other benefits to the industry and to the community more generally. Cover crops in inter rows may assist growers in several ways. There may be advantages in planting perennial native cover crops which do not require mowing or repeated planting, and these might possibly contribute to improved soil condition with fewer implications for water use. So, the management practices targeted here have potential for production benefits as well as increasing diversity of invertebrates to contribute to pest control and also potentially improve soil health. In addition, reducing chemical impacts, increasing vegetation associated with vineyards and using native cover crops also have broader environmental and sustainability advantages at a time when increasing environmental outcomes are relevant[5].

There may also be other potential positive benefits from these management practices; there is potential for cost saving in reduced fuel use for tractor runs, with a reduced need to apply chemicals and decreased requirement for mowing with establishment of perennial native cover crops. In an indirect way, reduced fuel use and chemical applications due to vegetation and cover crops may in the future be beneficial in carbon accounting. Currently, only fuel use is incorporated into the industry carbon accounting scheme (Australian Wine Carbon Calculator v1.0 April 2009 Winemakers Federation of Australia http://www.wfa.org.au/environment.htm) but there is future potential for C cost of farm chemicals to be included as well as C sequestration in woody vegetation and soil carbon.

While pest control is an immediate problem there are also future issues such as invasions of new pests, whether introduced despite quarantine (such as glassy winged sharp shooter), or whether from changes in distribution with climate change (Thomson *et al.*, 2009). Encouraging high levels of a diverse and abundant suite of natural enemies optimizes protection against new pest species.

7.3 Economic and environmental benefits to the industry

There are environmental benefits in identifying means of shifting the balance in pest control towards natural enemies and decreasing chemical applications. Natural enemies of vineyard pests are well known to growers and if we can increase natural enemies there is potential to increase control, especially of difficult pests. At the same time we can reduce pesticide inputs with resulting economic savings, and also reduced environmental impacts on vineyards and the surrounding environment.

The industry recognizes the value of developing a sustainable approach to grape growing particularly with reference to both increasing vegetation and decreasing chemical impacts.
'Vineyards have historically been established on land already modified for agricultural production, such as grazing, cropping and dairy. Although the wine industry has not been directly responsible for the clearing of large tracts of native vegetation, the industry does accept a role in reinstating areas of native habitat in the landscape.' [6]
Sustaining Success - 2002 set as a priority environmental issues including both the use of insecticides, fungicides and herbicides and maintaining and enhancing natural ecological systems and protecting biodiversity. Here we demonstrate overlap in achieving these goals, through sensitive use of chemicals (less toxic chemicals applied) and establishment/maintenance of vegetation to achieve environmental and pest control aims.

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[5]GWRDC 5 year plan
[6]Winemakers Federation of Australia Policy Position '*Statements on Biodiversity*'

Australia's 'clean and green' image is seen as critical to the industry's competitive advantage[7] as consumer demand for products which are natural, and environmentally friendly[8]. This research points to a way of reducing chemical input, decreasing the accumulation of chemicals within the soil and surface runoff of chemicals into neighbouring waterways. Social benefits associated with a cleaner and healthier environment flow from such environmental benefits. Vegetation softens the environmental impact of vineyards by providing a buffer between the vineyard and the community. Vegetation adjacent to vineyards provides habitat for desirable vertebrates and invertebrates, maximising biodiversity, and enhancing positive community perception of the industry. Our research indicates ways to manage these environments for maximum benefit to the growers.

8 Recommendations:

Grower response to our database on chemical impacts for increasing abundance and diversity of natural enemies underlines the importance of continuing to provide up to date information on chemical impacts and sustainable pest control. This requires at the very least continued provision to the industry of current chemical toxicity information as the available data increases and chemical inputs change. While the present study showed adjacent vegetation enhanced natural enemy abundance, some predators and parasitoids were not affected by local vegetation and many of these showed a response to landscape at the regional scale. These natural enemies may respond to wider features of the surrounding landscape and there are indications from the literature that for some natural enemies, availability of regional species pools may be more important than local resources (Schweiger *et al.*, 2005). For instance, larger undisturbed areas may be necessary to preserve abundant populations of larger parasitoids (Kruess and Tscharntke, 2000; Kruess, 2003). Hence, it would be useful to further investigate responses to vegetation at a wider scale to determine potential influences of wider non-crop habitat. Determining the relevant scale at which beneficials contribute would be of interest to the industry and wider community.

As the industry looks to the future, this project provides an enormous database regarding natural enemies, their distributions and means to encourage them. This database needs to be maintained and expanded as it is excellent first step to monitoring the broader impacts of climate change and new management practices on vineyards. If pest distributions change there may be new natural enemy complexes that can provide control or else natural enemies may migrate into well managed vineyards (Thomson *et al.*, 2009). Likely effects of climate change on viticultural pests will depend not only on direct potential effects on the pests in their responses to changes in temperature and water availability but also on how climate influences beneficial invertebrates that suppress pests. The database also provides a way of monitoring long term trends important for control, such as the apparent and concerning decrease in parasitism by wasps which has also been noted on a world wide scale.

Appendix 1: Communication:

Outcomes of this project have been communicated via 47 publications, including one book chapter and initiation and co-editing a special issue of the Australian Journal of Experimental Agriculture (vol 47: 2007) in response to a perceived need for guidelines in moves towards sustainability across agricultural industries in Australia. Publications comprise 16 (including 3 in review) peer reviewed and 6 industry publications, and establishment of a database to provide easy access for the industry to chemical information. Further communication has

[7] Winemakers Federation of Australia 10 year marketing strategy *'the Marketing Decade'* released in 2000

[8] Winemakers Federation of Australia *Strategy 2025*

taken place by oral presentations at 6 international and Australian meetings, including 2 at wine industry conferences and 6 poster presentations. We have also 12 industry presentation ranging from conference presentations to presentations to grower groups.

Publications are listed below and copies of the published articles are attached where available (indicated *).

Book chapters

Thomson, L. J. and A. A. Hoffmann (2006) Integrated strategies and bioindicators for sustainable grape production in Australia. Encyclopaedia of Pest management D. Pimentel (Ed.) Marcel Dekker, New York

Refereed journals

Chong, C.S., Hoffmann, A.A., Thomson, L.J. Local scale spatial dynamics of ants in a temperate agricultural ecosystem. Ecological Entomology, in review.

Thomson, L.J. and Hoffmann, A.A. Natural enemy responses and pest control: importance of local vegetation. Biological Control, in review.

Nash, M. A., Hoffmann, A. A. and Thomson, L. J. Identifying signatures of chemical applications in non-target invertebrate communities in vineyards. Ecological Applications, in review.

Thomson, L.J., Danne, A., Sharley, D. J., Penfold, C. M. and. Hoffmann, A. A. Effects of native grass cover crops on beneficial and pest invertebrates in Australian vineyards. Journal of Economic Entomology, in review.

Chong, C.S., D'Alberto, C.F., Thomson, L.J. and Hoffmann, A.A. Influence of native ants on arthropod communities in a vineyard. Agricultural and Forest Entomology, under revision.

*Thomson, L.J., Macfadyen, S. and Hoffmann, A.A. (2009) Predicting the effects of climate change on natural enemies of agricultural pests. Invited contribution to Special Issue of Biological Control *'Biological control: current state, future prospects.* Editors: Gurr, G.A., Ash, G. and Pilkington, L. Biological Control, doi:10.1016/j.biocontrol.2009.01.022.

*Thomson, L.J. and Hoffmann, A.A. (2009) Vegetation increases the abundance of natural enemies in vineyards. Biological Control, 49, 259–269.

*Sharley, D.J, Hoffmann, A. A. and Thomson, L. J. (2008) The effects of soil tillage on beneficial invertebrates within the vineyard. Agricultural and Forest Entomology 10, 233–243.

*Thomson, L.J. and Hoffmann, A.A. (2007) Ecologically sustainable chemical recommendations for agricultural pest control? Journal of Economic Entomology 100: 1741-1750.

*Chong, C. S., Hoffmann, A. A. and Thomson, L. J. (2007) Commercial agrochemical applications in vineyards do not influence ant communities. Environmental Entomology 36: 1374-1383.

*Thomson, L. J. and Hoffmann, A. A. (2007) Effects of ground cover (straw and compost) on the abundance of natural enemies and soil macro invertebrates in vineyards. Agricultural and Forest Entomology 9: 173-179.

*Paoletti, M. G.,Osler, G. H. R.,Kinnear, A.,Black. D. G., Thomson, L. J., Tsitsilas, A., Sharley, D. J., Judd, S. ,Neville, P. and D'Incà, A. (2007) Detritivores as indicators of landscape stress and soil degradation. Australian Journal of Experimental Agriculture 47: 412-423.

*Paoletti, Maurizio G, Thomson, L. J. and Hoffmann, A. A. (2007) Using invertebrate bioindicators to assess agricultural sustainability: proposals and current practices. Australian Journal of Experimental Agriculture 47: 379-383. Introduction to Special Issue.

*Thomson, L. J., Sharley, D. J. and Hoffmann, A. A. (2007) Beneficial organisms as bioindicators for environmental sustainability in the grape industry Australian Journal of Experimental Agriculture 47: 404-411 Special Issue.
*Thomson, L. J. and Hoffmann, A. A. (2006) Field validation of laboratory-derived IOBC toxicity ratings for natural enemies in commercial vineyards. Biological Control 39: 507-515.
*Thomson, L.J. (2006) Influence of reduced irrigation on beneficial invertebrates in vineyards. Australian Journal of Experimental Agriculture 46: 1389-1395.
*Tsitsilas, A., Stuckey, S., Hoffmann, A. A., Weeks, A. R. and Thomson, L. J. (2006) Shelterbelts in agricultural landscapes suppress invertebrate pests. Australian Journal of Experimental Agriculture 46: 1379-1388.

Industry publications

*Linda Thomson, Michael Nash and Ary Hoffmann (2009) Increasing natural enemy abundance and diversity in vineyards by reducing pesticide toxicity. Australian & New Zealand Grapegrower and Winemaker 37th Annual Technical Issue: 17-20.
*Linda Thomson, Alana Danne, David Sharley, Michael Nash, Chris Penfold and Ary Hoffmann (2009) Native grass cover crops can contribute to pest control in vineyards. Australian Viticulture 13: 54-58.
*Thomson, L.J. and Hoffmann, A.A. (2008) Vegetation increases abundance of natural enemies of common pests in vineyards. Australian & New Zealand Grapegrower & Winemaker 36th Annual Technical Issue 533: 34-37.
*Chong, C., 2008. The work of ants in vineyards. Australian Viticulture 7, 87-88.
*Thomson, L. J. and A. A. Hoffmann (2007) Natural enemies of vineyard pests: enhancing natural enemy populations using IOBC ratings to help select pesticides. Australian & New Zealand Grapegrower & Winemaker 516: 26-27.
*Thomson, L. J. and A. A. Hoffmann (2006) The influence of adjacent vegetation on the abundance and distribution of natural enemies in a vineyard Australian & New Zealand Grapegrower & Winemaker 514: 36-42.

Database

Thomson, L.J. Marshall, S. Thomson, E.C. and Hoffmann, A.A. (2008) Collateral Management for grapes in Australian vineyards: Minimising the toxicity of pesticides to beneficial invertebrates. Web based pesticide information tool for grape growers http://cesar.org.au/index.php?option=com_collateral_manage

Conference Presentations (oral)

Thomson, L. J. (2008) Influence of adjacent vegetation on the abundance and distribution of natural enemies in a vineyard in south eastern Australia. XXIII International Congress of Entomology, Durban, South Africa July 2008.
Thomson, L. J. and A. A. Hoffmann (2008) Ecologically sustainable chemical recommendations for agricultural pest control? XXIII International Congress of Entomology, Durban, South Africa July 2008.
Thomson, L.J. (2008) Invertebrates as Sustainability Indicators. Invited Seminar Department of Primary Industries Seminar, Knoxfield Victoria May 2008.
Hoffmann A.A. and L.J. Thomson (2008) Towards metrics for season-long assessments of chemical impact on beneficials. Australian and New Zealand BioControl Conference. Sydney February 2008
Hoffmann A.A. (2007) Sustainable pest control and climate change. NIPI meeting, Orange NSW.
Thomson, L.J. and A.A. Hoffmann (2007) Ecologically sustainable chemical recommendations for agricultural pest control? Australian Entomological Society Conference Beechworth, September 2007
M. A. Nash, L. J. Thomson and A. A. Hoffmann. (2006) Conservation, carabids & crops. Australian Entomological Society Conference, 2006

Conference Presentations (poster)

Chris Penfold and Linda Thomson (2009) Pursuing sustainability – the role of native cover crop species. 4th International South African Society for Enology and Viticulture conference on Enology &Viticulture – beyond 2010. Cape Town South Africa 28-30 July 2009.

Chee-Seng Chong, Linda J. Thomson and Ary A Hoffmann (2008) Vegetation effect on spatial distribution of ants in vineyards. XXIII International Congress of Entomology, Durban, South Africa July 2008.

Chee-Seng Chong, Linda J. Thomson and Ary A. Hoffmann (2008) Influence of ants on arthropod communities in a vineyard. XXIII International Congress of Entomology, Durban, South Africa July 2008.

Linda J Thomson, David J. Sharley and Ary A. Hoffmann (2008) The influence of vegetation adjacent to vineyards on natural enemies Australian and New Zealand BioControl Conference. Sydney February 2008.

Michael J. Nash, Linda J. Thomson, Paul A. Horne and Ary A. Hoffmann (2008) *Notonomus gravis* (Chaudoir) (Coleoptera: Carabidae) lying in wait for *Deroceras reticulatum* Müller (Gastropoda: Stylommatophora Australian and New Zealand BioControl Conference. Sydney February 2008.

Clare D'Alberto, Linda Thomson and Mark Elgar (2007) Spider predation: a double-edged sword? Determining the role of spiders in biocontrol using PCR-based gut content analysis. 17th International Congress of Arachnology. São Pedro, Brazil August 2007.

Industry Presentations/Workshops

Penfold, C. (2009) Native grass cover crops in vineyards. Field day at Nuriootpa March 2009.

Thomson, L.J. (2008) Collateral Management for Grapes. Invited Seminar. Grampians Winemakers Viticulture Group -Western Victoria Viticulture Seminar Ararat October 2008.

Thomson, L.J. (2008) Collateral Management for Grapes. Yarra Valley Winegrape Growers Annual Technical Sub Committee General Meeting. Healesville September 2008.

Thomson, L.J. (2008) Collateral Management for Grapes. Invited Seminar. Sustainable viticulture in day-to-day vineyard practice. Mornington Peninsula Vignerons Association . Main Ridge September 2008.

Thomson, L.J. (2008) The influence of remnant and shelterbelt vegetation on pests and natural enemies. Otways Agroforestry Network Annual General Meeting. Invited Seminar. Birregurra August 2008.

Thomson, L.J. (2008) The Influence of Remnant and Shelterbelt Vegetation on Pests and Natural Enemies. Greening Australia Gippsland, Glenmaggie May 2008.

Thomson, L.J. (2008) The Influence of Remnant and Shelterbelt Vegetation on Pests and Natural Enemies. Greening Australia Gippsland, Nambuk May 2008.

Hoffmann, A.A., Thomson, L. J. and Pearce, S. (2008) Responses of viticultural pests to climate change. Grape FACE (Free-Air CO_2 enrichment Facility) Workshop. Adelaide May 2008.

Thomson, L.J. (2007) Sustainable Winegrowing. Yarra Valley Wine Growers Association Technical Committee De Bortoli Yarra Glen November 2007.

Thomson, L. J. (2007) Reducing pesticide use in viticulture. 13th Australian Wine Industry Technical Conference Adelaide August 2007.

Thomson, L. J. (2007) Environmental Monitoring: Rapid Analytical Methods13th Australian Wine Industry Technical Conference Adelaide August 2007.

Thomson, L. J. (2006) Insects & benefits to farms. Benefits of Native Vegetation on Your Property. Training Series for Greening Australia. Connewarre November 2006.

Thomson, L. J. (2006) Sustainable management practices. Presentation to De Bortoli vineyard managers. Yarra Glen August 2006.

Further communication activities:
Field days and workshops are always valuable opportunities not only to inform of our research findings but also to discuss these with growers and we are always keen to accept invitations. We have approached the AWITC with a workshop proposal for the 2010 conference to reach a broad audience.

We would like to see the database appear on a website with greater grower access. In the future, we see the value in growers having easy access to pest and natural enemy images such as those provided by ' Insects Pests and Beneficials Guide' published by the Cotton CRC http://www.cottoncrc.org.au or Commonwealth government's 'Pest and Diseases Images Library' http://padil.gov.au and the grape industry site at http://www.winetitles.com.au/diagnosis. Such images could also be published as hard copy, perhaps added to the excellent Field Guide or in an independent guide.

Appendix 2: Intellectual Property:
None identified. The research outcomes have all been published and provided as a public benefit.

Appendix 3: References:

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