**Coccinellid abundance in shelterbelts is affected more by adjacent crop
type and aphid abundance than vegetation characteristics**

IAN M. SMITH, ARY A. HOFFMANN, LINDA J. THOMSON

School of BioSciences, Bio21 Institute, The University of Melbourne, 30 Flemington Road,
Parkville 3010, Victoria, Australia

Corresponding author: Ian M. Smith

Contact details:

Ian M. Smith: +613 8344 2519, imsmith@student.unimelb.edu.au

Linda J. Thomson: +613 9035 3128, lthom@unimelb.edu.au

Ary A. Hoffmann: +613 8344 2522, ary@unimelb.edu.au

Coccinellid abundance in shelterbelts is affected more by adjacent crop type and aphid abundance than vegetation characteristics

IAN M. SMITH, ARY A. HOFFMANN, LINDA J. THOMSON

1. Abstract/summary

Coccinellidae are important natural enemies of agricultural pests in a variety of crops and there is interest in landscape manipulation to enhance coccinellid populations. Here we investigate impacts of non-crop woody vegetation variables, adjacent crop type and abundance of aphid prey on coccinellid abundance in shelterbelts adjacent to vineyards or pasture near Melbourne, Australia. Sixty sites were sampled five times at monthly intervals using yellow sticky traps. The abundance of coccinellids in shelterbelts was influenced to a greater extent by adjacent crop type and aphid abundance rather than vegetation characteristics like canopy flowers. Abundance of some species was 2-5 times higher in riparian shelterbelts while increased litter depth decreased abundance. When the leaf litter depth of shelterbelts was experimentally increased, the abundance of coccinellids decreased, whereas an experimental decrease in porosity tended to have the opposite effect. These findings suggest that coccinellid abundance can be influenced to some extent by characteristics of shelterbelts, but crop type and prey availability is likely to have a relatively larger impact, perhaps reflecting the high movement rates of this group of natural enemies.

Key words. Pasture, vineyard, non-crop vegetation, conservation biological control, windbreak.

2. Introduction

In agricultural environments, many arthropod groups naturally occurring within or adjacent to crops act as important biological control agents. Increasing interest in integrated pest management techniques has resulted in studies investigating how the efficacy of these species on pest control could be enhanced (Collins et al., 2002; Gareau et al., 2013; Murphy et al., 1996). One such arthropod family of economic importance is the coccinellid family, with species from this group recognised internationally as predating on key agricultural pest species. Examples of pests attacked include the light brown apple moth *Epiphyas postvittana* Walker (Thomson et al., 2000), grape phylloxera *Daktulosphaira vitifoliae* Fitch (Wheeler and Jubb, 1979) and many species of mealybug and scale (Chacko et al., 1978; Geiger and Daane, 2001; Kairo et al., 2000 Michaud and Harwood, 2012, Obrycki and Kring, 1998; Rakimov et al. 2015). Some species of coccinellids are also known to consume non-arthropod pest species such as the Asian grapevine leaf rust fungus *Phakopsora euvitidis* Y. Ono (Culik et al., 2011). Within Australia, specific species of coccinellids are agriculturally-important biological control agents, for example *Diomus notescens* Blackburn is known to predate on eggs of light brown apple moth, the most economically significant insect pest in Australian vineyards (MacLellan, 1973; Thomson and Hoffmann, 2013).

Due to the potential of coccinellids to reduce economic damage caused by pest species, management actions could be taken to maintain or increase populations of these beneficial species. Previous research has indicated that coccinellid abundance can be enhanced both through direct and indirect management actions. Direct approaches include reducing the use of broad-spectrum chemicals, particularly organophosphates to which coccinellids are sensitive (Thomson and Hoffmann, 2006), providing resources such as artificial food or using semiochemicals (Obrycki *et al.*, 2009).

Indirect methods include provision of a range of resources not normally available within crops. Resources provided may include microclimates, food, alternative prey and habitat. These resources can be provided by addition of non-crop vegetation within the crop, or the establishment or conservation of perennial vegetation adjacent to crops. The density and amount of plants can influence coccinellid populations as this alters the microclimate; light levels and the composition of herbaceous plants, trees and shrubs can all influence the abundance of different species including coccinellids (Grez *et al.*, 2010; Honěk, 1985). Floral resources provided by flowering cover crops or flowering species of shelterbelt trees can provide coccinellids with food sources in the form of nectar and pollen (Bottrell *et al.*, 1998; Landis *et al.*, 2005; Rebek *et al.*, 2005), as well as providing a food source for alternative prey (Gurr *et al.*, 2003). Leaf litter can be used for shelter and diapause (Roy *et al.*, 2007). Additionally, adjacent crop types may influence coccinellid abundance by affecting the abundance and diversity of pest species in the area (Werling *et al.*, 2011; Woltz and Landis, 2014). Nearby crops can act as a population source for some beneficial species (Bell *et al.*, 2006), or provide an abundance of prey such as aphids, with which coccinellid abundance has been associated (Bianchi *et al.*, 2006; Schellhorn and Andow, 2005).

As a consequence of these resources, within-crop vegetation, such as weed strips and cover crops, can increase coccinellid numbers (Gurr *et al.*, 2003; Jose, 2009; Nicholls *et al.*, 2000). Grass cover may be particularly important both at a local scale (Bianchi *et al.*, 2006) as well as at a landscape scale (Gardiner *et al.*, 2009; Woltz and Landis, 2014). Woody vegetation adjacent to crops, such as shelterbelts and hedgerows (Gareau and Shennan, 2010), can also enhance coccinellid populations within adjacent crops (Grez *et al.*, 2010; Thomson and Hoffmann, 2010; 2013) and may be more important than other local factors (Paredes *et al.*, 2015).

These findings raise questions about the relative impact of different characteristics of agricultural habitats on the abundance of coccinellids. Is abundance largely a reflection of the availability of prey and the nature of local crops, or can other characteristics of non-crop vegetation have an impact on abundance? If so, what characteristics of non-crop vegetation are the most important: the presence of floral resources, structural features, litter or other factors?

Here we consider these questions by focussing on species of coccinellids within shelterbelts in an agricultural landscape consisting mostly of vineyards and pastures. Previous research focusing on vineyards in south-eastern Australia has indicated that woody vegetation can increase abundance of some species of coccinellids within vineyards (Thomson and Hoffmann, 2013, 2010, 2009). However it is unknown whether particular features of this vegetation promote a high abundance of coccinellids, or if these effects are relatively more important than the nature of the surrounding landscape.

3. Methods

3.1 Sites

Sixty areas of woody vegetation adjacent to agricultural land were selected for coccinellid sampling from within the Yarra Valley (Figure 1), a region located approximately 40 km north-east of Melbourne, Australia, around 80 m above sea level. Climatically the area has a mean annual temperature range of 20.2°C to 7.3°C with a mean annual rainfall of 726.7 mm (Bureau of Meteorology, 2014). Vineyards and grazing land (pasture) are the predominant forms of agricultural production in the Yarra Valley. Perennial crops were selected for study as they generally provide a relatively stable environment which is more amenable to conservation biological control compared to annual crops (Landis *et al.*, 2000). Additionally,

vineyards in the region commonly use agrochemicals of low toxicity to beneficial insects, further increasing environmental stability (Thomson and Hoffmann, 2010).

Of the 60 sites, 31 were located adjacent to vineyards and 29 adjacent to pasture. Thirty four were shelterbelts, 11 were riparian (7 adjacent to vineyards, 4 to pasture) and 15 were remnant (7 adjacent to vineyards, 8 to pasture). The width of the shelterbelts and riparian vegetation ranged between 1.2 and 33 m, while the remnant vegetation was measured up to 28 m wide. Only woody vegetation in which the canopy was predominantly Australian native species, typically indigenous *Eucalyptus*, was considered. Native *Eucalyptus* trees are the dominant tree planted for agroforestry in temperate wetter areas of Australia (Mead, 1995). Other non-native species in the Yarra Valley are typically densely planted cypress trees (*Cupressus* sp.), which can suppress understory growth and do not produce true flowers (Feyera *et al.*, 2002), important characteristics promoting beneficial species diversity, density and impact (Fukuda *et al.*, 2011; Gámez-Virués *et al.*, 2009; Nicholls *et al.*, 2000; Tsitsilas *et al.*, 2011). Due to the size of the study area and high plant diversity within this area, the influence of woody vegetation structure on coccinellids was studied rather than the influence of specific species.

3.2 Sampling

Five sampling points were used at each site. Sampling points consisted of five wooden stakes placed 10 m apart within the centre of the woody vegetation at each site. At riparian sites, stakes were placed halfway between the edge of the vegetation and the waterway. At the start of each month between October 2011 and February 2012 (5 collections), yellow sticky traps (Agrisense) measuring 240 mm by 100 mm were attached to each wooden stake. These were placed 1 m from the ground consistent with previous studies (Thomson and Hoffmann,

2009). Sticky traps were in place for 6-8 days. Yellow sticky traps were returned to the laboratory and captured coccinellids were assessed *in situ*, sorted to species level using a dissecting microscope at magnifications x20 to x100 using Ślipiński (2013) and Matthews (1992). Aphididae were also counted.

3.3 Vegetation

Three vegetation characteristics of the non-crop woody vegetation at the 60 sites were assessed: number of trees, numbers of shrubs and canopy cover. The number of trees and number of shrubs were recorded as a count of the number of canopy and woody understory plants respectively within the 40 m section between the first and the last sample point. A categorical visual estimate of the canopy cover was undertaken and canopy was rated as either <10% coverage, 10-30%, 30-50%, 50-70% or >70% (Lassau and Hochuli, 2005). For consistency a mirror was used to view the canopy and was compared to known cover percentage sample images.

In addition to woody vegetation, five characteristics (or variables) describing ground cover were also recorded. These variables were measured using a 10 m transect along the length of the vegetation, with intercept points every 40 cm for a total of 25 points as per Gaucherand & Lavorel (2007). At each intercept point, grass height, leaf litter depth, ground vegetation cover, native vegetation cover and introduced vegetation cover were recorded. Grass height was the average length of grass species at each transect point from base to tip. Litter depth was the average depth of any tree debris less than 10 cm in diameter including leaves, bark and twigs. Ground vegetation cover was scored as the number of points of the transect that intersected with grass or other plants, while native and introduced vegetation cover was scored as the number of native or introduced species intersecting. Native grasses included kangaroo grass *Themeda triandra* Forssk. and weeping grass *Microlaena stipoides*

Labill., while the introduced grasses were typically pasture species such as cock's foot *Dactylis glomerata* L. and sweet vernal grass *Anthoxanthum odoratum* L. All vegetation characteristics except for floral resources were recorded once only in the 40 m section between the first (0 m) and the last (40 m) coccinellid sampling point, or as part of the 10 m ground transect. In repeated sampling at some of the sites, we found that these characteristics did not change much between months.

Floral resources in the canopy and understory were assessed at each site. Floral resource abundance was assessed by estimating the amount of flowers within each site on a 5-point scale, adapted from Brereton *et al.* (2005) (none, few, many, dense and very dense flower amounts for both the canopy and understory), to obtain a floral resource score. This was repeated at the start of each month during the study period. The main flowering species in the canopy were native *Eucalyptus* trees including black gum *Eucalyptus ovata* Labill., narrow-leaved peppermint *E. radiata* Sieber ex DC., yellow box *E. melliodora* A.Cunn. ex Schauer, messmate stringybark *E. obliqua* L'Hér., red box *E. polyanthemos* Schauer, candlebark *E. rubida* H. Deane & Maiden and manna gum *E. viminalis* Labill. The dominant understory flowers were typically introduced dandelions, *Taraxacum* spp., and angled onion, *Allium triquetrum* L.

3.4 Analysis

Coccinellids were sorted to species level and the mean coccinellid abundances for the five collections pooled and used in analyses, with the exception of floral resources which were associated with monthly captures due to the ephemeral nature of flowering. Pooled data were used in order to assess activity of coccinellids and their prey over a growing season. In order to assess the influence of vegetation on coccinellid abundance, only species that were abundant and present at the majority of sites were selected for analysis.

Spearman correlations were used to determine associations between coccinellid species abundance and vegetation variables. Non-parametric tests were used as the distribution of many of the vegetation variables was not normally distributed. As correlations among the coccinellids tended to be positive (see below), a principal components analysis was also run to identify a common axis that captured coccinellid abundance generally. For one of the uncommon coccinellid species, a Mann-Whitney U test was conducted on its presence/absence versus aphid abundance to test for aphid effects. For discontinuous data we computed non-parametric Mann-Whitney U statistics to compare the influence of adjacent crop type, riparian and remnant vegetation on coccinellid numbers. Because site comparisons involved a number of variables we have interpreted marginally significant results cautiously. We also present *P* values corrected with the Bonferroni approach for the number of variables tested for vegetation structure (9) and location variables (3) although this correction is likely to be too conservative, particularly because we are testing specific *a priori* hypotheses.

4. Manipulative experiment

4.1 Site selection

For the manipulative experiment, a study site 2 km southeast of Yarra Glen was selected. This site was chosen as it contained two similar shelterbelts that were long, straight and uniform as well as being typical in design for the region. The shelterbelts were predominantly native species with a *Eucalyptus*-dominated canopy, with intermittent *Casuarina* and a shrub layer of *Callistemon* and *Acacia*. The ground layer contained a mixture of indigenous and introduced pasture grasses typical of the region, predominantly cock's foot, sweet vernal grass, knottybutt grass *Paspalidium constrictum* (Domin) C.E.Hubb. and kneed wallaby-grass *Rytidosperma geniculatum* (J.M.Black) Connor & Edgar. The shelterbelts are located within the centre of a vineyard (53 ha), providing a relatively uniform surrounding landscape. The

longest shelterbelt was 220 m long while the nearby shorter shelterbelt was 140 m. The two shelterbelts were 150 m apart separated by mown pasture grasses and a row of elm trees. The longer shelterbelt ran from the southwest to the northeast and the second northwest to southeast. The average height of the shelterbelt was 12 m from ground to canopy top.

4.2 Design

Two treatments were tested in different plots: the addition or removal of leaf litter and the addition or lack of fencing (porosity). For plots with leaf litter removed, as much leaf litter as possible was raked off the ground. This litter was then transferred to litter supplemented plots. Between 15 kg and 24 kg was added or removed from each plot. To test the effect of change in shelterbelt porosity, green 1 m high plastic barrier mesh with 8 cm x 4 cm holes separated by 1 cm mesh (Boddingtons barrier fencing mesh, medium weight, green) was added to sections of the shelterbelt to simulate dense shelterbelt vegetation structure. Two parallel rows of barrier mesh were erected through the centre of the shelterbelt 30 cm apart. The green barrier mesh reduced wind speed, while the large holes in the material prevented the mesh acting as a complete barrier to insect movement. Green barrier mesh also provided a consistent uniform coverage similar to planted vegetation. Green was chosen for the mesh colour to prevent bright colours attracting or repelling arthropods.

A block design was used across the two shelterbelts similar to Tsitsilas *et al.* (2011). The longer of the shelterbelts contained three blocks, the second contained two. Each block was 72 m long and divided into four 18 m wide treatment plots. For each of these 18 m wide plots, four treatments were randomly assigned: no fencing with leaf litter removed, no fencing with added leaf litter, added fencing with leaf litter removed and added fencing with added leaf litter.

Yellow sticky traps were used to sample arthropod abundance once per month over three months between March and May 2013. The traps placed within the fenced sections of shelterbelt were located either side of the barrier mesh with two sticky traps placed every 4.5 m along the shelterbelt, 2 m from each side of the barrier mesh (twice the height of the mesh), for a total of 6 traps in each treatment. For the treatments without fences, the sticky traps were placed in the same manner but 2.3 m from the centre line of the shelterbelt. Sticky traps were placed on both the northern and southern orientation of the shelterbelt to test orientation effects as shelterbelts can cause a greater amount of arthropod accumulation on the leeward side of a shelterbelt, potentially influencing treatment effects (Pasek, 1988).

4.3 Analysis

Replicate traps within a location were averaged, and mean captures for the three collections were also averaged to reflect invertebrates collected at a particular site. As many traps captured low numbers of coccinellids, data were fitted to a gamma distribution and analysed with a generalised linear model run in IBM SPSS Statistics 22 when assessing the association between coccinellids, fencing and leaf litter.

5. Results

5.1 Woody vegetation characteristics

On average, woody vegetation in the Yarra Valley consisted of an open canopy cover (median canopy cover score = 2, range = 1 – 5) with a limited number of shrubs (median count = 16.5, range = 0 – 400) and a median of 14 trees per research site section (range = 0 – 70). Ground cover comprised a median leaf litter depth of 16.8 mm (range 0 – 102.2 mm)

with tall grass (median height 551.8 mm, range 0 – 1359 mm) that covered 80% of the ground and was comprised of 70% introduced species.

Floral resources were highly seasonal, with most flowers blooming between October and December and few flowers blooming in January and February when most shelterbelts contained no canopy flowers and only occasional understory flowers. The average floral resource score over five months for all sites was higher for understory (median floral score = 6, range 0 – 14) than for canopy (median floral score = 1, range 1 – 10).

5.2 Coccinellidae

Across all sites and months, 1864 individuals from 13 coccinellid species were counted from yellow sticky traps. Five species were sufficiently abundant ($N > 196$) and present at most sites ($\geq 80\%$ of sites) for analysis: *Diomus sydneyensis* Blackburn ($N = 761$) (2.2 – 3.5 mm), *Diomus* sp. nov. 1 ($N = 437$) (1.14 – 1.26 mm), *Rhyzobius ventralis* Erichson ($N = 200$) (2.0 – 2.6 mm), *Diomus* sp. nov. 2 ($N = 197$) (2.1 – 2.7 mm) (Thomson *et al.*, 2010) and *Diomus* sp. nov. 3 ($N = 102$) (1.2 – 3.5 mm). The average capture rates per site and trap were lowest in October before rising to a peak in November then reducing in number until an apparent second peak in February (Figure 2).

Spearman rank correlations indicated significant associations between coccinellid species across sites pooled by month ($N = 60$). Several species were positively associated, with *D. sydneyensis* associated with *Diomus* sp. nov. 1 ($r = 0.286$, $P = 0.027$) and *Diomus* sp. nov. 2 ($r = 0.606$, $P = < 0.001$), as were *Diomus* sp. nov. 2 and *Diomus* sp. nov. 1 with each other ($r = 0.377$, $P = 0.003$) and with *R. ventralis* ($r = 0.320$, $P = 0.013$ and $r = 0.258$, $P = 0.046$ respectively). In the principal components analysis, one component with an eigenvalue substantially above 1 was isolated; this component accounted for 41.4% of variation, with all five coccinellid species loading positively onto this component (loadings > 0.5).

5.3 Effects of vegetation resources and structure

None of the variables related to vegetation structure (number of trees, canopy cover, and number of shrubs) were significantly correlated with any coccinellid species (Table 1). Of the ground cover variables, only leaf litter depth had a significant effect. *D. sydneyensis* ($r = -0.346$, $P = 0.007$) and *Diomus* sp. nov. 2 ($r = -0.270$, $P = 0.037$) exhibited a significantly negative correlation with this variable (although the latter is not significant after Bonferroni correction), while *Diomus* sp. nov. 1 was not correlated with this variable ($r = -0.084$, $P = 0.523$). The principal component reflecting general coccinellid abundance was not correlated ($r = -0.207$, $P = 0.113$) with litter depth.

There were no significant associations between monthly species collections and monthly floral resources (r values in the range $-0.230 - 0.260$, P values in the range $0.058 - 0.923$). Due to the lack of monthly correlations, floral resource scores for the five monthly collections were pooled. Pooled understory floral resources did not significantly correlate with any coccinellid species or group (r values in the range $-0.001 - -0.095$, P values in the range $0.470 - 0.992$), however canopy floral resources did correlate with the abundance of the most common species *D. sydneyensis* ($r = 0.289$, $P = 0.028$) and *Diomus* sp. nov. 2 ($r = 0.293$, $P = 0.025$), although these are not significant after Bonferroni correction. Canopy floral resources also significantly correlated with principal component scores ($r = 0.366$, $P = 0.005$) which were typically higher in sites with higher floral resource scores; for instance, the mean score for sites with a floral resource score of 0 was -0.238 , while for sites with a floral resource score of 4 it was 0.311 .

Two coccinellid species positively correlated with aphid abundance: *D. sydneyensis* ($r = 0.355$, $P = 0.005$) and *Diomus* sp. nov. 2 ($r = 0.309$, $P = 0.016$), although the latter is not significant after Bonferroni correction. Aphids were also more than twice as abundant at

vineyard sites ($P = 0.001$, vineyard median 7.92, pasture median 3.76) and were negatively correlated with leaf litter ($r = -0.411$, $P = 0.001$). Although *Diomus cuculifer* (Blackburn) was only present at 16.7% of sites and therefore not a focus of this study, a Mann–Whitney U test indicated that aphids were significantly less abundant ($P = 0.005$) in sites with *D. cuculifer*.

5.4 Effects of location variables

Abundance of Coccinellidae was associated with adjacent land type and use, being more abundant adjacent to vineyards and riparian area (Figure 3). The presence of riparian vegetation was associated with an increased abundance of *D. sydneyensis* ($P = 0.007$), *Diomus* sp. nov.1 ($P = 0.014$) and *Diomus* sp. nov. 2 ($P = 0.002$). These three species were also associated with adjacent land use, with *D. sydneyensis* ($P = 0.002$), *Diomus* sp. nov.1 ($P = 0.010$) and *Diomus* sp. nov. 2 ($P = 0.002$) significantly higher in abundance in vegetation adjacent to vineyards. The median of all captured coccinellid species was higher in vineyard than pasture sites. No species significantly correlated with remnant vegetation. The principal component scores were positively correlated with both adjacent crop type ($r = 0.457$, $P = 0.001$) and riparian sites ($r = 0.422$, $P = 0.001$). The principal components score was larger in vineyards (mean = 0.352) compared to pasture (mean = -0.376) and larger in riparian sites (mean = 1.10) compared to other sites (mean = -0.247).

5.5 Manipulative experiment

Three species were sufficiently abundant for analysis within the manipulative experiment: *Serangium bellum* Ślipiński & Burckhardt ($N = 597$), *Diomus sydneyensis* ($N = 184$) and *Diomus* sp. nov. 3 ($N = 185$). Other species captured in the observational study were too low in abundance for analysis including *Diomus* sp. nov. 1 ($N = 51$), *Diomus* sp. nov. 2 ($N = 4$) and *Rhyzobius ventralis* ($N = 9$).

The generalized model run with a log link indicated significant effects of treatments and orientation for some species. Addition of leaf litter only had a significant effect on *Serangium bellum* which decreased in abundance ($X^2 = 7.19$, $df = 1$, $P = 0.007$) (Figure 4). The total number of all three coccinellids was also found to be significantly affected by added leaf litter ($X^2 = 10.5$, $df = 1$, $P = 0.001$) involving a decrease in abundance.

Fencing yielded mixed results (Figure 5), with *S. bellum* significantly lower in fenced plots ($X^2 = 4.23$, $df = 1$, $P = 0.040$), while *Diomus* sp. nov. 3 was higher ($X^2 = 5.73$, $df = 1$, $P = 0.017$). *Diomus sydneyensis* was also higher in fenced plots; once an outlier value in block 4 was excluded from the model, *D. sydneyensis* was significantly higher in fenced plots ($X^2 = 6.56$, $df = 1$, $P = 0.010$).

Coccinellids were also found to be significantly influenced by orientation with all species found to be higher in abundance on the southern side of the shelterbelt.

6. Discussion

The results of this study suggest that the manipulation of porosity, canopy floral resources and leaf litter could have a significant influence on coccinellid abundance, with these features warranting further research on their practical potential to enhance biological control within adjacent agricultural crops. Higher porosity of shelterbelts may have increased coccinellid numbers by affecting local micro-climate conditions, and this could lead to an increased abundance in adjacent crops due to reduced wind speed improving flying or resulting in air turbulence causing deposition into crops (Lewis, 1965; Pasek, 1988; Smith and Lewis, 1972). Coccinellids have previously been found to be more abundant in sheltered sites than in surrounding fields, and to utilise shelterbelts as areas of shelter from windy conditions or high temperatures rather than for other resources (Dix *et al.*, 1997; Gareau *et al.*, 2013). However, we also found that a decrease in shelterbelt porosity provided by the

mesh fencing reduced the abundance of *Serangium bellum* in contrast to that of the other two species. The abundance of this species may have been influenced by other landscape features that can affect predatory arthropods (e.g. Bianchi *et al.*, 2007; Elliott *et al.*, 1998; Woltz and Landis, 2014) although features such as vegetation composition have previously been shown as unimportant for small coccinellids within Australian vineyards (Thomson *et al.*, 2010).

Although coccinellids are attracted to and utilise floral resources (Long *et al.*, 1998; Rebek *et al.*, 2005; Woltz *et al.*, 2012), we found a limited influence of flowers in the canopy or understory. Gareau *et al.* (2013) also noted that coccinellids were abundant in shelterbelts regardless of whether plants were flowering. Perhaps nectar and pollen are not limiting resources within our study site because adjacent areas provide similar resources. Coccinellids may also prefer extrafloral resources rather than floral resources (Almeida *et al.*, 2011; Lundgren, 2009). *Eucalyptus* flowers in the canopy have exposed nectaries which would be easier to utilise by predatory Coleoptera compared to the partially hidden or concealed nectaries of flowers commonly found within the understory of studied shelterbelts (Krenn *et al.*, 2005).

Consistent results were found between litter in the site survey and in the manipulative experiment. The removal and addition of litter in the manipulative experiment suggested that this negative relationship was causal, with removal resulting in higher abundance of coccinellids. The reason for this effect is not clear because leaf litter can be used by coccinellid species to diapause and for overwintering (Roy *et al.*, 2007). Perhaps leaf litter depth influences the abundance of predatory arthropods such as spiders, which could predate on coccinellids (Bultman and Uetz, 1982; Wagner *et al.*, 2003).

Although significant associations between these shelterbelt characteristics and abundance were found, the effects were not particularly large. For example, for the site with the highest canopy flower amounts (floral resource score of 10), the mean abundance of

Diomus sp. nov. 2 was 0.16, whereas at a site with a canopy score of 0 this species had a mean abundance of 0.08, reflecting a 2-fold difference in abundance. Similarly for the site that lacked leaf litter, there was a mean of 0.75 for *D. sydneyensis*, which reflected a 1.8-fold increase when compared to the site with the deepest (102 mm) leaf litter, where the mean abundance was 0.42.

The limited size of the above features may be due to landscape features having a greater influence than local resources. This is suggested by the significant correlations between coccinellids and adjacent crop type, riparian areas or local prey abundance. Individual coccinellid species were up to 7.5 times more abundant on average when sites were adjacent to vineyards compared to pasture. They were also up to 5.4 times more abundant when vegetation was riparian (adjacent to a water course) compared to non-riparian sites. Aphid numbers were on average 2.1 times higher in sites adjacent to vineyards and 1.5 times higher in riparian sites.

The substantial impact of adjacent crops on coccinellid numbers in this study suggest that there may be a spill-over effect of coccinellids from crops rather than an association with local resources. Some previous surveys have suggested that generalist predators such as coccinellids can increase in abundance near adjacent crops (Rand and Tschardt, 2007; Rand *et al.*, 2006). Presumably there may be a greater abundance of prey species such as aphids in vineyards than in pastures which could explain the higher abundance of coccinellids within vineyard sites compared to pasture sites. Most recorded *Diomus* species were associated with each other and typically with *R. ventralis*, and these coccinellids share similar resources (Dixon and Hemptinne, 2001). The *Diomus* diet is believed to consist of scale, aphids, mealybugs or whitefly, while *R. ventralis* feeds on scale (Ślipiński, 2013; Matthews, 1992; Rakimov *et al.*, 2015). Previous studies have indicated that coccinellid abundance is influenced by prey abundance, especially aphid distribution and abundance (Bianchi *et al.*,

2007; Evans and Richards, 1997). As well as being affected by high prey abundance, coccinellids could also be influenced by the lower levels of disturbance in adjacent vineyards as perennial crop systems (Landis *et al.*, 2000; Werling *et al.*, 2011).

The increase in abundance of two species of coccinellids in riparian areas is consistent with previous research indicating that natural enemy species can be more abundant in or adjacent to riparian areas (Whitaker *et al.*, 2000), particularly for native coccinellid species (Grez *et al.*, 2013). The reasons for this increased abundance are not clear, although riparian habitat can provide landscape connectivity and dispersal corridors (Landis *et al.*, 2005; Nicholls *et al.*, 2001).

7. Conclusion

In this study the abundance of coccinellids was influenced by features of non-crop vegetation as well as surrounding landscape features. This indicates that both factors need to be considered if attempting to manipulate species abundance for biological control. Adjacent crop type and prey abundance had the largest impact on coccinellid abundance in non-crop vegetation. Other factors that may have smaller influences include distance to riparian habitat, abundance of canopy flowers and depth of leaf litter. Within sites, it appears characteristics such as shelterbelt porosity and the presence of leaf litter can influence coccinellid abundance. Therefore a hypothetical area of non-crop vegetation with abundant canopy flowers, limited leaf litter and a location adjacent to riparian habitat and vineyards is likely to result in a relatively higher abundance of coccinellids and associated biological control. Whether this higher abundance within non-crop vegetation would have an economically significant effect on agricultural pest species requires further research.

441 8. Acknowledgment

442

443 Financial assistance for this study was provided by the Holsworth Wildlife Research
444 Endowment (grant number 084193) and by the Jasper Loftus-Hill Memorial Fund. Support
445 with experimental design was provided by Dr Michael Nash. Assistance with field and
446 laboratory work was provided by Ms Elke Schellekens and Mr Pim van de Mortel. Assistance
447 with Coccinellidae identification was provided by Dr Adam Ślipiński. Access to research
448 sites was generously granted by the landholders and managers in the Yarra Valley.

449

10. References

- Almeida, L.M., Corrêa, G.H., Giorgi, J.A., Grossi, P.C., 2011. New record of predatory ladybird beetle (Coleoptera , Coccinellidae) feeding on extrafloral nectaries. Rev. Bras. Entomol. 55, 447–450.
- Bell, V.A., Brightwell, R.J., Lester, P.J., 2006. Increasing vineyard floral resources may not enhance localised biological control of the leafroller *Epiphyas postvittana* (Lepidoptera: Tortricidae) by *Dolichogenidea* spp. (Hymenoptera: Braconidae) parasitoids. Biocontrol Sci. Technol. 16, 1031–1042. doi:10.1080/09583150600828502
- Bianchi, F.J.J.A., Booij, C.J., Tscharntke, T., 2006. Sustainable pest regulation in agricultural landscapes: a review on landscape composition, biodiversity and natural pest control. Proc. R. Soc. B Biol. Sci. 273, 1715–1727. doi:10.1098/rspb.2006.3530
- Bianchi, F.J.J.A., Honěk, A., Werf, W., 2007. Changes in agricultural land use can explain population decline in a ladybeetle species in the Czech Republic: evidence from a process-based spatially explicit model. Landsc. Ecol. 22, 1541–1554. doi:10.1007/s10980-007-9145-z
- Bottrell, D.G., Barbosa, P., Gould, F., 1998. Manipulating natural enemies by plant variety selection and modification: a realistic strategy? Annu. Rev. Entomol. 43, 347–67. doi:10.1146/annurev.ento.43.1.347
- Brereton, R., Mallick, S., Kennedy, S., 2005. Foraging preferences of Swift Parrots on Tasmanian Blue-gum: tree size, flowering frequency and flowering intensity. Emu 104, 377–383.

471 Bultman, T., Uetz, G., 1982. Abundance and community structure of forest floor spiders
 472 following litter manipulation. *Oecologia* 55, 34–41.

473 Bureau of Meteorology, 2014. Climate statistics for Australian locations [WWW Document].
 474 Bur. Meteorol. URL http://www.bom.gov.au/climate/averages/tables/cw_086383.shtml
 475 (accessed 1.28.14).

476 Chacko, M.J., Bhat, P.K., Rao, L.V.A., Deepak Singh, M.B., Ramanarayan, E.P., Sreedharan,
 477 K., 1978. The use of the ladybird beetle, *Cryptolaemus montrouzieri* for the control of
 478 coffee mealybugs. *J. Coffee Res.* 8, 14–19.

479 Collins, K., Boatman, N., Wilcox, a, Holland, J., Chaney, K., 2002. Influence of beetle
 480 banks on cereal aphid predation in winter wheat. *Agric. Ecosyst. Environ.* 93, 337–350.
 481 doi:10.1016/S0167-8809(01)00340-1

482 Culik, M.P., Ventura, J.A., de Almeida, L.M., Corrêa, G.H., 2011. Feeding by the coccinellid
 483 *Psyllobora rufosignata* (Coleoptera: Coccinellidae) on the Asian grapevine leaf rust
 484 fungus *Phakopsora euvitis* (Basidiomycota: Uredinales). *Biocontrol Sci. Technol.* 21,
 485 235–238. doi:10.1080/09583157.2010.538668

486 Dix, M.E., Hodges, L., Brandle, J., 1997. Effects of shelterbelts on the aerial distribution of
 487 insect pests in muskmelon. *J. Sustain. Agric.* 9, 5–24.

488 Dixon, A., Hemptinne, J., 2001. Body size distribution in predatory ladybird beetles reflects
 489 that of their prey. *Ecology* 82, 1847–1856.

490 Elliott, N., Kieckhefer, R., Lee, J., French, B., 1998. Influence of within-field and landscape
 491 factors on aphid predator populations in wheat. *Landsc. Ecol.* 14, 239–252.

492 Evans, E.W., Richards, D.R., 1997. Managing the dispersal of ladybird beetles (Col.:
 493 Coccinellidae): Use of artificial honeydew to manipulate spatial distributions.
 494 Entomophaga 42, 93–102. doi:10.1007/BF02769884

495 Feyera, S., Beck, E., Lüttge, U., 2002. Exotic trees as nurse-trees for the regeneration of
 496 natural tropical forests. Trees 16, 245–249. doi:10.1007/s00468-002-0161-y

497 Fukuda, Y., Moller, H., Burns, B., 2011. Effects of organic farming, fencing and vegetation
 498 origin on spiders and beetles within shelterbelts on dairy farms. New Zeal. J. Agric. Res.
 499 54, 155–176. doi:10.1080/00288233.2011.591402

500 Gámez-Virués, S., Gurr, G.M., Raman, A., Nicol, H.I., 2010. Plant diversity and habitat
 501 structure affect tree growth , herbivory and natural enemies in shelterbelts. Basic Appl.
 502 Ecol. 11, 542–549. doi:10.1016/j.baae.2010.02.011

503 Gámez-Virués, S., Gurr, G.M., Raman, A., Salle, J., Nicol, H.I., 2009. Effects of flowering
 504 groundcover vegetation on diversity and activity of wasps in a farm shelterbelt in
 505 temperate Australia. BioControl 54, 211–218. doi:10.1007/s10526-008-9182-9

506 Gardiner, M.M., Landis, D.A., Gratton, C., DiFonzo, C.D., O’Neal, M., Chacon, J.M., Wayo,
 507 M.T., Schmidt, N.P., Mueller, E.E., Heimpel, G.E., 2009. Landscape diversity enhances
 508 biological control of an introduced crop pest in the north-central USA. Ecol. Appl. 19,
 509 143–54.

510 Gareau, T., Letourneau, D., Shennan, C., 2013. Relative densities of natural enemy and pest
 511 insects within California hedgerows. Environ. Entomol. 42, 688–702.

512 Gareau, T.P., Shennan, C., 2010. Can Hedgerows Attract Beneficial Insects and Improve Pest
 513 Control? A Study of Hedgerows on Central Coast Farms [WWW Document]. Res.

514 Briefs, Cent. Agroecol. Sustain. Food Syst. UC St. Cruz. URL
 515 <http://escholarship.org/uc/item/11d3v8p9.pdf> (accessed 6.4.12).
 516

517 Gaucherand, S., Lavorel, S., 2007. New method for rapid assessment of the functional
 518 composition of herbaceous plant communities. *Austral Ecol.* 32, 927–936.
 519 doi:10.1111/j.1442-9993.2007.01781.x

520 Geiger, C., Daane, K., 2001. Seasonal movement and distribution of the grape mealybug
 521 (Homoptera: Pseudococcidae): developing a sampling program for San Joaquin Valley
 522 vineyards. *J. Econ. Entomol.* 94, 291–301.

523 Grez, A. A., Rand, T. A., Zaviezo, T., Castillo-Serey, F., 2013. Land use intensification
 524 differentially benefits alien over native predators in agricultural landscape mosaics.
 525 *Divers. Distrib.* 19, 749–759. doi:10.1111/ddi.12027

526 Grez, A., Torres, C., Zaviezo, T., 2010. Migration of coccinellids to alfalfa fields with
 527 varying adjacent vegetation in Central Chile. *Cienc. e Investig. Agrar.* 37, 111–121.

528 Gurr, G.M., Wratten, S.D., Luna, J.M., 2003. Multi-function agricultural biodiversity : pest
 529 management and other benefits. *Basic Appl. Ecol.* 4, 107–116.

530 Honěk, A., 1985. Habitat preferences of aphidophagous coccinellids [Coleoptera].
 531 *Entomophaga* 30, 253–264.

532 Jose, S., 2009. Agroforestry for ecosystem services and environmental benefits: an overview.
 533 *Agrofor. Syst.* 76, 1–10. doi:10.1007/s10457-009-9229-7

534 Kairo, M.T.K., Pollard, G. V., Peterkin, D.D., Lopez, V.F., 2000. Biological control of the
 535 hibiscus mealybug, *Maconellicoccus hirsutus* green (Hemiptera: Pseudococcidae) in the
 536 Caribbean. Integr. Pest Manag. Rev. 5, 241–254. doi:10.1023/A:1012997619132

537 Krenn, H.W., Plant, J.D., Szucsich, N.U., 2005. Mouthparts of flower-visiting insects.
 538 Arthropod Struct. Dev. 34, 1–40. doi:10.1016/j.asd.2004.10.002

539 Landis, D.A., Menalled, F.D., Costamagna, A.C., Wilkinson, T.K., 2005. Manipulating plant
 540 resources to enhance beneficial arthropods in agricultural landscapes. Weed Sci. 53,
 541 902–908. doi:10.1614/WS-04-050R1.1

542 Landis, D.A., Wratten, S.D., Gurr, G.M., 2000. Habitat management to conserve natural
 543 enemies of arthropod pests in agriculture. Annu. Rev. Entomol. 45, 175–201.

544 Lassau, S.A., Hochuli, D.F., 2005. Wasp community responses to habitat complexity in
 545 Sydney sandstone forests. Austral Ecol. 30, 179–187. doi:10.1111/j.1442-
 546 9993.2005.01435.x

547 Lewis, T., 1965. The effects of an artificial windbreak on the aerial distribution of flying
 548 insects. Ann. Appl. Biol. 55, 503–512.

549 Long, R., Corbett, A., Lamb, C., Reberg-Horton, C., Chandler, J., Stimmann, M., 1998.
 550 Beneficial insects move from flowering plants to nearby crops. Calif. Agric. 52, 23–26.

551 Lundgren, J.G., 2009. Nutritional aspects of non-prey foods in the life histories of predaceous
 552 Coccinellidae. Biol. Control 51, 294–305. doi:10.1016/j.biocontrol.2009.05.016

553 MacLellan, C.R., 1973. Natural enemies of the light brown apple moth, *Epiphyas postvittana*,
 554 in the Australian Capital Territory. Can. Entomol. 105, 681–700.

- 555 Matthews, E.G., 1992. A guide to the genera of beetles of South Australia. Part 6: Polyphaga:
556 Lymexyloidea, Cleroidea and Cucujoidea. South Australian Museum, Adelaide.
- 557 Mead, D.J., 1995. The role of agroforestry in industrialized nations: The southern hemisphere
558 perspective with special emphasis on Australia and New Zealand. *Agrofor. Syst.* 31,
559 143–156.
- 560 Michaud, J.P., Harwood, J.D., 2012. Quantifying the impact of coccinellids on their prey, in
561 ecology and behaviour of the ladybird beetles (Coccinellidae). John Wiley & Sons, Ltd,
562 Chichester, UK. doi:10.1002/9781118223208.ch10
- 563 Murphy, B.C., Rosenheim, J.A., Granett, J., 1996. Habitat diversification for improving
564 biological control: Abundance of *Anagrus epos* (Hymenoptera: Mymaridae) in grape
565 vineyards. *Environ. Entomol.* 25, 495–504.
- 566 Nicholls, C.I., Parrella, M., Altieri, M.A., 2000. Reducing the abundance of leafhoppers and
567 thrips in a northern California organic vineyard through maintenance of full season
568 floral diversity with summer cover crops. *Agric. For. Entomol.* 2, 107–113.
- 569 Nicholls, C.I., Parrella, M., Altieri, M.A., 2001. The effects of a vegetational corridor on the
570 abundance and dispersal of insect biodiversity within a northern California organic
571 vineyard. *Landsc. Ecol.* 16, 133–146.
- 572 Obrycki, J.J., Harwood, J.D., Kring, T.J., O’Neil, R.J., 2009. Aphidophagy by Coccinellidae:
573 application of biological control in agroecosystems. *Biol. Control* 51, 244–254.
574 doi:10.1016/j.biocontrol.2009.05.009
- 575 Paredes, D., Cayuela, L., Gurr, G.M., Campos, M., 2015. Is Ground Cover Vegetation an
576 Effective Biological Control Enhancement Strategy against Olive Pests. *PLoS One* 10.

- 577 Pasek, J., 1988. Influence of wind and windbreaks on local dispersal of insects. Agric.
578 Ecosyst. Environ. 22/23, 539–554.
- 579 Rakimov, A., Hoffmann, A.A., Malipatil, M.B., (2015) Natural enemies of soft scale insects
580 (Hemiptera:Coccoidea: Coccidae) in Australian vineyards. Australian Journal of Grape
581 and Wine Research. In press.
- 582 Rand, T., Tscharnkte, T., 2007. Contrasting effects of natural habitat loss on generalist and
583 specialist aphid natural enemies. Oikos 116, 1353–1362. doi:10.1111/j.2007.0030-
584 1299.15871.x
- 585 Rand, T., Tylianakis, J., Tscharnkte, T., 2006. Spillover edge effects: the dispersal of
586 agriculturally subsidized insect natural enemies into adjacent natural habitats. Ecol. Lett.
587 9, 603–614. doi:10.1111/j.1461-0248.2006.00911.x
- 588 Rebek, E.J., Sadof, C.S., Hanks, L.M., 2005. Manipulating the abundance of natural enemies
589 in ornamental landscapes with floral resource plants. Biol. Control 33, 203–216.
590 doi:10.1016/j.biocontrol.2005.02.011
- 591 Roy, H.E., Brown, P.M.J., Rothery, P., Ware, R.L., Majerus, M.E.N., 2007. Interactions
592 between the fungal pathogen *Beauveria bassiana* and three species of coccinellid:
593 *Harmonia axyridis*, *Coccinella septempunctata* and *Adalia bipunctata*. BioControl 53,
594 265–276. doi:10.1007/s10526-007-9122-0
- 595 Schellhorn, N. A., Andow, D. A., 2005. Response of coccinellids to their aphid prey at
596 different spatial scales. Popul. Ecol. 47, 71–76. doi:10.1007/s10144-004-0204-x
- 597 Ślipiński, A. 2013. Australian ladybird beetles (Coleoptera: Coccinellidae): their biology and
598 classification. CSIRO Publishing, Canberra.

599 Smith, B., Lewis, T., 1972. The effects of windbreaks on the blossom-visiting fauna of apple
600 orchards and on yield. *Ann. Appl. Biol.* 72, 229–238.

601 Thomson, L.J., Glenn, D., Hoffmann, A.A., 2000. Effects of sulfur on *Trichogramma* egg
602 parasitoids in vineyards: measuring toxic effects and establishing release windows. *Aust.*
603 *J. Exp. Agric.* 40, 1165–1171.

604 Thomson, L.J., Hoffmann, A.A., 2006. Field validation of laboratory-derived IOBC toxicity
605 ratings for natural enemies in commercial vineyards. *Biol. Control* 39, 507–515.
606 doi:10.1016/j.biocontrol.2006.06.009

607 Thomson, L.J., Hoffmann, A.A., 2009. Vegetation increases the abundance of natural
608 enemies in vineyards. *Biol. Control* 49, 259–269. doi:10.1016/j.biocontrol.2009.01.009

609 Thomson, L.J., Hoffmann, A.A., 2010. Natural enemy responses and pest control: Importance
610 of local vegetation. *Biol. Control* 52, 160–166. doi:10.1016/j.biocontrol.2009.10.008

611 Thomson, L.J., Hoffmann, A.A., 2013. Spatial scale of benefits from adjacent woody
612 vegetation on natural enemies within vineyards. *Biol. Control* 64, 57–65.
613 doi:10.1016/j.biocontrol.2012.09.019

614 Thomson, L.J., McKenzie, J., Sharley, D.J., Nash, M.A., Tsitsilas, A., Hoffmann, A.A., 2010.
615 Effect of woody vegetation at the landscape scale on the abundance of natural enemies
616 in Australian vineyards. *Biol. Control* 54, 248–254.
617 doi:10.1016/j.biocontrol.2010.05.018

618 Tsitsilas, A., Hoffmann, A.A., Weeks, A.R., Umina, P.A., 2011. Impact of groundcover
619 manipulations within windbreaks on mite pests and their natural enemies. *Aust. J.*
620 *Entomol.* 50, 37–47. doi:10.1111/j.1440-6055.2010.00779.x

- 621 Wagner, J., Toft, S., Wise, D., 2003. Spatial stratification in litter depth by forest-floor
622 spiders. *J. Arachnol.* 31, 28–39.
- 623 Werling, B.P., Meehan, T.D., Gratton, C., Landis, D.A., 2011. Influence of habitat and
624 landscape perennality on insect natural enemies in three candidate biofuel crops. *Biol.*
625 *Control* 59, 304–312. doi:10.1016/j.biocontrol.2011.06.014
- 626 Wheeler, A.J., Jubb, G.J., 1979. *Scymnus cervicalis* Mulsant, a predator of grape phylloxera,
627 with notes on *S. Brullei* Mulsant as a predator of woolly aphids on elm (Coleoptera:
628 Coccinellidae). *Coleopt. Bull.* 33, 199–204.
- 629 Whitaker, D.M., Carroll, A.L., Montevecchi, W. a., 2000. Elevated numbers of flying insects
630 and insectivorous birds in riparian buffer strips. *Can. J. Zool.* 78, 740–747.
631 doi:10.1139/cjz-78-5-740
- 632 Woltz, J.M., Isaacs, R., Landis, D. A., 2012. Landscape structure and habitat management
633 differentially influence insect natural enemies in an agricultural landscape. *Agric.*
634 *Ecosyst. Environ.* 152, 40–49. doi:10.1016/j.agee.2012.02.008
- 635 Woltz, J.M., Landis, D.A., 2014. Coccinellid response to landscape composition and
636 configuration. *Agric. For. Entomol.* 1–9. doi:10.1111/afe.12064

Figure 1: Map of the greater Melbourne area including the Yarra Valley. Black dots represent the location of each of the 60 sampling sites used in this study, light grey represents greater Melbourne and dark grey represents water.

Figure 2: Total Coccinellidae captured per month across all 60 sites used in the site comparison, including species identified in this study and other species .

649

650 **Figure 3:** Mean captures of coccinellid species per trap at all 60 sites adjacent to pasture
 651 versus vineyards. Error bars represent standard errors. Asterisk denotes significant difference
 652 between pasture and vineyard at ($P < 0.05$).

653

654

655

656 **Figure 4:** Median species abundance between sites with leaf litter added and leaf litter
657 removed across all collections. Error bars represent standard errors. Asterisk denotes
658 significant difference between leaf litter removed and leaf litter added at ($P < 0.05$).

659

660

661

662

663

664 **Figure 5:** Median species abundance between sites with and without fencing across all

665 collections. Error bars represent standard errors. Asterisk denotes significant difference

666 between no fencing and added fencing ($P < 0.05$).

Table 1: Spearman correlations between the five sampled Coccinellidae species and vegetation characteristics, as well as aphid abundance. Bold numbers represent significant correlations ($P < 0.05$).

		<i>D. sydneyensis</i>	<i>Diomus</i> sp. nov. 1	<i>Diomus</i> sp. nov. 2	<i>Diomus</i> sp. nov. 3	<i>Rhyzobius</i> <i>ventralis</i>
Number of trees	r	-0.133	0.036	-0.165	-0.043	0.219
	P	0.313	0.784	0.208	0.745	0.093
Canopy cover	r	-0.085	0.146	-0.137	0.049	0.004
	P	0.517	0.265	0.295	0.709	0.975
Number of shrubs	r	0.034	0.118	0.026	0.003	-0.008
	P	0.796	0.368	0.846	0.983	0.953
Canopy floral resources	r	0.289	0.199	0.293	0.090	0.129
	P	0.028	0.134	0.025	0.500	0.334
Understory floral resources	r	-0.011	-0.011	-0.001	-0.095	-0.025
	P	0.931	0.934	0.992	0.471	0.852
Grass height	r	0.079	-0.016	0.027	-0.090	-0.076
	P	0.550	0.906	0.835	0.493	0.566
Litter depth	r	-0.346	-0.084	-0.270	0.007	0.253
	P	0.007	0.523	0.037	0.957	0.051
Ground vegetation cover	r	0.096	-0.134	0.168	-0.111	-0.177
	P	0.464	0.307	0.199	0.400	0.176
Native vegetation cover	r	-0.045	-0.207	-0.142	0.120	0.090
	P	0.735	0.112	0.281	0.361	0.492
Aphid abundance	r	0.355	0.076	0.309	0.190	0.116
	P	0.005	0.562	0.016	0.146	0.379

Table 2: *P* values from Mann-Whitney U tests comparing non-crop woody vegetation sites against coccinellid abundance collected at 60 sites over 5 months. Bold type indicates significance ($P < 0.05$) symbol in brackets denotes direction of correlation.

	<i>D. sydneyensis</i>	<i>Diomus</i> sp. nov. 1	<i>Diomus</i> sp. nov. 2	<i>Diomus</i> sp. nov. 3	<i>R. ventralis</i>
Adjacent to Vineyard	0.002 (+)	0.010 (+)	0.002 (+)	0.557	0.160
Riparian	0.007 (+)	0.014 (+)	0.002 (+)	0.356	0.136
Remnant	0.550	0.452	0.787	0.394	0.725

Table 3: Generalised linear model of mean coccinellid captures against leaf litter and fence treatments, orientation of the traps, block and interactions. Bold type indicates significant effects ($P < 0.05$).

	Coccinellid species								
	<i>Diomus</i> sp. nov. 3			<i>S. bellum</i>			<i>D. sydneyensis</i>		
	X ²	df	P	X ²	df	P	X ²	df	P
Added leaf litter	2.236	1	0.135	7.193	1	0.007	1.382	1	0.240
Fence	5.734	1	0.017	4.231	1	0.040	1.882	1	0.170
Orientation	4.686	1	0.030	10.937	1	0.001	53.242	1	<0.001
Block	21.599	4	<0.001	23.390	4	<0.001	1.421	4	0.841
Added leaf litter * Fence	2.154	1	0.142	0.081	1	0.776	0.025	1	0.875
Added leaf litter * Orientation	0.827	1	0.363	1.680	1	0.195	4.947	1	0.026
Fence * Orientation	0.031	1	0.861	0.237	1	0.626	0.026	1	0.871
Added leaf litter * Fence * Orientation	2.829	1	0.093	3.789	1	0.052	0.181	1	0.670

685 11. Appendix

686

687 **Appendix 1:** Sum of individually identified coccinellids captured per month across all 60

688 sites used in the site comparison.

Minerva Access is the Institutional Repository of The University of Melbourne

Author/s:

Smith, IM;Hoffmann, AA;Thomson, LJ

Title:

Coccinellid abundance in shelterbelts is affected more by adjacent crop type and aphid abundance than vegetation characteristics

Date:

2015-08-01

Citation:

Smith, I. M., Hoffmann, A. A. & Thomson, L. J. (2015). Coccinellid abundance in shelterbelts is affected more by adjacent crop type and aphid abundance than vegetation characteristics. *BIOLOGICAL CONTROL*, 87, pp.47-55. <https://doi.org/10.1016/j.biocontrol.2015.04.004>.

Persistent Link:

<http://hdl.handle.net/11343/116028>