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Title:
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Date:
2012-08-01

Citation:
D'Alberto, C. F., Hoffmann, A. A. & Thomson, L. J. (2012). Limited benefits of non-crop vegetation on spiders in Australian vineyards: Regional or crop differences?. Biocontrol, 57 (4), pp.541-552. https://doi.org/10.1007/s10526-011-9435-x.

Persistent Link:
https://hdl.handle.net/11343/282930

Limited benefits of non-crop vegetation on spiders in Australian vineyards-regional or crop differences?

Abstract In crops, invertebrate natural enemies such as spiders have been documented as responding to non-crop vegetation at the local and landscape scales, particularly in northern Europe. Much of this information is based on data from arable or annual crops and it is possible that spider numbers in more persistent perennial systems including vineyards may be less dependent on non-crop vegetation. To test the relationship between spider abundance and non-crop vegetation within the context of Australian vineyards, we sampled spiders in 54 vineyards with adjacent non-crop vegetation, from three different regions. Landscape composition in the area surrounding each of the 54 sites was characterized at 11 spatial scales from 95 m to 3 km radius and spiders were sampled monthly using canopy sticky traps and ground pitfall traps. There were only weak relationships between pasture or woody vegetation and the abundance of spiders in vineyards at all spatial scales. At the local scale, abundance of most spider families tended to be greater in vineyards with adjacent pasture. At the landscape scale there were inconsistent patterns. We discuss possible reasons for these apparent contrasting patterns between perennial and annual crops and European compared to Australian agroecosystems.

Keywords Landscape, Pest control, Perennial, Region, Spatial scale

Introduction

Natural enemies contribute to pest control in agricultural ecosystems, and generalist predators such as spiders may have particularly useful characteristics – early season spiders are among the first predators to limit pests (Marc et al. 1999) and their ability to use alternative prey enables them to wait out periods of low prey abundance. The impact of spiders through their feeding behaviour can be substantial; a single *Larinioides cornutus* Clerk (Araneae: Araneidae) has been shown to catch a minimum of 6000 prey individuals during its whole life if it reaches the adult stage (Marc et al. 1999). In addition, pest control by spiders is enhanced beyond consumption by displacement of pests from the crop associated with spider presence. The presence of wolf spiders (Lycosidae) induces striped cucumber beetles *Acalymma vittatum* F. (Coleoptera: Chrysomelidae) to leave plants at higher rates (Williams and Wise 2003), and the re-climbing rate of aphids in alfalfa is reduced to 15% by spider presence (Duffield et al. 1996). While predation by spiders contributed to mortality of *Spodoptera littoralis* (Boisduval) (Lepidoptera: Noctuiidae) larval pests in apple orchards, their major effect in achieving a 40% reduction in crop damage is non-consumptive, through disturbance of recently hatched larvae (Mansour et al. 1981). Spiders are important predators of arthropods which include the principal insect pests of grapes, the Lepidoptera (Brust et al. 1986) and Homoptera (Nyffeler and Sunderland 2003).

Arthropod predators in annual crop fields depend strongly on the surrounding landscape because annual crops are ephemeral habitats characterised by periodical disturbances such as soil cultivation, pesticide applications and harvesting. Crops have to be recolonized by much of the arthropod fauna at least once per year (Wissinger 1997). Non-crop vegetation, through providing refuge and resources, can act as a source of natural enemies for reinvasion following disturbances within crops. The role of woody vegetation is well established in enhancing groups such as parasitoids and coccinellids known to benefit from nectar and pollen resources (Landis et al. 2000) though vegetation structure may be more important to spiders (Marc et al. 1999; Maudsley 2000), known to be highly sensitive to habitat structure and microclimatic conditions (Marc et al. 1999; Entling et al. 2007). Studies such as those of Bishop and Riechert (1990) and Schmidt and Tscharntke (2005) indicate that the wider landscape rather than adjoining habitat is important for arable spiders. The importance of semi-natural habitat in the surrounding landscape to spider abundance in arable fields has been demonstrated frequently (Weibull et al. 2003, Prasifka et al. 2004, Clough et al. 2005, Schmidt and Tscharntke 2005, Schmidt et al. 2005, Schweiger et al. 2005, Isaia et al. 2006, Öberg et al. 2007, Drapela et al. 2008). The most common non-crop component is grass (variously as ‘weedy strips’, pasture, meadows) adjacent to crops (Denys and Tscharntke 2002; Lemke and Poehling 2002; Halley et al. 1996) or present at the landscape scale (Thorbek and Topping 2005). Where woody vegetation components such as hedgerows or shelterbelts have a positive impact on spider numbers, their grassy understorey may be important (Tsitsilas et al. 2006, Le Viol et al. 2008; Tsitsilas et al. 2011), whereas a positive impact of woody vegetation itself on spider abundance in arable crops has been less commonly demonstrated (but see Frank et al. 2010).

It is possible that spider numbers in perennial agroecosystems such as orchards and vineyards are not affected in the same way, because these crops can provide suitable overwintering sites for spiders in terms of food and shelter. In Europe traditional orchards are considered to be species-rich environments (Cooper et al. 2007) which, together with other woody habitats, provide a refuge for arthropods and birds. Furthermore, spiders can successfully overwinter in vineyards (Costello and Daane 1999; Thomson and Hoffmann 2007) and orchards (Korenko and Pekar 2010). Hence it is possible that the benefits of non-crop vegetation will be reduced in perennial crops, where the effects of disturbance on natural enemies due to harvest, ploughing and pest control are less dramatic than in annual crops.

In previous studies in vineyards in Australia, we have found that woody vegetation at the local scale enhanced abundance of some parasitoids and coccinellids (Thomson and Hoffmann 2010), while woody vegetation at the landscape scale had a limited effect on these groups (Thomson et al. 2010). This result may be related to differences in landscape composition in Australia compared to in northern Europe (Thomson et al. 2010). In southeastern Australia, many vineyards are established on previously cleared land, creating a mosaic of pasture, crops and woody vegetation. The woody vegetation consists of ‘shelterbelts’, planted trees with an understory of shrubs and grasses, or occasional stands of original forested cover (here called remnant vegetation). This vegetation may pre-date the establishment of agriculture in the region or may represent regrowth following clearing, and in both cases reflect the original landscape. Areas of grass are usually planted with exotics with most of it grazed. These vineyards provide an opportunity to test the relationship between vegetation at the landscape scale and natural enemy abundance in an environment that is likely to differ from typical European landscapes with a long history of human influence on agricultural landscapes. It is unclear if non-crop vegetation has much impact on spider numbers and composition in vineyards, although the results from studies discussed above suggest that pasture rather than woody vegetation is likely to influence spider abundance.

Here we examine effects of pasture and woody vegetation at the local and landscape scales on spider abundance in vineyards. Spiders were sampled in the canopy and on the ground at 54 vineyards from 3 regions in southeastern Australia, and vegetation effects to 3000 m were considered. In the study presented here we test whetherabundance of spiders in vineyards is related to the availability of woody vegetation and pasture at the local and landscape scales.

Materials and methods

To examine the potential impact of non-crop land use at the adjacent and landscape scales, sampling was undertaken at 54 sites in commercial vineyards in 3 regions from South Australia: 17 in the Barossa Valley (34°38'S, 138°53'E), 27 at Wrattonbully (37°38'S, 140°49'E) and 10 at Padthaway (36°35'S, 140°52'E) (Thomson and Hoffmann 2010; Thomson et al. 2010). Padthaway and Wrattonbully are 300 km and 400 km south east of Barossa respectively. The vineyards are located in areas largely cleared and grazed, so there is a mosaic of vines, remnant and replanted woody vegetation and grassland (‘pasture’). Twenty six sites were selected with woody vegetation on one boundary of the vineyard, and 28 with pasture. For the sites with adjacent woody vegetation, we selected vineyards with linear complex shelterbelts (*sensu* Tsitsilas et al. 2006) - long narrow strips of trees with widths ranging from 4.0-9.1 m and including understorey plants) and blocks of remnant vegetation or replanted native vegetation, with areas ranging in size from 3.2-25.4 ha. At Barossa there were seven sites adjacent to woody vegetation (4 remnant and 3 shelterbelt) and 10 to pasture, at Wrattonbully there were 12 adjacent to woody vegetation (7, 5) and 15 to pasture and at Padthaway there were six adjacent to woody vegetation (3, 3) and four to pasture. Shelterbelts and remnant vegetation consisted of various tree species with complex understoreys of shrubs, small herbaceous plants and grasses. Woody vegetation consisted of various tree species (predominantly *Eucalyptus* and *Acacia*) with complex understoreys of shrubs, small herbaceous plants and grasses, most commonly indigenous. Pasture is so called ‘improved’, where the area has been planted with exotics, replacing native grasses, commonly perennial ryegrass (*Lolium perenne*), clover (*Trifolium repens*) bent grass (*Agrostis* spp.) and Yorkshire fog grass (*Holcus lanatus*), though small amounts of some native grasses such as *Vulpia* (silver grass), wallaby grass (*Austrodanthonia* sp.), spear grass (*Austrostipa nodosa*) and kangaroo grass (*Themeda triandra*) have reinvaded.

Each site consisted of a block of the same grape variety (Chardonnay) 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 also similar despite the number of sites considered; soil under the vines was bare earth following application of herbicides, and between the vines was mown grass (mainly perennial rye grass and phalaris *Phalaris* sp., with varying amounts of capeweed *Arctotheca calendula* and clover). Only chemicals of low toxicity to beneficials, based on IOBC ratings (http://www.koppert.nl) and related data - see Thomson and Hoffmann (2006)- were used at the sites, including sulphur (Thiovit®) (at the low dose of 200 g/100L) and tebufenozide (Mimic®).

Sampling

Five sampling points 10 m apart were established in a single row of vines 50 m into the crop from vineyard edge at each of the 54 vineyard blocks. At each sampling point we placed a pitfall trap to sample spiders at ground level and a yellow sticky trap to sample spiders in the canopy. Pitfall traps consisted of a glass test tube, 20 mm diameter x 150 mm deep with 4 cm of ethylene glycol, inserted to a plastic sleeve, 22 mm diameter x 150 mm deep, placed so that the top was flush with the surface. Ethics approval is required for installation of pitfall traps with the assurance that installation of such traps will not put at risk small vertebrates such as small reptiles and mammals. Larger pitfall traps increase the risk of killing native Australian frogs, lizards and marsupial mice, hence we prefer (and are often limited to) small pitfall size. As can be seen in results presented here, the diameter is adequate to capture larger spiders including Lycosidae. The yellow sticky traps were 240 mm x 100 mm (Agrisense) sheets suspended from the lower wire of a vertical two-wire trellis system, 1 m above the ground. Sampling was repeated five times with traps out for the first week of each month throughout the season to harvest, from October 2006 to March 2007. All adults were sorted to family with a microscope (Leica MS5) at magnification x20 to x100 using Hawkeswood (2003) and Raven et al. (2002). While analysis at species level may be desirable as species can show varying responses at the landscape scale (eg Schmidt et al. 2008), numbers collected here do not permit analysis at lower level than family for most taxa despite intense sampling effort (54 sites, 5 replicates at each site, 5 months of collection). Further, identification to species requires adult males, creating difficulties for females and juveniles and spider taxonomy in Australia is not as developed as in Europe and North America, with taxonomic resolution and occurrence of new species an ongoing issue. For example, the Lycosidae collected belong to two genera, Lycosa and Venatrix; there have been recent transfers of species between these two genera and the issue remains unresolved. As spiders are generalist predators, identification to coarser levels can nevertheless be important from a management perspective. Spiders on yellow sticky traps were assessed *in situ*, those from pitfall traps were transferred to a 10 cm Petri dish. The numbers of each spider family collected per sampling point (mean of five replicate traps pooled across five collections, log transformed for normality when required) within a vineyard were used in the analyses.

Spider abundance and local vegetation associations

To investigate effects of non-crop land-use (pasture or woody vegetation) adjacent to a vineyard on spider abundance in the vineyard 50 m from the vineyard edge, two way ANOVA (woody vegetation or pasture adjacent; and three regions) was carried out. Following ANOVA analysis, the power of the sampling effort to detect significant changes in abundance with treatment was estimated using power tests (following Zar 1996), comparing variation in means detected within treatment and between treatments to calculate the effect size at the 0.05 significance level.

Spider abundance and landscape vegetation associations

We considered the potential relationship between spiders and woody vegetation or pasture at the landscape scale. For each of the 54 landscapes, land use data were analysed within a GIS framework, overlaying aerial photographs from Nature Maps

(Department of Environment and Heritage 2006). Areas of non-crop land-use (pasture and woody vegetation) were calculated at 11 scales with radii between 95 and 3000 m around each vineyard, the area considered doubling with each subsequent radius. Because vegetation at different scales is likely to be correlated, associations at one scale will then be reflected at the next scale, so in order to consider only the contribution of vegetation at a particular scale, the effective area of vegetation at each spatial scale was calculated by subtracting the area of vegetation at one scale (A_i) from the previous scale (A_{i-1}), or $A_i = \pi * r_i^2 - \pi * r_{(i-1)}^2$ where r_i and $r_{i-1}$are the radii at the two scales, to give areas of one circle (95 m radius) and 10 annuli surrounding each of the 54 sampling points. These areas, similar to 'rings' of Bianchi et al. (2008), are referred to as 'subtracted vegetation'. Percentage land use values were angular transformed prior to analysis.

Because of the relatively low number of sites per region, we reduced the number of subtracted vegetation variables in the analyses by principal components analyses on woody vegetation and pasture separately. This also had the advantage of overcoming collinearity due to the strong correlations between vegetation across the adjacent annuli. This analysis identified two or three principal components contributing more than 10% to the variance for each region, with components reflecting vegetation near to the vineyards and more distant from them (see Results, Thomson et al. 2010). Regression analysis was used to consider the relationship between principal components and abundance of spider taxa. A stepwise approach was followed to find the best model and the scale where the strongest effects are exerted. Forward and backward elimination models were also run but these led to the same equations and are not presented.

The effect of land-use in the landscape on spider densities in each region was investigated by comparing abundance of families collected from the vineyard (50 m from the vineyard edge), to subtracted woody vegetation and pasture in the surrounding landscapes. Regions were selected to have a range of the percentage of woody vegetation in the area surrounding the vineyards: at Wrattonbully 22.29±4.80% woody vegetation in an area of radius 95 m surrounding the sites, Padthaway (32.96±2.04) and Barossa (49.59±4.34) and were analysed separately. All analyses were undertaken using SPSS for Windows v. 17 (SPSS Inc., Chicago, Illinois).

Results

From the ground, 1636 spiders (Araneae) were collected from all sites over 5 months of collection, including 419 immature spiders almost all collected in October. For adults, fourteen families were present (Araneidae, Clubionidae, Corinnidae, Dictynidae, Gnaphosidae, Linyphiidae, Lycosidae, Miturgidae, Oxyopidae, Prodidomidae, Salticidae, Tengellidae, Thomisidae, and Zoridae) and 7 (abundance greater than 35) were analysed independently (Table 1). There were 2630 spiders from eight families from the canopy, mainly Linyphiidae with some Araneidae, Tetragnathidae, Clubionidae and low numbers of Thomisidae, Theridiidae, Oxyopidae and Salticidae. Canopy spiders were analysed as a group (here referred to as Linyphiidae) as spiders could not be reliably assigned to family due to presence of immature spiders and method of sampling (Table 1).

Association of spider abundance to adjacent vegetation

Canopy spiders and Linyphiidae on the ground were more abundant in vineyards adjacent to woody vegetation as were Araneidae (Fig. 1). Gnaphosidae, Lycosidae, Salticidae, Zodariidae and immature spiders were more abundant in vineyards adjacent to pasture and Clubionidae showed no difference (Fig. 1). ANOVAs on spider abundance for all 54 sites from the three regions showed limited significant responses to wooded and pasture edges, four significant effects of region (immature spiders, Araneidae, Gnaphosidae and Salticidae) but no significant region and adjacent vegetation interactions (Table 1). On the ground 50 m into the vineyard, there was no significant effect with woody vegetation or pasture for abundance of immature spiders, Araneidae, Clubionidae, Gnaphosidae, Linyphiidae or Zodariidae (Table 1). Lycosidae and Salticidae on the ground were significantly more abundant with adjacent pasture when compared to woody vegetation and spiders collected in the canopy were more abundant with woody vegetation, but these were not significant following Dunn-Sidak correction for multiple comparisons (number of families compared). Despite low numbers of spiders detected for several families, post ANOVA power analysis indicated there was >80% probability of detecting 10% difference in the means with vegetation type at 0.05 level for all families with the exception of Clubionidae and Salticidae.

Woody vegetation and pasture at the landscape scale

Analysis of the subtracted area of woody vegetation at each distance for the three regions led to the isolation of two principal components or factors for Barossa, three for Wrattonbully and three for Padthaway (Table 2). For Barossa, the first factor (accounting for 52.1% of the variance) reflected an effect of vegetation from 95-530 m based on the strong loadings for this component, while the second (19.6%) reflected vegetation effects at 750-2120 m. For Wrattonbully, the three components (accounting for 33.2, 20.5 and 16.1% of the variance) showed positive loadings and reflected vegetation at 95-530, 750-3000 and 375-1060 m respectively. Analysis of Padthaway produced three components, contributing 43.9, 23.7 and 11.6% of the variance, reflecting effect of woody vegetation at 195-1500, 1060-3000 and 750 and 2120 m. Distances with positive loadings to principal components were consistent with factor 1 associated with smaller radii and factor 2 with greater radii for all three regions.

Analysis of the subtracted area of pasture at each distance for the three regions isolated three principal components or factors for each region (Table 3). For Barossa, the first factor (accounting for 37.8% of the variance) reflected an effect of pasture from 95-530 m based on the strong loadings for this component, while the second (24.7%) reflected pasture effects at 750-1500 m and factor 3, 14.3% variance loading at 1500-2120 m. For Wrattonbully, the three components (accounting for 44.5, 14.5 and 11.8% of the variance) showed positive loadings and reflected pasture at 95-750, 750-1500 and 1060-1500 m respectively. The three components identified at Padthaway, contributing 33.0, 24.0 and 11.8% of the variance, reflected pasture at 375-1060, 95-375 and 3000 m.

Association of natural enemy abundance with landscape vegetation

Regression analyses on the abundance of the spider families in vineyards against factors identified from non-crop vegetation in the surrounding landscape in the three regions revealed only four significant positive relationships, three with woody vegetation (Table 4) and one with pasture (Table 5). Two of the woody vegetation responses involved nearer vegetation (factor 1): Araneidae and Lycosidae both in Barossa. Two families, Gnaphosidae to woody vegetation at Padthaway and Linyphiidae to pasture at Wrattonbully, showed a positive response to more distant vegetation (factor 2). Only one relationship, that of Lycosidae to nearer woody vegetation at Barossa, remained significant following correction for multiple comparisons. Canopy spiders, juvenile spiders and families Clubionidae and Salticidae showed no significant response to woody vegetation or pasture with any factor.

Discussion

We found limited evidence for associations between woody vegetation or pasture and spider families at the local or landscape levels. The lack of response was consistent across three regions for four of the seven spider families considered as well as immature and canopy spiders. Lycosidae were the only family enhanced by nearer vegetation, adjacent pasture and near woody vegetation at Barossa, and this may indicate that this family is more likely to use cursorial dispersal. We have previously found lycosid abundance enhanced in vines adjacent to woody vegetation (Thomson and Hoffmann 2009) and in pasture adjacent to shelterbelts with grassy understorey (Tsitsilas et al. 2006).

The limited response to landscape pasture or woody vegetation contrasts with the many references to positive effects of non-crop vegetation, particularly pasture at the local (Denys and Tscharntke 2002; Bayram and Luff 1993; Huusela-Veistola 1998) and landscape (Schmidt and Tscharnkte 2005; Thorbek and Topping 2005; Gardiner et al. 2010; Clough et al. 2005; Schmidt et al. 2003; Rand and Tscharntke 2007) scales. Our previous analysis of Australian landscapes had shown only weak relationships between woody vegetation and the abundance of coccinellids and parasitoids at any spatial scale (Thomson et al. 2010) across two of these regions. These findings may reflect possible differences between landscapes in south eastern Australia and other regions where responses at the landscape scale have been considered, especially northern Europe.

We saw few differences in abundance of spider families at the local or landscape levels, despite having power to detect effects comparable to those described in other studies. This may reflect three factors – differences in landscape composition or complexity, diversity or abundance of spiders collected and/or nature of the crop. We have previously commented on the apparent contrasting patterns between European and southeastern Australian landscape patterns (Thomson et al. 2010). Unlike European landscapes, the relative abundance of woody vegetation in the wider landscape in the southeastern Australian landscape has little correlation with the local level. In the European studies, when there is a positive correlation at different levels, comparisons involve landscapes that have more woody (or other non-crop) vegetation consistently across the landscape whereas in the regions considered here we often encountered landscapes where a high abundance of non-crop vegetation around a vineyard might not be matched by a similar pattern in the broader landscape. Australian landscapes may be more similar to arable landscapes in the US, which typically lack variability in landscape complexity, land-use intensity and vegetative connectivity seen in Europe (Olson and Andow 2008).

A factor not considered in this study is landscape composition or patchiness, which could not be defined in the absence of detailed site information on understory and canopy vegetation. ‘Patchiness’ may be important to spiders due to their common method of dispersal, ballooning, where it is common for spiders to travel short distances in each ballooning event (Bell et al. 2001) so distance between patches would be more important than overall amount of suitable habitat. Habitat isolation effects were more important determinants of abundance of wood-preferring spiders in apple orchards than overall amount of woody vegetation in surrounding landscapes (Bailey et al. 2010).

The diversity of families contributing to the guild of spiders may also differ between geographical regions, and as families are associated with diverse hunting strategies this may have implications for pest control potential. The diversity we detected is more consistent with that of spider guild structure in the United States than common in Europe (Nyffeler and Sunderland 2003). Diversity of families present at the 54 sites is similar to that from in another grape region in south eastern Australia (Thomson and Hoffmann 2007) and in vineyards in California (Costello and Daane 1999) and other crops in the US (Greenstone 2001). In their review of differences in spider guilds in Europe and the United States (derived from hundreds of reports of agroecosystem spiders from the two continents), Nyffeler and Sunderland (2003) conclude that the spider fauna of European agroecosystems is strongly dominated by small linyphiid spiders (commonly over 90% of all spider individuals), which has been verified with several different sampling methods (Nyffeler and Sunderland 2003). In contrast, representatives of the family Linyphiidae are less common in the US (usually <25% of total spider) and typically a range of families comprising more complex spider guild structure is seen. Nyffeler and Sunderland (2003) suggest that this difference may be related to different farming intensity on the two continents, with farm size being much greater (order of 2X) in US compared to Europe.

Differences in spider abundance may be important in the difference in responses of spiders at the landscape scale seen here. We collected lower numbers of spiders than in European studies: our traps collected 0.16 spiders/cm trap/trap day, less than half the lowest number reported in pitfall traps from Germany (0.34) (Clough et al. 2005; Schmidt et al. 2005; Schmidt et al. 2008) and much lower than other studies (eg. 1.4 - Schweiger et al. 2005). In the US where fields and farms are an order of magnitude larger than in Europe, spider numbers are also much lower (Nyffeler and Sunderland 2003). Greenstone (2001) noted very low densities of spiders in US winter wheat compared to that reported for Europe (2-600/m^2 compared to 0.02-14 in US), and suggested the difference is related to “greater landscape diversity, due to smaller fields, more crop types, and greater use of hedgerows and other bordering vegetation in Europe than seen in this part of US at least.” Nevertheless, despite lower abundance, power analysis suggested that we could have detected a difference in abundance at the local level. In addition, a response to landscape composition has been demonstrated for diverse natural enemies including spiders (Schmidt et al. 2008) and parasitoids (Perovic et al. 2010) at abundances consistent with our minimum number used to investigate patterns (35): significant responses to increasing non-crop vegetation in the surrounding landscape were found for spiders in winter wheat crop in Germany when there were only 20 individuals for the lycosid *Trochusa ruricola* and 31 for the linyphiid *Tenuiphantes tenuis* (Schmidt et al. 2008). Similar responses have also been found with only 25 individuals of the parasitoid *Trichogramma* spp. (Hymenoptera: Trichogrammatidae) in Australian cotton (Perovic et al. 2010).

It is possible that the weaker response detected in this perennial environment compared to annual crops is related to the relatively low level of disturbance in vineyards. Spider diversity can be greater under favourable agricultural management than in natural habitats (Samu et al. 1999). Overwintering or alternative sites may be more important in annual than perennial crops due to the increased disturbance, particularly when there is low chemical use. Non-crop vegetation providing pollen and nectar may enhance groups such as parasitoids and some beetles, but spiders may not require these resources as they can overwinter in orchards (Marc et al. 1999). Previous data show that spiders remain in southeastern Australian vineyards throughout winter (Thomson 2006, Thomson and Hoffmann 2007) and also remain active in apple orchards of the Czech Republic throughout winter at average temperatures as low as 5°C (Korenko and Pekar 2010). Alternative prey for spiders such as Collembola, a main food source for many spiders (Bell et al. 2001), remains abundant in vineyards through winter (Thomson and Hoffmann 2007). In contrast, in annual crop systems, provision of non-crop refuges may be needed for overwinter survival of natural enemies (Landis et al. 2000). Some other studies in orchards and vineyards also suggest a lack of response of spiders to non-crop vegetation. In a study of the invertebrate natural enemies of Navel Orangeworm, *Amyelois transitella* Walker (Lepidoptera: Pyralidae), the abundance of spiders was not significantly related to the proportion of surrounding natural habitat in landscapes surrounding almond orchards although parasitoids were correlated (Eilers and Klein 2009). In vineyards and orchards in California, Bailey et al. (2010) report no effect of landscape on abundance of predatory spiders, and numbers were also not related to distance from woody vegetation (Hogg and Daane 2010). In fact, Korenko and Pekar (2010) suggest that orchards can act as non-crop refuges. Perennial crops like vineyards and orchards may be sink habitats for wood-related spider species (Bailey et al. 2010).

In summary, despite comprehensive collections across an entire season at many sites, our results indicate limited response of spiders in vineyards to non-crop vegetation, either at the local or landscape level. It is possible that unmeasured aspects of our non-crop vegetation including the configuration of patches in the landscape may be important (Bianchi and van der Werf 2003) or that differences between European and Australian landscapes and spider communities are responsible. It is also possible that the importance of non-crop vegetation is reduced in perennial crops such as vineyards. Assessment of landscape effects (including patch characteristics) on spider abundance in annual crops in Australia may help to provide further insight.

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Table 1. ANOVAs on effect of presence of local adjacent pasture or woody vegetation on log transformed abundance of spiders in the canopy and on the ground with woody vegetation (28 sites) and pasture (26 sites) and effect of region sampled. Numbers of each used in analyses (collected from the 54 sites over 5 months) indicated in brackets following Family. Mean squares (MS) are presented along with F ratios and *P* values. Bold values indicate significant effects ($P < 0.05$).

Family	Vegetation			Region			Interaction		
	MS	$F_{(1,53)}$	*P*	MS	$F_{(2,53)}$	*P*	MS	$F_{(3,53)}$	*P*
Canopy spiders									
mainly Linyphiidae (2630)	0.172	4.98	**0.030**	0.062	1.78	0.180	0.035	1.01	0.374
Ground spiders									
Immature (419)[a]	0.003	0.31	0.582	0.041	4.99	**0.011**	0.013	1.56	0.224
Araneidae (49)	0.001	1.31	0.259	0.004	4.78	**0.013**	0.001	1.55	0.223
Clubionidae (54)	0.001	0.01	0.986	0.004	2.58	0.087	0.001	0.12	0.883
Gnaphosidae (128)	0.006	2.11	0.153	0.013	4.47	**0.017**	0.003	0.96	0.390
Linyphiidae (156)	0.001	0.41	0.524	0.004	1.03	0.367	0.004	1.09	0.344
Lycosidae (685)	0.116	5.55	**0.023**	0.026	1.24	0.299	0.261	1.25	0.296

Salticidae (36)	0.006	5.97	**0.019**	0.006	6.49	**0.003**	0.002	2.56	0.089
Zodariidae (82)	0.001	0.13	0.716	0.014	2.34	0.108	0.001	0.01	0.991

[a] October only

Table 2. Factor loadings in Principal Components Analyses for woody vegetation at each spatial scale in radii from 95-3000 m in landscapes surrounding 54 vineyards in three regions: Barossa, Wrattonbully and Padthaway. Bold values represent factor loadings > 0.4.

	Barossa (17)		Wrattonbully (27)			Padthaway (10)		
Area[a]	PC 1	PC 2	PC 1	PC 2	PC 3	PC 1	PC 2	PC 3
95	**0.852**	-0.127	**0.892**	-0.020	-0.232	-0.638	-0.512	0.277
130	**0.932**	0.213	**0.873**	-0.100	-0.100	0.376	-0.649	0.255
195	**0.905**	0.229	**0.883**	-0.058	-0.213	**0.958**	-0.196	-0.020
265	**0.860**	0.022	**0.822**	-0.050	-0.147	**0.704**	-0.270	0.334
375	**0.899**	0.060	**0.641**	-0.149	**0.558**	**0.882**	-0.260	-0.172
530	**0.751**	-0.332	**0.422**	0.312	**0.731**	**0.277**	-0.549	**0.551**
750	-0.326	**0.699**	0.092	**0.513**	**0.475**	**0.820**	0.172	-0.226
1060	0.321	**0.818**	-0.060	**0.656**	**0.358**	**0.804**	**0.380**	0.322
1500	0.040	**0.774**	0.069	**0.691**	-0.031	**0.660**	**0.667**	-0.120
2120	-0.716	**0.386**	-0.017	**0.713**	-0.419	0.093	**0.716**	**0.607**
3000	-0.693	-0.130	0.177	**0.667**	-0.507	-0.493	**0.561**	0.379

[a] calculated from $A_i = \pi(r_i - r_{i-1})(r_i + r_{i-1})$

Table 3 Factor loadings in Principal Components Analyses for pasture at each spatial scale in radii from 95-3000 m in landscapes surrounding 54 vineyards in three regions: Barossa and Wrattonbully and Padthaway. Bold values represent factor loadings > 0.4.

	Barossa (17)			Wrattonbully (27)			Padthaway (10)		
Area[a]	PC 1	PC 2	PC 3	PC 1	PC 2	PC3	PC 1	PC 2	PC 3
95	**0.780**	0.250	0.150	**0.743**	-0.390	0.121	-0.181	**0.236**	0.007
130	**0.785**	0.082	0.285	**0.853**	-0.286	0.142	-0.545	**0.554**	-0.010
195	**0.852**	-0.163	-0.097	**0.915**	-0.190	0.063	0.150	**0.862**	0.149
265	**0.840**	-0.241	-0.272	**0.895**	-0.190	-0.058	0.109	**0.929**	-0.086
375	**0.907**	-0.054	-0.243	**0.903**	0.128	-0.031	**0.623**	**0.556**	0.137
530	**0.604**	0.104	0.142	**0.802**	0.304	-0.196	**0.797**	-0.191	0.349
750	-0.131	**0.761**	0.108	**0.416**	**0.544**	-0.548	**0.977**	0.042	0.118
1060	0.353	**0.840**	0.042	0.305	**0.328**	**0.716**	**0.493**	0.002	-0.630
1500	-0.133	**0.695**	**0.503**	0.157	**0.477**	**0.589**	-0.421	0.333	-0.612
2120	-0.016	-0.847	**0.482**	-0.469	-0.366	0.239	-0.848	-0.206	0.295
3000	-0.200	0.255	-0.897	-0.086	0.647	0.035	-0.382	0.411	**0.504**

[a] calculated from $A_i = \pi(r_i - r_{i-1})(r_i + r_{i-1})$

Table 4: Summary of spider family (where abundance in region is greater than 10) and regression coefficients derived from principal component analysis of subtracted woody vegetation at the 11 spatial scales. There were no significant responses to Factor 3 in any of the three regions (data not presented). B, standardized regression coefficient; $t_{(d.f),}$ t value from t test$_{(\text{degrees of freedom})}$; P, probability that regression coefficient differed significantly from 0. Significant positive regression coefficients in bold

	Barossa (17)						Wrattonbully (27)						Padthaway (10)					
	Factor 1			Factor 2			Factor 1			Factor 2			Factor 1			Factor 2		
	B	$t_{(14)}$	*P*	B	$t_{(14)}$	*P*	B	$t_{(25)}$	*P*	B	$t_{(25)}$	*P*	B	$t_{(8)}$	*P*	B	$t_{(8)}$	*P*
Canopy spiders	0.416	1.695	0.114	-0.148	-0.604	0.556	-0.254	-1.360	0.187	0.279	1.493	0.150	0.043	0.163	0.876	-0.577	-2.214	0.069
Ground spiders																		
immatures	-0.039	-0.144	0.888	-0.014	-0.050	0.961	-0.055	-0.263	0.795	0.037	0.173	0.864	-0.655	-2.885	0.028	0.508	2.235	0.067
Araneidae	0.565	2.631	**0.021**	-0.028	-0.131	0.898	-0.148	-0.743	0.465	0.307	1.540	0.138						
Clubionidae	-0.090	-0.372	0.716	-0.434	-1.797	0.096	-0.005	-0.024	0.981	-0.238	-1.107	0.281						
Gnaphosidae	-0.095	-0.349	0.733	-0.166	-0.699	0.497	0.167	0.782	0.443	0.036	0.166	0.870	-0.227	-1.055	0.332	0.819	3.812	**0.009**
Linyphiidae	-0.035	-0.132	0.897	0.071	0.265	0.795	0.046	0.229	0.821	0.283	1.394	0.178	0.095	0.274	0.794	-0.227	-0.652	0.539
Lycosidae	-0.696	-4.039	**0.001**	0.201	1.166	0.265	0.009	0.041	0.968	-0.119	-0.547	0.590	-0.286	-0.735	0.490	-0.043	-0.111	0.915
Salticidae							-0.360	-1.811	0.084	-0.230	-1.160	0.259	0.397	1.201	0.269	-0.281	-0.850	0.423
Zodariidae							-0.115	-0.548	0.590	-0.230	-1.082	0.292	-0.507	-1.595	0.162	0.080	0.250	0.811

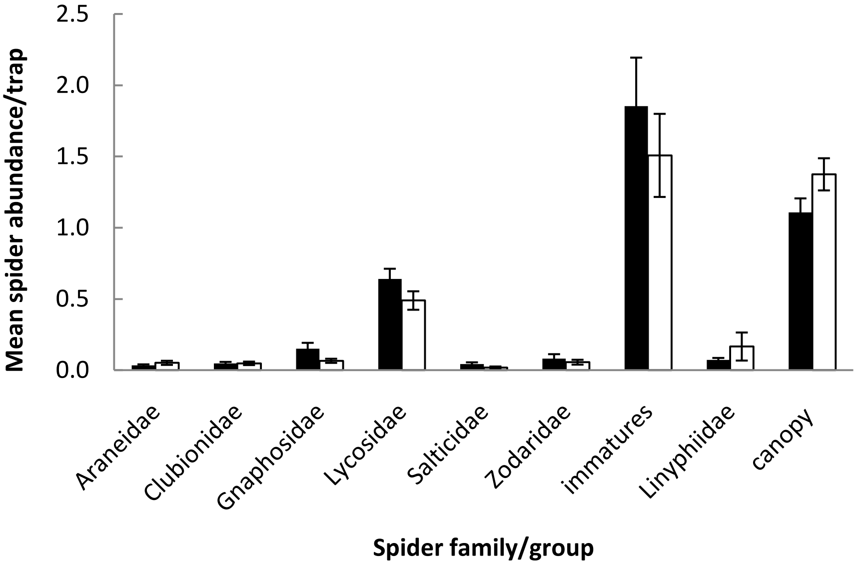
Table 5. Summary of spider family (where abundance in region is greater than 10) and regression coefficients derived from principal component analysis of subtracted pasture at the 11 spatial scales. There were no significant responses to Factor 3 in any of the three regions (data not presented). B, standardized regression coefficient; $t_{(d.f)}$, t value from t $test_{(degrees\ of\ freedom)}$; P, probability that regression coefficient differed significantly from 0. Significant positive regression coefficients in bold

	Barossa (17)						Wrattonbully (27)						Padthaway (10)					
	Factor 1			Factor 2			Factor 1			Factor 2			Factor 1			Factor 2		
	B	$t_{15)}$	*P*	B	$t_{(15)}$	*P*	B*	$t_{(25)}$	*P*	B	$t_{(25)}$	*P*	B*	$t_{(8)}$	*P*	B	$t_{(8)}$	*P*
Canopy spiders	-0.277	-1.131	0.279	0.143	0.585	0.569	0.171	0.838	0.411	0.265	1.297	0.209	-0.371	-1.240	0.261	0.433	1.448	0.198
Ground spiders																		
immatures	-0.264	-1.039	0.318	-0.174	-0.686	0.505	-0.020	-0.094	0.926	0.130	0.614	0.546	-0.373	-1.035	0.341	0.126	0.350	0.738
Araneidae	-0.144	-0.610	0.552	-0.407	-1.721	0.109	0.367	1.806	0.085	-0.036	-0.179	0.860						
Clubionidae	-0.290	-1.252	0.233	0.456	1.965	0.071	0.051	0.229	0.821	0.048	0.218	0.830						
Gnaphosidae	-0.437	-1.841	0.089	-0.166	-0.699	0.497	-0.293	-1.471	0.157	0.194	0.973	0.342	-0.259	-0.847	0.430	0.536	1.754	0.130
Linyphiidae	-0.045	-0.164	0.872	0.081	0.293	0.774	0.028	0.140	0.890	0.451	2.265	**0.035**	0.217	0.573	0.588	-0.262	-0.692	0.515
Lycosidae	-0.218	-0.880	0.395	0.291	1.174	0.261	0.000	0.002	0.999	-.0105	-0.484	0.633	0.101	0.318	0.761	-0.607	-1.917	0.104
Salticidae							-0.213	-0.970	0.344	0.113	0.516	0.611	-0.040	-0.100	0.924	-0.176	-0.438	0.677
Zodariidae							-0.306	-1.469	0.157	0.017	0.080	0.937	-0.450	-1.336	0.223	0.043	0.127	0.903

Figure captions

Figure 1. Mean spider abundance per trap of spider families collected with sticky traps in the canopy (‘canopy’) and pitfall traps on the ground at 54 sites 50 m from a vineyard edge of woody vegetation or pasture. Solid bars are pasture, open bars woody vegetation. Error bars represent standard errors.

Fig.1


2.5
2.0
1.5
1.0
0.5
0.0
Mean spider abundance/trap
Araneidae
Clubionidae
Gnaphosidae
Lycosidae
Salticidae
Zodaridae
immatures
Linyphiidae
canopy
Spider family/group