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3 **Limited benefits of non-crop vegetation on spiders in Australian vineyards-**

4 **regional or crop differences?**

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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

1 **Introduction**

2 Natural enemies contribute to pest control in agricultural ecosystems, and generalist
3 predators such as spiders may have particularly useful characteristics – early season
4 spiders are among the first predators to limit pests (Marc et al. 1999) and their ability
5 to use alternative prey enables them to wait out periods of low prey abundance. The
6 impact of spiders through their feeding behaviour can be substantial; a single
7 *Larinioides cornutus* Clerk (Araneae: Araneidae) has been shown to catch a minimum
8 of 6000 prey individuals during its whole life if it reaches the adult stage (Marc et al.
9 1999). In addition, pest control by spiders is enhanced beyond consumption by
10 displacement of pests from the crop associated with spider presence. The presence of
11 wolf spiders (Lycosidae) induces striped cucumber beetles *Acalymma vittatum* F.
12 (Coleoptera: Chrysomelidae) to leave plants at higher rates (Williams and Wise
13 2003), and the re-climbing rate of aphids in alfalfa is reduced to 15% by spider
14 presence (Duffield et al. 1996). While predation by spiders contributed to mortality of
15 *Spodoptera littoralis* (Boisduval) (Lepidoptera: Noctuidae) larval pests in apple
16 orchards, their major effect in achieving a 40% reduction in crop damage is non-
17 consumptive, through disturbance of recently hatched larvae (Mansour et al. 1981).
18 Spiders are important predators of arthropods which include the principal insect pests
19 of grapes, the Lepidoptera (Brust et al. 1986) and Homoptera (Nyffeler and
20 Sunderland 2003).

21 Arthropod predators in annual crop fields depend strongly on the surrounding
22 landscape because annual crops are ephemeral habitats characterised by periodical
23 disturbances such as soil cultivation, pesticide applications and harvesting. Crops
24 have to be recolonized by much of the arthropod fauna at least once per year
25 (Wissinger 1997). Non-crop vegetation, through providing refuge and resources, can

1 act as a source of natural enemies for reinvasion following disturbances within crops.
2 The role of woody vegetation is well established in enhancing groups such as
3 parasitoids and coccinellids known to benefit from nectar and pollen resources
4 (Landis et al. 2000) though vegetation structure may be more important to spiders
5 (Marc et al. 1999; Maudsley 2000), known to be highly sensitive to habitat structure
6 and microclimatic conditions (Marc et al. 1999; Entling et al. 2007). Studies such as
7 those of Bishop and Riechert (1990) and Schmidt and Tscharntke (2005) indicate that
8 the wider landscape rather than adjoining habitat is important for arable spiders. The
9 importance of semi-natural habitat in the surrounding landscape to spider abundance
10 in arable fields has been demonstrated frequently (Weibull et al. 2003, Prasifka et al.
11 2004, Clough et al. 2005, Schmidt and Tscharntke 2005, Schmidt et al. 2005,
12 Schweiger et al. 2005, Isaia et al. 2006, Öberg et al. 2007, Drapela et al. 2008). The
13 most common non-crop component is grass (variously as ‘weedy strips’, pasture,
14 meadows) adjacent to crops (Denys and Tscharntke 2002; Lemke and Poehling 2002;
15 Halley et al. 1996) or present at the landscape scale (Thorbek and Topping 2005).
16 Where woody vegetation components such as hedgerows or shelterbelts have a
17 positive impact on spider numbers, their grassy understorey may be important
18 (Tsitsilas et al. 2006, Le Viol et al. 2008; Tsitsilas et al. 2011), whereas a positive
19 impact of woody vegetation itself on spider abundance in arable crops has been less
20 commonly demonstrated (but see Frank et al. 2010).

21 It is possible that spider numbers in perennial agroecosystems such as orchards
22 and vineyards are not affected in the same way, because these crops can provide
23 suitable overwintering sites for spiders in terms of food and shelter. In Europe
24 traditional orchards are considered to be species-rich environments (Cooper et al.
25 2007) which, together with other woody habitats, provide a refuge for arthropods and

1 birds. Furthermore, spiders can successfully overwinter in vineyards (Costello and
2 Daane 1999; Thomson and Hoffmann 2007) and orchards (Korenko and Pekar 2010).
3 Hence it is possible that the benefits of non-crop vegetation will be reduced in
4 perennial crops, where the effects of disturbance on natural enemies due to harvest,
5 ploughing and pest control are less dramatic than in annual crops.

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

1 complex understoreys of shrubs, small herbaceous plants and grasses. Woody
2 vegetation consisted of various tree species (predominantly *Eucalyptus* and *Acacia*)
3 with complex understoreys of shrubs, small herbaceous plants and grasses, most
4 commonly indigenous. Pasture is so called 'improved', where the area has been
5 planted with exotics, replacing native grasses, commonly perennial ryegrass (*Lolium*
6 *perenne*), clover (*Trifolium repens*) bent grass (*Agrostis* spp.) and Yorkshire fog grass
7 (*Holcus lanatus*), though small amounts of some native grasses such as *Vulpia* (silver
8 grass), wallaby grass (*Austrodanthonia* sp.), spear grass (*Austrostipa nodosa*) and
9 kangaroo grass (*Themeda triandra*) have reinvaded.

10 Each site consisted of a block of the same grape variety (Chardonnay) with 3
11 m between rows, and rows consisting of vines 2 m apart planted to trellis with poles 5
12 m apart and of similar size (5-8 ha). Vine size and vigour were similar throughout the
13 blocks. Undervine and inter-row management practices were also similar despite the
14 number of sites considered; soil under the vines was bare earth following application
15 of herbicides, and between the vines was mown grass (mainly perennial rye grass and
16 phalaris *Phalaris* sp., with varying amounts of capeweed *Arctotheca calendula* and
17 clover). Only chemicals of low toxicity to beneficials, based on IOBC ratings
18 (<http://www.koppert.nl>) and related data - see Thomson and Hoffmann (2006)- were
19 used at the sites, including sulphur (Thiovit®) (at the low dose of 200 g/100L) and
20 tebufenozide (Mimic®).

21 22 23 Sampling 24

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

1 species between these two genera and the issue remains unresolved. As spiders are
2 generalist predators, identification to coarser levels can nevertheless be important
3 from a management perspective. Spiders on yellow sticky traps were assessed *in situ*,
4 those from pitfall traps were transferred to a 10 cm Petri dish. The numbers of each
5 spider family collected per sampling point (mean of five replicate traps pooled across
6 five collections, log transformed for normality when required) within a vineyard were
7 used in the analyses.

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10 Spider abundance and local vegetation associations

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

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21 Spider abundance and landscape vegetation associations

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

1 (Department of Environment and Heritage 2006). Areas of non-crop land-use (pasture
 2 and woody vegetation) were calculated at 11 scales with radii between 95 and 3000 m
 3 around each vineyard, the area considered doubling with each subsequent radius.
 4 Because vegetation at different scales is likely to be correlated, associations at one
 5 scale will then be reflected at the next scale, so in order to consider only the
 6 contribution of vegetation at a particular scale, the effective area of vegetation at each
 7 spatial scale was calculated by subtracting the area of vegetation at one scale (A_i)
 8 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
 9 two scales, to give areas of one circle (95 m radius) and 10 annuli surrounding each of
 10 the 54 sampling points. These areas, similar to ‘rings’ of Bianchi et al. (2008), are
 11 referred to as ‘subtracted vegetation’. Percentage land use values were angular
 12 transformed prior to analysis.

13 Because of the relatively low number of sites per region, we reduced the
 14 number of subtracted vegetation variables in the analyses by principal components
 15 analyses on woody vegetation and pasture separately. This also had the advantage of
 16 overcoming collinearity due to the strong correlations between vegetation across the
 17 adjacent annuli. This analysis identified two or three principal components
 18 contributing more than 10% to the variance for each region, with components
 19 reflecting vegetation near to the vineyards and more distant from them (see Results,
 20 Thomson et al. 2010). Regression analysis was used to consider the relationship
 21 between principal components and abundance of spider taxa. A stepwise approach
 22 was followed to find the best model and the scale where the strongest effects are
 23 exerted. Forward and backward elimination models were also run but these led to the
 24 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 Wrattenbully $22.29 \pm 4.80\%$ 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, Tenebrionidae, 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).

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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

1 Analysis of the subtracted area of woody vegetation at each distance for the three
2 regions led to the isolation of two principal components or factors for Barossa, three
3 for Wrattenbully and three for Padthaway (Table 2). For Barossa, the first factor
4 (accounting for 52.1% of the variance) reflected an effect of vegetation from 95-530
5 m based on the strong loadings for this component, while the second (19.6%)
6 reflected vegetation effects at 750-2120 m. For Wrattenbully, the three components
7 (accounting for 33.2, 20.5 and 16.1% of the variance) showed positive loadings and
8 reflected vegetation at 95-530, 750-3000 and 375-1060 m respectively. Analysis of
9 Padthaway produced three components, contributing 43.9, 23.7 and 11.6% of the
10 variance, reflecting effect of woody vegetation at 195-1500, 1060-3000 and 750 and
11 2120 m. Distances with positive loadings to principal components were consistent
12 with factor 1 associated with smaller radii and factor 2 with greater radii for all three
13 regions.

14 Analysis of the subtracted area of pasture at each distance for the three regions
15 isolated three principal components or factors for each region (Table 3). For Barossa,
16 the first factor (accounting for 37.8% of the variance) reflected an effect of pasture
17 from 95-530 m based on the strong loadings for this component, while the second
18 (24.7%) reflected pasture effects at 750-1500 m and factor 3, 14.3% variance loading
19 at 1500-2120 m. For Wrattenbully, the three components (accounting for 44.5, 14.5
20 and 11.8% of the variance) showed positive loadings and reflected pasture at 95-750,
21 750-1500 and 1060-1500 m respectively. The three components identified at
22 Padthaway, contributing 33.0, 24.0 and 11.8% of the variance, reflected pasture at
23 375-1060, 95-375 and 3000 m.

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

18 **Discussion**

21 We found limited evidence for associations between woody vegetation or pasture and
22 spider families at the local or landscape levels. The lack of response was consistent
23 across three regions for four of the seven spider families considered as well as
24 immature and canopy spiders. Lycosidae were the only family enhanced by nearer
25 vegetation, adjacent pasture and near woody vegetation at Barossa, and this may

1 indicate that this family is more likely to use cursorial dispersal. We have previously
2 found lycosid abundance enhanced in vines adjacent to woody vegetation (Thomson
3 and Hoffmann 2009) and in pasture adjacent to shelterbelts with grassy understorey
4 (Tsitsilas et al. 2006).

5 The limited response to landscape pasture or woody vegetation contrasts with
6 the many references to positive effects of non-crop vegetation, particularly pasture at
7 the local (Denys and Tscharnkte 2002; Bayram and Luff 1993; Huusela-Veistola
8 1998) and landscape (Schmidt and Tscharnkte 2005; Thorbek and Topping 2005;
9 Gardiner et al. 2010; Clough et al. 2005; Schmidt et al. 2003; Rand and Tscharnkte
10 2007) scales. Our previous analysis of Australian landscapes had shown only weak
11 relationships between woody vegetation and the abundance of coccinellids and
12 parasitoids at any spatial scale (Thomson et al. 2010) across two of these regions.
13 These findings may reflect possible differences between landscapes in south eastern
14 Australia and other regions where responses at the landscape scale have been
15 considered, especially northern Europe.

16 We saw few differences in abundance of spider families at the local or
17 landscape levels, despite having power to detect effects comparable to those described
18 in other studies. This may reflect three factors – differences in landscape composition
19 or complexity, diversity or abundance of spiders collected and/or nature of the crop.
20 We have previously commented on the apparent contrasting patterns between
21 European and southeastern Australian landscape patterns (Thomson et al. 2010).
22 Unlike European landscapes, the relative abundance of woody vegetation in the wider
23 landscape in the southeastern Australian landscape has little correlation with the local
24 level. In the European studies, when there is a positive correlation at different levels,
25 comparisons involve landscapes that have more woody (or other non-crop) vegetation

1 consistently across the landscape whereas in the regions considered here we often
2 encountered landscapes where a high abundance of non-crop vegetation around a
3 vineyard might not be matched by a similar pattern in the broader landscape.
4 Australian landscapes may be more similar to arable landscapes in the US, which
5 typically lack variability in landscape complexity, land-use intensity and vegetative
6 connectivity seen in Europe (Olson and Andow 2008).

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

16 The diversity of families contributing to the guild of spiders may also differ
17 between geographical regions, and as families are associated with diverse hunting
18 strategies this may have implications for pest control potential. The diversity we
19 detected is more consistent with that of spider guild structure in the United States than
20 common in Europe (Nyffeler and Sunderland 2003). Diversity of families present at
21 the 54 sites is similar to that from in another grape region in south eastern Australia
22 (Thomson and Hoffmann 2007) and in vineyards in California (Costello and Daane
23 1999) and other crops in the US (Greenstone 2001). In their review of differences in
24 spider guilds in Europe and the United States (derived from hundreds of reports of
25 agroecosystem spiders from the two continents), Nyffeler and Sunderland (2003)

1 conclude that the spider fauna of European agroecosystems is strongly dominated by
2 small linyphiid spiders (commonly over 90% of all spider individuals), which has
3 been verified with several different sampling methods (Nyffeler and Sunderland
4 2003). In contrast, representatives of the family Linyphiidae are less common in the
5 US (usually <25% of total spider) and typically a range of families comprising more
6 complex spider guild structure is seen. Nyffeler and Sunderland (2003) suggest that
7 this difference may be related to different farming intensity on the two continents,
8 with farm size being much greater (order of 2X) in US compared to Europe.

9 Differences in spider abundance may be important in the difference in
10 responses of spiders at the landscape scale seen here. We collected lower numbers of
11 spiders than in European studies: our traps collected 0.16 spiders/cm trap/trap day,
12 less than half the lowest number reported in pitfall traps from Germany (0.34)
13 (Clough et al. 2005; Schmidt et al. 2005; Schmidt et al. 2008) and much lower than
14 other studies (eg. 1.4 - Schweiger et al. 2005). In the US where fields and farms are an
15 order of magnitude larger than in Europe, spider numbers are also much lower
16 (Nyffeler and Sunderland 2003). Greenstone (2001) noted very low densities of
17 spiders in US winter wheat compared to that reported for Europe (2-600/m² compared
18 to 0.02-14 in US), and suggested the difference is related to “greater landscape
19 diversity, due to smaller fields, more crop types, and greater use of hedgerows and
20 other bordering vegetation in Europe than seen in this part of US at least.”

21 Nevertheless, despite lower abundance, power analysis suggested that we could have
22 detected a difference in abundance at the local level. In addition, a response to
23 landscape composition has been demonstrated for diverse natural enemies including
24 spiders (Schmidt et al. 2008) and parasitoids (Perovic et al. 2010) at abundances
25 consistent with our minimum number used to investigate patterns (35): significant

1 responses to increasing non-crop vegetation in the surrounding landscape were found
2 for spiders in winter wheat crop in Germany when there were only 20 individuals for
3 the lycosid *Trochusa ruricola* and 31 for the linyphiid *Tenuiphantes tenuis* (Schmidt
4 et al. 2008). Similar responses have also been found with only 25 individuals of the
5 parasitoid *Trichogramma* spp. (Hymenoptera: Trichogrammatidae) in Australian
6 cotton (Perovic et al. 2010).

7 It is possible that the weaker response detected in this perennial environment
8 compared to annual crops is related to the relatively low level of disturbance in
9 vineyards. Spider diversity can be greater under favourable agricultural management
10 than in natural habitats (Samu et al. 1999). Overwintering or alternative sites may be
11 more important in annual than perennial crops due to the increased disturbance,
12 particularly when there is low chemical use. Non-crop vegetation providing pollen
13 and nectar may enhance groups such as parasitoids and some beetles, but spiders may
14 not require these resources as they can overwinter in orchards (Marc et al. 1999).
15 Previous data show that spiders remain in southeastern Australian vineyards
16 throughout winter (Thomson 2006, Thomson and Hoffmann 2007) and also remain
17 active in apple orchards of the Czech Republic throughout winter at average
18 temperatures as low as 5°C (Korenko and Pekar 2010). Alternative prey for spiders
19 such as Collembola, a main food source for many spiders (Bell et al. 2001), remains
20 abundant in vineyards through winter (Thomson and Hoffmann 2007). In contrast, in
21 annual crop systems, provision of non-crop refuges may be needed for overwinter
22 survival of natural enemies (Landis et al. 2000). Some other studies in orchards and
23 vineyards also suggest a lack of response of spiders to non-crop vegetation. In a study
24 of the invertebrate natural enemies of Navel Orangeworm, *Amyelois transitella*
25 Walker (Lepidoptera: Pyralidae), the abundance of spiders was not significantly

1 related to the proportion of surrounding natural habitat in landscapes surrounding
2 almond orchards although parasitoids were correlated (Eilers and Klein 2009). In
3 vineyards and orchards in California, Bailey et al. (2010) report no effect of landscape
4 on abundance of predatory spiders, and numbers were also not related to distance
5 from woody vegetation (Hogg and Daane 2010). In fact, Korenko and Pekar (2010)
6 suggest that orchards can act as non-crop refuges. Perennial crops like vineyards and
7 orchards may be sink habitats for wood-related spider species (Bailey et al. 2010).

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

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14

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)	<i>P</i>	MS	F _(2,53)	<i>P</i>	MS	F _(3,53)	<i>P</i>
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, Wrattenbully and Padthaway. Bold values represent factor loadings > 0.4.

Area ^a	Barossa (17)		Wrattenbully (27)			Padthaway (10)		
	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

^acalculated 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 Wrattenbully and Padthaway. Bold values represent factor loadings > 0.4.

Area ^a	Barossa (17)			Wrattenbully (27)			Padthaway (10)		
	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

^acalculated 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 (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)						Wrattenbully (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	-0.0105	-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

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