Predatory arthropods associated with potential native insectary plants for Australian vineyards

M.J. RETALLACK[1,2] ⓘ, L.J. THOMSON[3] and M.A. KELLER[1]

[1] School of Agriculture, Food and Wine, The University of Adelaide, Glen Osmond, SA, 5064, Australia; [2] Retallack Viticulture Pty Ltd, Adelaide, SA, 5152, Australia; [3] School of BioSciences, The University of Melbourne, Melbourne, Vic., 3010, Australia
Corresponding author: Ms Mary Retallack, email mary@viti.com.au

Abstract

Background and Aims: We evaluated three native plants to determine their capacity to provide insectary benefits to predatory arthropods in vineyards, and thereby to enhance biological control of insect pests. Native plants are preferred as supplementary flora, as they are naturally adapted to Australia's climatic conditions.
Methods and Results: Stands of mature *Bursaria spinosa*, *Leptospermum continentale* and *Rytidosperma* ssp. located adjacent to or in the mid-rows of Adelaide Hills and Barossa Valley vineyards were sampled for arthropods in 2013/14. *Vitis vinifera* was also sampled. Twenty seven thousand and ninety-one individual invertebrate specimens were collected, comprising 20 orders and 287 morphospecies. Nine thousand and thirty-six predators, 6790 herbivores and 11 265 other specimens were collected. Predatory arthropods dominated the diversity of morphospecies present on each plant. Out of 100 predatory morphospecies, 69 were found on *B. spinosa*, 65 on *L. continentale*, 55 on *V. vinifera* and 37 in association with *Rytidosperma* ssp. The difference between predatory and herbivore morphospecies was highest on *Rytidosperma* ssp. (2.18:1 predators : herbivores), followed by *L. continentale*, *V. vinifera* and *B. spinosa*.
Conclusions: *Bursaria spinosa* and *L. continentale* have the potential to be used as insectary plants in association with Australian vineyards, as they support populations of predatory arthropods throughout the year. *Rytidosperma* ssp. could provide insectary benefits on sites where the black Portuguese millipede, *Ommatoiulus moreleti,* is not considered to be a problem.
Significance of the Study: This study confirms associations between predatory arthropods and three native plants. The opportunity to plant selected native insectary species could help winegrape growers save time and resources by producing fruit with lower pest incidence, while enhancing biodiversity of their vineyards.

Keywords: Bursaria spinosa, Leptospermum continentale, *native insectary,* Rytidosperma *ssp., vineyard*

Introduction

Grapevines, *Vitis vinifera* L., in Australia suffer varying levels of damage by pest species depending on the climatic zone (Scholefield and Morison 2010). Light brown apple moth (LBAM), *Epiphyas postvittana* (Walker), is the dominant insect pest causing damage to flower clusters and berry skins in Australian vineyards. Damaged skins provide infection sites for *Botrytis cinerea* (Pers.) and other bunch moulds, which result in a reduction in fruit quality and yield losses (Ferguson 1995). Annual national losses from *E. postvittana* and related bunch rots were estimated to be $70 million/-year in Australia in 2010, in addition to $0.5 million/year caused by garden weevils, grape phylloxera, mealybugs, scales and trunk boring insects (Scholefield and Morison 2010). Other vineyard pests include Australian grapevine moth, elephant weevil and mites (Bernard et al. 2007, Thomson et al. 2007).

Biological control is a key component of arthropod-mediated ecosystem services, which are used to manage pests in production landscapes (Isaacs et al. 2009). Biocontrol is estimated to provide five to ten times more control of pests than pesticides (Pimentel et al. 1992). A range of generalist predators and host specific parasitic wasps contribute to the biocontrol of *E. postvittana* and other vineyard pests (Bernard et al. 2006, Paull and Austin 2006, Yazdani et al.

2015, Feng et al. 2015a,b), and up to 90% of newly hatched leafroller larvae may be killed by predators in the absence of toxic chemicals (Helson 1939, Waterhouse and Sands 2001). Predatory arthropods, such as spiders, lacewings, predatory bugs, ladybird and carabid beetles, are commonly found in vineyards (Bernard et al. 2007, Thomson and Hoffmann 2009). The majority of predators that attack crop pests are native (Gagic et al. 2018). Their presence in the vineyard can be boosted by incorporating native insectary plants (Thomson and Hoffmann 2008).

Ecosystem services that plants provide include provisioning, regulating, cultural and supporting services (Mace et al. 2012, Schellhorn et al. 2015). Arthropod 'provisioning' services from insectary plants provide 'SNAP', an acronym that refers to shelter, nectar, alternative prey and pollen (Barnes et al. 2011, Gurr et al. 2017), which nourish predatory arthropods and can extend their presence in production landscapes (Gurr et al. 1998). In turn, predators provide 'regulating' ecosystem services, which involve biological suppression of vineyard pests. Stands of native vegetation adjacent to vineyards have been associated with increased biodiversity (Thomson and Hoffmann 2010, Smith et al. 2015) and provide season-long benefits to boost the activity of predators and parasitoids (Thomson and Hoffmann 2013, Zemenick et al. 2018). Much emphasis has been put on the

role of parasitoid wasps by Australian research in recent years (Bernard et al. 2006, Paull and Austin 2006, Perovic and Gurr 2012, Feng et al. 2015a,b, Feng et al. 2016, Yazdani et al. 2015). The relationship, however, between predators and individual species of native insectary plants has largely been neglected. We chose to address this gap in knowledge.

Biodiversity and provision of ecosystem services can be improved by at least 20% in vineyards by retaining inter-row vegetation cover in preference to intensive soil tillage and herbicide use (Winter et al. 2018) and can also lead to greater resilience within the system (Altieri 1991, Andow 1991, Ryszkowski et al. 1993, Stamps and Linit 1997, Schellhorn et al. 2015, Gagic et al. 2018). Exotic insectary species, such as buckwheat, alyssum, and phacelia, have been trialled in Australia with varying degrees of success, but they are not easy to establish and maintain in the dry Australian environment (Thomson et al. 2010). In contrast, native plants are naturally adapted to Australian conditions (Pandey et al. 2018) and are consistently reported as having low occurrence of pests and high occurrence of natural enemies (Gurr et al. 2017, Gagic et al. 2018). Thus, native plants may be better insectary plants in Australia.

Careful screening of candidate insectary plants is important to ensure success. Increasing biodiversity in general is no guarantee of pest suppression (Gurr et al. 2003, Karp et al. 2018) as planting incompatible plants may have unintended consequences by enhancing pest populations (Andow and Risch 1985, McQuillan 1992, Baggen and Gurr 1998, Gurr et al. 1998, Coventry et al. 2004, Winkler 2005). Insectary plants need to be attractive to predators but not to pests, and be easy to establish and maintain, without actively competing with grapevines.

Increased biodiversity is often promoted as an important indicator of vineyard health but it can be difficult to measure (Altieri 1999, Bruggisser et al. 2010, Winter et al. 2018). Thomson et al. (2007) suggest that a surrogate indicator such as the diversity of predatory arthropods, which have a direct impact on pest abundance, can be used as one way to assess the benefits of enhancing biodiversity. This study aimed to broaden our understanding of the ecosystem services that are provided by native flora in vineyards.

A detailed understanding of the associations between native insectary plants and predatory arthropods has not been identified previously in association with Australian vineyards. We aim to determine if selected candidate insectary plants have the capacity to support populations of predators throughout the year, and could provide habitat for economically damaging vineyard pests. The observed versus estimated morphospecies richness was used to demonstrate the adequacy of the sampling program (Gotelli and Colwell 2011).

We collected arthropods on the canopies of Christmas bush, *Bursaria spinosa* (Cav.), prickly tea-tree, *Leptospermum continentale* (Forst. & G.Forst) and wallaby grasses, *Rytidosperma*

ssp. (DC) adjacent to or in the mid-rows of Adelaide Hills, Barossa Valley and Eden Valley vineyards during 2013/14. *Vitis vinifera* was also sampled.

Materials and methods

Native insectary plant selection
Plants were selected from local, native plant community lists and screened for their potential attractiveness to predators, and likelihood of providing habitat for herbivorous pests (Fiedler and Landis 2007, Fiedler et al. 2008, Isaacs et al. 2009). The three native candidate insectary plants were selected for assessment based on their attributes and the availability of established plants adjacent to or in vineyards (Table 1).

Bursaria spinosa (Figure 1a) and *L. continentale* (Figure 1b) are erect, evergreen shrubs. They produce pollen and nectar, which attracts a wide range of arthropods. *Rytidosperma* ssp. are erect, perennial grasses (Figure 1c). They grow actively during spring and enter dormancy when soils dry out in summer (Penfold and McCarthy 2010). *Rytidosperma* ssp. are associated with a range of predatory arthropods (Danne et al. 2010, Penfold and McCarthy 2010, Wood et al. 2011) and can be selected for specific tolerance to site characteristics and low growing habit for use under perennial crops (Prescott 2017). Mixed plantings of wallaby grasses included in this study are as follows: common wallaby grass, *Rytidosperma caespitosum*; brown-back wallaby grass, *Rytidosperma duttonianum*; copper-awned wallaby grass, *Rytidosperma fulvum*; hairy wallaby grass, *Rytidosperma pilosum*; slender wallaby grass, *Rytidosperma racemosum*; and small-flowered wallaby grass, *Rytidosperma setaceum*. Each species is endemic to southern and eastern Australia.

Arthropod sampling survey and methods
Surveys were conducted at six locations in South Australia (Figure 2). Four sites were in the Adelaide Hills and one each in the Barossa Valley and Eden Valley. Site coordinates are available via the Figshare online digital repository (10. 25909/5bda767197447). Fungal disease pressure on each vineyard was managed using low inputs of fungicide sulphur and/or copper sprays. No broad spectrum insecticides were applied.

Three sampling methods were employed, tailored to each plant species. A modified sweep net was used to sample the native woody vegetation. Each sample from *B. spinosa* or *L. continentale* was collected by firmly shaking the foliage five times, inside an insect sweep net (370 mm in diameter), modified to hold a funnel and a 250 mL collection container. This process was repeated five times to form a composite sample. Samples from grapevines were collected by firmly striking the cordons five times with a rubber mallet, over a beat net (700 × 700 mm) that held a 250 mL collection container. This process was repeated five times for each composite sample, alternating between each

Table 1. Plant species, common name, family, plant type and food resources provided by each plant.

Plant species	Common name	Family	Plant type	Food resources
Vitis vinifera	Grapevine	Vitaceae	Deciduous vine fruit crop	Pollen and nectar
Bursaria spinosa	Christmas bush	Pittosporaceae	Native evergreen shrub	Pollen and nectar
Leptospermum continentale	Prickly tea-tree	Myrtaceae	Native evergreen shrub	Pollen and nectar
Rytidosperma ssp.	Wallaby grass	Poaceae	Native perennial grass	Pollen

(a)

(b)

(c)

Figure 1. Australian native insectary plants (a) *Bursaria spinosa*, (b) *Leptospermum continentale* and (c) *Rytidosperma* ssp.

side of a pair of vine rows. This provided an effective method of sampling non-flying arthropods from the grapevine canopy. Ten composite samples were collected per sampling date at each site with the modified sweep net and beat net capture techniques. Arthropods were killed in the field using ethyl acetate. Plants of *Rytidosperma* ssp. were sampled using ten pitfall traps at each site. Round plastic 850 mL containers with a diameter of 120 mm were placed in a polyvinyl chloride plastic sleeve, flush with the soil surface. Wire covers, 1 mm thick with 25 mm hexagonal gaps, were used to limit non-target catch. The pitfall traps were charged with propylene glycol to a height of approximately 30 mm. Plastic shields, 250 × 250 mm, were placed above the traps to exclude rainfall. Pitfall traps were exposed for 2 weeks prior to collection.

Sampling period and focus

Samples were collected fortnightly from September to December, and monthly in March, May and August.
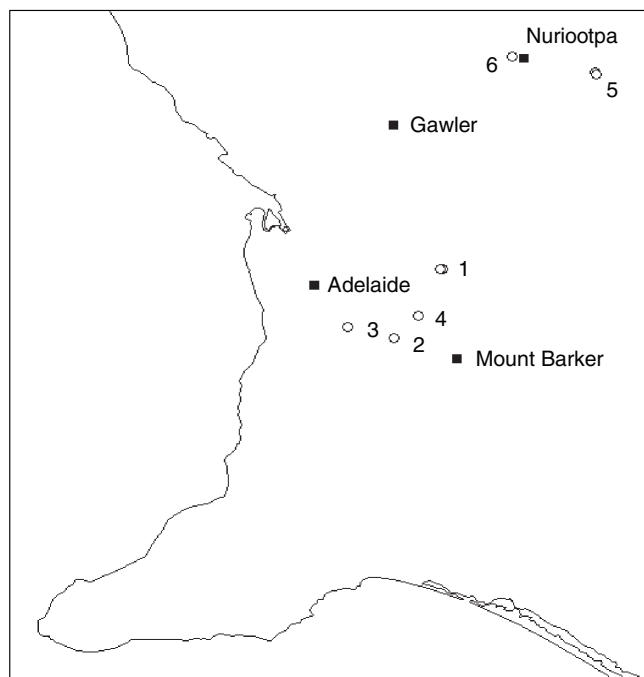

Figure 2. Location of data collection sites in South Australia. 1. Lenswood, (a) *Bursaria spinosa*, (b) *Leptospermum continentale*, (c) *Vitis vinifera* cv. Chardonnay; 2. Aldgate, *B. spinosa*; 3. Belair, *B. spinosa* and *L. continentale*; 4. Balhannah, *B. spinosa*; 5. Keyneton, (a) *Rytidosperma* spp., (b) *Rytidosperma* spp. *and V. vinifera* cv. Shiraz; 6. Nuriootpa, *Rytidosperma* spp. and *V. vinifera* cv. Shiraz.

Arthropods were extracted, sorted to order, family and/or morphospecies and then stored in 80% ethanol (EtOH) in 100 mL plastic containers. Further identification was determined using Naumann's (1991) arthropod identification keys. The sampling focus was on ground and canopy based predatory arthropods with prominent chewing and/or piercing mouthparts and/or herbivore pest species. Springtails (Collembola) and other tiny arthropods were not assessed due to their high abundance and lack of relevance to this study. Parasitoids were not considered in detail as they were not part of the focal group, the complexity of identifying each specimen to family, and the trapping methods utilised were not suited to capturing a representative sample of flying arthropods. Canopy samples were collected at the same time of day for each trapping method to minimise bias. Because of the differences among sampling methods only qualitative, rather than quantitative, comparisons can be made between plant species. Six hundred and eighty-one reference specimens were either mounted or preserved in 95% EtOH and transferred to the Waite Insect and Nematode Collection.

Analytical methods

Due to zero inflated data the ten sweep net samples, ten beat net samples, and ten pitfall samples were each pooled to give a single sample for each vegetation type, each of the nine sample sites and each sampling date. Replicate dates were subsequently pooled by month, so a single monthly data point resulted for each vegetation type. Replicated incidence data were assessed to determine observed versus estimated species richness and proportion of morphospecies found in samples following Chao's bias corrected method for replicated samples (Gotelli and Colwell 2011). Data were cast in contingency tables and analysed with the Fisher's exact test to determine the proportion of elephant weevil, *Orthorhinus cylindrirostris* (Schönherr) (Coleoptera: Curculionidae), present on *L. continentale* compared to the other plants sampled (pooled). The larvae of Tortricidae have no defining morphological features, so they were identified to species using molecular methods during an associated study (Retallack et al. 2018).

The datasets generated and analysed during the study are available in The University of Adelaide Figshare online digital repository (10.4225/55/5b0a3a2e6b2e9, 10.4225/55/5b0a3a5d6f519).

Results

Arthropods

Twenty-seven thousand and ninety-one individual specimens were collected, comprising 20 orders and

Table 2. Predator, herbivore and other arthropod taxa, number of morphospecies and of individuals associated with each plant species.

Taxa	*Bursaria spinosa*		*Leptospermum continentale*		*Vitis vinifera*		*Rytidosperma* ssp.	
	spp.	In	spp.	In	spp.	In	spp.	In
Predator taxa								
INSECTA								
ODONATA	1	1	0	0	0	0	0	0
DERMAPTERA								
Forficulidae§	1	1	1	14	1	893	1	1547
MANTODEA	1	15	1	6	1	1	0	0
HEMIPTERA	6	91	6	53	6	77	6	139
Anthocoridae	1	1	1	4	0	0	0	0
Nabidae	1	5	1	9	1	9	1	4
Pentatomidae	2	47	2	33	2	65	1	100
Reduviidae	2	38	2	7	3	3	4	35
HYMENOPTERA†	13	242	12	349	3	85	5	119
Formicidae§	1	4		70	1	65	1	29
NEUROPTERA	3	308	3	138	2	482	2	245
Chrysopidae	1	95	1	19	1	22	1	3
Hemerobiidae	1	208	1	118	1	460	1	242
Mantispidae	1	5	1	1	0	0	0	0
COLEOPTERA	16	179	14	234	10	946	6	90
Anthicidae	1	3	0	0	0	0	0	0
Cantharidae	1	12	1	85	0	0	0	0
Carabidae§	1	16	1	27	1	6	4	87
Cleridae¶	7	27	6	26	2	2	0	0
Coccinellidae	5	69	5	77	6	898	1	2
Melyridae§	1	52	1	19	1	40	0	0
Staphylinidae	0	0	0	0	0	0	1	1
DIPTERA	0	0	1	3	0	0	1	2
Syrphidae	0	0	0	0	0	0	1	2
Asilidae	0	0	1	3	0	0	0	0
ARACHNIDA								
ACARI	0	0	0	0	1	8	0	0
ARANEAE	27	834	27	508	30	488	13	828
Araneidae	7	158	5	95	6	136	2	18
Deinopidae	1	10	1	1	1	2	1	2
Dysderidae	1	5	0	0	1	15	0	0
Gnaphosidae	2	13	2	16	3	29	3	6
Linyphiidae	0	0	0	0	1	2	1	19
Lycosidae	1	8	1	21	1	15	1	766
Oxyopidae	1	3	1	1	1	3	0	0
Philodromidae	1	36	1	2	1	8	0	0
Pholcidae	1	4	1	2	0	0	0	0
Salticidae	3	156	4	77	4	87	1	3
Sparassidae	1	20	1	24	1	18	0	0
Tetragnathidae	2	117	2	123	2	124	0	0
Theridiidae	0	0	0	0	0	0	1	4
Thomisidae	3	165	4	94	4	13	1	1
Zodariidae	1	2	1	1	1	1	1	7
PSEUDOSCORPIONES	0	0	0	0	1	3	0	0
CHILOPODA¶	1	1	0	0	0	0	3	106
Herbivore taxa								
INSECTA								
ORTHOPTERA	8	11	3	9	3	18	2	10
Acrididae	1	1	0	0	1	10	0	0
HEMIPTERA	17	365	11	208	10	111	6	18
Alydidae§	0	0	1	5	1	4	2	7
Cicadellidae	4	137	3	20	2	2	1	3
Coccidae	1	3	0	0	2	37	1	2
Miridae	3	151	2	94	2	11	0	0
Lygaeidae§	1	54	1	61	1	6	1	1
Pentatomidae	7	19	3	25	2	51	1	5
Tingidae	1	1	1	3	0	0	0	0
COLEOPTERA	12	51	13	200	12	137	6	43
Cerambycidae	3	12	1	1	0	0	0	0
Curculionidae	9	39	12	199	12	137	6	43
LEPIDOPTERA	4	21	3	39	4	16	2	318
Geometridae	1	13	1	32	1	2	0	0
Noctuidae	0	0	0	0	1	12	2	318
Tortricidae	2	8	2	7	2	2	0	0
DIPLOPODA								
JULIDA								
Julidae¶	1	347	1	62	1	2177	1	2629

Table 2. Continued

Taxa	Bursaria spinosa		Leptospermum continentale		Vitis vinifera		Rytidosperma ssp.	
	spp.	In	spp.	In	spp.	In	spp.	In
Other taxa								
INSECTA								
ORTHOPTERA	1	1	0	0	1	2	2	16
PHASMATODEA								
Phasmatidae	0	0	1	6	0	0	0	0
BLATTODEA¶	1	1	0	0	3	14	6	347
HEMIPTERA	20	380	11	741	10	148	5	17
Miridae‡	5	224	4	598	4	88	2	2
Pentatomidae‡	7	66	3	61	3	27	1	1
THYSANOPTERA	3	94	1	42	0	0	0	0
PSOCOPTERA	0	0	0	0	1	1	0	0
HYMENOPTERA	1	1	1	1	1	1	2	13
Apidae	1	1	1	1	1	1	1	9
COLEOPTERA	23	3570	19	1624	14	391	17	2881
Buprestidae¶	2	6	2	5	1	1	1	4
Chrysomelidae‡	2	22	2	7	0	0	0	0
Elateridae¶	1	4	1	1	1	13	1	103
Latridiidae¶	1	3354	1	1136	2	352	0	0
Mordellidae	2	104	1	11	0	0	0	0
Scarabaeidae¶	3	7	4	339	1	1	5	537
Tenebrionidae¶	1	10	0	0	4	15	6	2230
LEPIDOPTERA	5	31	6	16	1	6	2	9
Psychidae	0	0	2	2	0	0	0	0
DIPTERA	8	39	4	8	2	2	2	4
ARACHNIDA								
ACARI	1	1	0	0	0	0	1	5
MALACOSTRACA								
ISOPODA								
Armadillidiidae¶	0	0	0	0	2	5	3	529
Singletons: undetermined	11	213	8	79	7	14	6	12

†Parasitoid. ‡Herbivore. §Scavenger, omnivore, seed or pollen feeder. ¶Detritivore. In, number of individuals; spp., number of morphospecies.

287 morphospecies on *Rytidosperma* ssp. (*n* = 9927), *B. spinosa* (*n* = 6798), *V. vinifera* (*n* = 6026) and *L. continentale* (*n* = 4340) (Table 2). Of the 20 orders found the most abundant, in order were Coleoptera, Diplopoda, Araneae, Dermaptera, Hemiptera, Neuroptera and Hymenoptera, which made up 92% (*n* = 25 006) individuals and 200 morphospecies. Thirteen orders made up the remaining 8% (*n* = 2085) comprising 87 morphospecies.

Arthropods were categorised into different functional groups, as either predators (including parasitoids) (*n* = 9036), herbivores (*n* = 6790) or other (alternative prey, scavenger, seed or pollen feeders, detritivores) (*n* = 11 265), following the feeding habits outlined in Naumann (1991). Captures on *B. spinosa* resulted in the greatest number of arthropod morphospecies (*n* = 185), followed by *L. continentale* (*n* = 147), *V. vinifera* (*n* = 127) and *Rytidosperma* ssp. (*n* = 100).

Arthropod morphospecies richness. The majority of arthropod species present associated with each plant was estimated to have been collected in samples (Table 3), which indicates sampling protocols were adequate. A range between 68.4% of total morphospecies was collected on *V. vinifera* to 79.5% in association with *Rytidosperma* ssp. The lower proportion of observed versus estimated other morphospecies, can be attributed to a higher abundance of singletons and undetermined specimens, which are considered to be transient and inconsequential to this study.

Morphospecies and individual arthropods. Predatory arthropods dominated the morphospecies present on each plant (Figure 3). The ratio of predator to herbivore morphospecies on each plant (pooled for all sites) was highest for *Rytidosperma* ssp. (2.18:1 predators : herbivores). Out of a total of 100 predatory morphospecies, 69 were found on *B. spinosa*, 65 on *L. continentale*, 55 on *V. vinifera* and 37 in association with *Rytidosperma* ssp.

Table 3. Estimated morphospecies richness based on Chao's species richness estimator equation.

Functional group	Bursaria spinosa			Leptospermum continentale			Vitis vinifera			Rytidosperma ssp.		
	Obs.	Est.	%	Obs.	Est.	%	Obs.	Est.	%	Obs.	Est.	%
All	185	261	70.8	147	215	68.5	127	186	68.4	100	126	79.5
Predators	69	80	86.2	65	82	79.1	55	64	85.5	37	44	84.8
Herbivores	42	61	69.2	31	35	89.1	30	39	76.5	17	18	93.6
Other	74	120	61.9	51	123	41.5	42	91	46.3	46	62	73.6

%, proportion of the estimated total number of arthropod species observed; Est., estimated total number of arthropod species; Obs., observed number of arthropod species.
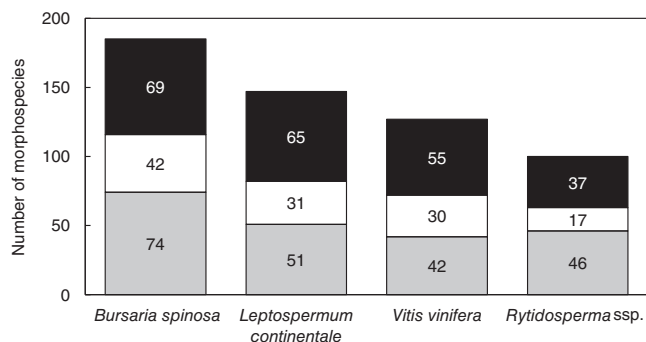
Figure 3. Number of predator (■), herbivore (□) and other arthropod (▤) morphospecies recorded over a 12-month period and the ratio of predator to herbivore morphospecies (pooled for all sites) on *Bursaria spinosa* (1.64:1), *Leptospermum continentale* (2.10:1), *Vitis vinifera* (1.83:1) and *Rytidosperma* spp. (2.18:1).

Insectary plants

Flowering phenology was assessed for each plant. The flowering period of *V. vinifera* occurred from 30 November to 13 December 2013 and the fruit was picked on 3 April 2014 in the Adelaide Hills. The flowering period of *V. vinifera* occurred from 11 to 18 November 2013 and the fruit was picked on 14 March in the Barossa Valley and 7 April 2014 in the Eden Valley. *Leptospermum continentale* flowered from August to December, *Rytidosperma* ssp. flowered in December and *B. spinosa* flowered from December to February (Table 4). The insectary plants flowered at times which overlapped with the flowering and fruitset period of *V. vinifera*, which is a critical time for *E. postvittana* activity and potential crop damage.

Predatory arthropods showed a clear pattern of seasonal abundance on all plants. Natural enemies were most abundant from October to January on *B. spinosa, L. continentale* and *V. vinifera* and from October to December on *Rytidosperma* ssp. (Figure 4). This period coincides with the peak time that predators are needed for crop protection during flowering and in the lead up to harvest. The presence of predatory arthropods reduced as weather conditions became less favourable and access to floral resources diminished.

Functional group: predators

Araneae (spiders). Araneae were the highest number of predatory specimens (*n* = 2658). The most abundant families were the Lycosidae, Araneidae, Tetragnathidae, Salticidae and Thomisidae, comprising 82% of all spiders and 19 morphospecies. The most speciose of these was Araneidae with eight morphospecies, followed by Salticidae and Thomisidae (four morphospecies each). Among the Araneae, 69% (*n* = 1841 individuals) were active hunters or ambush spiders, while the remainder were sedentary or web dwelling. The diversity of Araneae showing mode of predation (behaviour), habitat and proportion present by
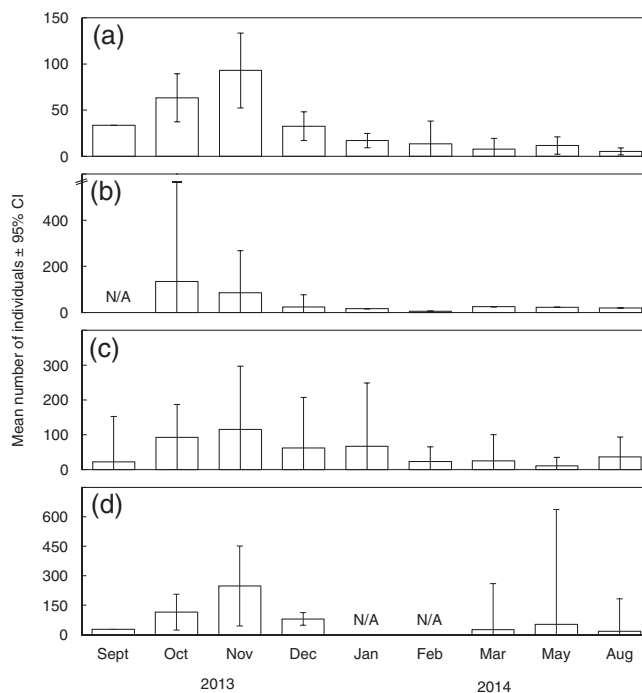

Figure 4. Temporal abundance of predator arthropods pooled across all (a) *Bursaria spinosa*; (b) *Leptospermum continentale*; (c) *Vitis vinifera*; and (d) *Rytidosperma* spp. sites over a 12-month period (mean ± 95% confidence interval per month). Means per sampling date were pooled for each month. N/A, no data collected.

plant is available via the Figshare online digital repository (10.25909/5bda753f80027).

Dermaptera (earwigs). A single species of the European earwig, *Forficula auricularia* (Dermaptera: Forficulidae), was the most abundant predatory morphospecies and was present throughout the year. It was primarily found in association with *Rytidosperma* ssp. (*n* = 1547) and *V. vinifera* (*n* = 893).

Coleoptera (beetles). The Coleoptera were the most speciose order with 85 morphospecies for all trap types. The most abundant predatory groups of beetles were the Coccinellidae, Carabidae (some species are also seed predators), and Melyridae. Transverse ladybird beetle, *Coccinella transversalis* (Fabricius) (Coleoptera: Coccinellidae) was the most abundant ladybird, followed by *Scymnus* ssp. and common spotted ladybird, *Harmonia conformis* (Boisduval). Other species included minute two-spotted ladybeetle, *Diomus notescens* (Blackburn), and *Cryptolaemus montrouzieri* (Mulsant). Coccinellidae were present throughout the year.

Neuroptera (lacewings). The brown lacewing, *Micromus tasmaniae* (Rambur) (Neuroptera: Hemerobiidae) was the most abundant morphospecies of Neuroptera, followed by the green lacewing, *Mallada signata* (Schneider) (Neuroptera:

Table 4. Flowering phenology of *Vitis vinifera, Bursaria spinosa, Leptospermum continentale* and *Rytidosperma* ssp. from August 2013 to February 2014.

Plant species	Common name	Family	A	S	O	N	D	J	F
Vitis vinifera	Grapevine	Vitaceae							
Bursaria spinosa	Christmas bush	Pittosporaceae							
Leptospermum continentale	Prickly tea-tree	Myrtaceae							
Rytidosperma ssp.	Wallaby grasses	Poaceae							

Chrysopidae), and a mantid lacewing (Neuroptera: Mantispidae).

Hymenoptera (wasps and ants). The Hymenoptera were represented by 19 morphospecies (*n* = 811) on all vegetation types. Hymenoptera was not a key focus of this study and no further details are provided.

Hemiptera (true bugs). The Hemiptera were the second most speciose order with 55 morphospecies pooled for all plant types. The most abundant predatory groups within Hemiptera were the Pentatomidae, Reduviidae and Nabidae. Two predatory morphospecies of Pentatomidae were observed. The glossy shield bug, *Cermatulus nasalis* (Westwood), had the highest abundance and was present at all sites, followed by the predatory shield bug, *Oechalia schellenbergii* (Guérin), which was found on *B. spinosa* and *L. continentale*. Both *C. nasalis* and *O. schellenbergii* were present throughout the entire season. The orange assassin bug, *Gminatus australis* (Erichson) was the most abundant morphospecies of Reduviidae and was found on *B. spinosa and L. continentale*. Other morphospecies of Reduviidae included the black ground assassin bug, *Peirates* ssp. (Serville), brown assassin bug, *Coranus* ssp. (Curtis), *Coranus granosus* (Stål) and *Pnirsus cinctipes* (Stål). The Pacific damsel bug, *Nabis kinbergii* (Reuter) (Hemiptera: Nabidae) was captured on all plant species. The minute pirate bug, *Orius* ssp. (Wolff) (Hemiptera: Anthocoridae) was found on *B. spinosa* and *L. continentale* only.

Functional group: herbivores
Julida (millipedes). The invasive black Portuguese millipede, *Ommatoiulus moreleti* (Julida: Julidae), was the common species found across all sites. Populations of *O. moreleti* were highest in association with *Rytidosperma* ssp. (*n* = 2629) and on *V. vinifera* (*n* = 2177). Their abundance on grapevines was highest early in the growing season, declining during the warmer months of December to February. Following rainfall events in February, millipedes dominated 92% of all individual arthropods found (*n* = 1335) on *V. vinifera* in March 2014.

Coleoptera (weevils). Four hundred and eighteen individual specimens and 18 morphospecies of Curculionidae were recorded, including 17 specimens of *O. cylindrirostris* on all species except *Rytidosperma* ssp. *Orthorhinus cylindrirostris* was only present on *L. continentale* 10% of the time over the 20 sampling dates, at low abundance (*n* = 11). This indicates that *O. cylindrirostris* was no more likely to be found on *L. continentale* than on the other plants sampled (*P* = 0.66, Fisher's exact test).

Lepidoptera (moths). Four hundred and fifty-six specimens and 16 morphospecies of Lepidoptera were found comprising the families of Noctuidae, Geometridae, Tortricidae and Psychidae. Three morphospecies of Noctuidae were found comprising Australian grapevine moth, *Phalaenoides glycinae* (Lewin); herringbone cut worm, *Agrotis* ssp. (Ochsenheimer); and common armyworm, *Leucania convecta* (Walker). Australian grapevine moth is a native pest of grapevines (Magarey et al. 1994) and was found in low abundance. *Agrotis* ssp. and *L. convecta* were found exclusively in association with *Rytidosperma* ssp., in relatively high abundance compared to other arthropods during August, September and October. A single morphospecies of apple looper, *Phrissogonus laticostata* (Walker) (Lepidoptera:

Geometridae), two species of Tortricidae, *E. postvittana* and *Acropolitis rudisana* (Walker) and two morphospecies of Psychidae were also found.

Discussion

Associations between insectary plants and predatory arthropods
This study identified associations between three native Australian plants, *B. spinosa*, *L. continentale*, *Rytidosperma* ssp., and predatory arthropods that could support biocontrol of pests in vineyards. *Bursaria spinosa* and *L. continentale* were associated with a wide range of spiders, lacewings, predatory bugs and beetles. Wolf spiders, earwigs, brown lacewings and predatory beetles found abundant in association with *Rytidosperma* ssp.

Seasonal synchrony and overwintering
Native plants are naturally adapted and can provide insectary benefits throughout the year. The species selected provide floral resources, which presence increases the potential of predators to provide control during the critical spring/summer period when pests typically move into the vineyard. Grapevines are deciduous. The reduction in insectary resources during dormancy may result in a resource bottleneck, resulting in an interruption in the presence of predators and parasitoids that may otherwise breed continuously (Schellhorn et al. 2015). In contrast, *B. spinosa* and *L. continentale* are both evergreen plants and have the capacity to support populations of mobile predators throughout the year that can passively populate vineyards and provide continuity of resources. The seasonality of ecosystem services could be extended by planting a range of suitable native perennial plants, such as *B. spinosa*, *L. continentale* and *Rytidosperma* ssp., to ensure habitat permanency and synchrony of provisioning services is continuous. Furthermore, wallaby grasses appear to have unique attributes that create strong associations with wolf spiders, brown lacewings and glossy shield bugs. This indicates that *Rytidosperma* ssp. offers complementarity and is an attractive component to a mix of native, woody plants to enhance insectary benefits.

Arthropods
Vineyard predators. We found a range of predators that were abundant. High abundance values are often associated with species adapted to site characteristics and are regarded as being present in a 'suitable' habitat (VanDerWal et al. 2009). We were able to determine the common predators relevant to Australian vineyards. Predators with a range of functionalities and habitat preferences, which are present at the same time, and/or succeed one another are needed to optimise complementarity, enhancing their capacity to attack different life stages of the pest simultaneously (Holt and Lawton 1994, Losey and Denno 1999, Cardinale et al. 2003).

Spiders were found in abundance from a range of functional groups. Some species exhibited separate ground or canopy locale preferences (Costello and Daane 1995). For example, wolf spiders were abundant in association with *Rytidosperma* ssp. but rare on the other plants. This is important as spiders can successfully overwinter in vineyards (Costello and Daane 1999, Thomson and Hoffmann 2007) and are likely to feed on larvae of Lepidoptera and other pests that often shelter on broad leafed weeds early in the

growing season (D'Alberto et al. 2012). D'Alberto et al. (2012) found that there were limited benefits of non-crop woody vegetation on spiders in Australian vineyards. Conversely, individuals of Salticidae and Thomisidae were found abundantly on *B. spinosa* and *L. continentale*. Another tea-tree species, *L. aevigatum* (Gaertn.) F. Muell (Myrtaceae) is reported to boost the presence of two hunting spiders in California, measurably reducing the number of *E. postvittana* larvae (Hogg et al. 2014). Hogg and Daane (2011) also reported that natural habitat is a key source of spiders in California vineyards.

European earwig, *F. auricularia*, is an important omnivorous predator of *E. postvittana* in vineyards (Danthanarayana 1980, Bernard et al. 2007, Frank et al. 2007, Kehrli et al. 2012) but may cause minor, isolated damage to newly emerging growth just after budburst (Magarey et al. 1994). Any risk is likely to be offset, however, by the biocontrol benefits *F. auricularia* provides in vineyards especially in the period leading up to harvest, when chemical control options are limited (Frank et al. 2007).

The brown lacewing was predominantly found in association with *Rytidosperma* ssp. Wood et al. (2011) found that brown lacewings most likely breed on wallaby grass, *R. bipartitum* (previously *Austrodanthonia linkii*). Daane et al. (2018) also found that native grasses provide good resources and habitat for natural enemies. This association may be important for manipulating populations of brown lacewings at the property scale. It is anticipated that by incorporating *B. spinosa* and *L. continental* into vineyards this will help support the presence of a multitude of predatory arthropods.

Vineyard pests. The incidence of herbivores on the native insectary plants assessed was negligible. These plants were not found to be breeding sites for vineyard herbivores and are not considered a threat when planting them in and around mature vineyards. A low abundance of leafrollers was found on the woody plants only. The benefits of planting *Rytidosperma* ssp. between vines are supported with direct evidence of increased predation of *E. postvittana* eggs where *Rytidosperma* ssp. and windmill grass, *Chloris truncata*, were present (Thomson and Hoffmann 2009, Danne et al. 2010).

Populations of *O. moreleti* are not as susceptible to predation as they eject highly repellent chemical compounds called benzoquinones from their defensive glands when attacked, rendering them inedible (Sekulic et al. 2014, Vujisic et al. 2014, Shear 2015, Makarov et al. 2017). They are widespread in southern Australia and tend to be more abundant where leaf litter and soil moisture are present (Paoletti et al. 2007). Damage to the skins of winegrapes may result in a quality downgrade or rejection of fruit in the vineyard. Their presence in picking bins often results in wine taint in grape ferments (Stankovic et al. 2016).

Orthorhinus cylindrirostris is a wood-boring pest of grapevines (Coventry et al. 2004, Bernard et al. 2007, Scholefield and Morison 2010). Despite adult elephant weevil being observed briefly on *L. continentale* it is not considered a larval host plant. There is no evidence to suggest it poses a threat as weevils may transiently acquire pollen and nectar from a range of flowering plants.

While individual species of herbivores were observed in this study, little is known about how different habitats and plant communities influence the dynamics of multiple herbivore species and their potential impact on fruit production (Perez-Alvarez et al. 2018).

Future research
Further research is required to elucidate the potential of a broader suite of native insectary plants to support the diversity of predatory arthropods in vineyards. Assessment of the optimal size, layout and composition of insectary plantings is required, as well as the anticipated benefit of boosting natural biocontrol, with minimal intervention required in the vineyard. This research identified the morphospecies present in native vegetation and vineyards and their temporal abundance throughout the year. An outstanding issue is that we are not sure that all predators will readily move between native vegetation and vineyards. To build on this research further work is required to quantify the movement of predators from insectary plants into the vineyard. An integrated approach is required to assess the capacity of predatory arthropods and parasitic wasps to contribute to the biocontrol of economically damaging pests and the individual contributions each predator makes. Similarly, it is anticipated that a multi-species insectary plant community is preferable to single species planted in strategic locations. This assumption needs to be tested.

Conclusion
This study identified associations between native insectary plants *B. spinosa*, *L. continentale* and *Rytidosperma* ssp., and predatory arthropods in and around vineyards, which have not been identified before in Australia. The sampling program recovered the majority of estimated species diversity in the samples, which indicates sampling protocols were adequate. Each plant species supports diverse predatory species, which should attack a range of other arthropods across their life stages. The native insectary plants assessed in this study were not found to be breeding sites for vineyard herbivores and are not considered a threat when planting them in or around mature vineyards. The native plants are naturally adapted and can provide insectary benefits throughout the year, especially during spring and summer to boost the activity of predators and reduce pest pressure on developing fruit. Vineyard managers are encouraged to explore the use of *B. spinosa*, *L. continentale* and *Rytidosperma* ssp. as insectary plants in their vineyards. This information should help winegrape growers save time and resources by producing fruit with lower pest incidence, while enhancing biodiversity of their vineyards. In addition, the results of this study may be applicable to a range of Australian production systems.

Acknowledgements

References

Altieri, M.A. (1991) Increasing biodiversity to improve insect pest-management in agroecosystems. Hawksworth, D.L., ed. Biodiversity of microorganisms and invertebrates: its role in sustainable agriculture (CAB International: Wallingford, England) pp. 165–182.

Altieri, M.A. (1999) The ecological role of biodiversity in agroecosystems. Agriculture Ecosystems and Environment 74, 19–31.

Andow, D.A. (1991) Vegetational diversity and arthropod population response. Annual Review of Entomology 36, 561–586.

Andow, D.A. and Risch, S.J. (1985) Predation in diversified agroecosystems – relations between a Coccinellid predator Colemegilla maculata and its food. Journal of Applied Ecology 22, 357–372.

Baggen, L.R. and Gurr, G.M. (1998) The influence of food on Copidosoma koehleri (Hymenoptera: Encyrtidae), and the use of flowering plants as a habitat management tool to enhance biological control of potato moth, Phthorimaea operculella (Lepidoptera: Gelechiidae). Biological Control 11, 9–17.

Barnes, A.M., Wratten, S.D. and Sandhu, H.S. (2011) Harnessing biodiversity to improve vineyard sustainability. Blair R.J., Lee T.H. and Pretorius I.S., eds. Proceedings of the 14th Australian wine industry technical conference; 3–8 July 2010; Adelaide, SA, Australia (The Australian Wine Industry Technical Conference: Glen Osmond, SA, Australia) pp. 240–244.

Bernard, M., Semerato, L., Carter, V. and Wratten, S.D. (2006) Beneficial insects in vineyards: parasitoids of LBAM and grapevine moth in south-east Australia. Australian & New Zealand Grapegrower & Winemaker (513), 21–28.

Bernard, M., Herbert, K.S., Weppler, R., Wratten, S.D., Powell, K.S., Kourmouzis, T., Evans, K.J., Yen, A.L., Horne, P.A., Rakimov, A., Papacek, D. and Jacometti, M.A. (2007) Guidelines for environmentally sustainable winegrape production in Australia: IPM adoption self-assessment guide for growers. Australian & New Zealand Grapegrower & Winemaker (518), 24–35.

Bruggisser, O.T., Schmidt-Entling, M.H. and Bacher, S. (2010) Effects of vineyard management on biodiversity at three trophic levels. Biological Conservation 143, 1521–1528.

Cardinale, B.J., Harvey, C.T., Gross, K. and Ives, A.R. (2003) Biodiversity and biocontrol: emergent impacts of a multi-enemy assemblage on pest suppression and crop yield in an agroecosystem. Ecology Letters 6, 857–865.

Costello, M.J. and Daane, K.M. (1995) Spider (Araneae) species composition and seasonal abundance in San Joaquin Valley grape vineyards. Environmental Entomology 24, 823–831.

Costello, M.J. and Daane, K.M. (1999) Abundance of spiders and insect predators on grapes in Central California. Journal of Arachnology 27, 531–538.

Coventry, S.A., Jaensch, L.J., Keller, M.A. and Wood, F.J. (2004) Observations of elephant weevil in the Langhorne Creek wine region. Australian & New Zealand Grapegrower & Winemaker (488), 75.

Daane, K.M., Hogg, B.N., Wilson, H. and Yokota, G.Y. (2018) Native grass ground covers provide multiple ecosystem services in Californian vineyards. Journal of Applied Ecology 55, 2473–2483.

D'Alberto, C.F., Hoffmann, A.A. and Thomson, L.J. (2012) Limited benefits of non-crop vegetation on spiders in Australian vineyards: regional or crop differences? BioControl 57, 541–552.

Danne, A., Thomson, L.J., Sharley, D.J., Penfold, C.M. and Hoffmann, A.A. (2010) Effects of native grass cover crops on beneficial and pest invertebrates in Australian vineyards. Environmental Entomology 39, 970–978.

Danthanarayana, W. (1980) Parasitism of the light brown apple moth, Epiphyas postvittana (Walker), by its larval ectoparasite, Goniozus Jacintae Farrugia (Hymenoptera: Bethylidae), in natural populations in Victoria. Australian Journal of Zoology 28, 685–692.

Feng, Y., Wratten, S., Sandhu, H. and Keller, M. (2015a) Host plants affect the foraging success of two parasitoids that attack light brown apple moth Epiphyas postvittana (Walker) (Lepidoptera: Tortricidae). PLoS One 10, 1–20.

Feng, Y., Wratten, S., Sandhu, H. and Keller, M. (2015b) Interspecific competition between two generalist parasitoids that attack the leafroller Epiphyas postvittana (Lepidoptera: Tortricidae). Bulletin of Entomological Research 105, 426–433.

Feng, Y., Kravchuk, O., Sandhu, H., Wratten, S.D. and Keller, M.A. (2016) The activities of generalist parasitoids can be segregated between crop and adjacent non-crop habitats. Journal of Pest Science 90, 275–286.

Ferguson, K.L. (1995) Association of Botrytis bunch rot with light-brown apple moth. Honours Thesis, The University of Adelaide, Adelaide, SA, Australia.

Fiedler, A.K. and Landis, D.A. (2007) Plant characteristics associated with natural enemy abundance at Michigan native plants. Environmental Entomology 36, 878–886.

Fiedler, A.K., Landis, D.A. and Wratten, S.D. (2008) Maximizing ecosystem services from conservation biological control: the role of habitat management. Biological Control 45, 254–271.

Frank, S.D., Wratten, S.D., Sandhu, H.S. and Shrewsbury, P.M. (2007) Video analysis to determine how habitat strata affects predator diversity and predation of Epiphyas postvittana (Lepidoptera: Tortricidae) in a vineyard. Biological Control 41, 230–236.

Gagic, V., Paull, C. and Schellhorn, N.A. (2018) Ecosystem service of biological pest control in Australia: the role of non-crop habitats within landscapes. Austral Entomology 57, 194–206.

Gotelli, N.J. and Colwell, R.K. (2011) Estimating species richness. Magurran A.E. and McGill B.J., eds. Biological diversity: frontiers in measurement and assessment (Oxford University Press: Oxford, England) pp. 39–54.

Gurr, G.M., Wratten, S.D. and Luna, J.M. (2003) Multi-function agricultural biodiversity: pest management and other benefits. Basic and Applied Ecology 4, 107–116.

Gurr, G.M., Wratten, S.D., Landis, D.A. and You, M.S. (2017) Habitat management to suppress pest populations: progress and prospects. Annual Review of Entomology 62, 91–109.

Gurr, G.M., Wratten, S.D., Irvin, N.A., Hossain, Z., Baggen, L.R., Mensah, R.K. and Walker, P.W. (1998) Habitat manipulation in Australasia: recent biological control progress and prospects for adoption. Zaluki, M.P., Drew, R.A.I. and White, G.G., eds. Pest management - future challenges. Proceedings of the 6th Australasian applied entomological research conference; 29 September–2 October 1998; Brisbane, Qld, Australia, (The University of Queensland: Brisbane, Qld, Australia) 2, A225–A235.

Helson, G.A.H. (1939) The oriental peach moth (Cydia molesta Busck). Investigations in the Goulburn Valley, Victoria. Progress report for the seasons 1935–1938. Pamphlet 88 (Council for Scientific and Industrial Research: Melbourne, Vic., Australia), 23 pp.

Hogg, B.N. and Daane, K.M. (2011) Ecosystem services in the face of invasion: the persistence of native and nonnative spiders in an agricultural landscape. Ecological Applications 21, 565–576.

Hogg, B.N., Wang, X.G., Mills, N.J. and Daane, K.M. (2014) Resident spiders as predators of the recently introduced light brown apple moth, Epiphyas postvittana. Entomologia Experimentalis et Applicata 151, 65–74.

Holt, R.D. and Lawton, J.H. (1994) The ecological consequences of shared natural enemies. Annual Review of Ecology and Systematics 25, 495–520.

Isaacs, R., Tuell, J.K., Fiedler, A.K., Gardiner, M. and Landis, D.A. (2009) Maximizing arthropod-mediated ecosystem services in agricultural landscapes: the role of native plants. Frontiers in Ecology and the Environment 7, 196–203.

Karp, D.S., et al. (2018) Crop pests and predators exhibit inconsistent responses to surrounding landscape composition. Proceedings of the National Academy of Sciences of the United States of America 115, 7863–7870.

Kehrli, P., Karp, J., Burdet, J.P., Deneulin, P., Danthe, E., Lorenzini, F. and Linder, C. (2012) Impact of processed earwigs and their faeces on the aroma and taste of 'Chasselas' and 'Pinot Noir' wines. Vitis 51, 87–93.

Losey, J.E. and Denno, R.F. (1999) Factors facilitating synergistic predation: the central role of synchrony. Ecological Applications 9, 378–386.

Mace, G.M., Norris, K. and Fitter, A.H. (2012) Biodiversity and ecosystem services: a multilayered relationship. Trends in Ecology and Evolution 27, 19–26.

Magarey, P.A., Nicholas, P.R. and Wachtel, M.F. (1994) Control of the diseases of grapes in Australia and New Zealand. Wine Industry Journal 9, 197–225.

Makarov, S.E., Bodner, M., Reineke, D., Vujisic, L.V., Todosijevic, M.M., Antic, D.Z., Vagalinski, B., Lucic, L.R., Mitic, B.M., Mitov, P., Andelkovic, B.D., Lucic, S.P., Vajs, V., Tomic, V.T. and Raspotnig, G. (2017) Chemical ecology of cave-dwelling millipedes: defensive secretions of the Typhloiulini (Diplopoda, Julida, Julidae). Journal of Chemical Ecology 43, 317–326.

McQuillan, P.B. (1992) A checklist of the Tasmanian tortricid moths (Lepidoptera: Tortricidae) and their host-plant relationships.

Papers and Proceedings of the Royal Society of Tasmania **126**, 77–89.

Naumann, I.D. (1991) The insects of Australia: a textbook for students and research workers, 2d ed. (CSIRO Publishing: Melbourne, Vic., Australia).

Pandey, S., Rahman, A. and Gurr, G.M. (2018) Australian native flowering plants enhance the longevity of three parasitoids of brassica pests. Entomologia Experimentalis et Applicata **166**, 265–276.

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

Paull, C. and Austin, A.D. (2006) The hymenopteran parasitoids of light brown apple moth, *Epiphyas postvittana* (Walker) (Lepidoptera: Tortricidae) in Australia. Australian Journal of Entomology **45**, 142–156.

Penfold, C.M. and McCarthy, M.G. (2010) Soil management for yield and quality – sub-project 'Pursuing sustainability – the role of native ground cover species' (Grape and Wine Research and Development Corporation: Adelaide, SA, Australia).

Perez-Alvarez, R., Nault, B.A. and Poveda, K. (2018) Contrasting effects of landscape composition on crop yield mediated by specialist herbivores. Ecological Applications **28**, 842–853.

Perovic, D.J. and Gurr, G.M. (2012) Geostatistical analysis shows species-specific habitat preferences for parasitoids. Biocontrol Science and Technology **22**, 243–247.

Pimentel, D., Stachow, U., Takacs, D.A., Brubaker, H.W., Dumas, A.R., Meaney, J.J., Oneil, J.A.S., Onsi, D.E. and Corzilius, D.B. (1992) Conserving biological diversity in agricultural forestry systems – most biological diversity exists in human managed ecosystems. Bioscience **42**, 354–362.

Prescott, A. (2017) Native grasses. A regional guide (Government of South Australia: Adelaide, SA, Australia). https://www.naturalresources.sa.gov.au/files/sharedassets/adelaide_and_mt_lofty_ranges/land/native-grasses-2017.pdf

Retallack, M.J., Mackay, D., Thomson, L.J. and Keller, M.A. (2018) Which species of Tortricidae leafrollers are key insect pests in South Australian vineyards? Transactions of the Royal Society of South Australia **142**, 130–142.

Ryszkowski, L., Karg, J., Margarit, G., Paoletti, M.G. and Zlotin, R. (1993) Above ground insects biomass in agricultural landscapes of Europe. Bunce, R.G.H., Ryszkowski, L. and Paoletti, M.G., eds. Landscape ecology and agroecosystem (Lewis Publishers: Boca Raton, FL, USA) pp. 71–82.

Schellhorn, N.A., Gagic, V. and Bommarco, R. (2015) Time will tell: resource continuity bolsters ecosystem services. Trends in Ecology & Evolution **30**, 524–530.

Scholefield, P.B. and Morison, J. (2010) Assessment of economic cost of endemic pest and diseases on the Australian grape and wine industry. GWR 08/04 (Grape and Wine Research and Development Corporation: Adelaide, SA, Australia).

Sekulic, T.L., Vujisic, L.V., Curcic, B.P.M., Mandic, B.M., Antic, D.Z., Trifunovic, S.S., Godevac, D.M., Vajs, V.E., Tomic, V.T. and Makarov, S.E. (2014) Quinones and non-quinones from the defensive secretion of *Unciger transsilvanicus* (Verhoeff, 1899) (Diplopoda, Julida, Julidae), from Serbia. Archives of Biological Sciences **66**, 385–391.

Shear, W.A. (2015) The chemical defenses of millipedes (Diplopoda): biochemistry, physiology and ecology. Biochemical Systematics and Ecology **61**, 78–117.

Smith, I.M., Hoffmann, A.A. and Thomson, L.J. (2015) Ground cover and floral resources in shelterbelts increase the abundance of beneficial hymenopteran families. Agricultural and Forest Entomology **17**, 120–128.

Stamps, W.T. and Linit, M.J. (1997) Plant diversity and arthropod communities: implications for temperate agroforestry. Agroforestry Systems **39**, 73–89.

Stankovic, S., Dimkic, I., Vujisic, L., Pavkovic-Lucic, S., Jovanovic, Z., Stevic, T., Sofrenic, I., Mitic, B. and Tomic, V. (2016) Chemical defence in a millipede: evaluation and characterization of antimicrobial activity of the defensive secretion from *Pachyiulus hungaricus* (Karsch, 1881) (Diplopoda, Julida, Julidae). PLoS One **11**, 1–14.

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

Thomson, L.J. and Hoffmann, A.A. (2008) Vegetation increases abundance of natural enemies of common pests in vineyards. Australian & New Zealand Grapegrower & Winemaker **(533a)**, 34–37.

Thomson, L.J. and Hoffmann, A.A. (2009) Sustainable viticulture 2010 and beyond: vineyard management to maximize beneficial invertebrates to increase the bottom line (Grape and Wine Research and Development Corporation: Adelaide, SA, Australia) p. 56.

Thomson, L.J. and Hoffmann, A.A. (2010) Natural enemy responses and pest control: importance of local vegetation. Biological Control **52**, 160–166.

Thomson, L.J. and Hoffmann, A.A. (2013) Spatial scale of benefits from adjacent woody vegetation on natural enemies within vineyards. Biological Control **64**, 57–65.

Thomson, L.J., Macfadyen, S. and Hoffmann, A.A. (2010) Predicting the effects of climate change on natural enemies of agricultural pests. Biological Control **52**, 296–306.

Thomson, L.J., Sharley, D.J. and Hoffmann, A.A. (2007) Beneficial organisms as bioindicators for environmental sustainability in the grape industry in Australia. Australian Journal of Experimental Agriculture **47**, 404–411.

VanDerWal, J., Shoo, L.P., Johnson, C.N. and Williams, S.E. (2009) Abundance and the environmental niche: environmental suitability estimated from niche models predicts the upper limit of local abundance. American Naturalist **174**, 282–291.

Vujisic, L.V., Antic, D.Z., Vuckovic, I.M., Sekulic, T.L,. Tomic, V.T., Mandic, B.M., Tesevic, V.V., Curcic, B.P.M., Vajs, V.E. and Makarov, S.E. (2014) Chemical defense in millipedes (Myriapoda, Diplopoda): do representatives of the Family Blaniulidae belong to the 'Quinone' clade? Chemistry and Biodiversity **11**, 483–490.

Waterhouse, D.F. and Sands, D.P.A. (2001) Classical biological control of arthropods in Australia (CSIRO Entomology: Canberra, ACT, Australia)).

Winkler, K. (2005) Assessing the risks and benefits of flowering field edges. Strategic use of nectar sources to boost biological control. Thesis, Wageningen University, Wageningen, The Netherlands.

Winter, S., Bauer, T., Strauss, P., Kratschmer, S., Paredes, D., Popescu, D., Landa, B., Guzman, G., Gomez, J.A., Guernion, M., Zaller, J.G. and Batary, P. (2018) Effects of vegetation management intensity on biodiversity and ecosystem services in vineyards: a meta-analysis. Journal of Applied Ecology **55**, 2484–2495.

Wood, G., Glatz, R., DeGraaf, H., Siekmann, G. and Stephens, C. (2011) Revegetation by design – promoting the 'on farm' use of native vegetation as agents of 'natural pest control' (Rural Industries Research and Development Corporation: Canberra, ACT, Australia).

Yazdani, M., Feng, Y., Glatz, R. and Keller, M.A. (2015) Host stage preference of *Dolichogenidea tasmanica* (Cameron, 1912) (Hymenoptera: Braconidae), a parasitoid of Epiphyas postvittana (Walker, 1863) (Lepidoptera: Tortricidae). Austral Entomology **54**, 325–331.

Zemenick, A.T., Kula, R.R., Russo, L. and Tooker, J.F. (2018) A network approach reveals parasitoid wasps to be generalized nectar foragers. Arthropod-Plant Interactions. https://doi.org/10.1007/s11829-018-9642-9

Supporting information

Additional supporting information may be found in the online version of this article at the publisher's website: http://onlinelibrary.wiley.com/doi/10.1111/ajgw.12383/abstract.

Appendix S1. Arthropod survey locations.
Table S1. Diversity of Araneae collected for all traps showing mode of predation (behaviour), habitat and % presence by plant. Undetermined morphospecies comprised juveniles that could not be identified with confidence to family but resembled Gnaphosidae or Salticidae.