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Wine Australia

Charles Sturt University

FUNCTIONAL BIODIVERSITY SOLUTIONS FOR AUSTRALIAN VINEYARDS: HARNESSING GROUNDCOVERS, VINEYARD SURROUNDS AND NATIVE PLANTS TO DELIVER KEY ECOSYSTEM SERVICES



FINAL REPORT TO WINE AUSTRALIA

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Principal Investigator: **GEOFF GURR**

Research Organisation: **CHARLES STURT UNIVERSITY**

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1. Abstract

This project identified the benefits of vineyard groundcovers and vegetation in the landscape. Laboratory, field trial and survey studies encompassed 32 vineyards in the 2021-2022 and 2022 - 2023 seasons. Several plant species produced nectar that promoted beneficial wasps but denied benefit to lightbrown apple moth. Field trials showed that groundcovers were challenging to establish but can replace taller weeds and reduce levels of pest damage and associated bunch rot. Surveys showed that beneficial insect densities in vineyards were promoted by linear riparian and roadside vegetation, especially when this extended to the wider landscape. A suite of grower-facing communications has been produced.

2. Executive summary

This project aimed to determine the extent of pest, plant disease and weed suppression and changes in frost risk that arise from the planting of the selected groundcovers. A blend of laboratory, field trial and field survey methods were used, encompassing 32 vineyards in the 2021-2022 and 2022-2023 seasons.

A suite of plant species, including several Australian natives, were able to promote the lifespan of two species of parasitoid wasp. These beneficial wasps attack the major Australian vineyard pest lightbrown apple moth (LBAM). *Trichogramma carverae* and *T. pretiosum*, had improved fecundity under laboratory conditions when feeding on nectar of selected species. Several of these plant species did not provide an equivalent benefit to LBAM so can be considered 'selective food plants' that could be used in vineyards to promote the parasitoids without inadvertently promoting the pest. This laboratory screening also identified several groundcover species that do benefit LBAM so should be avoided in future plantings.

Field trials in two NSW vineyards showed that undervine and midrow groundcovers can reduce levels of LBAM damage and the associated bunch rot. Most of the tested groundcover species were shorter growing than the spontaneous weedy vegetation they replaced. This offers several advantages including the promotion of air flow in the vineyard conferring lower risk of frost damage and fungal disease. Generally, however, the addition of groundcover vegetation to established vineyards was logistically challenging, especially under organic production conditions where herbicide control of existing vegetation was constrained. Groundcover establishment prior to or in the early stages of vineyard establishment is likely to be easier.

More broadly than the results obtained for the particular plant species used in the laboratory and field trial studies, it is possible to infer the major traits of plants that are indicative of benefit in a vineyard context. These are: white flowers, capable of blooming early in the season and for a prolonged period, prostrate or short-growing growth habit, vigorous early vegetative growth, dense and competitive habit, and low susceptibility to frost. Ease of availability of inexpensive planting material (seeds or young plants) is a further consideration. None of the plants tested in the present study are considered to present a significant weed risk because all are native or widely grown exotics that have not already become weeds. Growers exploring wider species choice options should consider potential weed risk including toxicity or injury to livestock that may be used in the vineyard. Whilst there is growing interest in the Australian vineyard sector in the use of native plants in and around vineyards for wildlife conservation and aesthetic reasons, it is not possible to make a

general recommendation to use Australian native plants to provide pest management related benefits. Some native plants, such as *Acacia*, did not promote beneficials when used as groundcovers whilst others, such as *Myoporum*, did.

Field surveys revealed that the density of beneficial arthropods (insects and spiders) within a given vineyards is far from uniform and is influenced by the nature of adjacent land use. Densities of beneficials on vines were promoted by linear riparian and roadside vegetation in adjacent areas. This is likely to reflect the facts that these forms of vegetation are lightly managed and have low levels of disturbances such as spraying, grazing and cultivation. Reflecting this, these areas are characterised by structural complexity (e.g. banks and ridges, tussocky and woody vegetation of different heights and ages, standing and fallen timber) and taxonomic diversity in plants that would tend to make resources such as nectar and pollen available for extended periods compared with less diverse vegetation. In addition to those attributes, the fact that riparian and roadside vegetation is – by definition – linear in form. This allows such land uses to provide habitat linkage between vineyards and more remote habitat patches that may serve as refuges for beneficial arthropods.

At spatial scales wider than the vineyard-adjacent land use, there were strong effects of vegetation patterns on densities of beneficial in vineyards. At the scale of 5 km from a given vineyard, an abundance of non-perennial crops and pastures tended to be associated with higher abundance of beneficial arthropods as a whole, and parasitoids as one of the numerically dominant types of beneficial, on vines. This effect could result from those crops harbouring pest species that allowed beneficial insects and spiders to build up in density and 'spill-over' into nearby vineyards. Such an effect would be promoted by the disturbance regimes of those systems in which harvesting or grazing might propose emigration of beneficials. Densities of beneficials on sampled vines were also favoured by landscapes in which there was native woodland present in configurations that led to relatively high edge density (e.g., small patches and strips rather than low numbers of larger patches).

Consistent with this finding, beneficials were also favoured by linear strips of vegetation of the type that were also favourable when located immediately adjacent to vineyard.

Results have been communicated to industry at the Australian Wine Industry Technical Conference (AWITC) where Geoff Gurr gave an invited presentation. He also co-convened a workshop at the AWITC with Mary Retallack entitled 'Managing non-vine vegetation in and around the vineyard to deliver production benefits'. Both Prof Gurr and co-investigator Dr Jian Liu presented talks on aspects of the project. Additionally, findings have been presented in *Grapegrower and Winemaker* and at six regional workshops in the NSW Department of Primary Industries Spring Vine Heath Field Days.

This work was financially supported by Wine Australia and Charles Sturt University. The authors gratefully acknowledge See Saw Wines and Angullong Vineyard for hosting field trials and the dozens of vineyard owners and managers who allowed data and samples to be collected. We thank Mark Bourne, NSW Wine Industry Association; Nicole Samodol, Rowlee Wines; Brendan Jarrett, See Saw Wines; Stephen McKenzie, Angullong Vineyard for their service on the project's Industry advisory Panel and Anne Johnson (PhD student) for invaluable assistance.

3. Background

Earlier work by Prof Gurr has established that biodiversity-based solutions can be delivered by simple vegetation management strategies in vineyards[1] and a range of other system including rice and horticultural crops[2]. Accordingly, the stage is set to allow the Australian viticulture sector to literally 'grow sustainable environments' and thereby achieve strategy 4 of its 2020-2025 Strategic Plan. Crucially, however, whilst success and subsequent adoption of biodiversity based solutions has been strong in rice[3], it is clear that selection of the right plant species is key to maximise benefits and avoid unforeseen, negative effects in this and other systems[1,4]. Accordingly, the major constraint to the Australian viticulture sector rapidly moving ahead with biodiversity based solutions to pest, weed and disease problems is that research to date has focused on only limited numbers of plant species and ecosystem services. For example, pioneering work by Retallack[5] covered only three plant species and only from the perspective of promoting biological control. The more recent South Australian work in the EcoVineyards project expanded the range of plant species for which information is available but was confined to pest suppression. We aim to build on existing information to establish a much wider evidence base involving many more plant species and additional ecosystems services including weed control and vineyard airflow to reduce disease risk from humidity and frost damage. Importantly we will use an ecological traits approach to plant selection so that results and recommendations have wide applicability across regions.

Vineyard problems range from endemic and potential exotic pests of vines (e.g. spotted wing drosophila and glassy-winged sharpshooter), as well for weeds and diseases. Realising the opportunity of biodiversity based solutions for these problems requires strategic investment to identify the types of vegetation (species and traits) that are optimal for maximising benefits and avoiding trade-offs, and working with industry to develop practical delivery mechanisms such as undervine and midrow groundcovers, along with an understanding of the effects of differing vegetation types in vineyard surrounds.

Key points arising from the literature survey are as follows:

Undervine and interrow groundcovers can:

- increase densities of natural enemies of vineyard pests [5]
- increase the longevity of beneficials such as the lightbrown apple moth parasitoid *Trichogramma carverae* [6]
- increase the rate of field predation of lightbrown apple moth [1] (This pest is widely distributed in Australian wine regions and is recognised as one of the major pests as

a result of its feeding damage and elevating risk of bunch rot. Growers in central Western NSW (including our proposed hosts of trials) regard it as the most damaging insect pest).

- decrease overall pest (i.e. not restricted to caterpillar/ moth pests) numbers [7]
- increase the rate of decomposition of prunings and thereby reduce subsequent risk of vine reinfection by important fungal pathogens [8]
- form a dense, self-sowing strip of vegetation (in the case of alyssum) that can exclude weeds and, because it is prostrate, will allow airflow under the vine (reducing risk of frost damage) [1]

4. Project Aims

The general aims planned were as follows.

- Develop practical, evidence-based recommendations for Australian vineyard managers to benefit from biodiversity-based solutions to pests including those that are common and widespread (moths and mites), sporadic but highly damaging during localised outbreaks (mealybugs and scale) and species that are likely to arrive in Australia and present new problems requiring preparedness (glassy-winged sharpshooter, spotted wing drosophila).
- Determine, from field trials and associated laboratory studies, the extent of pest, plant disease and weed suppression and changes in frost risk resulting from vineyard floor vegetation management using a range of plant species from which optimal treatments will be identified. Species in trials will include species that have been selected by the host managers (legumes), commercially available blends selected by host managers (Pasture Genetics' SOWsmart Viti Horti products) and alyssum (the optimal species from Gurr's earlier vineyard trials). Species choice is based on Australian work and preferences of Australian growers and seed merchants rather than on New Zealand or European species studies. Results from overseas work (and ongoing collaboration with overseas collaborators) will help guide groundcover management and extension of findings. Species in the laboratory trials will emphasise native plants, reflecting the recent work led by Gurr that identified the benefits of natives for beneficials that attack vegetable crop pests (Pandey, Gurr (2019) Conservation biological control using Australian native plants in a brassica crop system: Seeking complementary ecosystem services. *Agriculture, Ecosystems and Environment*, 280: 77-84). Following the methods developed in that project for efficient screening of candidate plants, we will quantify benefits from at least 10 species from 5 genera representing a range of ecological traits (height, flower colour etc).
- Determine, from vineyard field studies and GIS analyses the effects on pest suppression by vegetation types in vineyard surrounds so that growers will benefit from an understating of what constitutes high and low risk sites and under which circumstances groundcover plantings will be most effective. This part of the project will complement the laboratory studies to identify native plants that are especially beneficial (e.g., provide food for enemies of key pests) so that these can be recommended for 'functional biodiversity plantings' within vineyards themselves.

- Develop a package of communication materials on the practicalities of harnessing benefits from groundcovers and vineyard surround vegetation including aspects such as ease of establishment and maintenance, flowering periods for midrow and undervine planting options. The package will include video case studies that show the short- and longer-term benefits of adopting functional biodiversity, similar to the video production about Prof Gurr's research in other agroecosystems (research.csu.edu.au/engage-with-us/research-impact/ecological-pest-control). To further encourage adoption, we will calculate benefit: cost ratios as was done in a very recent project for Horticulture Innovation that showed ratios as high as 8:1 from use of flowering groundcover strips in brassica vegetables.
- Identify the functional traits of undervine and midrow groundcover species (e.g., plant height, blooming period, flower colour) that are associated with strong benefit to growers so that species other than those we study can be reliably predicted for utility. This focus on traits is important practically (and in line with current ecological research themes) because it will allow results from NSW trials to be transferrable to other production areas with differing climates and soils. For example, if alyssum performs optimally for delivery of biodiversity-based solutions in our NSW trials but is considered unsuitable for growth in other areas (e.g., wetter and with alkaline soils), growers in those areas can select locally appropriate species that share with alyssum the traits of white flowers, prostrate growth habit and nectar availability in the spring period of vine vulnerability to early season pests. Alyssum seed is more costly per kg that that of many groundcover species but this is offset by lower seed rate and the fact that it rapidly matures and produces seed that leads to the establishment of a resilient, self-sustaining and year-round-blooming strip. Our earlier field trials in vineyards, and in vegetable crops in SA, NSW, QLD and VIC, found that it was rapid to begin flowering and, in brassica crops gave benefit: cost ratios up to 8:1 arising from reductions in pest damage by attracting beneficial insects and spiders.
- In conjunction with the proposed sister project led by Jason Smith, develop an understanding of water use by groundcovers in order that grower recommendations consider the implications of groundcovers in terms of advantages (e.g., avoided use by weed growth) and disadvantages (water used by groundcovers). This, in-turn, will guide grower implementation of findings in relation to the selection of groundcover species for use below vines and/or in midrows.

Specific outputs and performance targets for each year of the project (Table 1).

Table 1. Planned outputs and activities for the project on functional biodiversity solutions for Australian vineyards: harnessing groundcovers, vineyard surrounds and native plants to deliver key ecosystem services.

Financial Year One

Output	Target Date	Activities
Industry advisory panel confirmed. Project personnel appointed.	30/04/2021	Industry advisory panel established by formal invitations. Dr Liu and part-time technical appointments made.
Laboratory colony of lightbrown apple moth (LBAM) established.	30/05/2021	Lightbrown apple moth founders collected from local field sites and all minor equipment and consumables in place.
Completion of autumn sowings of groundcovers. Additional vineyards (n=25) identified for surveys of effects of vineyard surrounds.	30/06/2021	Field operations with host growers. GIS and ground-truthing field work.

Financial Year Two

Output	Target Date	Activities
Initial set of laboratory results on the effects on LBAM and its parasitoid *Trichogramma carverae* of flowering plants grown in the lab and collected from the field (for autumn to winter-blooming species).	31/08/2021	Lab studies following the methods used in earlier study in Prof Gurr's lab (Pandey S., Gurr G.M. (2019) Conservation biological control using Australian native plants in a brassica crop system: Seeking complementary ecosystem services. *Agriculture, Ecosystems and Environment*, 280: 77-84.).
Set of season one results from field trial of the effects of candidate groundcover species on biotic threats and frost risk.	31/04/2022	Assessment of effects of groundcovers on: - LBAM egg parasitism and predation using bait sentinel cards, - naturally occurring levels of pest

		infestation and symptom severity (for mites, mealybug and scale), - naturally occurring levels of vine diseases, - weed suppression, - groundcover plant height and growth habit (to inferred effects on air flow) and direst assessment of any reduction in frost damage, Following methods used by Begum, Gurr et al. (2006) Using selective food plants to maximize biological control of vineyard pests. *Journal of Applied Ecology,* 43: 547-554.
Set of season one results from surveys of 25 vineyards on effects of vineyard surrounds	31/04/2022	Assessment of effects on: - LBAM egg parasitism and predation using bait sentinel cards, - naturally occurring levels of pest infestation and symptom severity (for mites, mealybug and scale), - naturally occurring levels of vine diseases (bunch rot, sooty mould and powdery and downy mildew),
Concluding set of laboratory results on the effects on LBAM and its parasitoid *Trichogramma carverae* of flowering plants grown in the lab and collected from the field (for spring to summer blooming species).	31/05/2022	Lab studies following the methods used in earlier study in Prof Gurr's lab (Pandey S., Gurr G.M. (2019) Conservation biological control using Australian native plants in a brassica crop system: Seeking complementary ecosystem services. *Agriculture, Ecosystems and Environment*, 280: 77-84).
Article in Grapegrower and Winemaker.	31/05/2022	Writing.
Annual report.	31/06/2022	Data analysis, interpretation of results in consultation with the Industry advisory panel

Financial Year Three

Output	Target Date	Activities
Set of season two results from field trial of the effects of candidate groundcover species on biotic threats and frost risk.	31/04/2023	Assessment of effects of groundcovers on: - LBAM egg parasitism and predation using bait sentinel cards, - naturally occurring levels of pest infestation and symptom severity (for mites, scale and mealybug), - naturally occurring levels of vine diseases (bunch rot, sooty mould and powdery and downy mildew), - weed suppression, - groundcover plant height and growth habit (to inferred effects on air flow) and direst assessment of any reduction in frost damage.
Set of season two results from surveys of 25 vineyards on effects vineyard surrounds.	31/04/2023	Assessment of effects on: - LBAM egg parasitism and predation using bait sentinel cards, - naturally occurring levels of pest infestation and symptom severity (for mites), - naturally occurring levels of vine diseases (bunch rot, sooty mould and powdery and downy mildew), With spatial analyses based on methods used in recent Horticulture Innovation project (Akter, Gurr et al. Landscape context mediates the effects of local vegetation on in-field abundance of pests and natural enemies. *Journal of Applied Ecology* (in review))
Set of recommendations integrating results of the project with those from the sister project on water use and to incorporate results into Cover crop Finder online tool.	31/04/2023	Liaison with industry advisory panel and stakeholders.

Articles in *Grapegrower and Winemaker,* video case study production, factsheet, webinar, journal articles and other communication activities (x2).	31/05/2023	Writing and associated communications activities.
Project final report submitted to Wine Australia (WITH MINOR REVISIONS AND ADDITIONS IN DECEMBER 2023)	30/06/2023	Completion of data analysis and report to funding body of research findings.

Changes to the original targets

1. A delay in the LBAM laboratory studies was reported to Wine Australia resulting from initial difficulties with colony vigour. This was resolved and the planned work was completed in year two.
2. Year 1 vineyard survey work was expanded from 25 to 30 sites.
3. Levels of LBAM parasitism and predation in the field studies were low so the time consuming use of sentinel bait cards was discontinued.

5. Method

5.1. Vineyard Trials

In accordance with the original plan, field trials were conducted on two sites in the Orange region: See Saw Wine's organically managed Balmoral vineyard (900 m asl) and the, conventionally-managed Angullong vineyard (600 m asl). At each site, one trial compared undervine ground cover treatments whilst a second compared midrow ground cover treatments. A randomised block design was employed in all trials.

Undervine treatments were:

1. control (existing vegetation with no added plants),
2. alyssum (direct seeded after existing vegetation removed),
3. undervine See Saw Blend (a commercial seed mix comprising Balansa clover cv. Cobra (*Trifolium michelianum*) 42%, Persian clover cv SARDI (*Trifolium resupinatum*) 42%, and plantain cv. Tonic (*Plantago lanceolata*) 16%), (direct seeded after existing vegetation removed)
4. undervine native mix (*Pratia pedunculata, Viola hederaceae, Dichondra repens, Dampiera diversifolia, Myoporum parvifolium*) (seedlings planted after existing vegetation removed)

Midrow treatment were:

1. control (existing vegetation with no added plants),
2. buckwheat, (direct seeded after cultivation),
3. midrow See Saw Blend (a commercial seed mix comprising, Field pea 70%, Hybrid turnip x Chinese cabbage cv. Bouncer 8%, red clover cv. Mammoth 8%, Balansa clover cv. Cobra (*Trifolium michelianum*) 7%, Persian clover cv SARDI (*Trifolium resupinatum*) 7%, (direct seeded after cultivation),
4. midrow native mix (*Grevillea lanigera* 'Mt Tamboritha', *Correa reflexs* x *pulchella* 'Dusky bells', *Leptospermum scoparium* 'Pink Cascade', *Rhagodia spinescens*). (seedlings planted after cultivation, weed mat placed around seedlings)

Native plants were established from small, commercial nursery-sourced seedlings whilst other plants were established from seed. Plots extended in length to cover two panels (12 metres) with the undervine treatments applied to a single vine row from which samples and

data were collected (Figure 1). The midrow plants were established in two adjacent midrows either side of a vine row from which samples and data were collected.

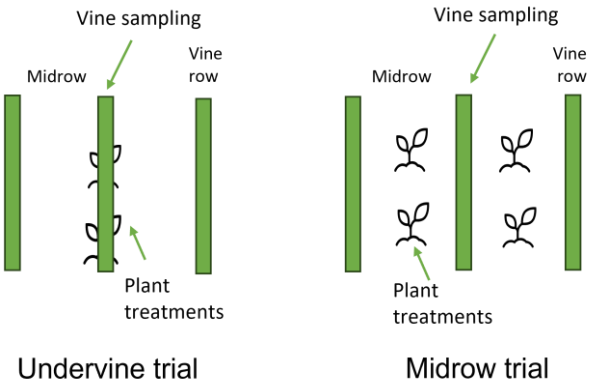


Figure 1. Schematic illustration of undervine (left) and midrow (right) planting positions in relation to vine rows and sampling areas.

To assess arthropod densities, a sample was taken using a modified garden leaf blower/vacuum such that dislodged insects and spiders were held in a mesh sleeve attached to the inlet port. Vac-sampling was timed for 2-minutes per vine canopy and ground cover vegetation samples (Figure 2). The vacuum samples were immediately placed in a portable freezer to avoid predation of animals and taken back to the laboratory for sorting. All arthropods were picked out of the samples and identified into categories of natural enemies (including sub-categories of parasitic wasps, predatory insects, spiders), pests and neutral arthropods.



Figure 2. Vacuum sampling of vine vegetation.

Visual assessments of grapevine canopy and fruit bunches were done by a two person team, one as assessor and one as scribe. Each plot was allocated five minutes for a visual scan through the grapevine foliage and canes of the plot, calling out pests and natural enemies sighted. A second such assessment was used to record disease symptoms on foliage. A third scan assessed fruit bunches for pests, natural enemies and diseases. Additionally, at the bunch ripening stage of growth, groundcover plant heights were measured using a calibrated cane and groundcover composition were measured by visual assessment to quantify the percentage of bare ground, added plant coverage, and spontaneous plant (weed) coverage.

5.2. Laboratory Studies

Laboratory tests was conducted using two species of parasitic wasps *Trichogramma carverae* and *Trichogramma pretiosum*. The former species is native to Australia while the latter species was introduced to Australia in classical biological control program. Plant species used in the laboratory tests are listed below. For each plant species, the two treatments were 1) with flowers intact and 2) with flowers removed. This allowed effects of nectar to be measured rather than effects from plant volatiles or other factors. Nectar feeding could be assumed when wasps performed strongly with access to flowers (the treatment type ‘with_flower’) and did not performed strongly with access to plant shoots with no flowers (treatment type ‘flower_removed’). Control treatments were a positive control of honey solution and negative control of water-only.

Flowering plants used in the laboratory tests with parasitoids were as follows.

- *Acacia vestita*
- *Acacia sp.*
- *Dillwynia phylicoides*
- *Erigeron karvinskianus*
- *Eucalyptus sideroxylon*
- *Fagopyrum esculentum*
- *Grevillea 'Bronze Rambler'*
- *Grevillea rosmarinifolia*
- *Hakea salicifolia*
- *Indigofera australis*
- *Kunzea ambigua 'Pink'*
- *Leptospermum flavescens 'Cardwell'*
- *Leptospermum scoparium*

- *Lobularia maritima 'Benthamii'*
- *Melaleuca pallida*
- *Myoporum parvifolium*
- *Philotheca myoporoides*
- *Pratia pedunculata*
- *Trifolium repens*
- *Trifolium spumosum*
- *Viola hederacea*
- *Westringia fruticosa*
- *Eucalyptus melliodora*

Ten pairs of adult parasitic wasp (less than 24h from emergence) were introduced into each flight cage. A host egg card bearing eggs of the factitious host *Ephestia kuehniella* was inserted for female wasp oviposition and a shoot of the relevant type of plant was added (Figure 3). These flight cage assemblies were kept at 25±2 °C,70±5H, 14:10 of light/dark cycle in incubators (Figure 3) and the egg cards and flower shoots renewed every five days. *Ephestia* eggs would turn dark grey or black in colour around one week after being parasitised whilst unparasitised eggs remained cream in colour and by this means it was possible to measure both reproductive performance of the wasps in each flight cage and infer their longevity.

The impact of flowering plants on light brown apple moth (*Epiphyas postvittana*) was assessed using a flight cage assembly similar to that described above for se with *Trichogramma* wasps. In this instance, cages held one pair of newly emerged LBAM moth (one female and one male) with a flowering shoot or control treatment of 10% honey solution or water-only. Moth survival was recorded every second day to assess longevity. The female moth would lay eggs on any surface inside the cage so, every seven days, the live moths were transferred into a fresh cage with the renewed flower or control (honey solution or water) resources. The number of eggs laid was recorded to compare fecundity across treatments.



Figure 3**.** Laboratory test of parasitic wasp *Trichogramma* performance with plant flowering resources. A, flight cage assembly. B, egg cards showing parasitied eggs (black) and unparasitized eggs (cream). C, shoot of test plant held in water vial to maintain turgidity. D, Randomised flight cages in incubator.

5.3. Vineyard Survey

The survey work was extended from the planned 25 sites to a total of 30 vineyards in year 1. Numbers of sites was reduced to 25 in year 2. At each site, one vineyard block was selected for sampling in consultation with the owner or manager. Blocks with contrasting land uses in the immediately adjacent areas were selected. Adjacent land uses were categorised as

follows. 1. perennial horticulture including orchards, and vineyards; 2. extensive trees; 3. narrow linear non-crop vegetation including road, tree line, non-crop vegetation belt/line, 4. waterbody include dam or river; 5. grassland including grazed or non-grazing areas; 6. built infrastructure such as a cellar door, residential house, shed. ArcGIS10.8 was used to extract land use data from the database “Catchment scale land use of Australia – Update December 2020” by the Department of Agriculture, Fisheries and Forestry.

Sampling positions for each vineyard were, 1) central point of the block and 2) the vineyard margins with a different sample for each adjacent land use. Margin samples were taken in the vines from the second row in from the edge or, in the case of smaller blocks, the inner edge of the outermost row. For edges where the vine rows met at right angles, the samples were taken at about 3 m from the ends of row. Between two and four margin samples were taken at each vineyard.

At each sampling position, vacuum samples were taken using a modified garden leaf blower/vac vacuuming (see above). These arthropod data were analysed in relation to land uses in the adjoining landscape to the scale so 250 m, 500 m, 1000 m, 2500 m and 5000 m from each vineyard centre. Vineyard centre values for arthropod catches were used because the earlier analyses of the effects of adjacent land use had shown that numbers in the edges of vineyards were strongly affected by immediately adjacent land use. This analysis, in contrast, sought to detect any possible effect of larger scale effects.

Specific landscape properties analysed were:

1. composition (i.e., proportion of the landscape of a given type) that discriminated, for example, landscapes dominated by woodland from those dominated by perennial horticulture or water bodies; and
2. edge density (i.e. the length of the edges of a given land use) that discriminated, for example, landscapes dominated by a single large woodland from those with scattered patches and corridors of woodland.

6. Results/Discussion

6.1. Vineyard Trials

In accordance with the original plan, field trials were conducted on two sites in the Orange district: See Saw Wine's organically managed Balmoral vineyard and the lower elevation, conventionally-managed Angullong Vineyard. Each vineyard hosted one trial of undervine groundcover treatments and a second trial of midrow treatments. Results from this highly labour-intensive research exercise have been discussed with the Industry Advisory Panel. Findings from the first year of work were highly encouraging and were presented to the Australian Wine Industry Technical Conference and a satellite workshop at that meeting. Whilst season one results from 2021-2022 field trials yielded encouraging results, levels of persistence of the groundcover plots over the winter and into the spring of season two were poor. At the Balmoral site this was exacerbated by waterlogging in the low-lying vineyard block in which the trials were located. For this reason, both the undervine and the midrow trials were re-established in a better drained site but growth of plants was slow in the early season period and, later in the season, a hailstorm severely damaged plots and the vines making it impossible to collect meaningful data on foliar and bunch parameters. At the Angullong site, additional seed and planting of native plants was undertaken in spring 2022 to compensate for poor over-winter persistence. On this site, however, plots were adversely affected by inadvertent mowing and spraying operations by staff leading to very low levels of ground coverage and there were no statistically significant effects evident for any variable. Accordingly, the results set out below are - with the exception of the final section on potential economic benefit – are for season one.

Several native and non-native plant species that are agronomically suited for use as vineyard groundcovers achieved significant ground coverage in year one, though coverage was greater at the Angullong site where weed competition was lower, possibly due to the historical use of herbicides in that block (Figure 4). Among the undervine treatments, the 'See Saw blend' treatment was superior in terms of measured soil area coverage and the resulting weed exclusion. At the organic Balmoral site intense weed competition (including from the soil seed bank following manual removal of existing weeds at planting/sowing) led to lower levels of soil coverage by the treatment plants. Coverage by weeds at the two sites reflected the levels of cover achieved by use of the sown plants. At Angullong, where alyssum and See Saw blend groundcovers covered approximately half of the soil surface, weed coverage was dramatically reduced, especially by the latter treatment. At Balmoral, weeds occupied the majority of the soil surface in all treatments. The native plants,

established as small potted plants, had the lowest levels of coverage but persisted well on both sites and by season's end were large and expanding vigorously (Figure 5a).

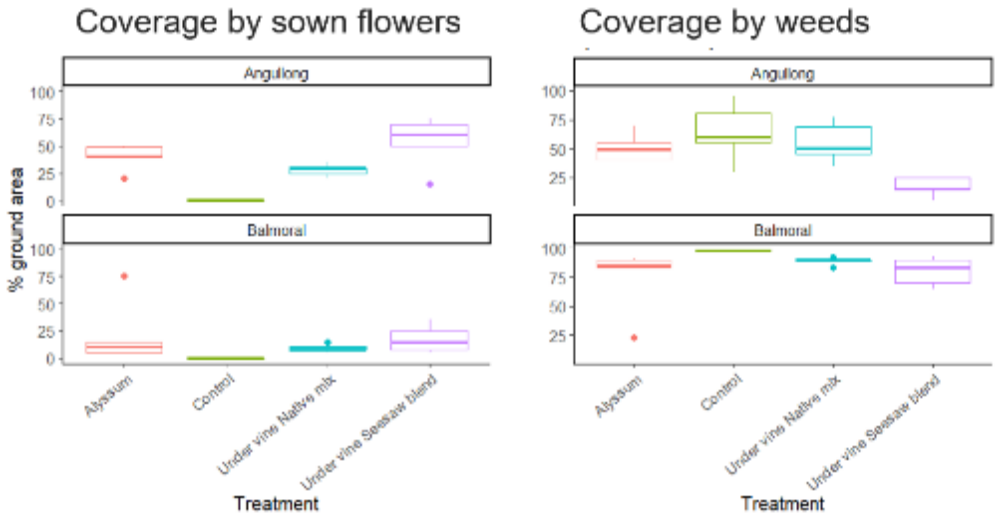


Figure 4. Cover crop plant vigour and evidence of weed suppression undervine.



Figure 5. a) Left: The low-growing native shrub, *Myoporum parvifolium*, grew vigorously beneath vines achieving, by late summer, significant levels of ground cover. b) Right: Successful early season establishment of buckwheat sown in midrow at Balmoral.

In trials of midrow treatments, buckwheat established vigorously at both sites and performed well at Balmoral (Figure 5b) before being inadvertently slashed during vineyard operations. At Angullong, however, this plant grew well and coverd approximately one third of the soil

area that led to much lower levels of weed coverage than in the control treatment (Figure 6). Other midrow cover crop species had low-moderate establishment in year one suggesting that (i) seed bed preparation needs to be optimised for annuals and (ii) natives require time to spread.

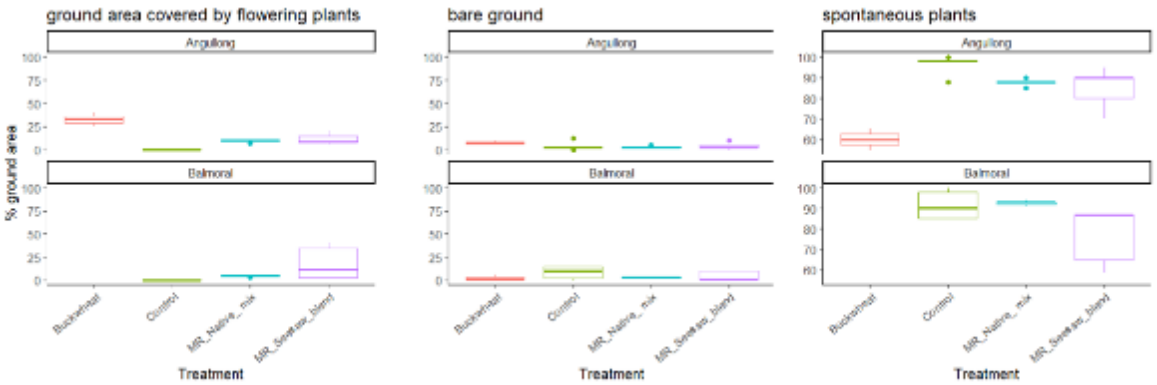
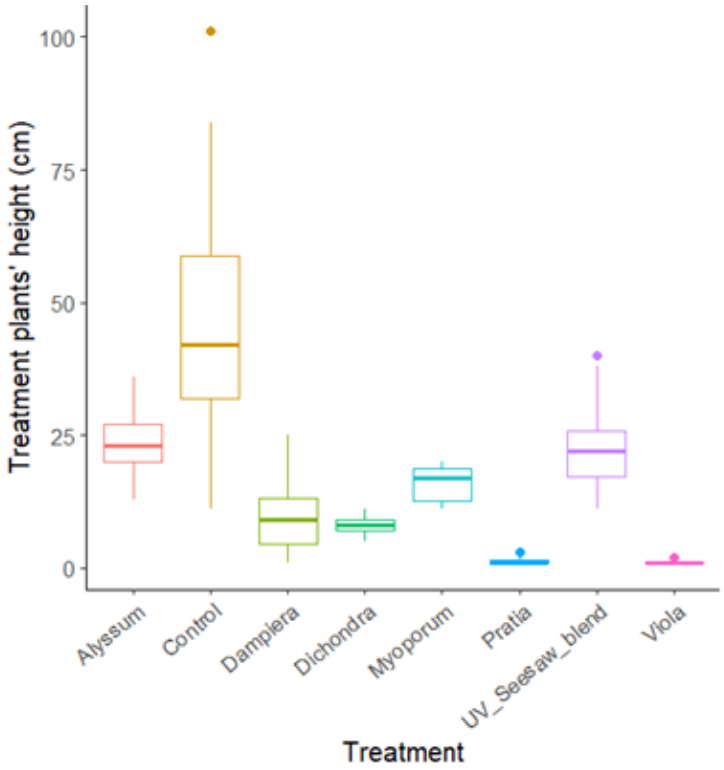


Figure 6. Cover crop plant vigour and evidence of weed suppression midrow by buckwheat at Angullong site.

Figure 7. Undervine cover crop plant height (mean of both trial sites).



Plant height was recorded in late summer to gauge whether undervine cover crops were more prostrate than the weedy vegetation they replaced, this being a key factor for air flow through the vine canopy and minimising humidity and risk of fungal disease. Mean plant height in the weedy control treatment was 44.9 cm and considerably lower in all cover crop

types ranging from 23.7 cm for alyssum to less than 2 cm for the native plants *Pratia* and *Viola* (Figure 7). Even the tallest (alyssum), provided a large amount of open space beneath the vines (Figure 8).



Figure 8. Alyssum was the tallest growing of the undervine treatments but even this species reached a mean height of only 23.7 cm by late summer, leaving plenty of open space between it and the vines to air flow.

End of season assessment of fruit bunch attack by lightbrown apple moth revealed that severity of bunch damage was greatly reduced by alyssum at both sites (Figure 9). Alyssum had strongest effect. The potential mechanism for these effects is that the flowers attracted and supported beneficial insects such as parasitoid wasps and predatory insects that attack by lightbrown apple moth. Both types of beneficial are known to utilise nectar and pollen. Laboratory studies in this project did demonstrate enhancement of *Trichogramma* species when provided with alyssum flowers (see below). At Angullong, the mix of native plants and the See Saw blend treatments both gave considerable reductions in lightbrown apple moth damage, but these treatments were less effective at Balmoral.

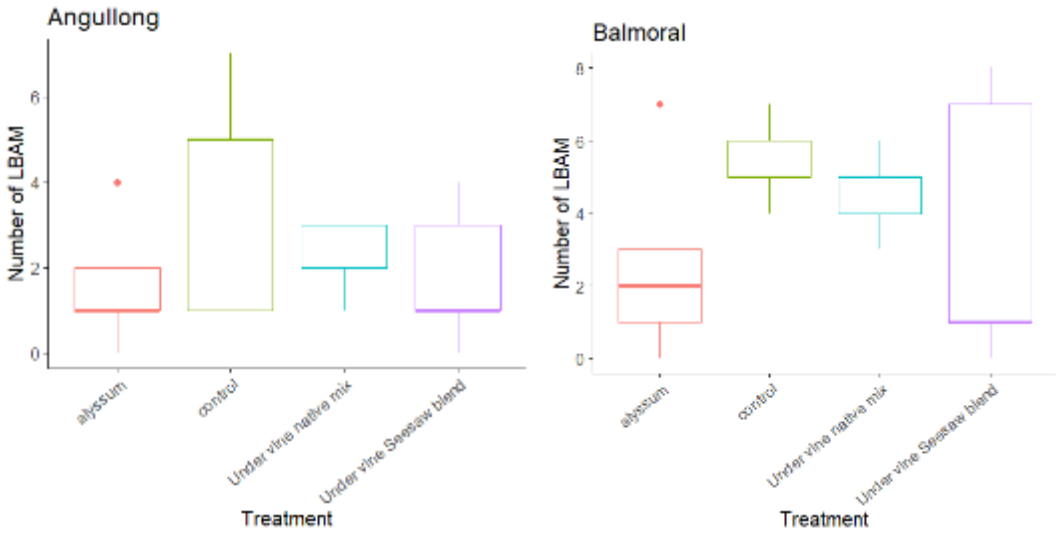


Figure 9. Undervine cover crops and evidence of insect pest control: fruit bunches attacked by lightbrown apple moth (LBAM)

Results for the midrow groundcover treatments were broadly similar to the undervine trials. Strong levels of lightbrown apple moth damage alleviation were evident in the experimental treatments compared with the weedy control treatment at Angullong (Figure 10). At Balmoral, however, where damage levels were numerically greater, only the buckwheat treatment gave strong levels of damage alleviation. Laboratory studies in this project did demonstrate enhancement of *Trichogramma* wasp species when provided with buckwheat flowers (see below).

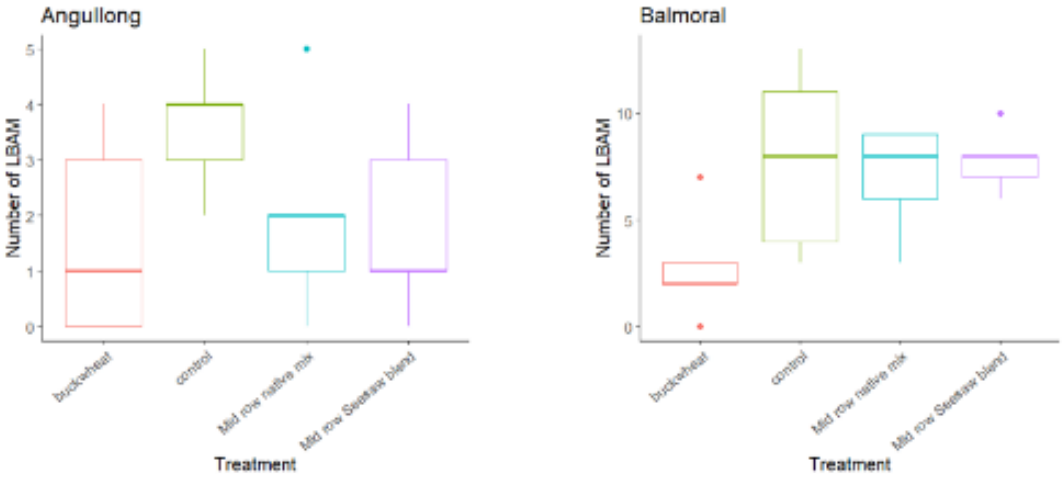


Figure 10. Midrow cover crops and evidence of insect pest control: fruit bunches attacked by lightbrown apple moth (LBAM)

The incidence and severity of botrytis bunch rot was reduced by undervine groundcover treatments, especially at the Angullong site and most strongly for the alyssum treatment (Figure 11). This finding suggests that reductions in the severity of lightbrown apple moth attack (noted above) can have a knock-on effect in reducing the presence and size of botrytis fungus infection courts within bunches; that is, reduced caterpillar feeding damage makes the bunches less likely to become infected by botrytis fungus.

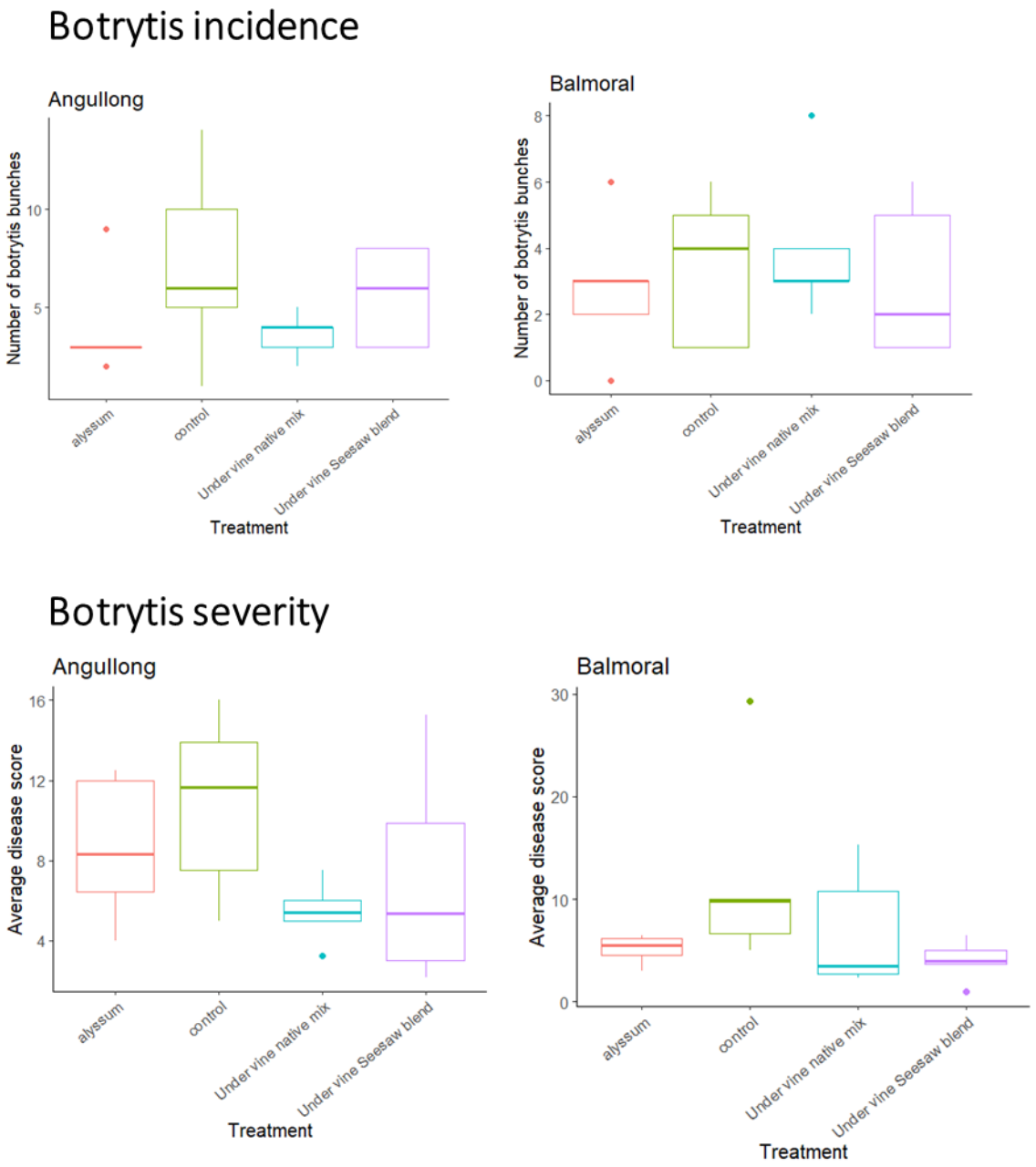


Figure 11. Undervine cover crop evidence of pathogen suppression - fruit bunches affected by botrytis.

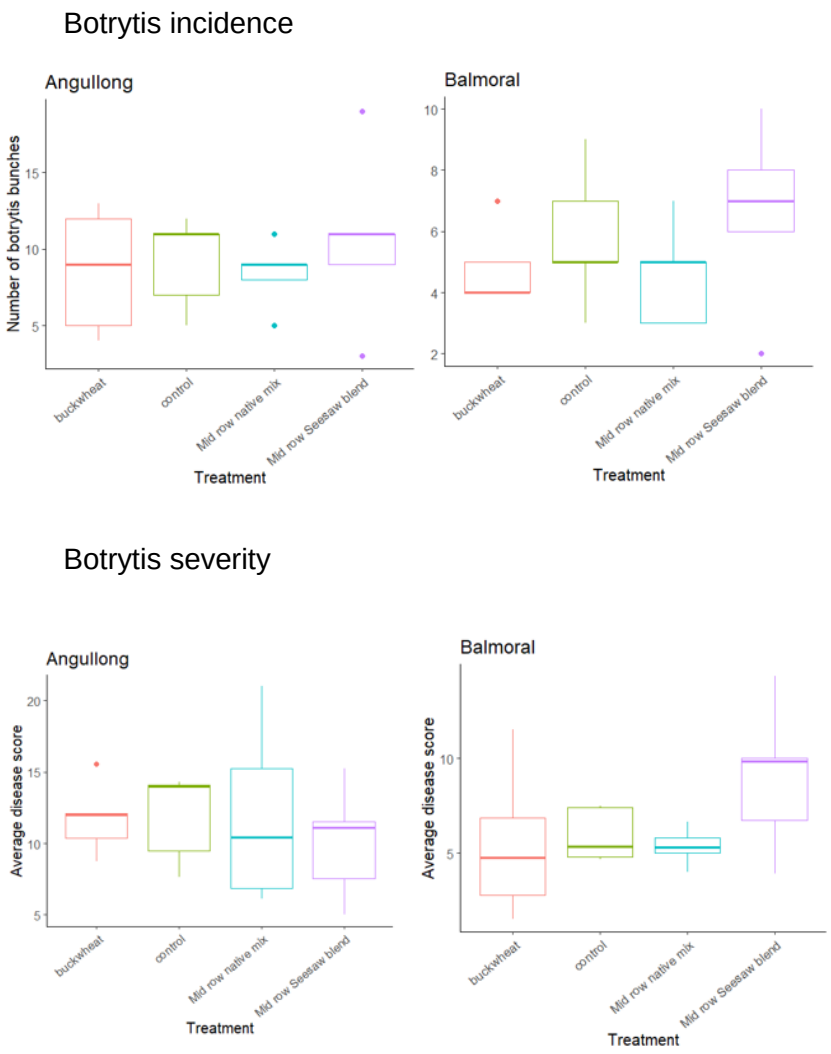


Figure 12. Midrow cover crop evidence of pathogen suppression - fruit bunches affected by botrytis.

In the midrow trials, there was less strong evidence of groundcovers suppressing incidence and severity of botrytis bunch rot with only buckwheat exhibiting an effect on incidence in the Balmoral trial (Figure 12).

For non-botrytis rots, there were less strong effects of undervine treatments than was the case for botrytis rots (Figure 1313, 14). At Balmoral, severity (but not incidence) appeared to have been increased by the See Saw blend compared with the control.

For midrow treatments, beneficial effects on incidence of non-botrytis rots were evident for all three treatments at Angullong and this was reflected also for the severity of symptoms on affected bunches for the native mix and See Saw blend treatments. At Balmoral, however, incidence of bunch symptoms was much lower than at Angullong and the sown groundcover treatments appeared to have less to some increase compared with the control.

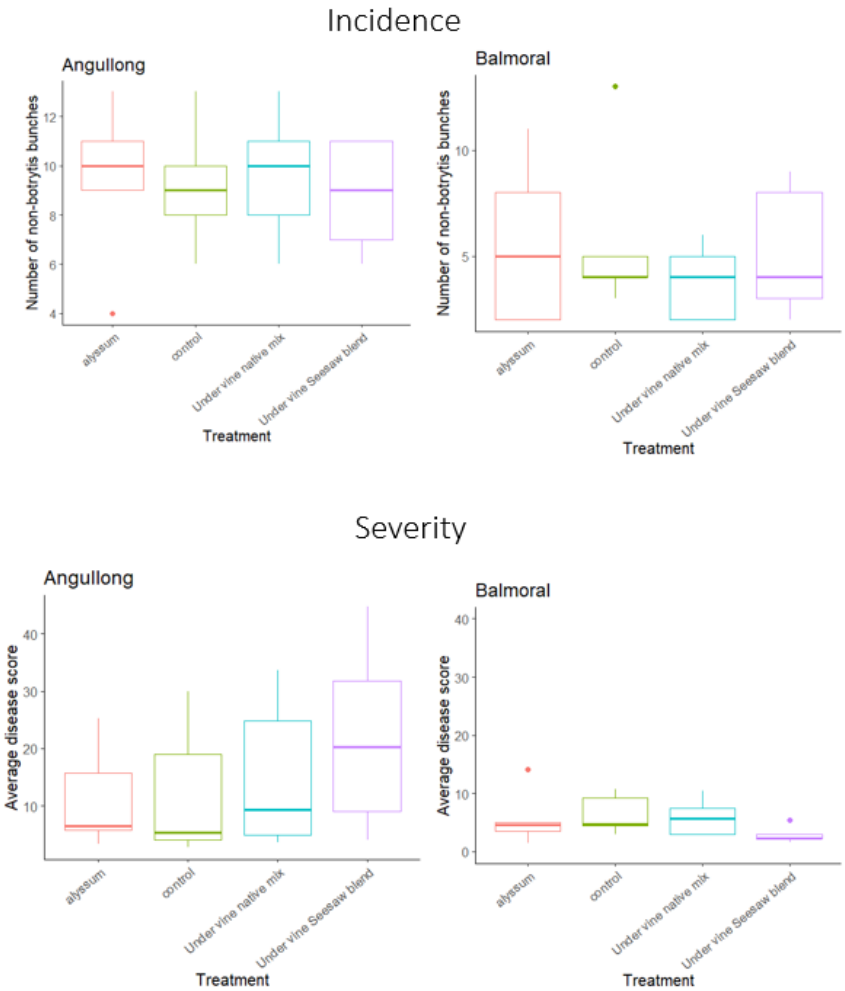


Figure 13. Undervine cover crop evidence of pathogen suppression - fruit bunches affected by non-botrytis rot.

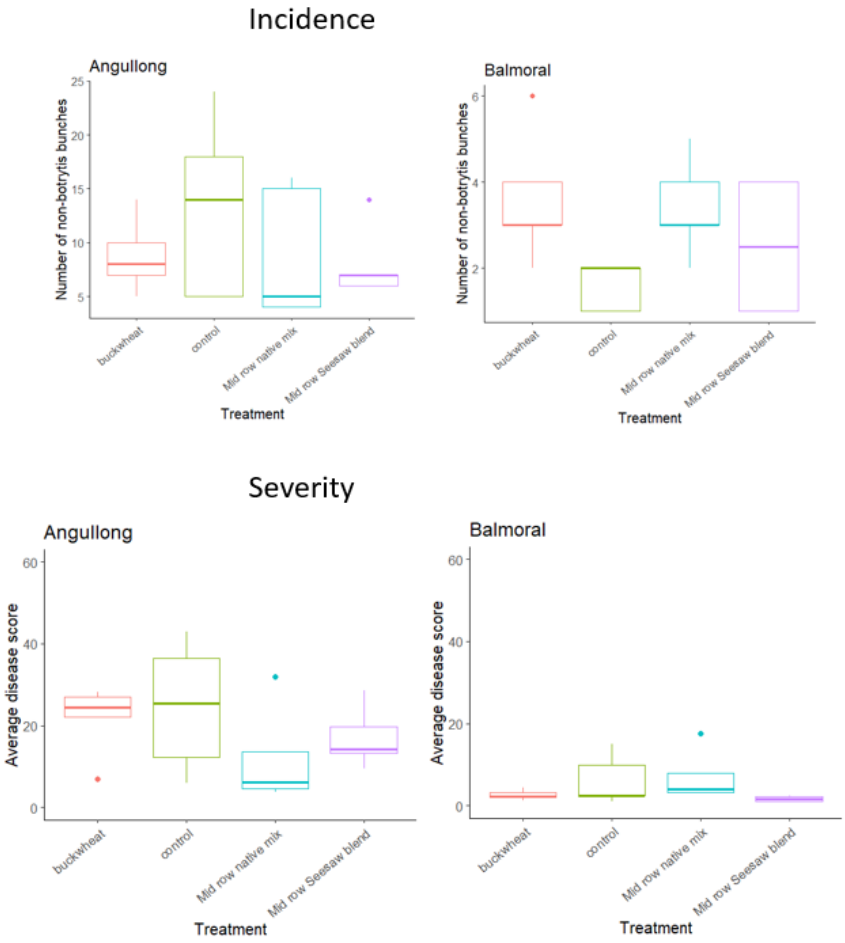


Figure 14. Midrow cover crop evidence of pathogen suppression - fruit bunches affected by non-botrytis rot.

6.2 Laboratory tests comparing effects of differing plants on beneficial and pests

6.2.1 Effects on beneficials.

Laboratory tests were conducted using two species of parasitic wasp, *Trichogramma carverae* and *Trichogramma pretiosum.* The former species is native to Australia while the later species is present in Australia as a result of an earlier classical biological control program.

Some flowers greatly improved performance of parasitoid wasps (Figure 15). Such effects can be assumed to arise from nectar feeding rather than plant volatiles or other factors because it was apparent only when wasps had access to flowers (the treatment type 'with_flower') and not when equivalent plant shoots had no flowers (treatment type 'flower_removed').

This screening provides important guidance for selection of species to use as groundcovers in vineyards, plantings or landscape. Among exotic plant species that had been used in the field trials, buckwheat (*Fagopyrum esculentum*) greatly improved performance of both wasp species and alyssum (*Lobularia maritima*) provided benefit to *T. pretiosum,* (it was not tested against *T. carverae*). Many, but not all, of the natives provided benefit to wasps. For example, the *Eucalyptus* species tested strongly enhanced *Trichogramma* egg laying but both *Acacia* species had no effect. Though these large woody species cannot be accommodated as vineyard groundcovers, they are well represented in vineyard adjacent vegetation and in wider landscapes so information on their effects (or lack of effect) on parasitoid wasps is important in relation to interpreting the results from the field survey and in formulating recommendations. Among the native plants used in vineyard trials, *Myoporum parvifolium* provided strong benefit to *T. carverae* (it was not tested against *T. pretiosum*). The reason that not all plants were tested against both wasp species is the logistical complexity of having sufficient numbers of newly emerged wasps available to run the replicated experiments at the same time as plants were blooming.

6.2.2 Effects on the pest, lightbrown apple moth

Effects of plant species on the pest, lightbrown apple moth, were assessed under laboratory conditions, seeking species that denied benefit to the adult (moth) yet were capable of boosting performance of parasitoids. For the key response variable of female fecundity, buckwheat, white clover, and the natives *Acacia, Erigeron, Indigofera, Melaluca, Myoporum*

all led to a moth performance no better than the water (control) treatment so can be considered the safest choice for use in vineyards (Figure 16). Conversely, several natives and exotics, especially *Trifolium spumosum* appeared to benefit the moth's fecundity so are likely not to be suitable as groundcovers in sites where lightbrown apple moth is a known issue. The complementary measurement of female longevity revealed results broadly comparable to the fecundity results except that the extent of denial to benefit was lower than for fecundity to the extent that only *Acacia,* and *Myoporum* gave a longevity that was statistically lower than the honey solution (positive control) treatment (Figure 17). Male moth longevity was also recorded and this revealed that whilst *Pratea* strongly supported pest performance, the other natives *Acacia, Hakea, Indigofera, Melaleuca* and *Myoporum* all denied benefit to the pest (Figure 18).

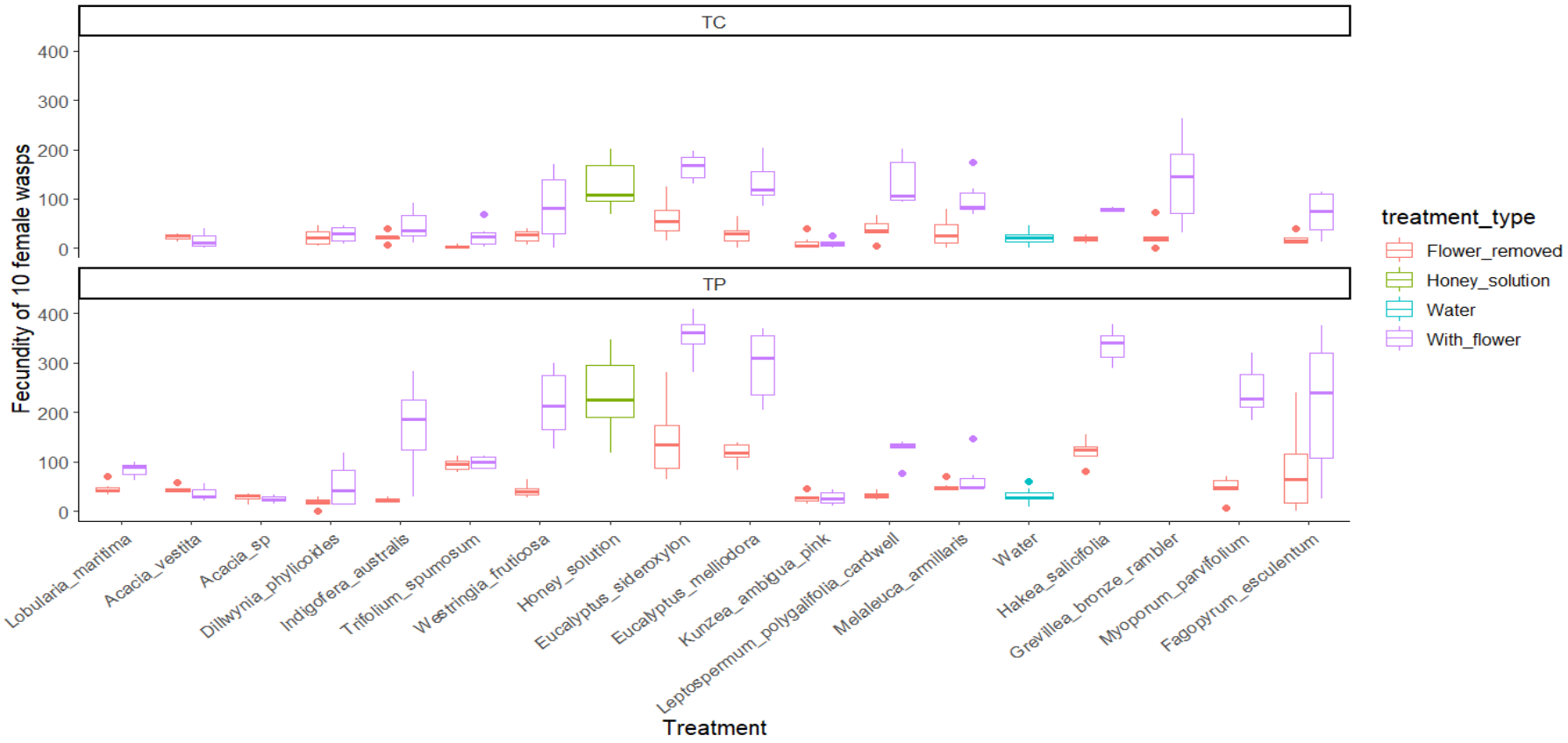


Figure 15. Effect of flowering plants on fecundity of parasitoids *Trichogramma carverae* (TC – top panel) and *T. pretiosum* (TP – lower panel) Treatment type: 'with flower' providing nectar and 'flower removed' denying nectar availability but otherwise identical.

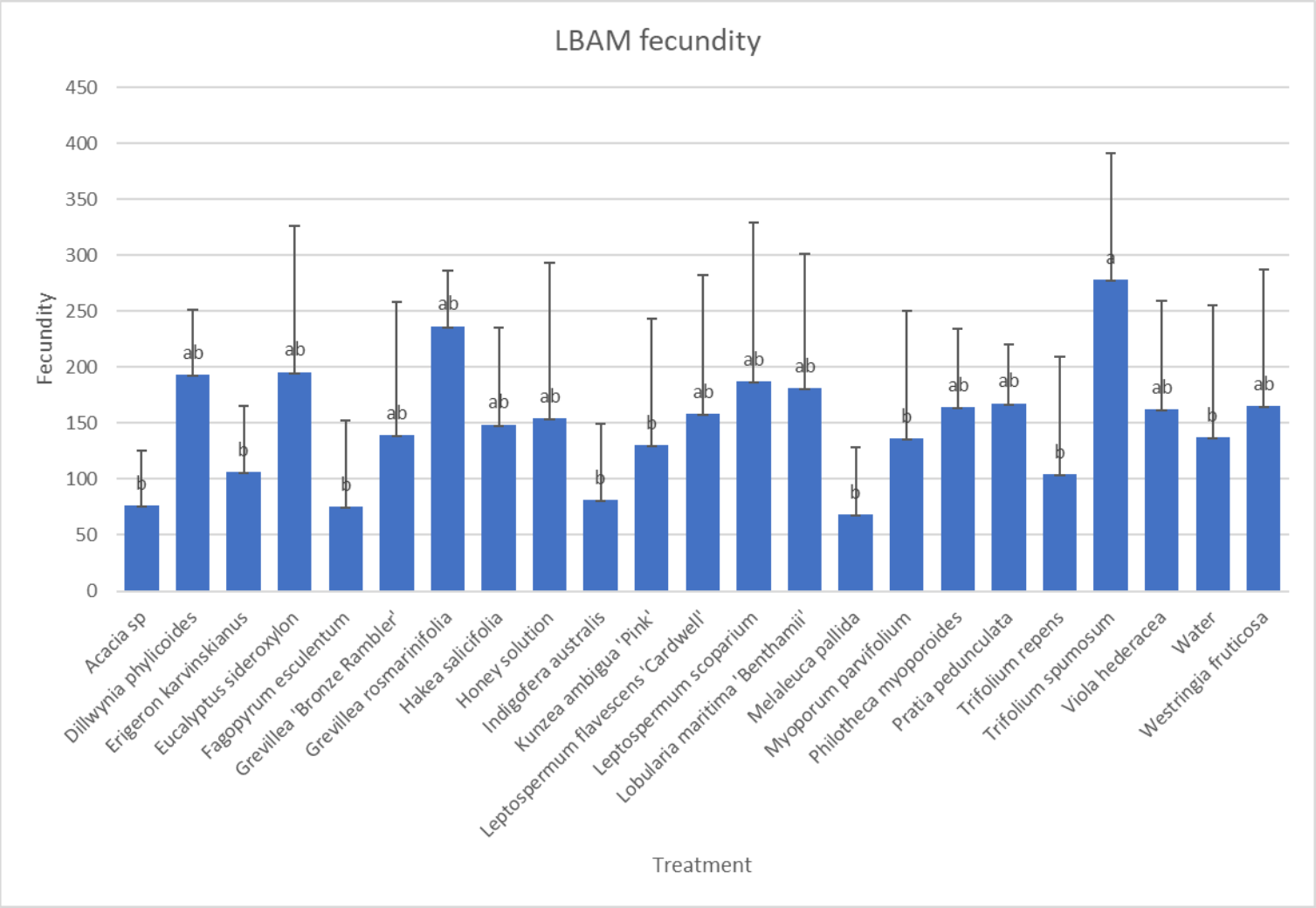


Figure 16. Effect of flowering plant on fecundity of lightbrown apple moth.

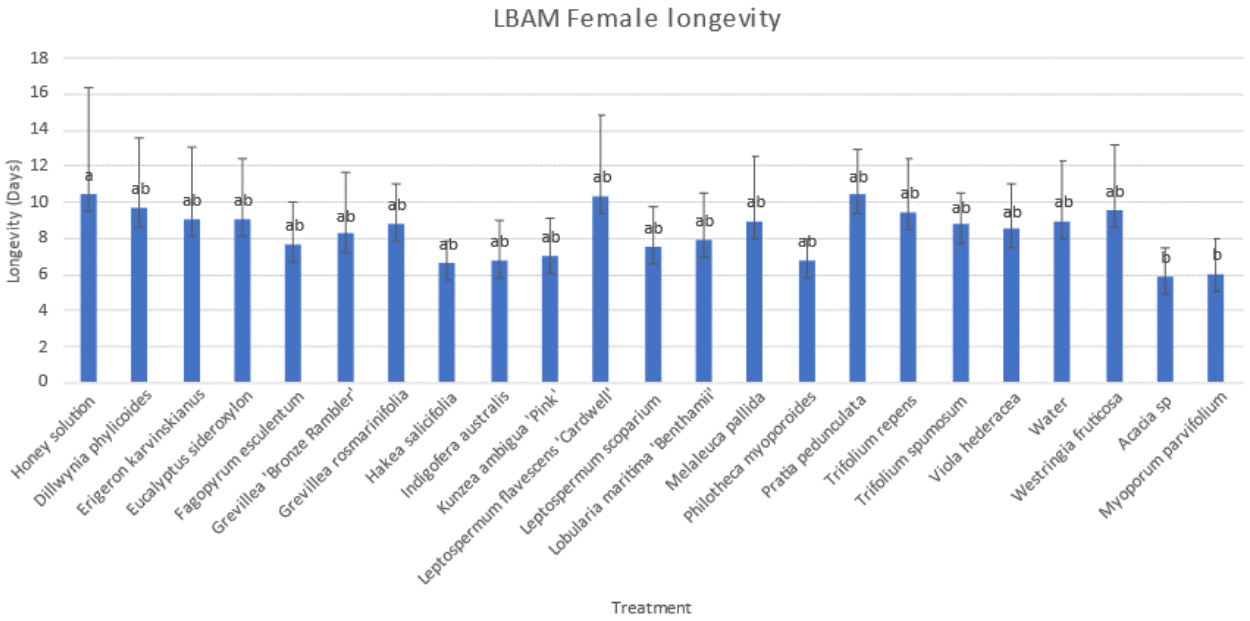


Figure 17. Effect of flowering plant on female longevity of lightbrown apple moth adults.

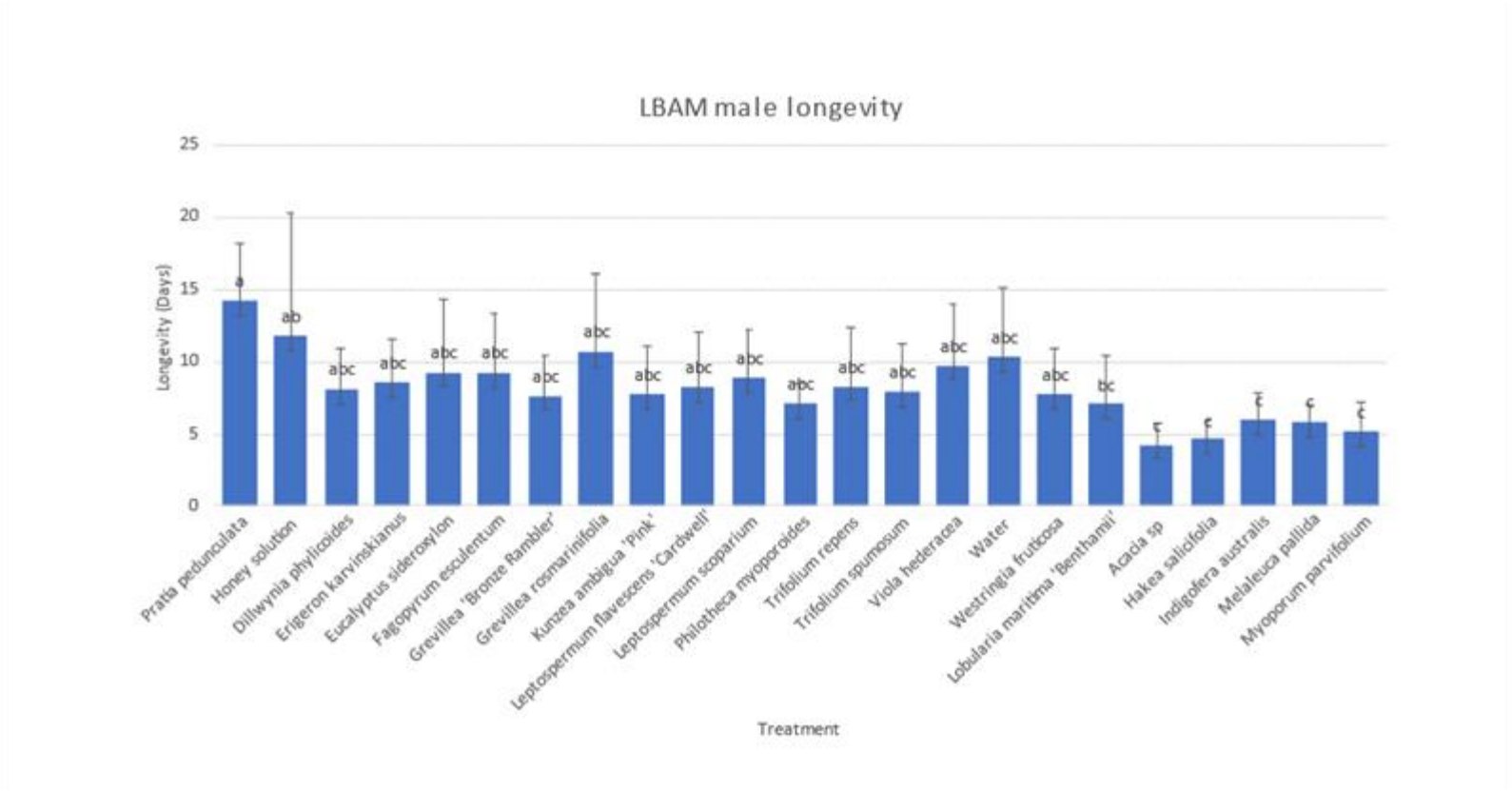


Figure 18. Effect of flowering plant on male longevity of lightbrown apple moth adults.

6.3 Vineyard Survey

6.3.1 Adjacent land use effects

The headline finding from this work is that densities of the numerically dominant natural enemies found in the surveyed vineyards, spiders, predatory insects, parasitoid wasps and total numbers of all natural enemies, are not uniform within a given vineyards. Rather, densities of these beneficials differ in accordance with the adjacent land uses and vegetation types (Figure 19). Overall, these beneficials are scarcer in the central parts of the vineyard. This reveals potentially useful guidance for pest management. For example, some types of vineyard surrounds are effectively donor habitat from which natural enemies spill into the adjacent areas of vines. The most consistently supportive land use category was narrow linear non-crop vegetation (shelterbelts, riparian vegetation and roadways with their margin of relatively undisturbed vegetation). In the first survey year, this land use promoted all of the foregoing groups of natural enemies. In addition to the effects of linear features, water bodies such as farm dams tended to increase numbers of predatory insects and spiders in adjacent vines. Parasitoids responded to waterbodies in the opposite way but were promoted by areas of extensive trees.

In the second year, linear non-crop vegetation features again promoted all categories of natural enemies but grassland also had a strong promoting effects for parasitoids. The effect of water bodies on parasitoids was positive this year whilst spider numbers were lowered by adjacent perennial horticulture and extensive areas of trees.

Most of the sites sampled were common across the two years of sampling so the few cases of effects differing from year to year are likely to reflect seasonal conditions such as the much cooler spring experienced in the second year which may have slowed arthropod population build up by temperature effects on physiology or, more likely, via effects on food plant and prey availability.

Overall, the results provide a strong signal that narrow linear non crop features promote densities of natural enemies in adjacent areas of vineyards. The effect of this form of land use likely reflects the facts that these forms of vegetation are lightly managed and have low levels of disturbances such as spraying, grazing and cultivation. Reflecting this, these areas are characterised by structural complexity (e.g. banks and ridges, tussocky and woody vegetation of different heights and ages, standing and fallen timber) and taxonomic diversity in plants that would tend to make resources such as nectar and pollen available for extended periods compared with less diverse vegetation. In addition to those attributes, the fact that riparian and roadside vegetation is – by definition – linear in form. This allows such land

uses to provide habitat linkage between vineyards and more remote habitat patches that may serve as refuges for beneficial arthropods.

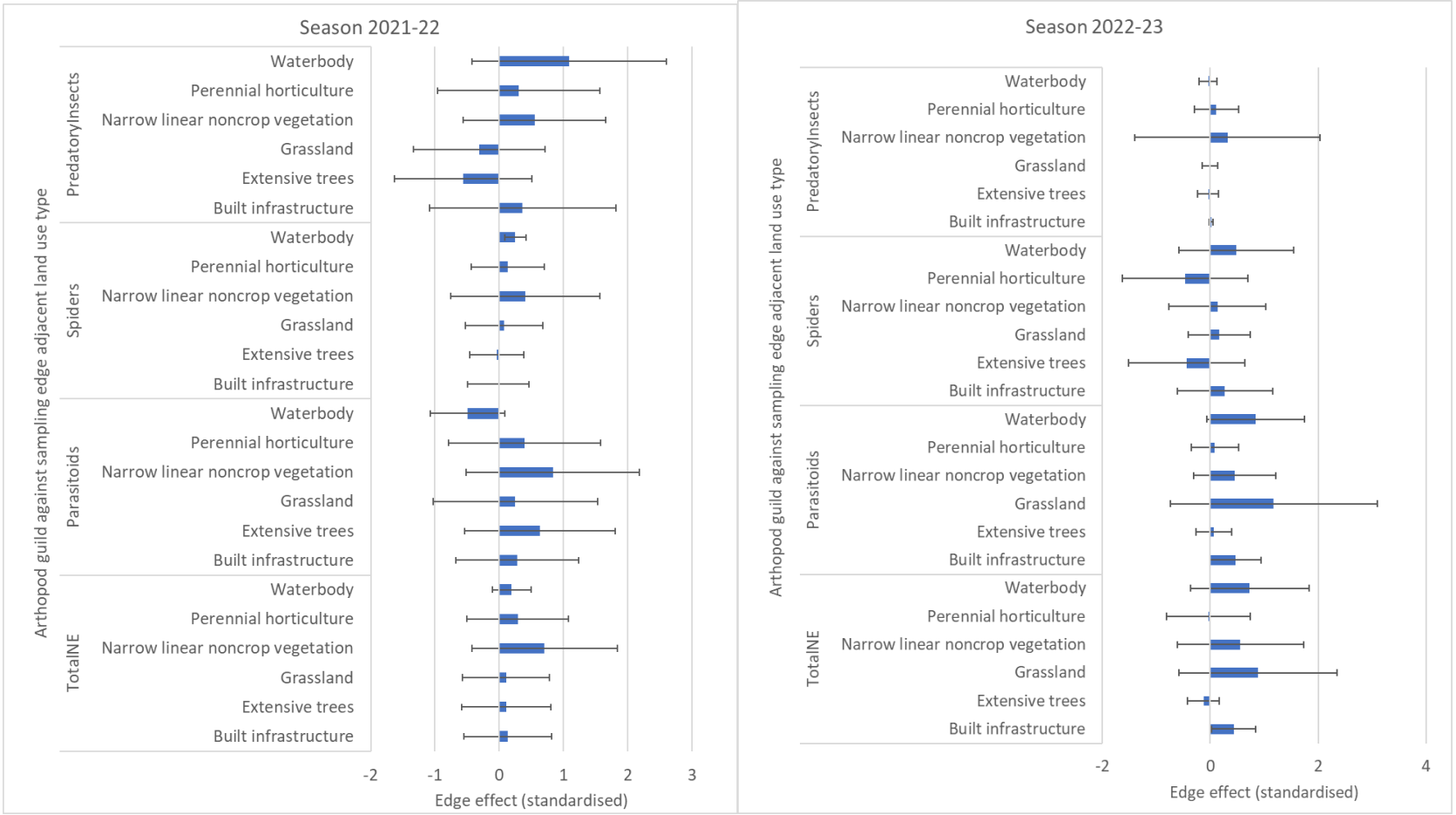


Figure 19. Impact of adjacent land use on density of natural enemy (NE) groups and of 'TotalAbundance' of all arthropod types (see text for detail). Edge effects compare the number of arthropods caught from vines close to the relevant neighbouring land use type compared with catches from vines in the centre of the same vineyard. Positive effects show an enhancing effect of adjacent land use and vice versa. Left panel, year 1 n=30; Right panel, year 2 n=25.

6.3.2 Landscape scale effects

To explore the wider scale effects of land uses and landscape patterns on vineyard arthropods, data on arthropod catches from the vineyard centres were analysed conjunction with GIS data. Numbers of pests were very low in vacuum samples but spiders, parasitoids, predatory insects were numerous enough to allow meaningful analyses. Significant effects on the total numbers of all natural enemies and on the foregoing categories of natural enemies were evident at all spatial scales from 250 m from the vineyard centre to 5000 m.

Remarkably, at the 5000 m scale, the numbers of natural enemies were strongly affected by landscape. In these landscapes, agricultural production annual crops and pastures) was the dominant form of land use, accounting for 60% of the land area (Figure 20). The total number of natural enemies in the centre of vineyards increased significantly ($P<0.001$) with the area of the landscape allocated to agricultural production (annual crops and pastures) as opposed to perennial horticulture ($P>0.05$) (Figure 21). This may reflect the phenomenon of natural enemy flux such that annual crops and pastures are net donors of natural enemies to vineyards. Such an effect could result from the densities of pest insects in annual crops and pastures allowing a build up of natural enemy densities to the extent that these spilled over into vineyards. The relatively high disturbance levels of those habitats (with at least annual harvesting and tillage in crop fields and grazing or mowing operations in pastures) compared with the less disturbed habitats of perennial horticulture or wooded land uses. Consistent with this explanation, total natural enemy numbers in vineyards declined significantly as the proportion of the landscape covered by linear vegetation features ($P<0.05$) or native woodland ($P<0.001$) increased. Clearly, the larger the proportion of land used for these types of vegetation, the smaller is the amount of land that can mathematically be occupied by annual crops and grasslands. The more granular analysis of specific natural enemy categories (Appendix 6) showed that these same trends applied to a significant extent for both parasitoids and spiders.

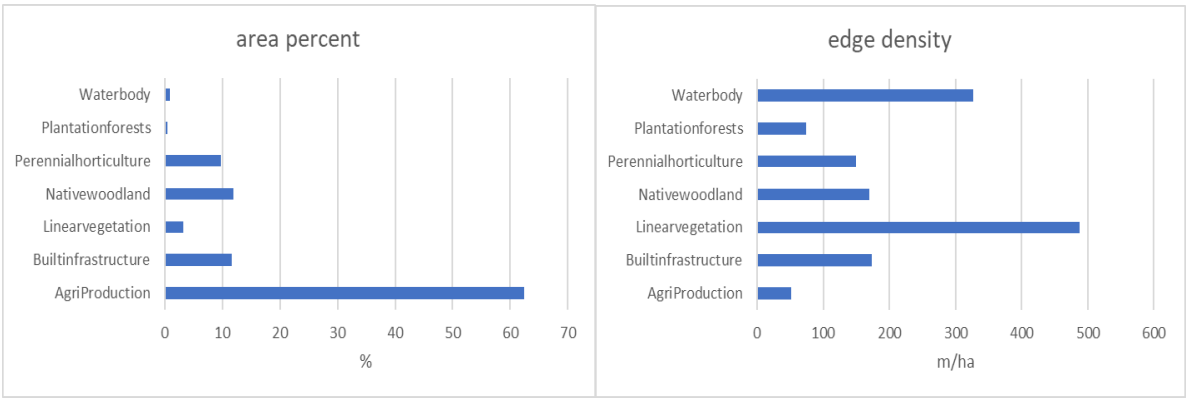


Figure 20. Land use categories within 5000m of vineyards.

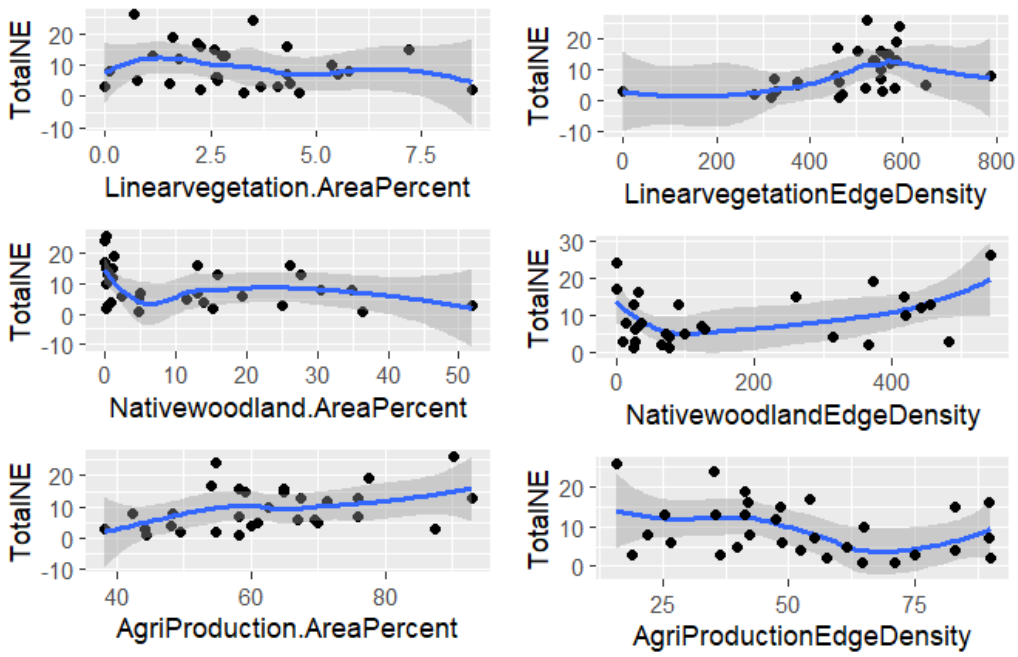


Figure 21. Effects on natural enemy density in vineyards of land use and edge density categories within 5000m of vineyards.

Aside from the aforementioned effect of landscape composition, the analysis of natural enemy responses to landscape characters revealed significant effects of edge density. Total natural enemy numbers in the centre of vineyards fell significantly ($P<0.001$) as the edge density of agricultural production increased and increased significantly as the edge density of linear vegetation ($P<0.001$) and native woodland increased. ($P<0.01$) Those three relationships are the opposite form compared with the foregoing effects of the composition (cf edge density) of each land use type. This is likely to reflect the following factors. First, the analysis of the effects of vineyard adjacent land use revealed a strong beneficial effect of narrow linear vegetation features. It was supposed that a contributing factor to the positive effect of these linear features is that they facilitated a corridor effect such that vineyards were well linked with other types of habitats that were refuges for natural enemies and by which they could move to vineyards. Accordingly, the finding that such linear features in the wider landscape – indeed, to the scale of 5,000m - promote densities of natural enemies in vineyards is consistent with the much shorter range effects of their presence adjacent to vineyards. Such landscapes represent a virtual network of corridors for natural enemy movement. Second, the favourable effect of high edge density of native woodland is broadly comparable with the corridor effect of linear features because a given area of native woodland that is present as a single patch in a configuration close to a disc is less likely to be able to donate natural enemies than a comparable area of woodland that is present as

multiple patches and with configurations that are more elongate (i.e. conferring higher edge density per unit of area). Third, the negative effect of agricultural production edge density is likely to reflect the fact that actual values of edge density for this land use fell across a very low range, all less than 100 m per hectare compared with values that extended to above 400m for native woodland and above 800m for linear features. In practical terms this means all of the surveyed landscapes had low edge densities for agricultural production despite this being, on average, the dominant form of land use, i.e., annual crops and pastures were present as relatively large units of land that were ‘field shaped’ (rectangular). Accordingly, edge densities recorded in the data set were largely a consequence of the size and number of such fields rather than the more variable spatial forms of native woodland that often occupy irregularly shaped non arable areas.

As was observed for the effects of landscape composition on different natural enemy types, effects of edge density of differing land uses were significant for parasitoids and spiders (but not predatory insects) as well as for total natural enemy numbers.

At smaller spatial scales, findings were broadly consistent with the above-described effects for the 5000 m scale (Appendix 6). An important point of contrast is that the proportional area and the edge density of perennial horticulture increased at smaller spatial scales (especially at 250 m) because these measures of landscape radius are from the centre point of each vineyard. Accordingly, the study vineyard itself constituted a significant land use, especially in the case of larger vineyards.

7. Outcome/Conclusion

Overall, this program of laboratory, field trial and field survey studies has revealed good scope to realise the ambition of the project's title: "Functional Biodiversity Solutions for Australian Vineyards: Harnessing Groundcovers, Vineyard Surrounds and Native Plants To Deliver Key Ecosystem Services". More specifically, our recommendations identify ways in which growers can use plant species and vegetation patterns as a means to benefit vines, especially for promotion of beneficial species such as *Trichogramma* species parasitoids and pest suppression. Our detailed results include multiple plant species that could be introduced into vineyards as undervine or midrow groundcovers. Several of these species are named as options for use as groundcovers. Our findings have led to a series of plant traits (characterises) that are predictive of value and these traits can be used by growers to select locally appropriate species that are likely to deliver ecosystem services. More generally, these findings serve as valuable proof of concept that replacing weedy spontaneous groundcover vegetation, or bare earth, with appropriate groundcovers is a viable strategy for delivering tangible benefits. Specifically, groundcover plants should have the following traits.

- white flowers,
- capable of blooming early in the season and for a prolonged period,
- prostrate or short-growing growth habit,
- vigorous early vegetative growth,
- dense and competitive habit,
- low susceptibility to frost.

Ease of availability of inexpensive planting material (seeds or young plants) is a further consideration.

Potentially, such groundcovers can deliver the following benefits to vineyard managers.

- Provide resources to natural enemies, especially nectar for parasitoids,
- Reduce pest numbers and damage (our findings having demonstrated this in the field for LBAM bunch damage),
- Reduce risk of fungal disease severity (our findings having demonstrated that most trial treatments grew shorter than the vegetation they replaced so will favour air flow in the vineyard and reduce humidity),

- Reduce actual plant disease severity (our findings having demonstrated this in the field for bunch rot incidence and severity),
- Reduce risk of frost damage to vine tissues (our findings having demonstrated that most trial treatments grew shorter than the vegetation they replaced so will favour air flow in the vineyard and allow chilled air to drain downhill from the vineyard),
- Reduce weed problems and need for weed management costs (our findings having demonstrated that some trial treatments grew competitively and outcompeted weeds).
- Several native plant species proved to be effective in delivering these benefits and their use (rather than use of exotic plant species) will also confer advantages of constituting a tangible measure to conserve native plants and the animals associated with them; a potential advantage in terms of aesthetics and wellbeing for vineyard staff and visitors including customers, a potential marketing advantage and enhanced social license to operate. There is also future scope for biodiversity offset payments for vineyards in which conservation value is derived from use of native plants.

Despite these potential benefits, the four field trials demonstrated the practical challenges involved in establishing groundcovers in an established vineyard site. Aside from the inevitable direct costs of panting materials and labour there is a strong need to minimise competition in sites where spontaneous, weedy vegetation is being replaced. Achieving this under certified organic production conditions is especially challenging. In consultation with the project's Industry Advisory Panel, three main tactics have been identified that offer the strongest prospects for the ready establishment of groundcovers.

First, for midrow groundcovers, a single narrow strip between the wheel ruts is considered relatively easy to establish and maintain. This approach can make use of common, tractor mounted equipment to achieve effective control of pre-existing vegetation by herbicidal or mechanical means and to produce a suitable seed bed.

Second, for establishment of undervine strips, a narrow, tractor mounted seeder can be used to run a single line of seed immediately adjacent to the posts and vine trunks of a row and ideally repeat this on the second side of the same row. Where undervine vegetation requires control prior to seeding, herbicide use (including organically allowable products) can be used. Specialised tillage machines to mechanically remove vegetation under vines is becoming more available.

Third, consideration can be given to establishing suitable groundcovers in a site prior to the establishment of a new vineyard block. This approach provides maximal freedom of use of mechanical and chemical control of pre-existing vegetation. It is, however, important to avoid competition for water between the groundcover and the young vines. This may require the pre-plant use of tilled or herbicide-treated strips along intended vine rows or spot spraying individual vine locations.

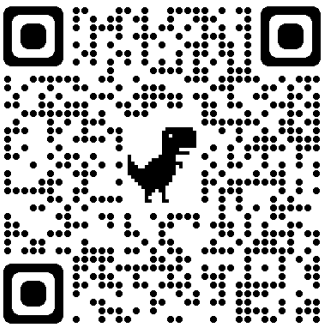
Aside from work on groundcovers, laboratory work identified a suite of perennial, woody plants that, whilst too tall to be accommodated within a vineyard, promoted performance of *Trichogramma* spp. parasitoids so should be favoured in features such as shelterbelts and insectary or biodiversity 'islands' adjacent to vines. Supporting the viability of this tactic, we also identify vineyard-adjacent land uses that promote the densities of beneficial arthropods on vines. Of particular benefit was the presence of narrow linear vegetation strips such as riparian strips, shelterbelts, roadside vegetation strips that provide shelter and other resources (e.g., nectar) to natural enemies and also provide connectivity that links vineyards to other habitats in the wider landscape (see below) that might be refuges for natural enemies. The utility of this information extends beyond informing management choices such as plant types to be used in plantings on vineyard properties, it also provides potentially valuable guidance on which edges of a vineyard, or which whole vineyards, are most likely (given the adjacent land uses) to have either high or low densities of natural enemies. Arising from this, managers will be able to focus pest monitoring efforts or releases of mass reared natural enemies in areas most likely to be at risk of pest outbreaks.

At the still greater spatial scale, the survey of multiple vineyards across NSW over two years provided strong evidence that natural enemy densities in vineyards are affected by landscape characteristics (composition and edge density) even at the 5 km scale. Landscapes that include annual cropping and pastures appear to promote abundance of natural enemies in co-sited vineyards by serving as donor habitat. This effect appeared to be complemented if the landscapes also had high edge densities of linear vegetation features and native woodland. In plain English terms this translates to landscapes with features such as riparian strips, shelterbelts, roadside vegetation strips and patches of native bush. Given the large spatial scale at which these effects occur, not all land that likely to exert an effect on a given vineyard will be owned by that property and under the control of a given vineyard manager. However, this finding does allow the identification of areas that are relatively high- or low-risk in terms of the potential for pests to escape from effective biological control by beneficials. Ongoing management of established vineyards, and the choice of site for new vineyards can take into account this new information.

Communications Outputs & Publicity

The project has produced a suite of communications outputs and associated publicity. The major items are as follows.

1. Website with project information and photographs complemented by a video case study production on project sampling and sorting of arthropod catches, and PowerPoint presentation of project results with audio voice-over (https://sway.office.com/EWpG5dAN9LikpIrN).



2. Project results communicated in article “Ecosystem services can reduce the ‘heavy lifting’ in vineyard (Wine Australia, RD&A News. December 2021). (https://www.wineaustralia.com/news/articles/ecosystem-services-can-reduce-the-heavy-lifting-in-vineyards).

3. Project results communicated in article “Vineyard biodiversity – how to put it to work using cover crops’ (Gurr, Liu & Smith, *Grapegrower and Winemaker* October 2022). (https://www.wineaustralia.com/news/articles/ecosystem-services-can-reduce-the-heavy-lifting-in-vineyards).

4. Project results communicated in article “Vineyard biodiversity – how to put it to work using cover crops’ (Gurr, Liu & Smith *WineLand Magazine, South Africa* (May 2023). (https://www.wineaustralia.com/news/articles/ecosystem-services-can-reduce-the-heavy-lifting-in-vineyards). (republished from Grapegrower and Winemaker, Issue 705, October 2022, with permission).

5. Project results featured in article “Fungicide resistance Effective management practices for healthy vines and budgets” (Madden-Grey, Grapegrower and Winemaker March 2023). (https://winetitles.com.au/gwm/articles/march-710/fungicide-resistance-effective-management-practices-for-healthy-vines-and-budgets/)

6. A talk by Geoff Gurr summarising project results at the 2022 AWITC (https://awitc.com.au/speaker/dr-geoff-gurr/).
7. A half-day workshop convened with Mary Retallack at the 2022 AWITC including presentations by Geoff Gurr, Jian Liu and Anne Johnson. (https://awitc.com.au/wp-content/uploads/2022/03/18th-AWITC-TECHNICAL-Workshop-booklet-V3.pdf)
8. Six grower-facing presentations in the NSW DPI 2022 Spring Vine Health Field Days in Orange, Griffith, Tumbarumba, Mudgee, Murrumbateman and Hunter Valley.
9. Project summary in the NSW DPI Grapevine management guide 2022–23. (https://www.dpi.nsw.gov.au/__data/assets/pdf_file/0009/1418661/Grapevine-management-guide-2022-23.pdf)
10. Full page article in the international scientific journal *Nature* featuring the project (https://www.nature.com/articles/d41586-022-00218-z.pdf).
11. Invited presentation by Geoff Gurr at the15th Tasmanian Viticulture Field Day – "Soils: From the ground up" (Hobart, 27th of September 2022).
12. Radio interview of Geoff Gurr by Cassandra Hough from the ABC SA's Country Hour program. Monday 27 June 2022.
13. Project results featured in article "Can gum tree nectar help wasps attack vineyard-eating moths? Research gets results for grape growers" (*CSU News* article May 2022) (https://news.csu.edu.au/opinion/can-gum-tree-nectar-help-wasps-attack-vineyard-eating-moths-research-gets-results-for-grape-growers).

This extension work also included a webinar as part of the AWRI series (24 August 2023) and providing text and photographs for species fact sheets to Dr Mary Retallack for inclusion in the revised Cover Crops Finder Tool.

8. Recommendations

1. Ecosystem Services From Undervine Groundcovers. The Australian vineyard sector should re-double its long-standing interest in the use of undervine groundcovers. The two field trials of undervine treatments provided evidence that replacing the existing, weedy vegetation beneath vines provided measurable benefits to: lightbrown apple moth damage levels to bunches, reduced severity and incidence of botrytis bunch rot, exclusion of weeds by competition, and led to marked reduction in the height of vegetation beneath vines that would, by virtue of increased air flow likely reduce risk of frost damage and fungal disease severity. Relative benefits of specific groundcover plant species are outlined below.

2. Establishment. The initial establishment of groundcover vegetation is a practical challenge. Section 7 of this report and relevant communications outputs provide detail on strategies most likely to lead to effective establishment: narrow midrow strips between wheel ruts, single row seeding to one or both sides of vine trunks and posts, and the establishment of groundcovers in new blocks prior to planting young vines.

3. Under Vine Species Choice. Species choice will depend, in part, on the particular circumstances of a site including biophysical conditions. The use of mixed-species groundcovers offers the advantage of spreading risk in that some of the included species are likely to be favoured by microsite conditions (e.g., high and dry versus lower and moister parts of a vineyard block), variations in climate and weather (e.g., La Niña and La Niña periods). The major outcomes sought in each setting are also key and these are explained below.

   3a. Weed Suppression. Suppression of spontaneous weedy vegetation was greatest for the Undervine See Saw Blend treatment (comprising:), followed by Alyssum and then the Undervine Native Mix (comprising:). Levels of ground coverage in year one after establishment exceeded 70% at the Angullong vineyard were prior vegetation density was low but no higher than 25 percent at the organic Balmoral site where weed control was more challenging. Reflecting these results, coverage by weedy vegetation was lower at Angullong than Balmoral and most effectively achieved by the See Saw Undervine Mix. Each of these three groundcover treatments is considered suitable for use in vineyards where weed suppress is a consideration but the See Saw Undervine Mix was most effective and the Native Mix slower to establish.

   3b. Frost Risk. Among the species used in under vine treatments, the shortest plants were the natives, Dampiera, Dichondra, Myoporum and especially Pratia and Viola. Each of these had an average height of less than 20cm. Plant height was greater in the case of Alyssum and the Undervine See Saw Blend treatments (approximately 25 cm) but even these were markedly shorter than the spontaneous weedy vegetation they replaced which exceeded 40cm. On sites where frost risk is a major consideration, the native plants are most suitable given that

they are so short and, because these are perennial, will provide competitive groundcover in spring when otherwise weedy plants could grow and impede air flow.

3c. Plant Disease Risk. The foregoing account of frost risk has parallels for maximising the flow of air under vines and thereby reducing humidity that can favour fungal diseases. Accordingly, whilst all the tested undervine treatments were preferable to the pre-existing vegetation, natives such as Pratia and Viola are most suitable for maximising air flow and reducing fungal disease risk. In terms of actual, measured effects on vine diseases, botrytis bunch rot was the only disease that responded significantly to the experimental treatments. In this instance, both incidence (numbers of bunches) and severity were greatly reduced by the alyssum and Undervine Native Mix treatments and these, rather than the less consistently beneficial Undervine See Saw Blend, are best suited for use in vineyards where botrytis is a major consideration.

3d. Pest risk. Among undervine treatments, alyssum and the Undervine See Saw Blend treatments gave the highest level of suppression of LBAM damage to grape bunches and these, rather than le less consistently effective Undervine Native Mix are preferable in setting where LBAM is a significant risk to crop health.

4. Ecosystem Services From Mid-row Groundcovers. The Australian vineyard sector should re-double its long-standing interest in the use of midrow groundcovers. The two field trials of undervine treatments provided evidence that replacing the existing, weedy vegetation between vines provided measurable benefits to: lightbrown apple moth damage levels to bunches, reduced severity and incidence of botrytis bunch rot, and exclusion of weeds by competition. Relative benefits of specific groundcover plant species are outlined below.

5. Midrow Vine Species Choice.

5a. Weed Suppression. Suppression of spontaneous weedy vegetation was greatest for the buckwheat treatment that established vigorously at both sites and performed well but was inadvertently slashed during vineyard operations at Balmoral. At Angullong, buckwheat covered approximately one third of the soil area that led to much lower levels of weed coverage than in the control treatment. Buckwheat is recommended as most likely among the midrow treatmetns to provide weed suppression. The Mid Row Native Mix and Mid Row See Saw Blend treatments were less effective at suppresing weeds.

5b. Plant Disease Risk. In terms of actual, measured effects on vine diseases, botrytis bunch rot was the only disease that responded significantly to the experimental treatments. In this instance, both incidence (numbers of bunches) and severity were most strongly reduced by the buckwheat and Midrow Native Mix treatments and these, rather than the less beneficial

Midrow See Saw Blend, are best suited for use in vineyards where botrytis is a major consideration.

5c. Pest risk. Among mid row treatments, buckwheat gave the highest level of suppression of LBAM damage to grape bunches across both trial sites and this, rather than the less consistently effective Midrow Native Mix and Midrow See Saw Blend is preferable in settings where LBAM is a significant risk to crop health. Practical issues that need to be considered with buckwheat are its susceptibility to frost and short blooming period. The first of these demands that sowing is deferred until after the main frost danger period has passed. Whilst this means a delay compared with alternative groundcover species, buckwheat is fast to begin blooming so provision of nectar to natural enemies is not likely to be slower than for other groundcover choices. The short blooming period of buckwheat can be addressed by slashing areas (e.g., one half of the width or rows, sections of rows, or alternate rows). This promotes axillary growth and the formation of lateral shoots that are quick to produce a new flush of flowers. Such slashing can occur on multiple occasions during a season. Buckwheat will also self-seed to produce a new cohort of plants during the season when moisture conditions allow.

6. Water Use. The CSU vineyard water use project has compared transpiration and root growth traits of the main ground cover species found at the Angullong and Balmoral vineyards. The results suggest species such as tall fescue, paspalum and ryegrass, that are common in vineyard groundcover vegetation, use large amounts of soil water and can compete very significantly with vines. This is due to high leaf transpiration rates, deep root systems and longer active growth periods than grapevines. The roots of tall fescue (*Festuca arundinacea*), have been observed to extend at least 1.6m from the soil surface. Accordingly, a valid first approximation is that replacing such vegetation with virtually any alternative species will lessen water stress to vines during dry periods. Among some of the species included in the sown blends, clovers and plantain also tend to have higher transpiration rates per given leaf area than grapevines and start using water in spring before vines have developed sufficient leaf area to compete. However, early findings suggest they have less extensive root systems than the perennial grasses and are sensitive to the onset of water stress. Therefore, as the grapevine canopies reach full size, and summer water deficits develop, their impact on the vineyard water situation through to mid to later stages of the season is likely to be small. Native plants such as those that proved to confer complementary ecosystem services are likely to low users of soil water, reflecting their evolutionary history of adaptation to relatively dry and variable conditions of the Australian climate. Some of the tested non-native species, alyssum, for example, are also likely to be relatively low water use with low leaf area and growth habit and is certainly able to persist during periods of very dry conditions in a semi dormant state. As a concluding observation, it is much more difficult to demonstrate negative

impact of water competition from a particular plant species amongst established groundcover than it is to demonstrate their benefits for other ecosystem services in vineyards. An adaptive management strategy that could be used in dry years is to remove a pre-established groundcover by tillage or herbicide application to minimise water loss. Whilst this would not be an attractive option for perennial native groundcover species such as Myoporum, it would be viable for annual species such as alyssum or buckwheat. Such groundcover species are likely to spontaneously recover from the soil seed bank when moisture allows or are inexpensive to re-sow.

7. Effects of Vineyard-Adjacent Land Uses. The land use category that most strongly enhanced natural enemy numbers in adjacent vines was narrow linear non-crop vegetation (shelterbelts, riparian vegetation and roadways with their margin of relatively undisturbed vegetation). It is recommended that such vegetation is established or promoted adjacent to vineyards, especially where this provides a linking corridor to similar existing vegetation. Vineyards, or areas of large vineyards without such adjacent vegetation should be considered relatively high risk for pest outbreaks and are recommended to be the highest priority for pest monitoring efforts.

8. Landscape Scale Effects. Vineyards situated in landscapes (to a scale of up to 5,000m) with relatively high proportional land area used for annual crops and pastures tended to have higher densities of natural enemies so are less at risk of pest outbreaks. If landscapes also have a high edge density of linear vegetation features and native woodland (i.e., rather than having such vegetation as a few large patches), this also is associated with higher natural enemy densities in vineyards. It is recommended that vineyards in other types of landscapes should be considered relatively high risk for pest outbreaks and are recommended to be the highest priority for pest monitoring efforts.

9. Relevance of Laboratory Screening of Groundcover Plant Species. Relevance of Laboratory Screening of Groundcover Plant Species. The results of this study provide data on an expanded range of plant species in relation to their effect on *Trichogramma* species and LBAM. For use in vineyards, alyssum, buckwheat, *Grevillea* 'Bronze Rambler', and *Myoporum parvifolium* were shown to have potential for promoting one or both species of *Trichogramma.* Among the taller-growing plant species that cannot be accommodated within vineyards, *Dillwynia phylicoides, Indigofera australis, Westringia fruticosa, Eucalyptus sideroxylon, Eucalyptus melliodora, Leptospermum flavescens* 'Cardwell', *Melaleuca armillaris,* and *Hakea salicifolia* all have potential for promoting one or both species of *Trichogramma* when used in features such as shelterbelts or biodiversity islands. These native species also would be likely to promote parasitoids, if present in the wider landscape. In contrast, *Acacia* species and *Kunzea ambigua* 'Pink' appear to have no value to *Trichogramma* parasitoids. An important practical consideration that moderates choice of

species used to promote biological control is whether the plants also provide benefit to key pests. In the vineyard context, the laboratory screening of plants against LBAM is relevant. Buckwheat, white clover, and the natives *Acacia, Erigeron, Indigofera, Melaleuca, Myoporum* all led to a moth performance no better than the water (control) treatment so can be considered the safest choice for use in vineyards. Overall, the most recommended plant species for use in vineyard groundcovers is *Myoporum parvifolium* since it was beneficial to parasitoids but not to LBAM.

10. Priorities of Specific Vineyards.
    Individual managers are recommended to interpret the results in this report in relation to the priorities of their specific vineyards. Some will prioritise pest suppression and natural enemy numbers whilst others may be more concerned with weed or disease suppression. As a general first approximation, however, growers are recommended to select plants such as alyssum or *Myoporum parvifolium* that have the traits of white flowers, capable of blooming early in the season and for a prolonged period, prostrate or short-growing growth habit, vigorous early vegetative growth, dense and competitive habit, and low susceptibility to frost. Growers exploring wider species choice options should consider potential weed risk including toxicity or injury to livestock that may be used in the vineyard.

11. Extension and Uptake. The findings of this project have already been communicated in grower-facing outputs such as a talk and a workshop at the 2022 AWITC, multiple presentations in the NSW DPI 2022 Spring Vine Health Field Days, and an article in *Grapegrower and Winemaker*. A pair of video productions has also been produced that demonstrate the sampling of arthropods from vines and that summarise major findings. This extension work also included a webinar within the AWRI series on 24 August 2023 and providing text and photographs for species fact sheets to Dr Mary Retallack for inclusion in the future, revised Cover Crops Finder Tool. It is also recommended that further discussion between Wine Australia and the project team explores options for maximising grower access to the above-listed communications devices. An overarching theme recommended by the Industry Advisory Panel for the final suite of communications outputs is a ‘Toolbox’. This would comprise a package of the practical tactics summarised in these recommendations presented in easy-to-understand and readily-implemented forms.

12. Priorities for Future Research. Inevitably for such research project, more work remains to be done. A wider range of plant species could be screened and the use of laboratory studies using the protocols developed in this project would be a cost efficient way of doing this for an expanded range of natural enemy and pest species. This would allow only the highly promising species to be used in more labour-demanding field trials. A related priority for future field work is to use more in-depth and specialised monitoring methods to study scale insect pest and their natural enemies that were present in the sample of the present project but in

numbers too low to allow meaningful analysis or the formulation of recommendations. Future work to assess the economic case for groundcovers would also be useful in order to provide a more compelling case for adoption. This would include capturing data on the economic value of the phenomena observed in the present study (e.g., reduced LBAM damage and botrytis severity) as well as calculating avoided fuel, labour and maintenance costs arising from groundcovers lessening the need for slashing or applying herbicides. The new Charles Sturt University ‘Vineyard of the Future’ initiative may play a role in future research by serving as an anchor site for experimentation and demonstration purposes.

9. Appendices

Appendix 1: Communication

Appendix 2: Intellectual Property

Appendix 3: References

Appendix 4: Staff

Appendix 5: Industry Advisory Panel

Appendix 6: Supplementary Results

Appendix 7: Material for cover crops finder tool.

Appendices

Appendix 1: Communication

Appendix 2: Intellectual Property

Appendix 3: References

Appendix 4: Staff

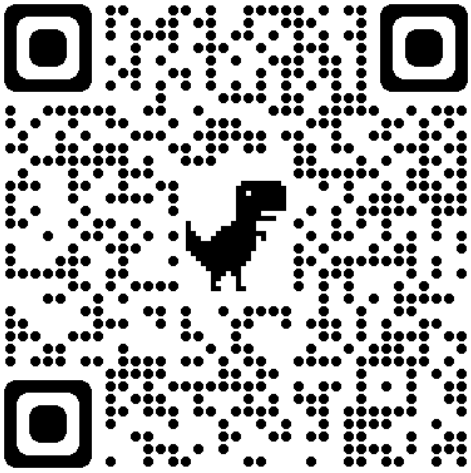
Appendix 5: Industry Advisory Panel

Appendix 6: Supplementary Results

Appendix 1: Communication (This appendix provides a copy of non-copyright-protected materials. Additional communications outputs are provided as RL links to the original publication).

Numbered list of outputs

1. Website with project information and photographs complemented by a video case study production on project sampling and sorting of arthropod catches, and PowerPoint presentation of project results with audio voice-over (https://sway.office.com/EWpG5dAN9LikpIrN).





Functional biodiversity solutions for Australian vineyards: harnessing groundcovers, vineyard surrounds and native plants to deliver key ecosystem services

Funding bodies and collaborators:



Wine Australia-funded collaboration with See Saw Wines and Angullong Vineyard
Program Area:
Strategy 4: Grow sustainable environments
Project Supervisor, Chief Investigator
Name: Prof Geoff Gurr
Organisation: Charles Sturt University
Address: Leeds Parade, Orange, NSW 2800
Email: ggurr@csu.edu.au Phone: 02 6365 7551

Research aims:

To develop practical, evidence-based strategies to promote ecosystem services for vineyard management and reduce use of chemical inputs for pest and disease management so lessen production costs

Industry outcomes and relevance:

Key grower deliverables from enhanced functional diversity are based on the following ecosystem services.

- boosting densities of beneficial insects to suppress insect and mite pests by providing nectar, pollen and shelter;

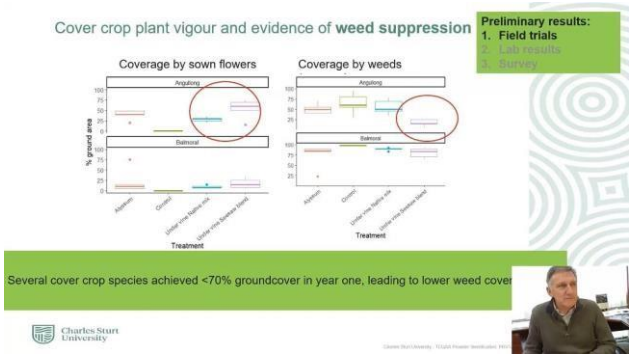
- accelerating decomposition of vine residues (eg prunings) that harbour disease inocula, thereby reducing spore survival from autumn to spring, and reduced bunch rot via control of lightbrown apple moth, and from reduced sooty mould via reduced scale and mealybug levels;
- suppressing weed growth with competitive groundcovers, especially in the area directly under vines;
- prostrate growth habit groundcovers that will promote air flow beneath vines to reduce risk from frost and disease-promoting humidity.

This project will deliver a package of extension materials including video productions that will allow results to be applied across multiple production zones in Australia.

Presenting research findings in a series of 'Spring Vine Health' talks: Using cover crops to promote vine health



In 2022, the research team joined a series of 'Spring Vine Health' workshops in winegrape growing regions in NSW. A recorded presentation is available in the link below
https://charlessturt.zoom.us/rec/share/kv0YFCJk7n74biw1zHp7Q5_GNvjNpYNkbVHQmDncFXHXg4G6rO
AXICTZEmFuL5vH.u1XZtgp7meKnCPFK?startTime=1688015645000



https://onedrive.live.com/embed?cid=B48AFBB7A383E147&resid=B48AFBB7A383E147!1658&authkey=AL-iM0HBOeUFW44

NSW state wide GIS survey



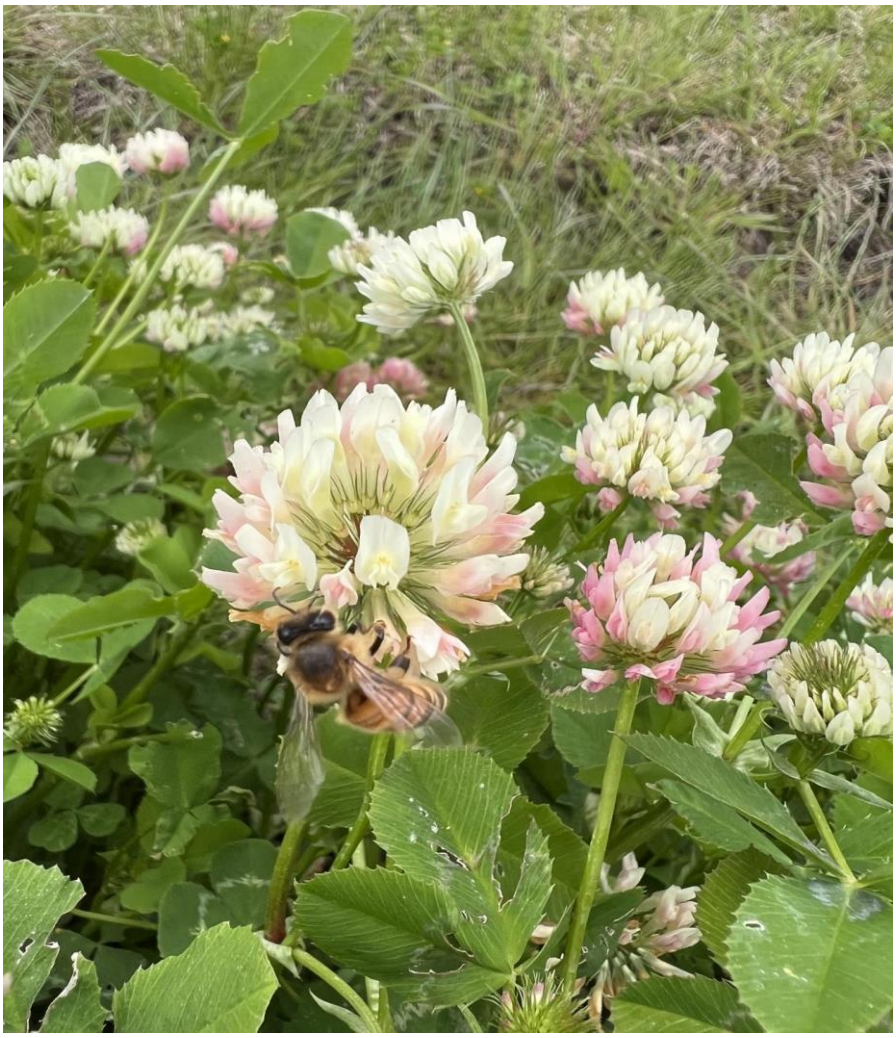
In 2021-22 season and 2022-23 we collected samples from over 30 vineyards to study adjacent land use and landscape scale land use impact on arthropod diversity in the vineyard. Vacuum samples were taken and sorted in the lab to identify individual arthropod into taxonomy guild e.g. parasitic wasps, predatory insects, spiders, pests or neutral insects.



https://onedrive.live.com/embed?cid=B48AFBB7A383E147&resid=B48AFBB7A383E147!1659&authkey=AEqelz7zYmGKS9I

1 - The vacuum sampling method is shown in this short video.

Field trial method



Under-vine treatments were:

1. control (existing vegetation with no added plants),
2. alyssum,
3. undervine See Saw Blend (a commercial seed mix comprising Balansa clover cv. Cobra (*Trifolium michelianum*) 42%, Persian clover cv SARDI (*Trifolium resupinatum*) 42%, and plantain cv. Tonic (*Plantago lanceolata*) 16%),

4. undervine native mix (Pratia pedunculata, Viola hederaceae, Dichondra repens, Dampiera diversifolia, Myoporum parvifolium).

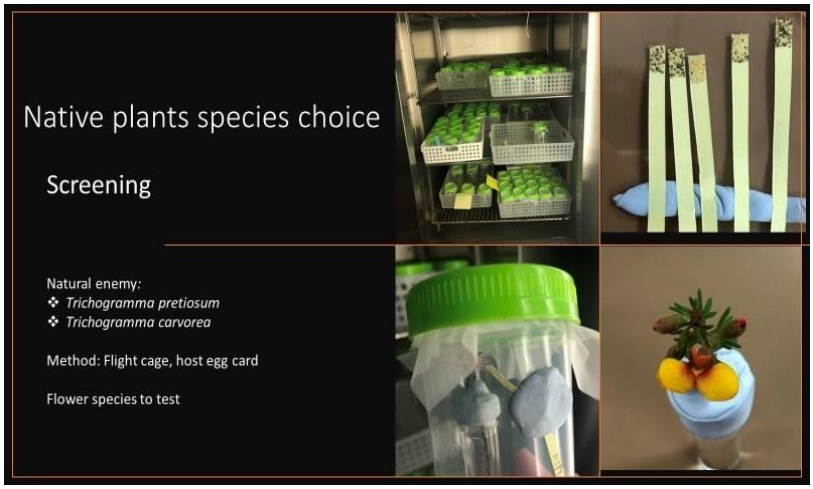
Mid-row treatment were:

1. control (existing vegetation with no added plants),
2. buckwheat,
3. midrow See Saw Blend (a commercial seed mix comprising, Field pea 70%, Hybrid turnip x
Chinese cabbage cv. Bouncer 8%, red clover cv. Mammoth 8%, Balansa clover cv. Cobra (*Trifolium michelianum*) 7%, Persian clover cv SARDI (*Trifolium resupinatum*) 7%
4. midrow native mix (*Grevillea lanigera* 'Mt Tamboritha', *Correa reflexa* x *pulchella* 'Dusky bells', *Leptospermum scoparium* 'Pink Cascade', *Rhagodia spinescens*).

Lab experiment



Flowering plant material for laboratory tests with parasitoids



2 -

- Acacia vestita
- Acacia sp.
- Dillwynia phylicoides
- Erigeron karvinskianus
- Eucalyptus sideroxylon
- Fagopyrum esculentum
- Grevillea 'Bronze Rambler'
- Grevillea rosmarinifolia
- Hakea salicifolia
- Indigofera australis
- Kunzea ambigua 'Pink'
- Leptospermum flavescens 'Cardwell'
- Leptospermum scoparium
- Lobularia maritima 'Benthamii'
- Melaleuca pallida
- Myoporum parvifolium
- Philotheca myoporoides
- Pratia pedunculata
- Trifolium repens
- Trifolium spumosum
- Viola hederacea
- Westringia fruticosa
- Eucalyptus melliodora

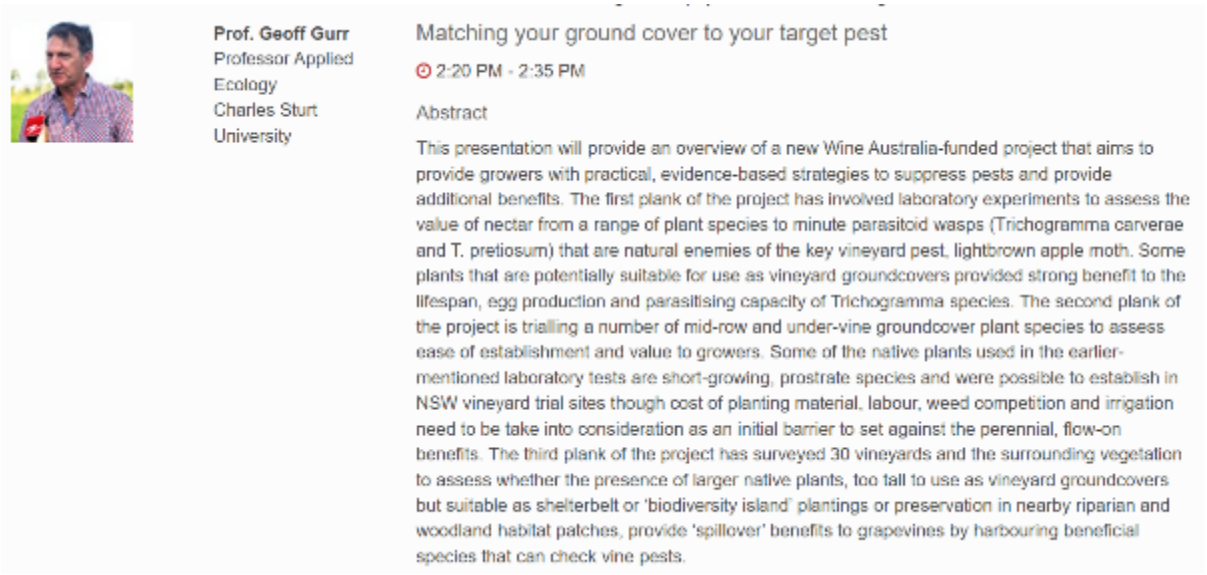
2. Project results communicated in article “Ecosystem services can reduce the ‘heavy lifting’ in vineyard (Wine Australia, RD&A News. December 2021). (https://www.wineaustralia.com/news/articles/ecosystem-services-can-reduce-the-heavy-lifting-in-vineyards).

3. Project results communicated in article “Vineyard biodiversity – how to put it to work using cover crops’ (Gurr, Liu & Smith, *Grapegrower and Winemaker* October 2022). (https://www.wineaustralia.com/news/articles/ecosystem-services-can-reduce-the-heavy-lifting-in-vineyards).

4. Project results communicated in article “Vineyard biodiversity – how to put it to work using cover crops’ (Gurr, Liu & Smith *WineLand Magazine, South Africa* (May 2023). (https://www.wineaustralia.com/news/articles/ecosystem-services-can-reduce-the-heavy-lifting-in-vineyards). (republished from Grapegrower and Winemaker, Issue 705, October 2022, with permission).

5. Project results featured in article “Fungicide resistance Effective management practices for healthy vines and budgets” (Madden-Grey, Grapegrower and Winemaker March 2023). (https://winetitles.com.au/gwm/articles/march-710/fungicide-resistance-effective-management-practices-for-healthy-vines-and-budgets/)

6. Talk by Geoff Gurr summarising project results at the 2022 AWITC (https://awitc.com.au/speaker/dr-geoff-gurr/).



Prof. Geoff Gurr
Professor Applied Ecology
Charles Sturt University

Matching your ground cover to your target pest

2:20 PM - 2:35 PM

Abstract

This presentation will provide an overview of a new Wine Australia-funded project that aims to provide growers with practical, evidence-based strategies to suppress pests and provide additional benefits. The first plank of the project has involved laboratory experiments to assess the value of nectar from a range of plant species to minute parasitoid wasps (Trichogramma carverae and T. pretiosum) that are natural enemies of the key vineyard pest, lightbrown apple moth. Some plants that are potentially suitable for use as vineyard groundcovers provided strong benefit to the lifespan, egg production and parasitising capacity of Trichogramma species. The second plank of the project is trialling a number of mid-row and under-vine groundcover plant species to assess ease of establishment and value to growers. Some of the native plants used in the earlier-mentioned laboratory tests are short-growing, prostrate species and were possible to establish in NSW vineyard trial sites though cost of planting material, labour, weed competition and irrigation need to be take into consideration as an initial barrier to set against the perennial, flow-on benefits. The third plank of the project has surveyed 30 vineyards and the surrounding vegetation to assess whether the presence of larger native plants, too tall to use as vineyard groundcovers but suitable as shelterbelt or ‘biodiversity island’ plantings or preservation in nearby riparian and woodland habitat patches, provide ‘spillover’ benefits to grapevines by harbouring beneficial species that can check vine pests.

7. A half-day workshop convened with Mary Retallack at the 2022 AWITC including presentations by Geoff Gurr, Jian Liu and Anne Johnson. (https://awitc.com.au/wp-content/uploads/2022/03/18th-AWITC-TECHNICAL-Workshop-booklet-V3.pdf).



Technical Workshop Program
Sunday, 26 June 2022

W04

Managing non-vine vegetation in and around the vineyard to grow resilience and deliver production benefits

Date: Sunday, 26 June 2022
Time: Session 1: 08:30 - 11:00
Theme: Viticulture
Type: Seminar
Ticket Price: $150

There is mounting industry interest in sustainability, biodiversity and future-proofing against threats such as biosecurity incursions. This workshop will provide a series of presentations and a discussion panel to bring participants up-to-date with the latest research and industry innovations to provide some practical strategies that vineyard managers can implement. The coverage will range from cover crops (mid row and under-vine), vineyard-edge biodiversity plantings, and the effects of vegetation patterns in the wider landscape.

Attendees will leave with an understanding of recent and current research in vineyard functional diversity and with ideas on practical strategies they can begin to implement. This will include the important EcoVineyards program in South Australia. Benefits of optimally managing vegetation in and around vineyards include: chemical-free suppression of pests, weeds and diseases, reduced frost risk, reduced water use, soil biological activity enhancement, carbon sequestration, aesthetics and marketing advantages.

Primary convenor:
Geoff Gurr, Charles Sturt University

Prof. Geoff Gurr is a member of the National Wine and Grape Industry Centre at Charles Sturt University. He trained in ecology in the UK and, since migrating to Australia 30 years ago, has been applying his ecological expertise to sustainability issues in horticulture and agriculture. Based on the Orange campus, he has been well positioned to conduct vineyard research in this booming cool climate production zone. His work in the early 2000s showed the potential for promoting beneficial insects using flowering groundcover vegetation and this has now developed into a wider research program delivering multiple ecosystem services.

7b. Title slide of Dr Jian Liu's talk at the Australian Wine Industry Technical Conference Workshop ''Managing non-vine vegetation in and around the vineyard to deliver production benefits'.



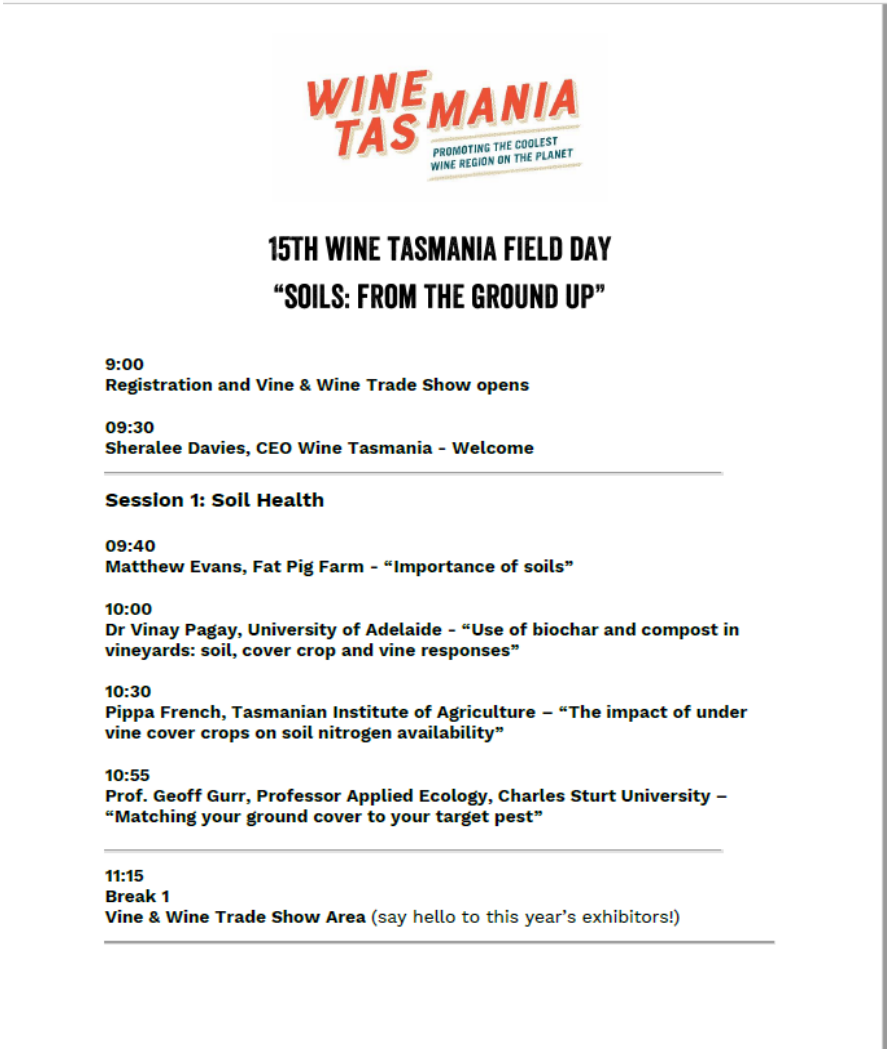
8. NSW DPI 2022 Spring Vine Health Field Days in Orange, Griffith, Tumbarumba, Mudgee, Murrumbateman and Hunter Valley.

   Associated media coverage:
   https://www.griffithphoenix.com.au/spring-vine-health-days
   https://www.yassphoenix.com.au/spring-vine-health-field-days.

9. NSW DPI Grapevine management guide 2022–23.
   (https://www.dpi.nsw.gov.au/__data/assets/pdf_file/0009/1418661/Grapevine-management-guide-2022-23.pdf)

10. Article in the international scientific journal *Nature* featuring the project
    (https://www.nature.com/articles/d41586-022-00218-z.pdf).

11. Invited presentation by Geoff Gurr at the15th Tasmanian Viticulture Field Day – “Soils: From the ground up” (Hobart, 27th of September 2022).



WINE TASMANIA
PROMOTING THE COOLEST WINE REGION ON THE PLANET

15TH WINE TASMANIA FIELD DAY

“SOILS: FROM THE GROUND UP”

9:00
Registration and Vine & Wine Trade Show opens

09:30
Sheralee Davies, CEO Wine Tasmania - Welcome

Session 1: Soil Health

09:40
Matthew Evans, Fat Pig Farm - “Importance of soils”

10:00
Dr Vinay Pagay, University of Adelaide - “Use of biochar and compost in vineyards: soil, cover crop and vine responses”

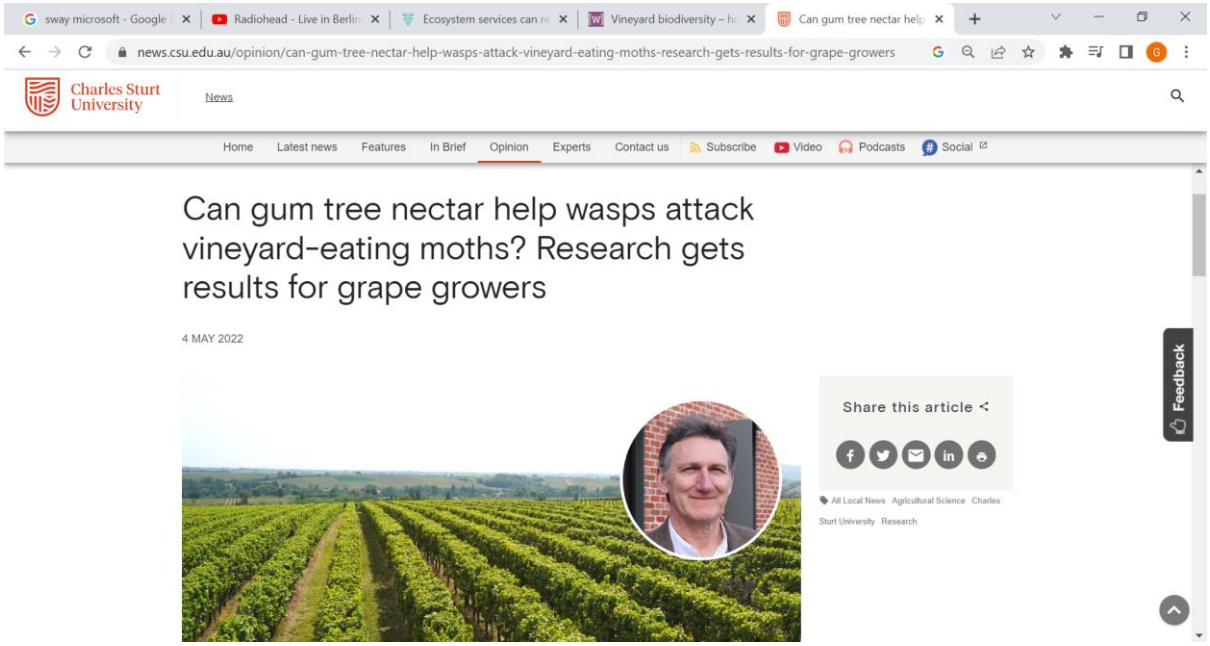
10:30
Pippa French, Tasmanian Institute of Agriculture – “The impact of under vine cover crops on soil nitrogen availability”

10:55
Prof. Geoff Gurr, Professor Applied Ecology, Charles Sturt University – “Matching your ground cover to your target pest”

11:15
Break 1
Vine & Wine Trade Show Area (say hello to this year’s exhibitors!)

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12. Project results featured in article “Can gum tree nectar help wasps attack vineyard-eating moths? Research gets results for grape growers” (*CSU News* article May 2022) (https://news.csu.edu.au/opinion/can-gum-tree-nectar-help-wasps-attack-vineyard-eating-moths-research-gets-results-for-grape-growers).



Appendix 2: Intellectual Property

CSU brought existing IP to the project in the form of knowledge on applied ecology and methodologies, the sharing of which was covered as part of the National Wine Grape Industry Centre agreement, and in most cases is already available in the public domain as industry and research publications such as those listed in the References Cited Appendix 3. It was not anticipated that any third party IP will be used in the project.

The IP produced by the project comprised new knowledge around vineyard management and how existing tools and information can be more effectively integrated to promote ecosystem services. The work was undertaken to the benefit of the whole Australian wine industry, and patentable outputs were neither planned or forthcoming. Findings have been communicated to industry in Grapegrower and Winemaker and other means as set out in Appendix 1.

It is proposed that the valuable information generated by the project continues to be used in grower-facing communication outputs without restraints.

Appendix 3: References

1 Begum, M., **Gurr**, G. M. et al. Using selective food plants to maximize biological control of vineyard pests. *J. Appl. Ecol.* **43**, 547-554, doi:10.1111/j.1365-2664.2006.01168.x (2006).

2 Pandey, S., Rahman, A. & **Gurr**, G. M. Australian native flowering plants enhance the longevity of three parasitoids of brassica pests. *Entomologia experimentalis et applicata* **166**, 265-276 (2018).

3 **Gurr**, G. M. *et al.* Multi-country evidence that crop diversification promotes ecological intensification of agriculture. *Nature Plants* **2**, doi:ARTN 1601410.1038/nplants.2016.14 (2016).

4 Danne, A. et al. Effects of Native Grass Cover Crops on Beneficial and Pest Invertebrates in Australian Vineyards. *Environ. Entomol.* **39**, 970-978, doi:10.1603/en09144 (2010).

5 Retallack, M. et al. Predatory arthropods associated with potential native insectary plants for Australian vineyards. *Australian Journal of Grape and Wine Research* **25**, 233-242 (2019).

6 **Gurr**, G. M. & Nicol, H.I. Effect of food on longevity of adults of *Trichogramma carverae* Oatman and Pinto and *Trichogramma* nr *brassicae* Bezdenko (Hymenoptera: Trichogrammatidae). Australian Journal of Entomology. (2001). https://doi.org/10.1046/j.1440-6055.2000.00159.x

7 Daane, K. M. et al. Native grass ground covers provide multiple ecosystem services in Californian vineyards. *J. Appl. Ecol.* **55**, 2473-2483, doi:10.1111/1365-2664.13145 (2018).

8 Jacometti, M. A. et al. Management of understorey to reduce the primary inoculum of *Botrytis cinerea*: Enhancing ecosystem services in vineyards. *Biological Control* **40**, 57-64, doi:10.1016/j.biocontrol.2006.10.001 (2007).

Appendix 4: Staff

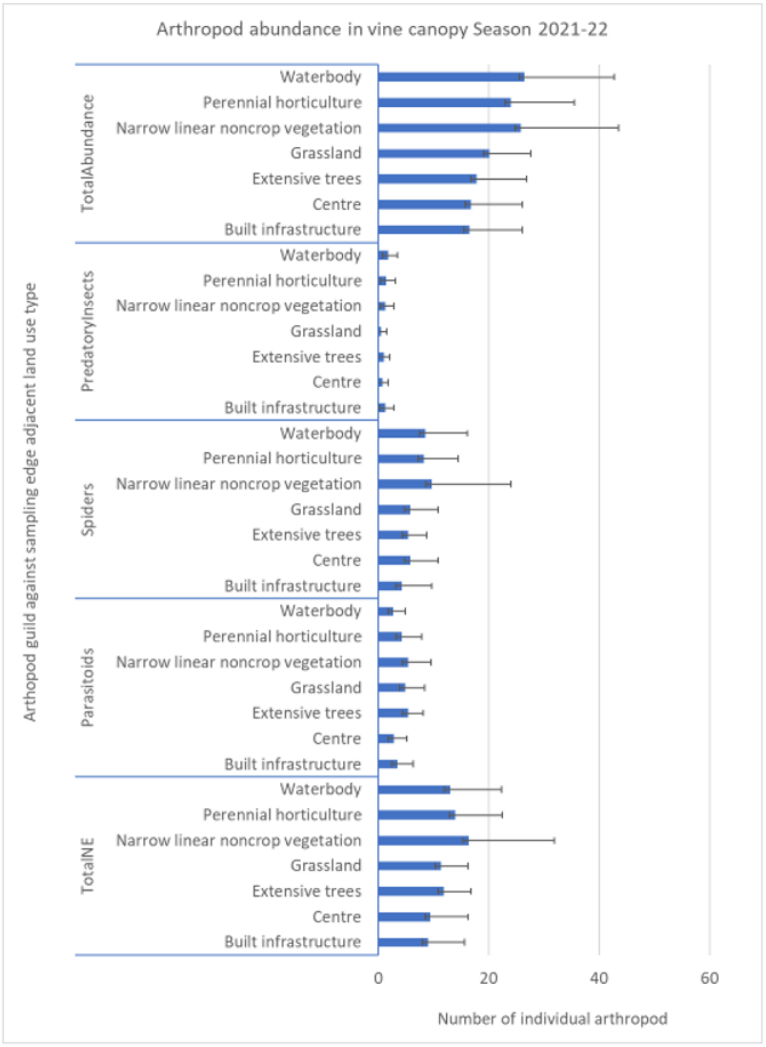
Jian Liu, Project Research Fellow (Full time)
Geoff Gurr, Prof Applied Ecology
Jason Smith, Senior Research Fellow
Nan Wang, Casual Research Assistant
Alexandra Bastic, Casual Research Assistant
Megan Moppett, Casual Research Assistant
Mudassir Rehman, Casual Research Assistant
Colin Starkey, Casual Research Assistant

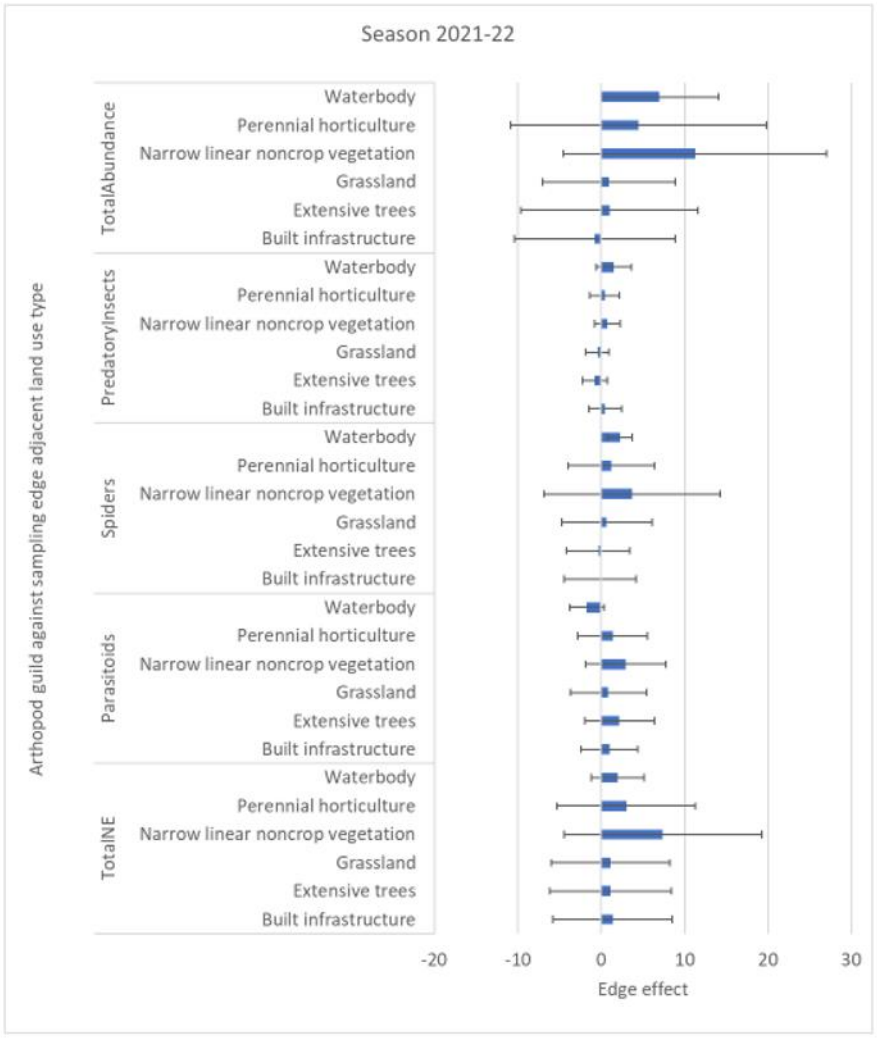
Appendix 5: Industry Advisory Panel

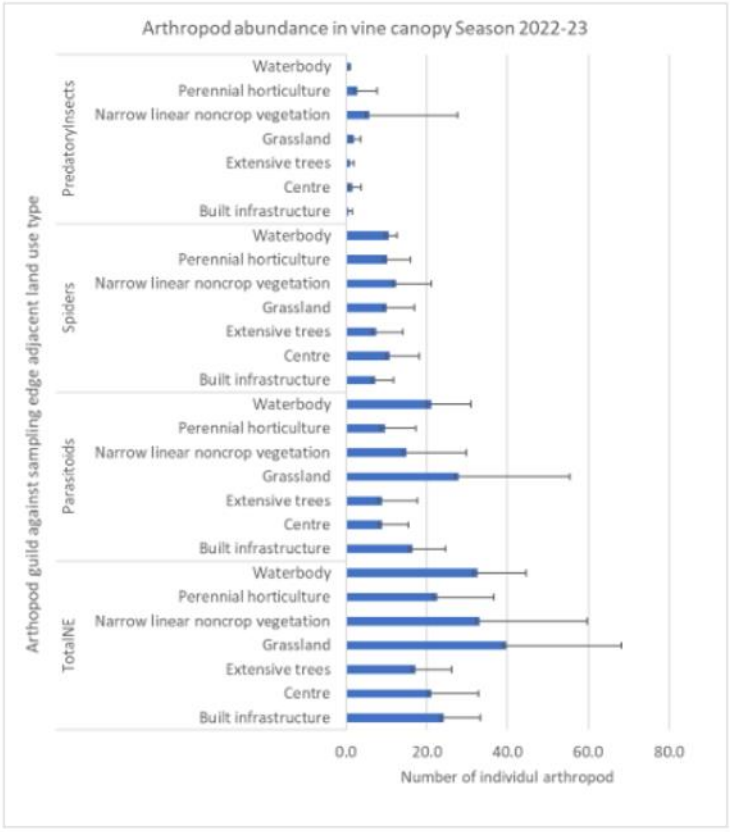
Membership:
Mark Bourne, NSW Wine Industry Association;
Nicole Samodol, Rowlee Wines;
Brendan Jarrett, See Saw Wines;
Stephen McKenzie, Angullong Vineyard.

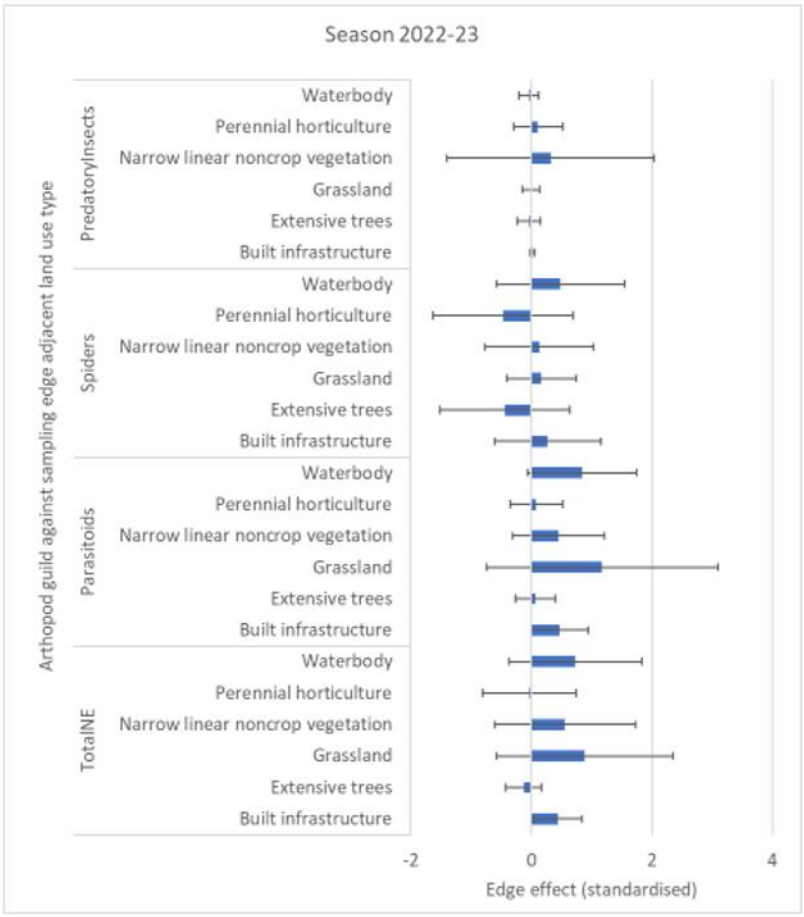
Formal Meetings:
June 2022.
June 2023.

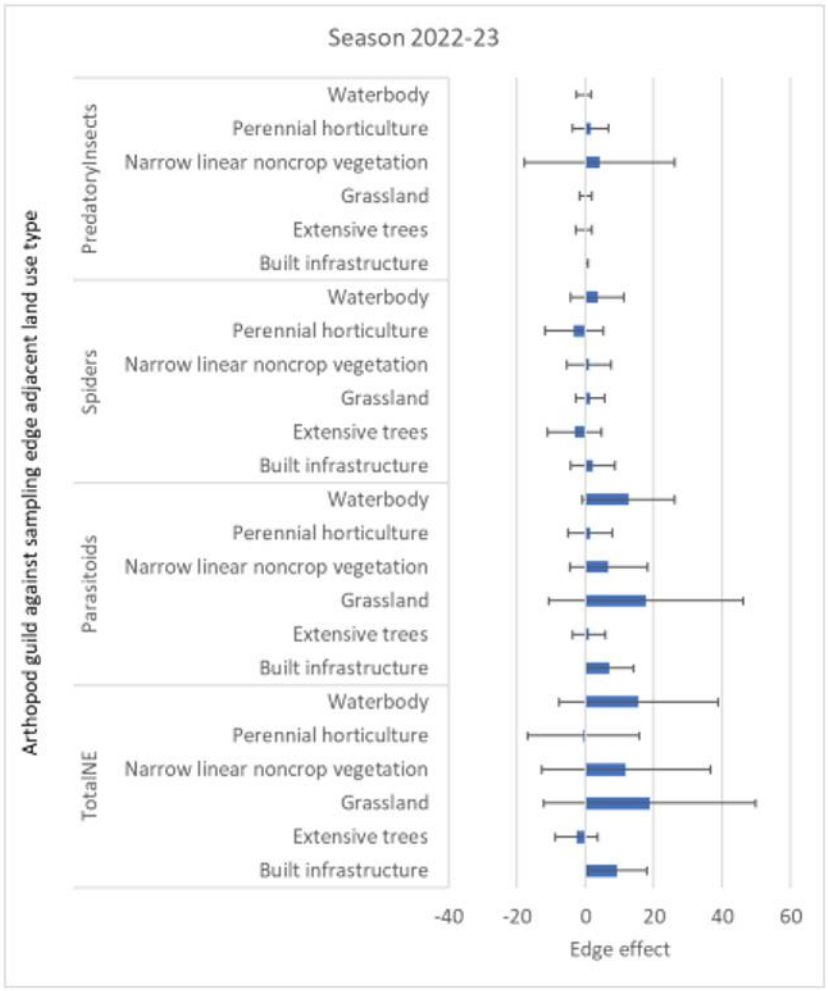
Appendix 6: Supplementary Results

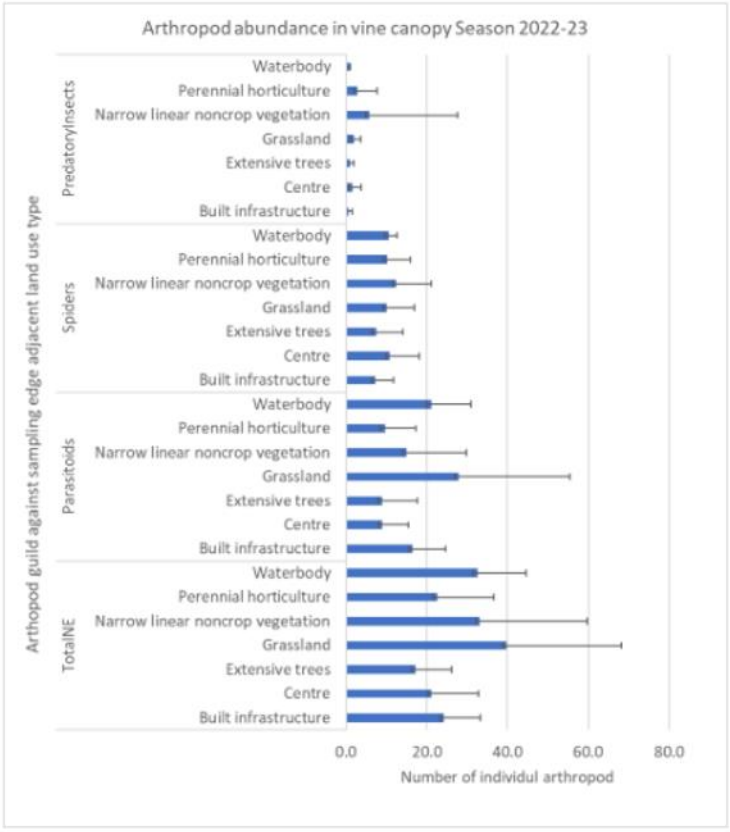

Arthropod abundance in vine canopy Season 2021-22
Arthopod guild against sampling edge adjacent land use type
TotalAbundance
PredatoryInsects
Spiders
Parasitoids
TotalNE
Waterbody
Perennial horticulture
Narrow linear noncrop vegetation
Grassland
Extensive trees
Centre
Built infrastructure
0
20
40
60
Number of individual arthropod


Season 2021-22
Arthopod guild against sampling edge adjacent land use type
TotalAbundance
PredatoryInsects
Spiders
Parasitoids
TotalNE
Waterbody
Perennial horticulture
Narrow linear noncrop vegetation
Grassland
Extensive trees
Built infrastructure
-20
-10
0
10
20
30
Edge effect


Arthropod abundance in vine canopy Season 2022-23
Arthopod guild against sampling edge adjacent land use type
PredatoryInsects
Spiders
Parasitoids
TotalNE
Waterbody
Perennial horticulture
Narrow linear noncrop vegetation
Grassland
Extensive trees
Centre
Built infrastructure
0.0
20.0
40.0
60.0
80.0
Number of individul arthropod

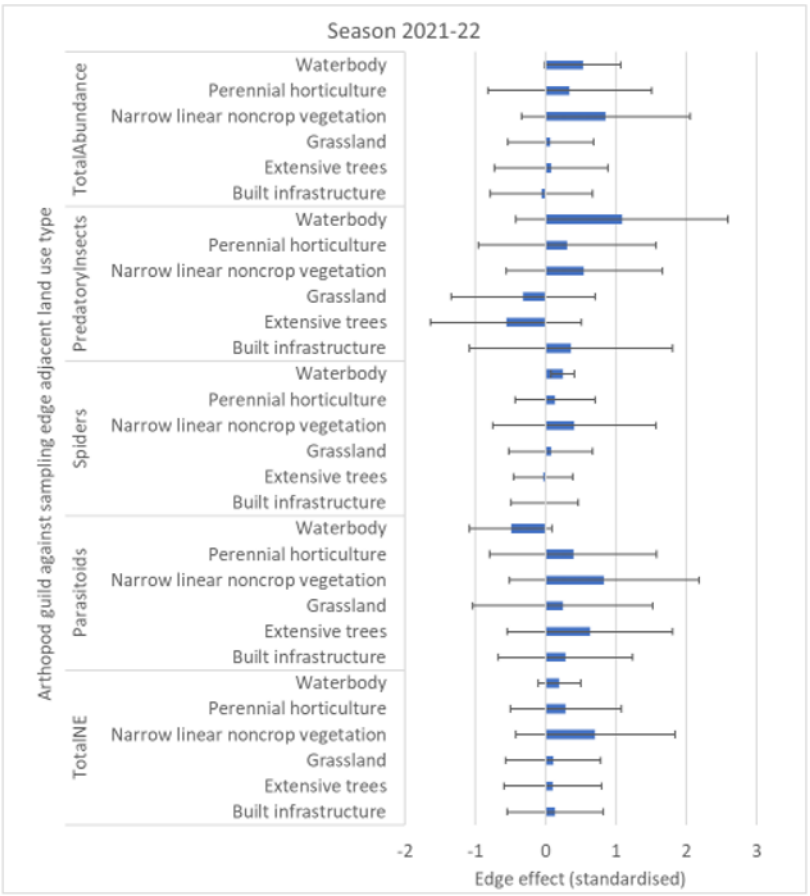

Season 2022-23
Arthopod guild against sampling edge adjacent land use type
PredatoryInsects
Spiders
Parasitoids
TotalNE
Waterbody
Perennial horticulture
Narrow linear noncrop vegetation
Grassland
Extensive trees
Built infrastructure
-2
0
2
4
Edge effect (standardised)


Season 2022-23
Arthopod guild against sampling edge adjacent land use type
PredatoryInsects
Spiders
Parasitoids
TotalNE
Waterbody
Perennial horticulture
Narrow linear noncrop vegetation
Grassland
Extensive trees
Built infrastructure
-40
-20
0
20
40
60
Edge effect


Arthropod abundance in vine canopy Season 2022-23
Arthopod guild against sampling edge adjacent land use type
PredatoryInsects
Spiders
Parasitoids
TotalNE
Waterbody
Perennial horticulture
Narrow linear noncrop vegetation
Grassland
Extensive trees
Centre
Built infrastructure
0.0
20.0
40.0
60.0
80.0
Number of individul arthropod

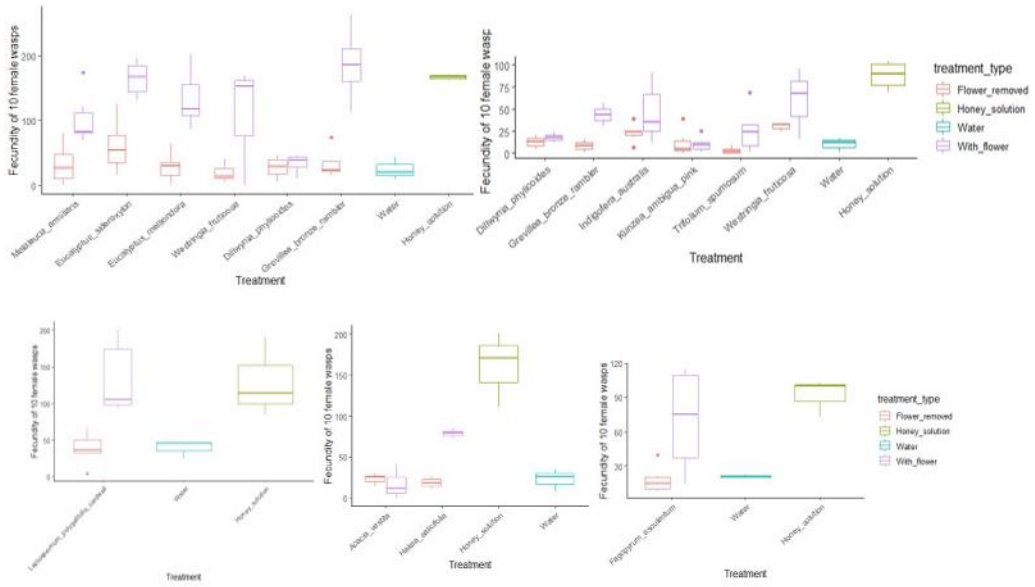
NSW wide vineyard landscape survey 2022-23

- Arthropod abundance in vine canopy at sampling location

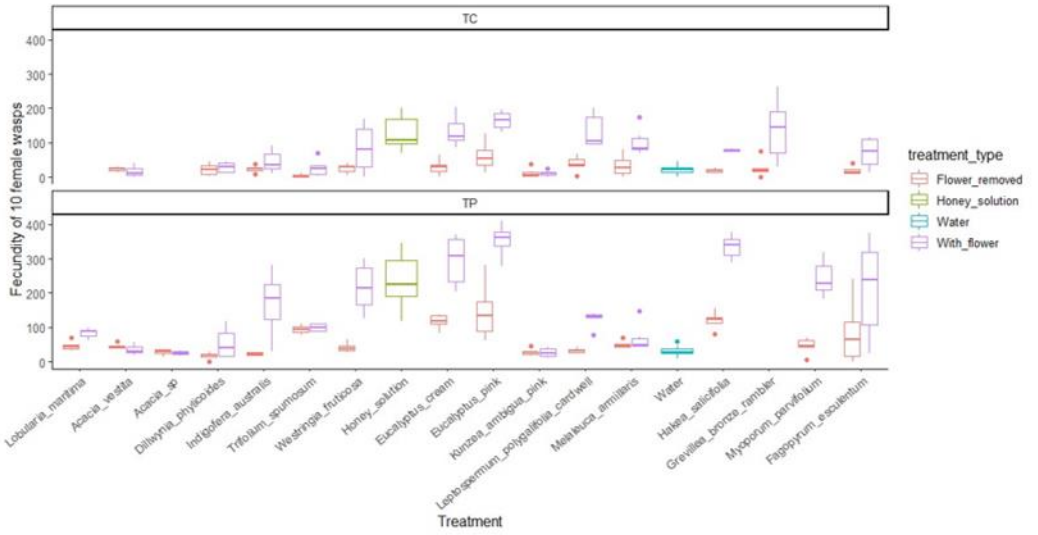

Season 2021-22
Arthopod guild against sampling edge adjacent land use type
TotalAbundance
PredatoryInsects
Spiders
Parasitoids
TotalNE
Waterbody
Perennial horticulture
Narrow linear noncrop vegetation
Grassland
Extensive trees
Built infrastructure
-2
-1
0
1
2
3
Edge effect (standardised)

Lab flower species screening for *Trichogramma carverae* and *Trichogramma pretiosum*

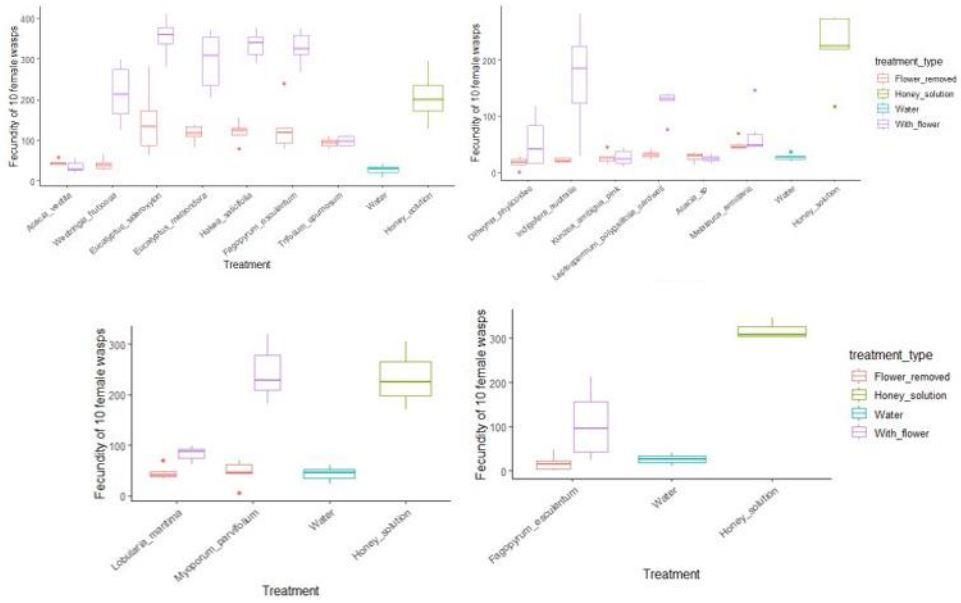
TC
Separate experiments

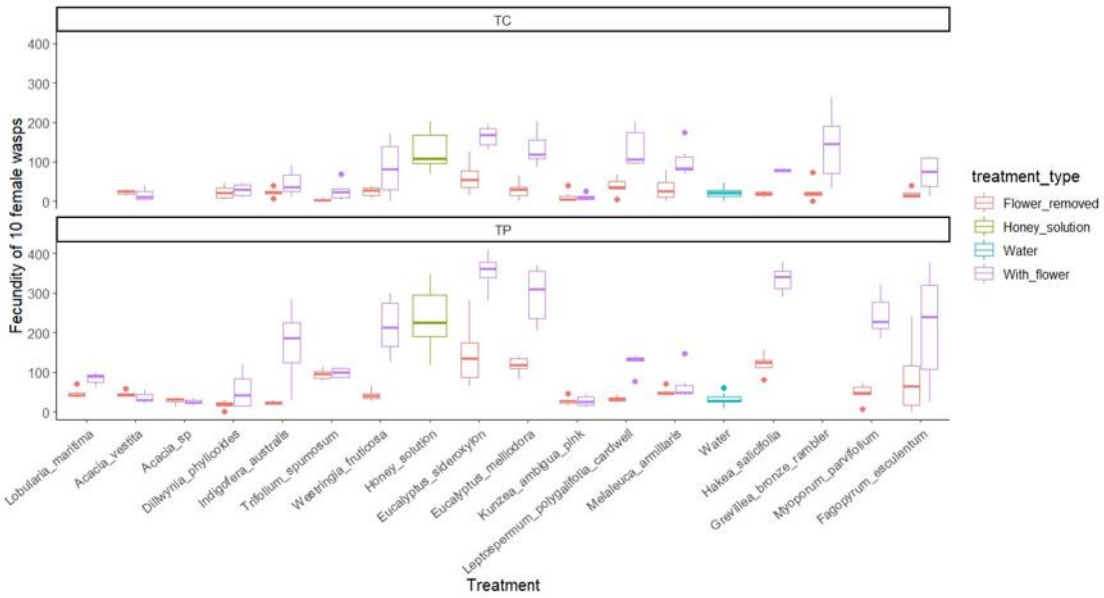


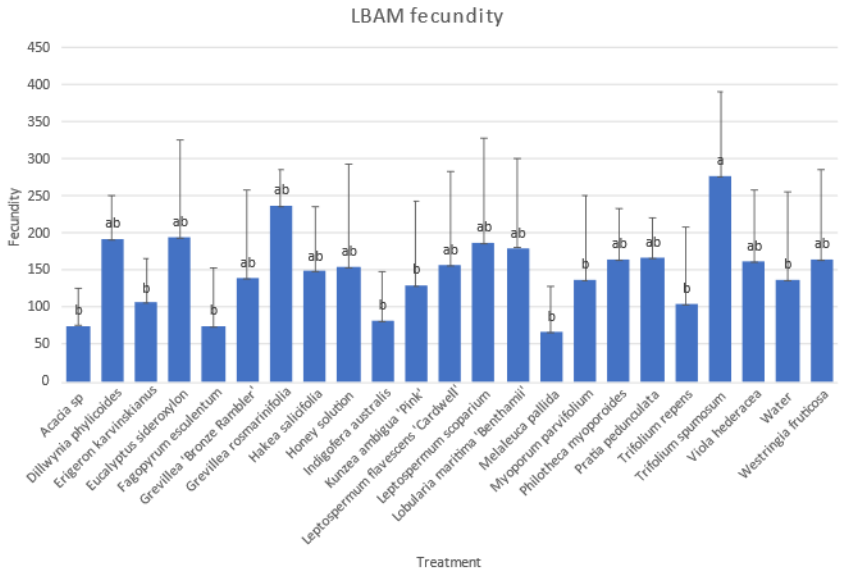
Data analysed together

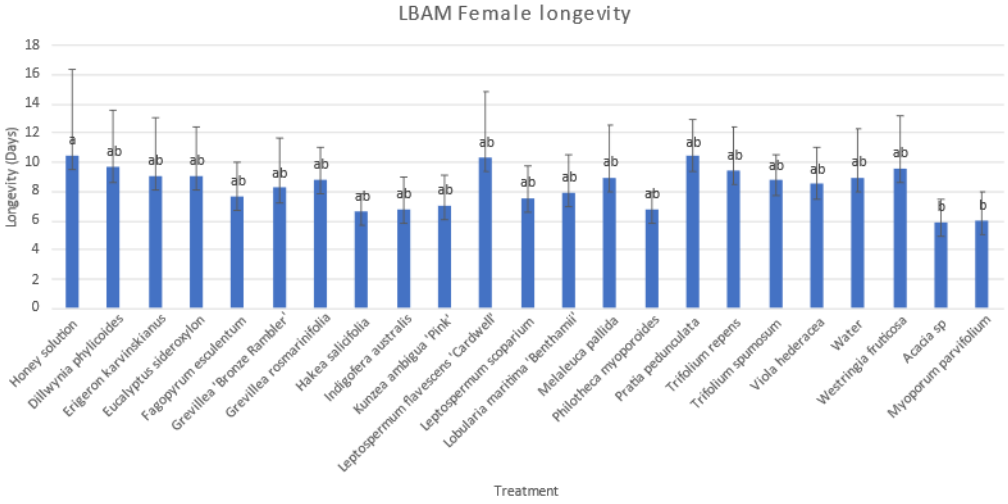


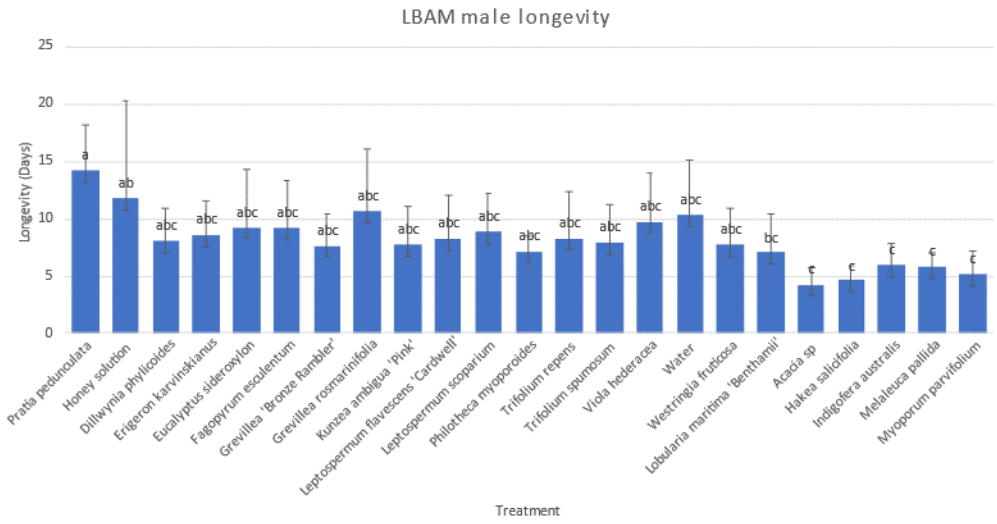
TP
Separate experiments



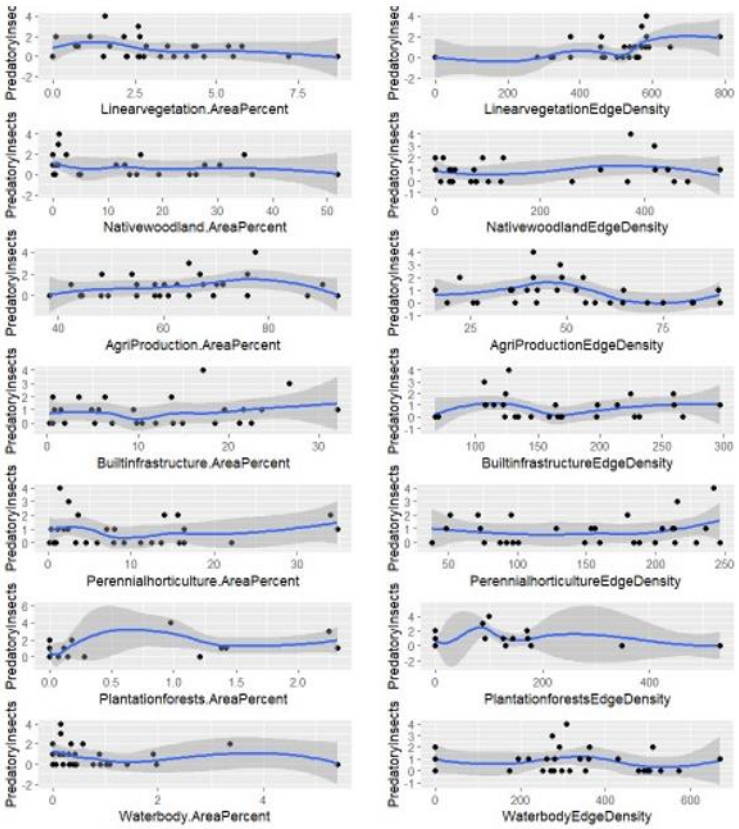



LBAM fecundity
Fecundity
450
400
350
300
250
200
150
100
50
0
b
ab
b
ab
b
ab
ab
ab
ab
b
b
ab
ab
ab
b
b
ab
ab
ab
b
a
ab
b
ab
Acacia sp
Dillwynia phylicoides
Erigeron karvinskianus
Eucalyptus sideroxylon
Fagopyrum esculentum
Grevillea 'Bronze Rambler'
Grevillea rosmarinifolia
Hakea salicifolia
Honey solution
Indigofera australis
Kunzea ambigua 'Pink'
Leptospermum flavescens 'Cardwell'
Leptospermum scoparium
Lobularia maritima 'Benthamii'
Melaleuca pallida
Myoporum parvifolium
Philotheca myoporoides
Pratia pedunculata
Trifolium repens
Trifolium spumosum
Viola hederacea
Water
Westringia fruticosa
Treatment


LBAM Female longevity
Longevity (Days)
18
16
14
12
10
8
6
4
2
0
a
ab
ab
ab
ab
ab
ab
ab
ab
ab
ab
ab
ab
ab
ab
ab
ab
ab
ab
ab
ab
b
b
Honey solution
Dillwynia phylicoides
Erigeron karvinskianus
Eucalyptus sideroxylon
Fagopyrum esculentum
Grevillea 'Bronze Rambler'
Grevillea rosmarinifolia
Hakea salicifolia
Indigofera australis
Kunzea ambigua 'Pink'
Leptospermum flavescens 'Cardwell'
Leptospermum scoparium
Lobularia maritima 'Benthamii'
Melaleuca pallida
Philotheca myoporoides
Pratia pedunculata
Trifolium repens
Trifolium spumosum
Viola hederacea
Water
Westringia fruticosa
Acacia sp
Myoporum parvifolium
Treatment

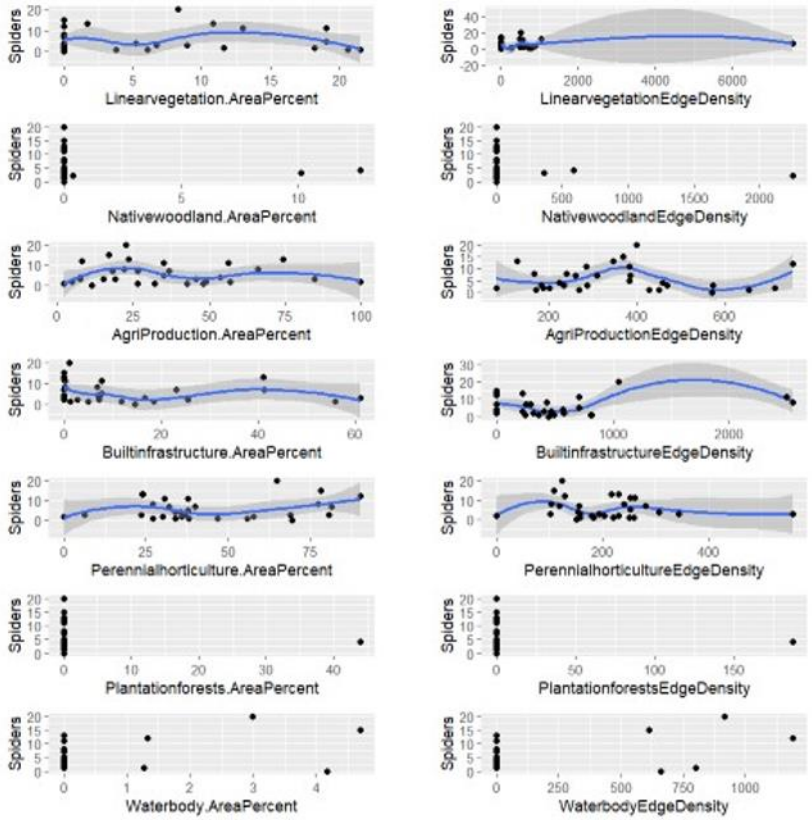

LBAM male longevity
Longevity (Days)
25
20
15
10
5
0
a
ab
abc
abc
abc
abc
abc
abc
abc
abc
abc
abc
abc
abc
abc
abc
abc
bc
c
c
c
c
Pratia pedunculata
Honey solution
Dillwynia phylicoides
Erigeron karvinskianus
Eucalyptus sideroxylon
Fagopyrum esculentum
Grevillea 'Bronze Rambler'
Grevillea rosmarinifolia
Kunzea ambigua 'Pink'
Leptospermum flavescens 'Cardwell'
Leptospermum scoparium
Philotheca myoporoides
Trifolium repens
Trifolium spumosum
Viola hederacea
Water
Westringia fruticosa
Lobularia maritima 'Benthamii'
Acacia sp
Hakea salicifolia
Indigofera australis
Melaleuca pallida
Myoporum parvifolium
Treatment

5000m from centre



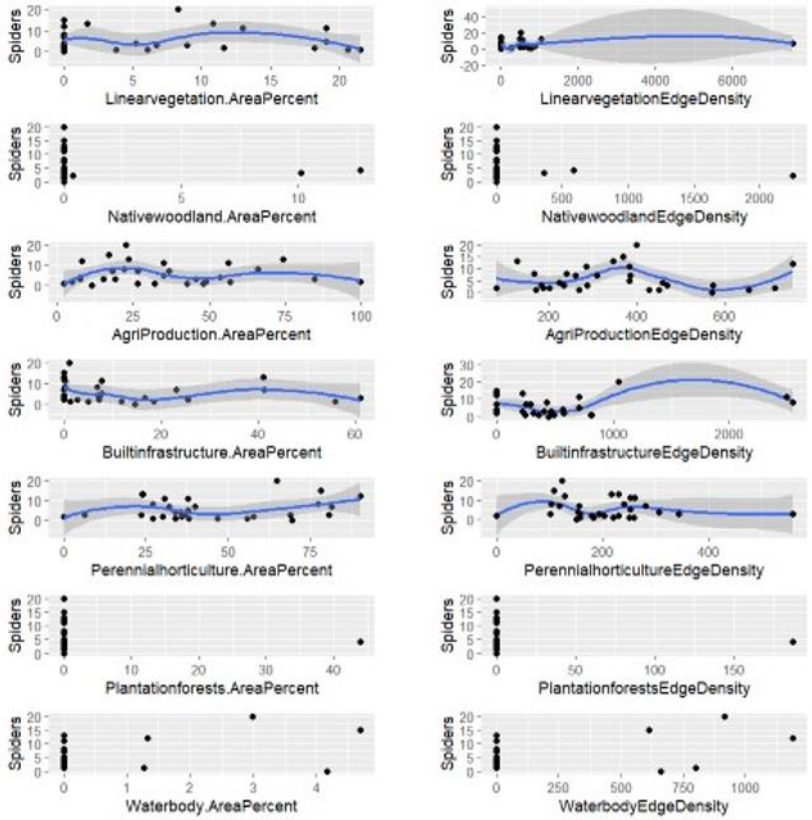
Plantationforests.AreaPercent	0.506	0.2293	2.207	0.0273*
LinearvegetationEdgeDensity	0.004918	0.001751	2.808	0.00498**

250m



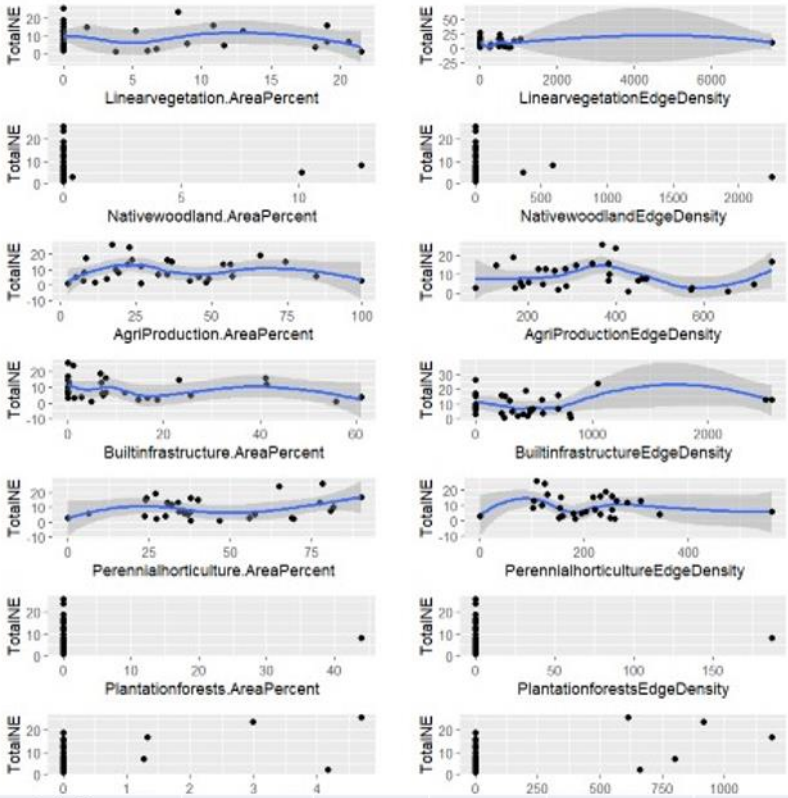
Builtinfrastructure.AreaPercent	-0.01123	0.005357	-2.096	0.0361*
Perennialhorticulture.AreaPercent	0.008286	0.003263	2.539	0.0111*
Waterbody.AreaPercent	0.18664	0.04771	3.912	9.15E-05***
WaterbodyEdgeDensity	0.000794	0.000186	4.268	1.98E-05***

250m



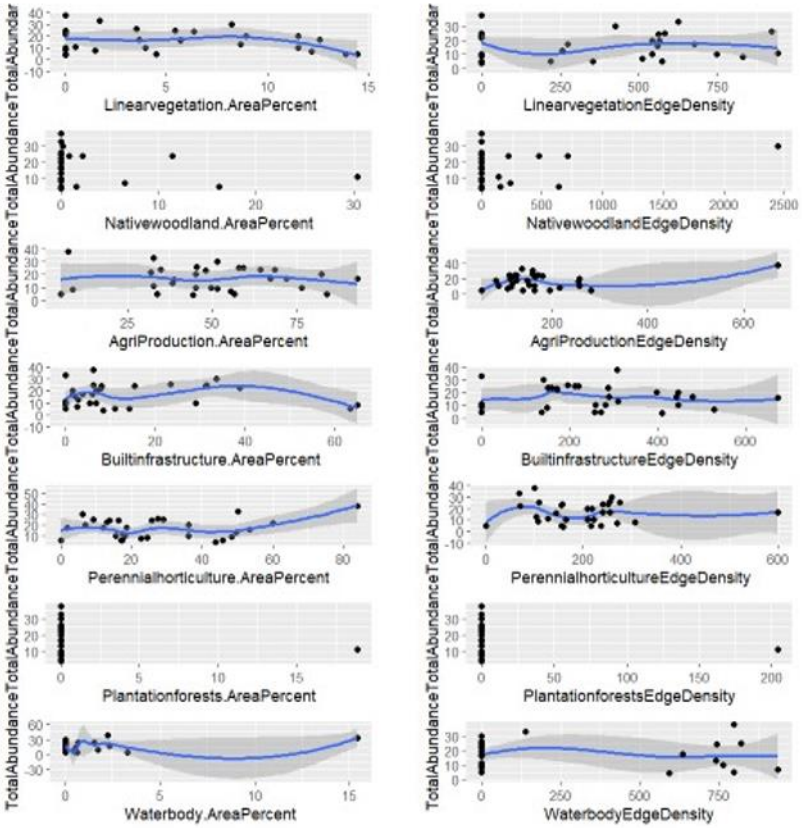
Builtinfrastructure.AreaPercent	-0.01123	0.005357	-2.096	0.0361*
Perennialhorticulture.AreaPercent	0.008286	0.003263	2.539	0.0111*
Waterbody.AreaPercent	0.18664	0.04771	3.912	9.15E-05***
WaterbodyEdgeDensity	0.000794	0.000186	4.268	1.98E-05***

250m

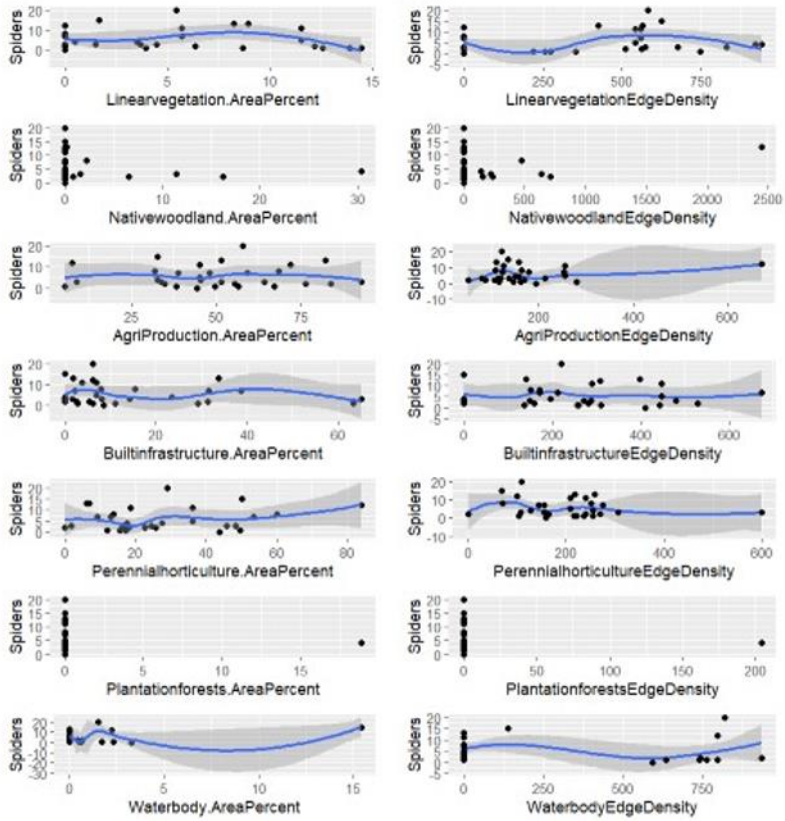


Linearvegetation..AreaPercent	-0.01325	0.008485	-1.562	0.118
Nativewoodland..AreaPercent	-0.03397	0.02481	-1.369	0.171
AgriProduction..AreaPercent	-0.00053	0.002467	-0.214	0.83
Builtinfrastructure.AreaPercent	-0.01174	0.004213	-2.787	0.00532**
Perennialhorticulture.AreaPercent	0.007358	0.002552	2.883	0.00394**
Plantationforests..AreaPercent	-0.00395	0.008163	-0.484	0.628
Waterbody.AreaPercent	0.1748	0.0378	4.623	3.78E-06***
LinearvegetationEdgeDensity	2.44E-06	4.38E-05	0.056	0.956
NativewoodlandEdgeDensity	-0.00057	0.000244	-2.322	0.0202*
AgriProductionEdgeDensity	-0.00031	0.000356	-0.862	0.389
BuiltinfrastructureEdgeDensity	1.05E-04	9.06E-05	1.164	0.244
PerennialhorticultureEdgeDensity	-0.001	0.000647	-1.541	0.123
PlantationforestsEdgeDensity	-0.00093	0.001915	-0.484	0.628
WaterbodyEdgeDensity	0.000689	0.000149	4.618	3.87E-06***

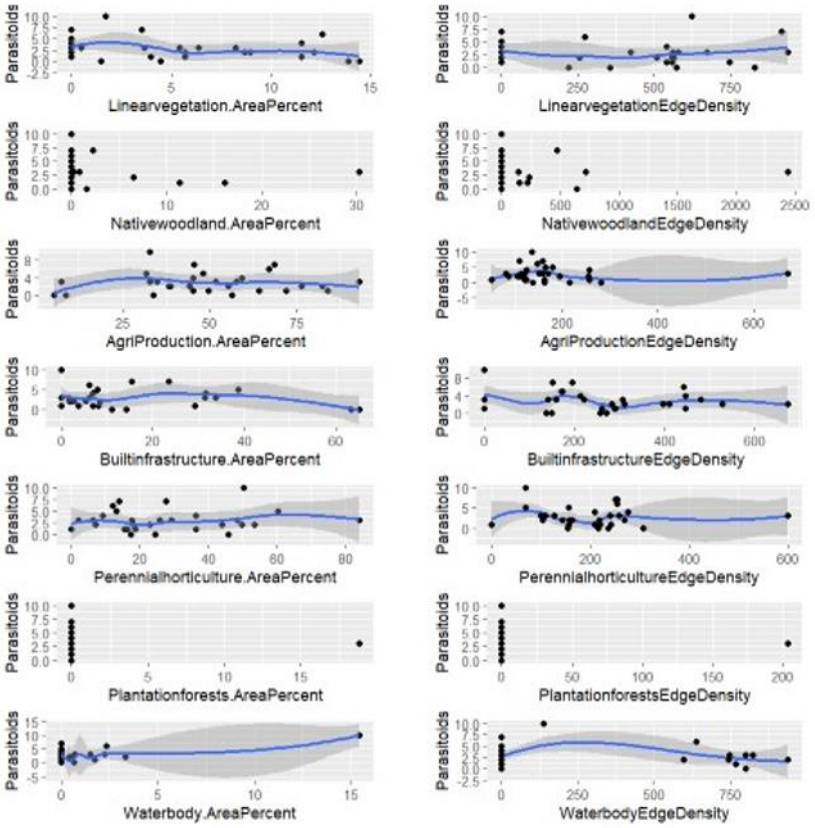
500m


TotalAbundance
Linearvegetation.AreaPercent
Nativewoodland.AreaPercent
AgriProduction.AreaPercent
Builtinfrastructure.AreaPercent
Perennialhorticulture.AreaPercent
Plantationforests.AreaPercent
Waterbody.AreaPercent
LinearvegetationEdgeDensity
NativewoodlandEdgeDensity
AgriProductionEdgeDensity
BuiltinfrastructureEdgeDensity
PerennialhorticultureEdgeDensity
PlantationforestsEdgeDensity
WaterbodyEdgeDensity

500m

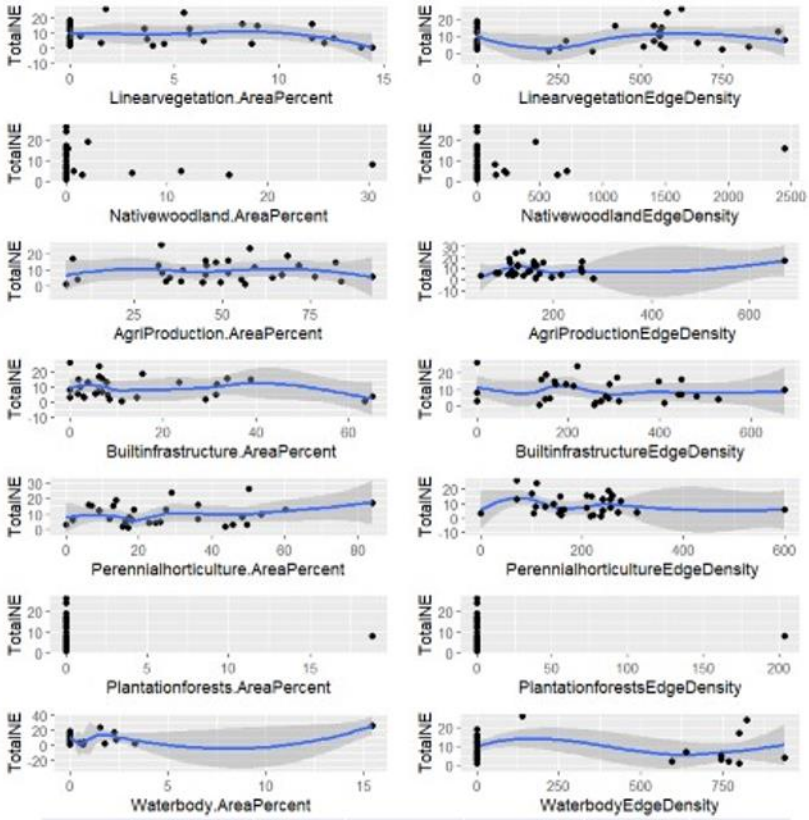

Spiders
Linearvegetation.AreaPercent
LinearvegetationEdgeDensity
Nativewoodland.AreaPercent
NativewoodlandEdgeDensity
AgriProduction.AreaPercent
AgriProductionEdgeDensity
Builtinfrastructure.AreaPercent
BuiltinfrastructureEdgeDensity
Perennialhorticulture.AreaPercent
PerennialhorticultureEdgeDensity
Plantationforests.AreaPercent
PlantationforestsEdgeDensity
Waterbody.AreaPercent
WaterbodyEdgeDensity

500m



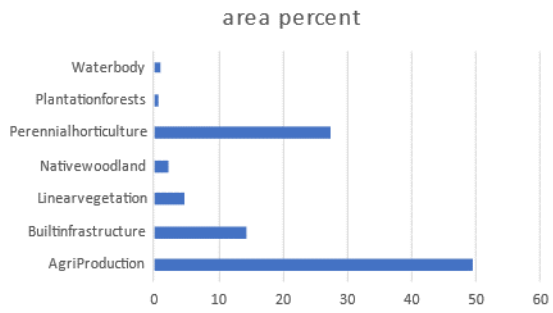
Waterbody.AreaPercent	0.08815	0.02241	3.934	8.36E-05	***

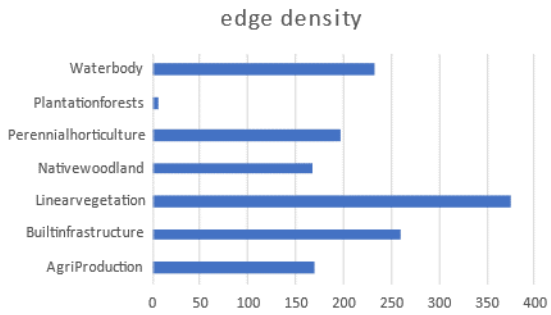
500m



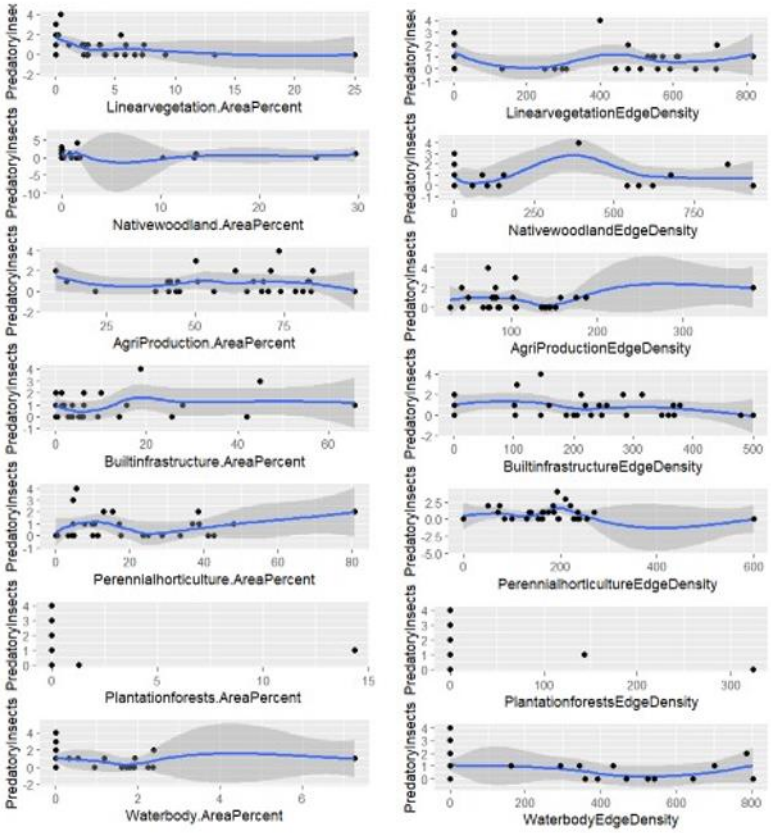
Linearvegetation.AreaPercent	-0.03318	0.01295	-2.562	0.0104*
Nativewoodland.AreaPercent	-0.02581	0.01227	-2.103	0.0355*
AgriProduction.AreaPercent	0.000988	0.002802	0.353	0.724
Builtinfrastructure.AreaPercent	-0.00853	0.00387	-2.203	0.0276*
Perennialhorticulture.AreaPercent	0.00667	0.002901	2.299	0.0215*
Plantationforests.AreaPercent	-0.00921	0.019026	-0.484	0.628
Waterbody.AreaPercent	0.0669	0.01392	4.807	1.53E-06***
LinearvegetationEdgeDensity	8.64E-05	1.92E-04	0.45	0.653
NativewoodlandEdgeDensity	0.000139	0.000113	1.235	0.217
AgriProductionEdgeDensity	0.000803	0.000476	1.687	0.0916.
BuiltinfrastructureEdgeDensity	-0.00074	0.000372	-1.988	0.0468*
PerennialhorticultureEdgeDensity	-0.00129	0.000624	-2.064	0.0391*
PlantationforestsEdgeDensity	-0.00085	0.001757	-0.484	0.628
WaterbodyEdgeDensity	-0.00035	0.000181	-1.947	0.0516.

500m


area percent
Waterbody
Plantationforests
Perennialhorticulture
Nativewoodland
Linearvegetation
Builtinfrastructure
AgriProduction
0
10
20
30
40
50
60

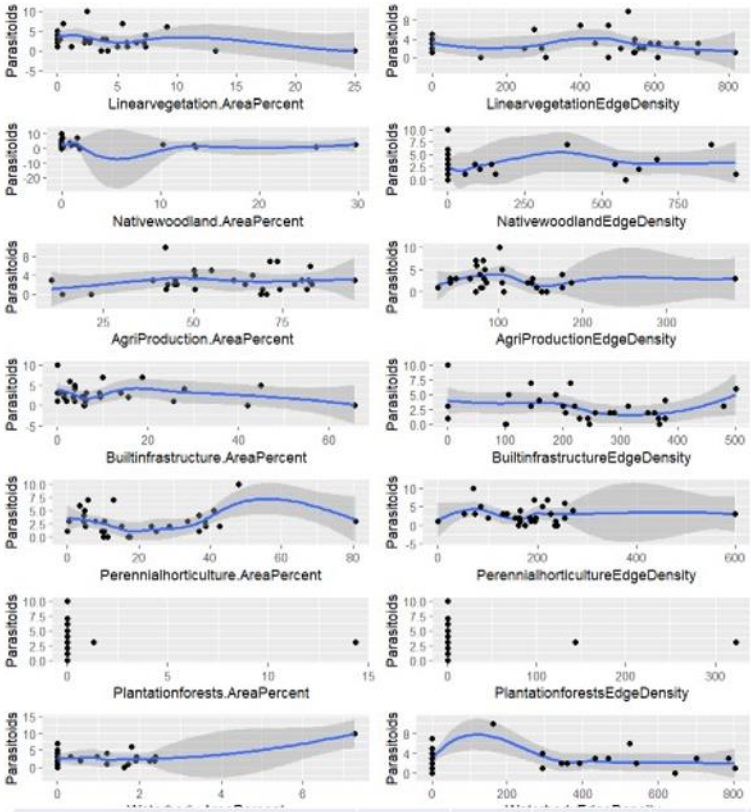

edge density
Waterbody
Plantationforests
Perennialhorticulture
Nativewoodland
Linearvegetation
Builtinfrastructure
AgriProduction
0
50
100
150
200
250
300
350
400

1000m



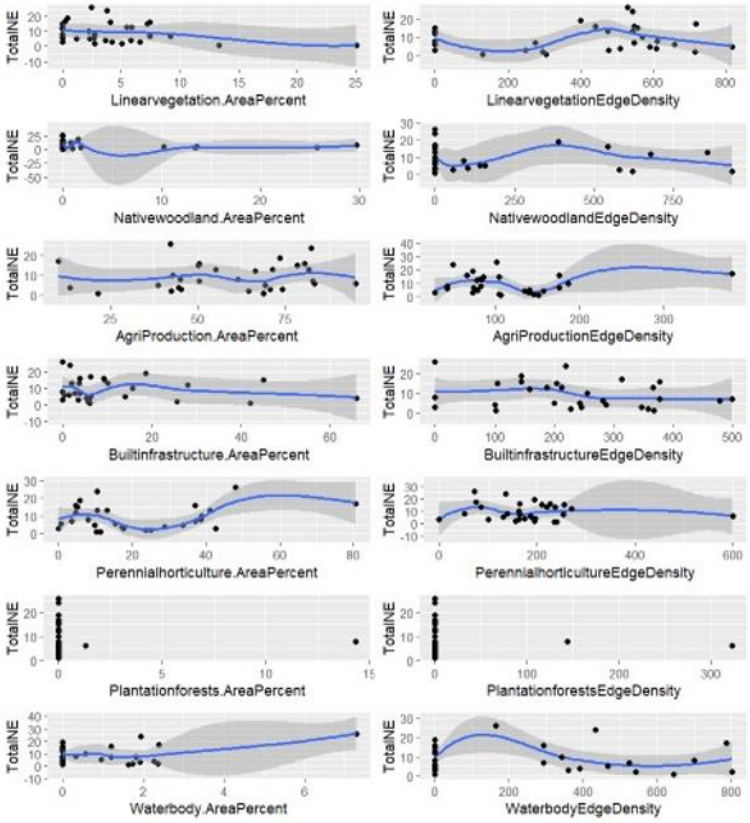
Linearvegetation.AreaPercent -0.2139 0.084 -2.562 0.0104 *

1000m



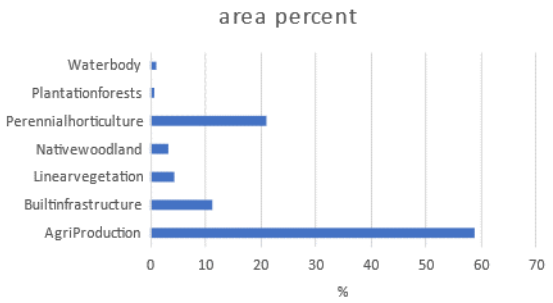
Linearvegetation.AreaPercent	-0.07453	0.032	-2.364	0.0181*
Nativewoodland.AreaPercent	-0.01922	0.017	-1.116	0.265
AgriProduction.AreaPercent	0.004513	0.005	0.858	0.3911
Builtinfrastructure.AreaPercent	-0.010337	0.008	-1.243	0.214
Perennialhorticulture.AreaPercent	0.005061	0.006	0.901	0.368
Plantationforests.AreaPercent	0.003567	0.041	0.087	0.93
Waterbody.AreaPercent	0.1644	0.052	3.134	0.00172**
LinearvegetationEdgeDensity	-0.0003362	4E-04	-0.786	0.432
NativewoodlandEdgeDensity	0.0002185	4E-04	0.602	0.547
AgriProductionEdgeDensity	-0.001674	0.002	-0.909	0.363
BuiltinfrastructureEdgeDensity	-0.0010634	8E-04	-1.326	0.185
PerennialhorticultureEdgeDensity	-0.00046	0.001	-0.412	0.68
PlantationforestsEdgeDensity	0.0001798	0.002	0.107	0.915
WaterbodyEdgeDensity	-0.0003012	4E-04	-0.736	0.462

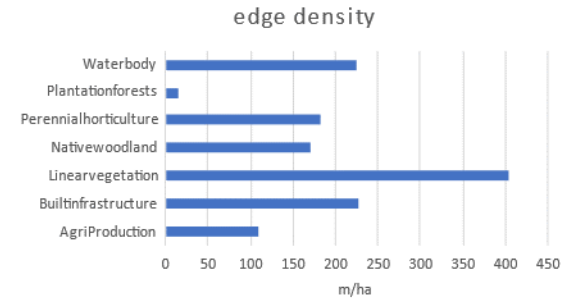
1000m



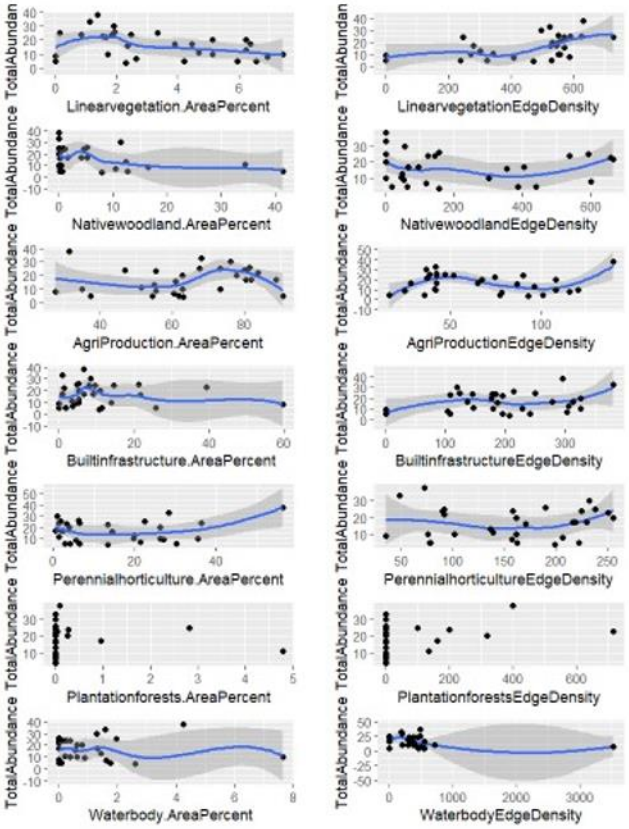
Land use	Area percent Coefficients	Edge density Coefficients
Linearvegetation	-0.06209***	0.0003375
Nativewoodland	-0.03181**	-0.0002663
AgriProduction	0.003842	0.0003922
Builtinfrastructure	-0.007305.	-0.0011261*
Perennialhorticulture	0.00593.	-0.0009173
Plantationforests	-0.01493	-0.001434
Waterbody	0.11862***	-0.0004006.

1000m


area percent
Waterbody
Plantationforests
Perennialhorticulture
Nativewoodland
Linearvegetation
Builtinfrastructure
AgriProduction
0
10
20
30
40
50
60
70
%

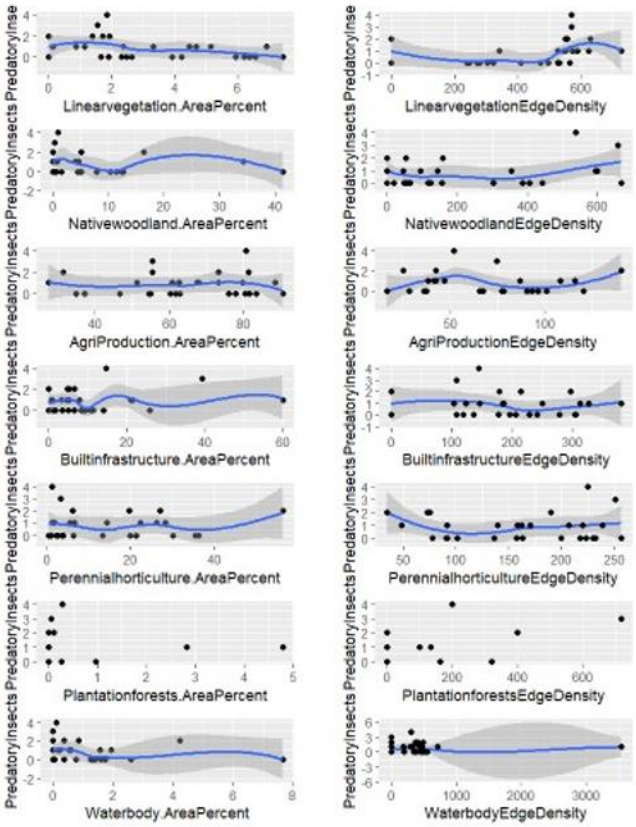

edge density
Waterbody
Plantationforests
Perennialhorticulture
Nativewoodland
Linearvegetation
Builtinfrastructure
AgriProduction
0
50
100
150
200
250
300
350
400
450
m/ha

2500m



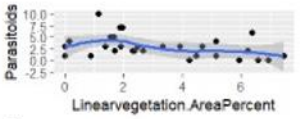
Land use	Area percent Coefficients	Edge density Coefficients
Linearvegetation	-0.10249***	0.0019117***
Nativewoodland	-0.026108***	-6.79E-05
AgriProduction	0.00611*	-0.001047
Builtinfrastructure	-0.004244	0.0015121**
Perennialhorticulture	0.00642*	0.0002692
Plantationforests	0.002459	0.0010052***
Waterbody	0.01254	-0.0002877**

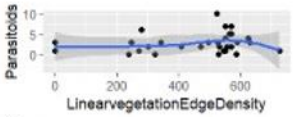
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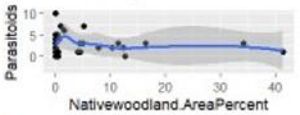


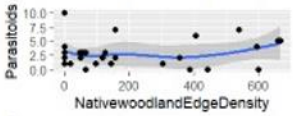
Linearvegetation.AreaPercent	-0.2512	0.105	-2.392	0.0167*
PlantationforestsEdgeDensity	0.002243	0.000807	2.78	0.00543**

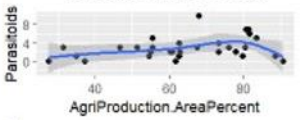
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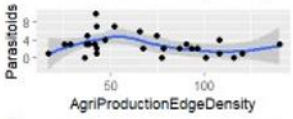


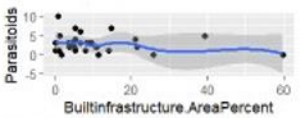


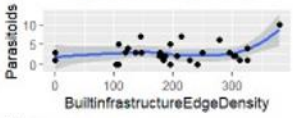


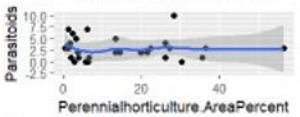


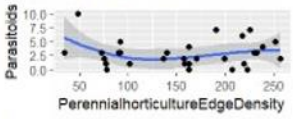


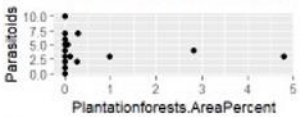


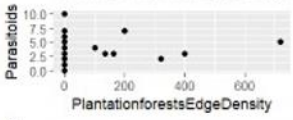


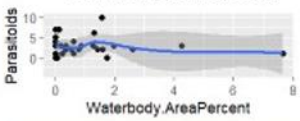


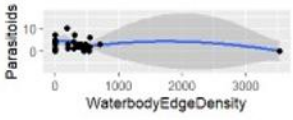






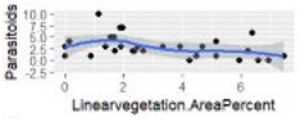


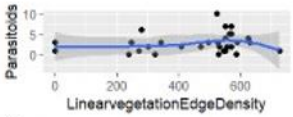


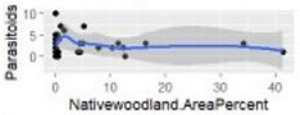


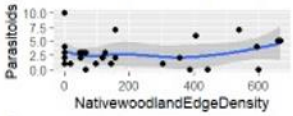
Linearvegetation.AreaPercent	-0.15221	0.05227	-2.912	0.00359	**
Nativewoodland.AreaPercent	-0.01742	0.01352	-1.288	0.198	
AgriProduction.AreaPercent	0.015939	0.006949	2.294	0.0218	*
Builtinfrastructure.AreaPercent	-0.0142	0.01066	-1.333	0.183	
Perennialhorticulture.AreaPercent	-0.00126	0.007913	-0.159	0.874	
Plantationforests.AreaPercent	0.0545	0.09923	0.549	0.583	
Waterbody.AreaPercent	-0.05218	0.07718	-0.676	0.499	
LinearvegetationEdgeDensity	0.000923	0.000679	1.358	0.1744	
NativewoodlandEdgeDensity	0.000399	0.000466	0.858	0.391	
AgriProductionEdgeDensity	-0.00711	0.003564	-1.994	0.0461	*
BuiltinfrastructureEdgeDensity	0.001955	0.001202	1.626	0.1038	
PerennialhorticultureEdgeDensity	-0.00022	0.001647	-0.133	0.894	
PlantationforestsEdgeDensity	0.000889	0.000568	1.565	0.118	
WaterbodyEdgeDensity	-0.00083	0.00041	-2.017	0.0437	*

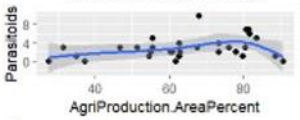
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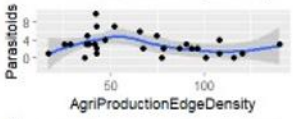


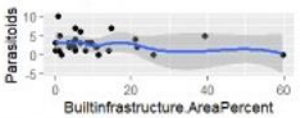


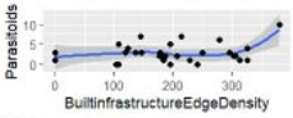


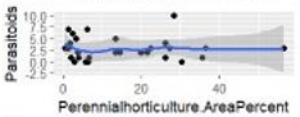


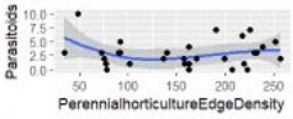


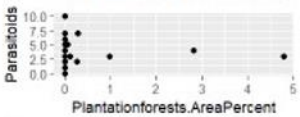


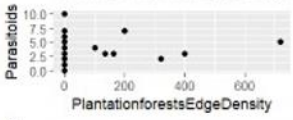


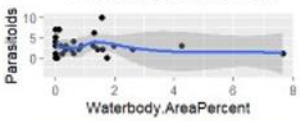


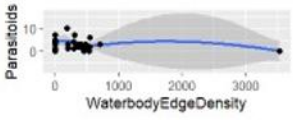






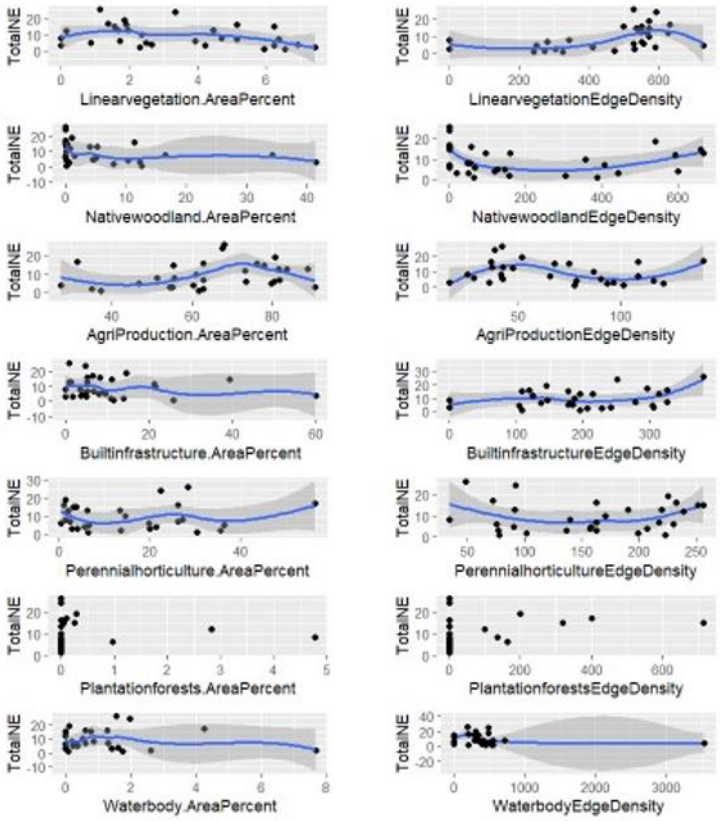






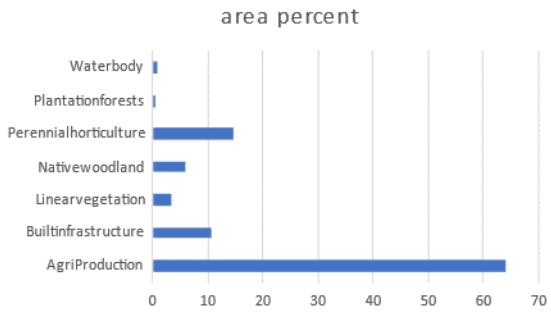
Linearvegetation.AreaPercent	-0.15221	0.05227	-2.912	0.00359	**
Nativewoodland.AreaPercent	-0.01742	0.01352	-1.288	0.198	
AgriProduction.AreaPercent	0.015939	0.006949	2.294	0.0218	*
Builtinfrastructure.AreaPercent	-0.0142	0.01066	-1.333	0.183	
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LinearvegetationEdgeDensity	0.000923	0.000679	1.358	0.1744	
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BuiltinfrastructureEdgeDensity	0.001955	0.001202	1.626	0.1038	
PerennialhorticultureEdgeDensity	-0.00022	0.001647	-0.133	0.894	
PlantationforestsEdgeDensity	0.000889	0.000568	1.565	0.118	
WaterbodyEdgeDensity	-0.00083	0.00041	-2.017	0.0437	*

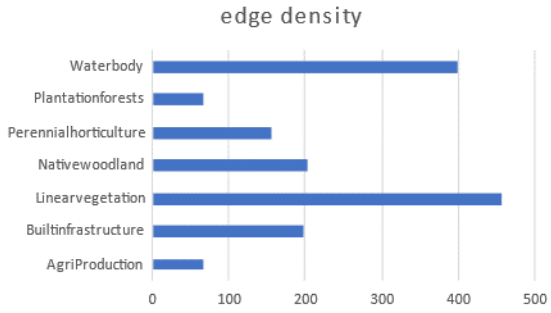
2500m



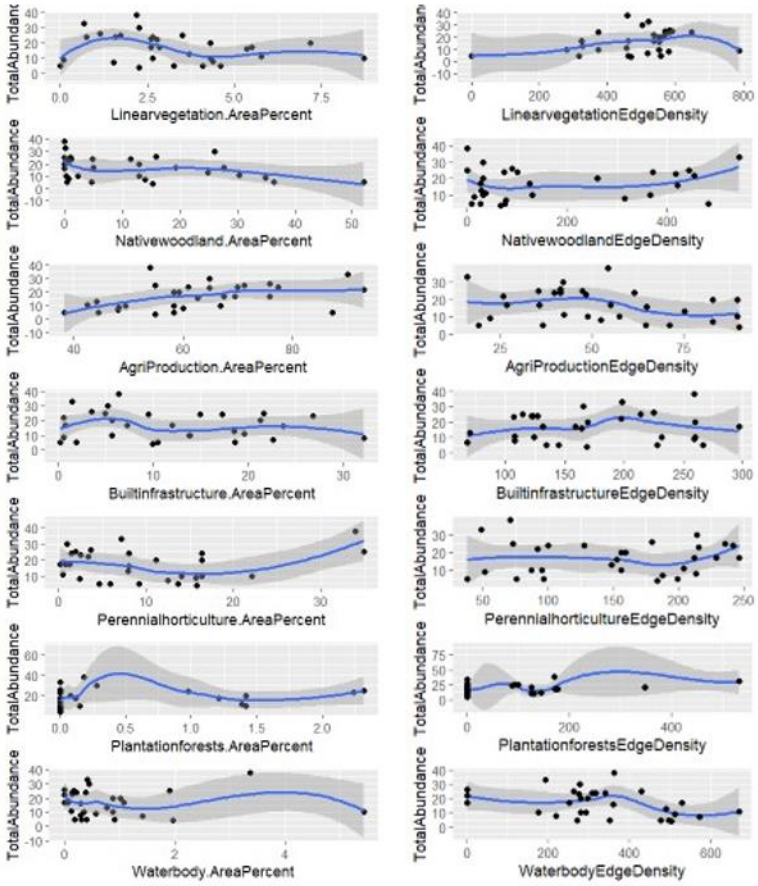
Linearvegetation.AreaPercent	-0.11407	0.02804	-4.068	4.75E-05***
Nativewoodland.AreaPercent	-0.0307	0.008653	-3.548	0.000388***
AgriProduction.AreaPercent	0.012151	0.003746	3.243	0.00118**
Builtinfrastructure.AreaPercent	-0.00828	0.005383	-1.538	0.124
Perennialhorticulture.AreaPercent	0.003056	0.004225	0.723	0.47
Plantationforests.AreaPercent	0.006834	0.059477	0.115	0.909
Waterbody.AreaPercent	-0.02437	0.04	-0.609	0.542
LinearvegetationEdgeDensity	0.002399	0.000437	5.491	3.99E-08***
NativewoodlandEdgeDensity	-0.00021	0.000272	-0.789	0.43
AgriProductionEdgeDensity	-0.00474	0.001911	-2.48	0.0131*
BuiltinfrastructureEdgeDensity	0.002158	0.000663	3.255	0.00113**
PerennialhorticultureEdgeDensity	7.99E-05	9.08E-04	0.088	0.93
PlantationforestsEdgeDensity	0.00113	0.000297	3.805	0.000142***
WaterbodyEdgeDensity	-0.00035	0.000149	-2.357	0.0184*

2500m from centre

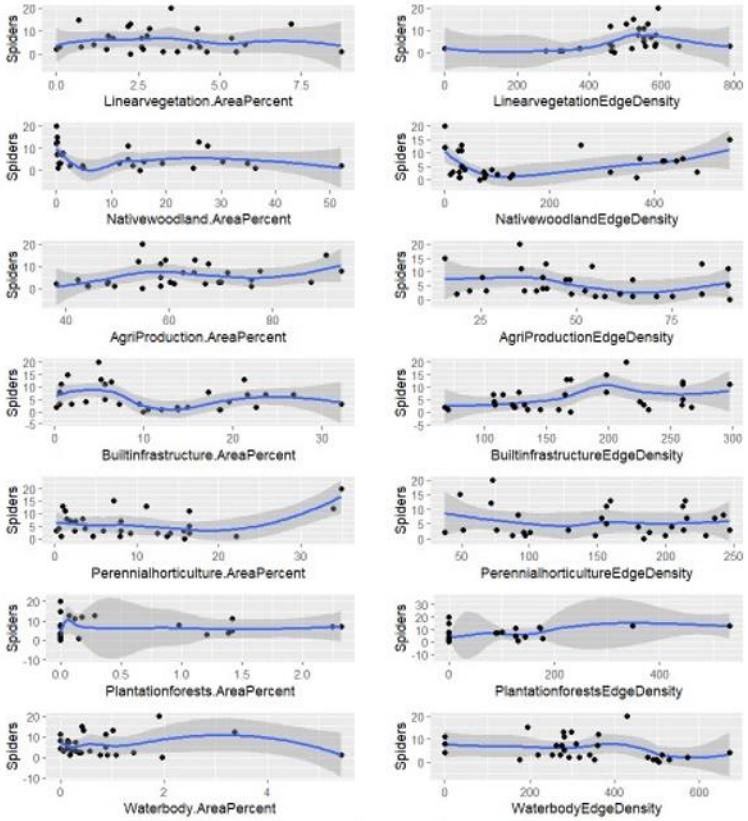




5000m from centre

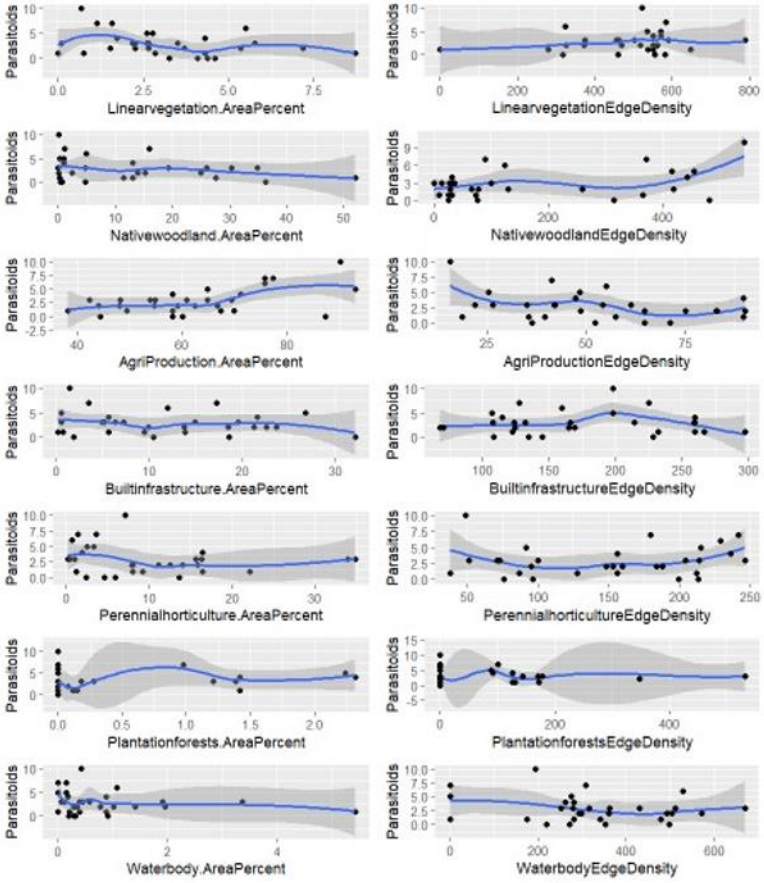


5000m from centre

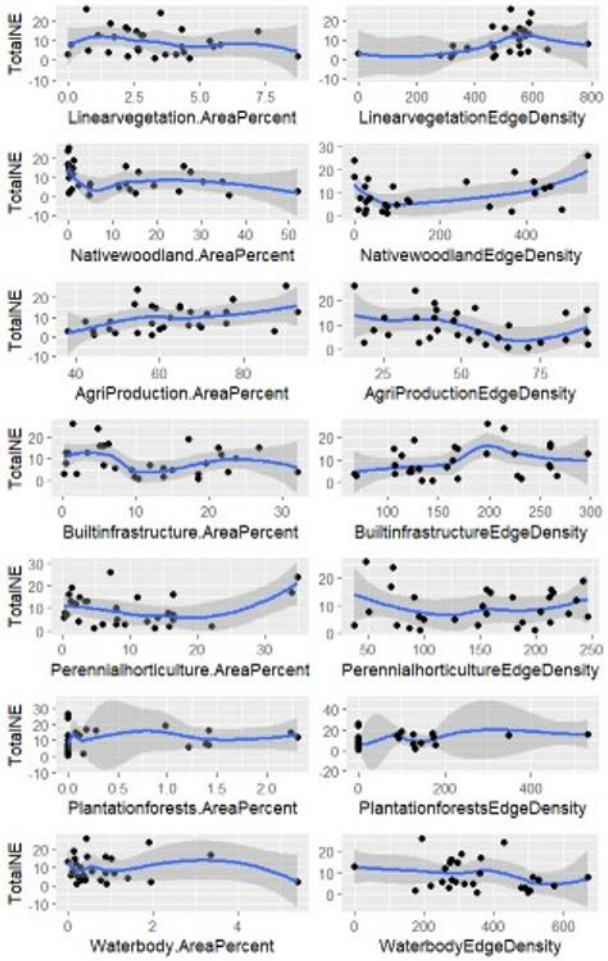


Land use	Area percent Coefficients	Edge density Coefficients
Linearvegetation	-0.01899	0.002774***
Nativewoodland	-0.02084**	0.0006261
AgriProduction	0.01568**	-0.008865*
Builtinfrastructure	-0.024894**	0.004621***
Perennialhorticulture	0.022276**	-0.0014
Plantationforests	0.13407	0.0023365***
Waterbody	0.01221	-0.0015599***

5000m from centre

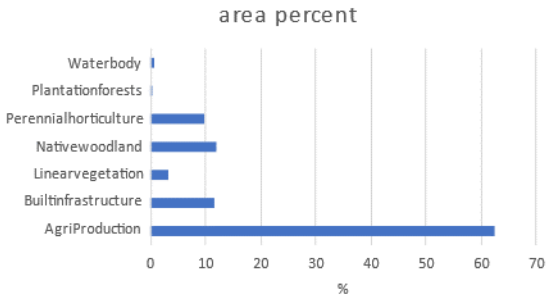


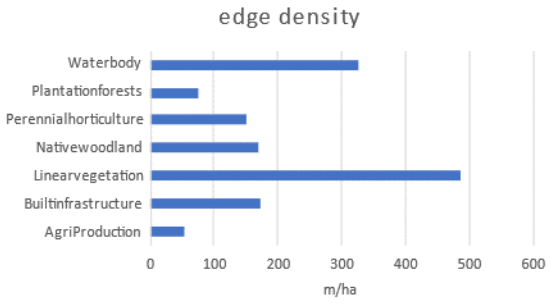
Land use	Area percent Coefficients	Edge density Coefficients
Linearvegetation	-0.14134*	0.0013099
Nativewoodland	-0.017423.	0.0014386*
AgriProduction	0.029655***	-0.013584*
Builtinfrastructure	-0.01598	-4.98E-05
Perennialhorticulture	-0.01978	0.00112
Plantationforests	0.2213	-9.58E-05
Waterbody	-0.1555	-0.0011117.

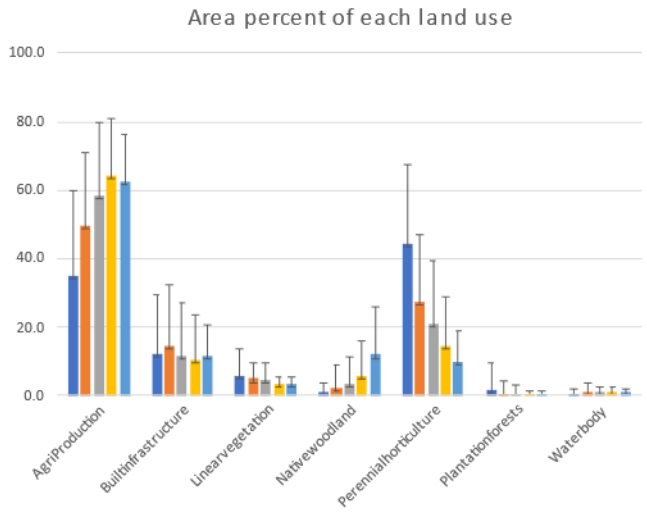


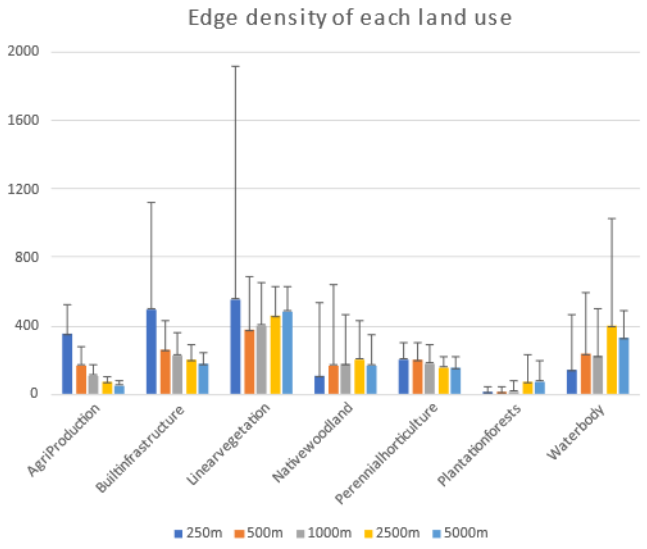
Land use	Area percent Coefficients	Edge density Coefficients
Linearvegetation	-0.07086*	0.0024839***
Nativewoodland	-0.019862***	0.0009173**
AgriProduction	0.019873***	-0.010659***
Builtinfrastructure	-0.018326**	0.0028709**
Perennialhorticulture	0.009534	-0.0003101
Plantationforests	0.19857*	0.0015362***
Waterbody	-0.04841	-0.0013866***

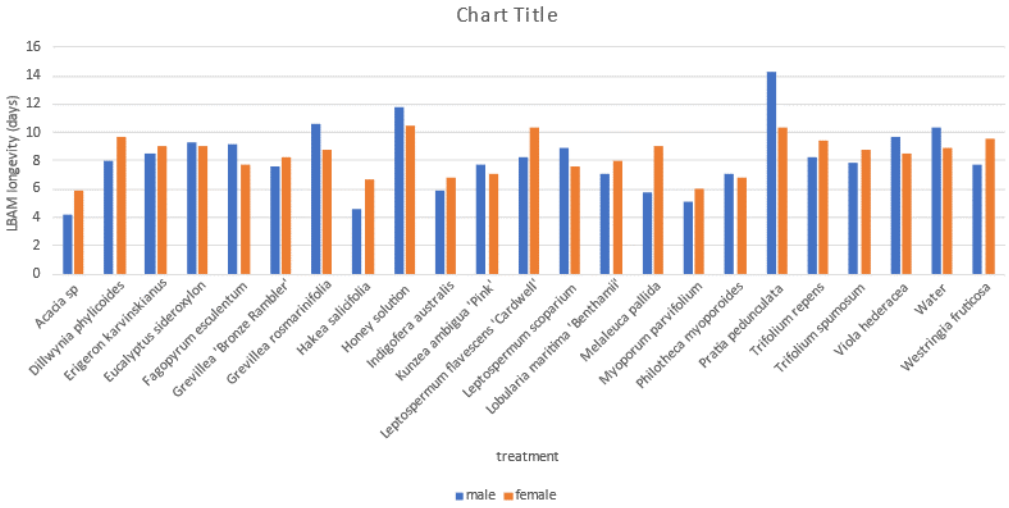
Land use (area percentage, edge density) in 5000m from the centre of the sampling block vs abundance at centre

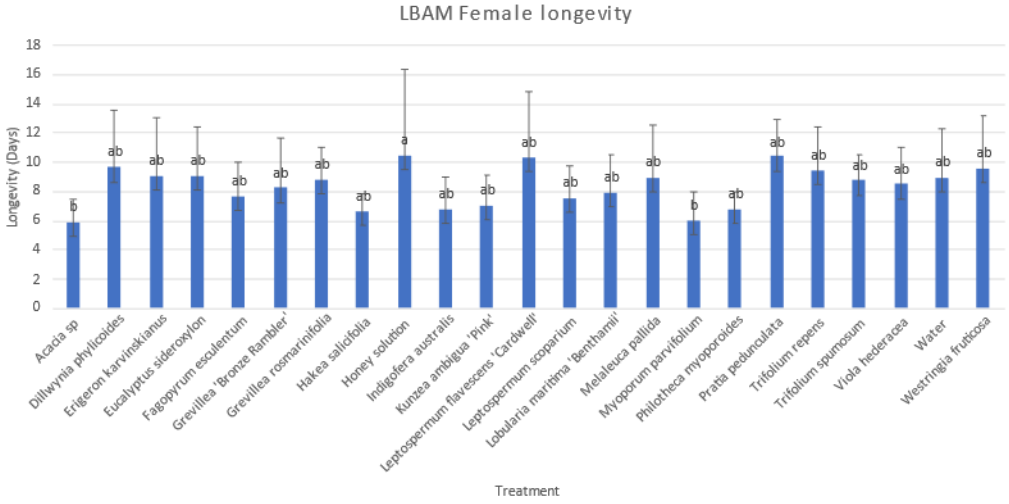


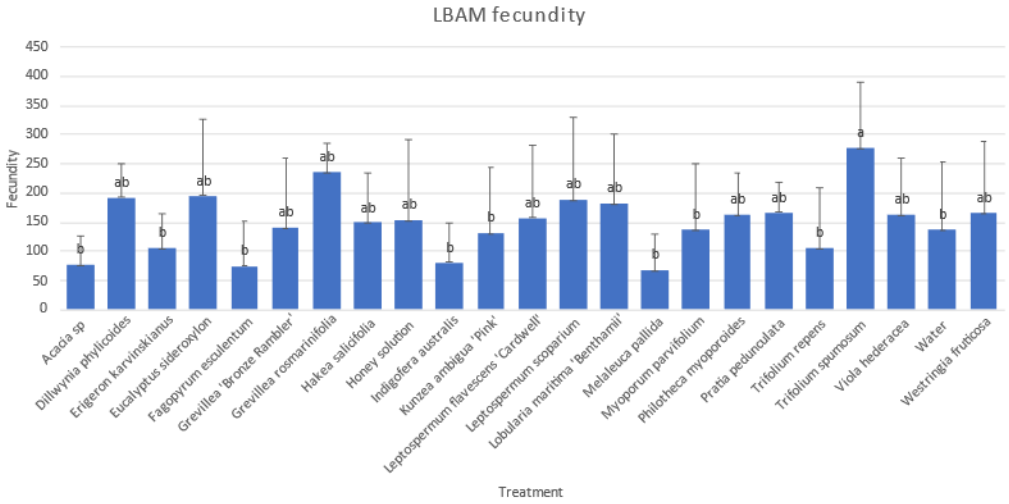



Area percent of each land use
100.0
80.0
60.0
40.0
20.0
0.0
AgriProduction
Builtinfrastructure
Linearvegetation
Nativewoodland
Perennialhorticulture
Plantationforests
Waterbody


Edge density of each land use
2000
1600
1200
800
400
0
AgriProduction
Builtinfrastructure
Linearvegetation
Nativewoodland
Perennialhorticulture
Plantationforests
Waterbody
250m
500m
1000m
2500m
5000m


Chart Title
LBAM longevity (days)
16
14
12
10
8
6
4
2
0
Acacia sp
Dillwynia phylicoides
Erigeron karvinskianus
Eucalyptus sideroxylon
Fagopyrum esculentum
Grevillea 'Bronze Rambler'
Grevillea rosmarinifolia
Hakea salicifolia
Honey solution
Indigofera australis
Kunzea ambigua 'Pink'
Leptospermum flavescens 'Cardwell'
Leptospermum scoparium
Lobularia maritima 'Benthamii'
Melaleuca pallida
Myoporum parvifolium
Philotheca myoporoides
Pratia peduncolata
Trifolium repens
Trifolium spumosum
Viola hederacea
Water
Westringia fruticosa
treatment
male
female


LBAM Female longevity
Longevity (Days)
18
16
14
12
10
8
6
4
2
0
b
ab
ab
ab
ab
ab
ab
ab
a
ab
ab
ab
ab
ab
ab
b
ab
ab
ab
ab
ab
ab
Acacia sp
Dillwynia phylicoides
Erigeron karvinskianus
Eucalyptus sideroxylon
Fagopyrum esculentum
Grevillea 'Bronze Rambler'
Grevillea rosmarinifolia
Hakea salicifolia
Honey solution
Indigofera australis
Kunzea ambigua 'Pink'
Leptospermum flavescens 'Cardwell'
Leptospermum scoparium
Lobularia maritima 'Benthamii'
Melaleuca pallida
Myoporum parvifolium
Philotheca myoporoides
Pratia peduncolata
Trifolium repens
Trifolium spumosum
Viola hederacea
Water
Westringia fruticosa
Treatment


LBAM fecundity
Fecundity
450
400
350
300
250
200
150
100
50
0
b
ab
b
ab
b
ab
ab
ab
ab
b
b
ab
ab
ab
b
b
ab
ab
ab
b
a
ab
b
ab
Acacia sp
Dillwynia phylicoides
Erigeron karvinskianus
Eucalyptus sideroxylon
Fagopyrum esculentum
Grevillea 'Bronze Rambler'
Grevillea rosmarinifolia
Hakea salicifolia
Honey solution
Indigofera australis
Kunzea ambigua 'Pink'
Leptospermum flavescens 'Cardwell'
Leptospermum scoparium
Lobularia maritima 'Benthamii'
Melaleuca pallida
Myoporum parvifolium
Philotheca myoporoides
Pratia pedunculata
Trifolium repens
Trifolium spumosum
Viola hederacea
Water
Westringia fruticosa
Treatment

Appendix 7: Material for cover crops finder tool.

Myoporum (*Myoporum parvifolium*)

Myoporum is a low-growing native Australian plant species that attained an average height of 20cm under NSW vineyard conditions. It grew especially well under well drained conditions but less well on a waterlogged site. Planted as a mixed species cover crop, that also contained *Pratia pedunculata, Viola hederaceae, Dichondra repens,* and *Dampiera diversifolia,* these natives grew from small transplants to occupy approximately 70% of the area in under-vine plots by mid-summer. This helped suppress weed regrowth. On the well drained site, competition by the sown native plant mix reduced weed coverage to less than 20% compared with over 60 % in the control plots where the original spontaneous vegetation remained. Plots were established using small potted plants set approximately one meter apart but this approach would be prohibitively expensive for large areas. More widely spaced plantings could be used to reduce cost and these allowed to expand coverage over subsequent years.

Beneath vines, the low height of Myoporum (about 20cm) left plenty of open space between it and the vines allowing more airflow than did the weedy vegetation it replaced. The weedy vegetation in NSW field trials averaged approximately 40cm tall. Accordingly, Myoporum is likely to increase air flow in vineyards so be useful in reducing the risk of frost and fungal disease damage.

Whilst field conditions in the trial period did not provide an opportunity to measure frost damage, effects were apparent for severity and incidence of botrytis. On a well-drained site where Myoporum grew best, the incidence was reduced to approximately 4 affected bunches per plot compared with approximately 6 in the control plots which had weedy groundcover. Severity of botrytis in affected bunches also was reduced, from a score of 12 in the control plot down to 6 in the Myoporum plot. Aside from the effect of improved air flow on the severity of botrytis, damage to bunches by insect feeding can also be important. Accordingly, reductions in lightbrown apple moth damage to bunches (see below) are likely to have contributed to the lower levels of botrytis in plots with Myoporum groundcovers. Myoporum ground covers beneath vine rows on the well drained site reduced the number of bunches affected by lightbrown apple moth to a mean of approximately 2 compared with approximately 5 in control plots that had weedy groundcover. This reduction can be attributed to the flowers of Myoporum providing nectar that attracts and nourishes beneficials such as parasitic wasps that then attack the pests. Evidence for this comes from laboratory experiments in which female parasitic wasps (*Trichogramma pretiosum*) were caged with flowering Myoporum shoots and these lived long enough to each parasitise an average of approximately 22 host insects compared with only 3 when they were caged with water only (and no nectar source). It is important that any ground cover vegetation added to a vineyard does not have unanticipated negative effects such as providing nectar to lightbrown apple moth. This risk was assessed in laboratory studies and Myoporum flowers were found not to increase egg laying by the moths compared with a control treatment of water and no nectar source.

Future effects of Myoporum will vary according to site and year.

From a practical perspective, growers need to weigh-up the time and expense involved in establishing groundcover vegetation against the types of benefits that are possible. To suppress pest insects, it may be sufficient to plant only every 10th vine row. This is because beneficial insects such as *Trichogramma* wasps are able to fly so are able to move from vine rows with a ground cover strip and easily reach other rows. In the case of achieving suppression of lightbrown apple moth, this potentially has a flow-on effect of reducing botrytis. In contrast, if a grower is more concerned with

suppressing weed growth and improving air flow to address fungal disease or frost risk, establishing ground covers beneath a larger proportion of the vineyard can be expected to maximise benefit.

Acknowledgement: This information arises from a Wine Australia-funded project “Functional biodiversity solutions for Australian vineyards: harnessing groundcovers, vineyard surrounds and native plants to deliver key ecosystem services” conducted by Charles Sturt University.

Photo caption: Myoporum growing as an undervine groundcover.

Photo credit: Jian Liu.



Material for Cover Crop Finder species fact sheets.

Alyssum (*Lobularia maritima*)

Alyssum is a low-growing plant species that attained an average height of 25cm under NSW vineyard conditions. It grew rapidly on a well drained site, occupying approximately 30% of the area in sown under-vine plots by mid-summer and this helped suppress weed regrowth. It did not thrive on a waterlogged site. More general experience of alyssum in field trials indicates that individual plants can survive for more than one year and that seed production leads to recruitment of young plants. Accordingly, it is capable of producing a persistent, long-term groundcover. For initial establishment, surface sowing onto moist, bare soil is best, as sunlight is required for germination.

Beneath vines its low height left plenty of open space between it and the vines allowing more airflow than did the weedy vegetation it replaced. The weedy vegetation in NSW field trials averaged approximately 40cm tall. Accordingly, alyssum is likely to increase air flow in vineyards so be useful in reducing the risk of frost and fungal disease damage.

Whilst field conditions in the trial period did not provide an opportunity to measure frost damage, effects were apparent for severity and incidence of botrytis. On a well-drained site where alyssum grew best, botrytis incidence was halved to approximately 3 affected bunches per plot compared with approximately 6 in the control plots which had weedy groundcover. Severity of botrytis in affected bunches also was reduced, from a score of 12 in the control plot down to 8 in the alyssum plot. Aside from the effect of improved air flow on the severity of botrytis, damage to bunches by insect feeding can also be important. Accordingly, reductions in lightbrown apple moth damage to bunches (see below) are likely to have contributed to the lower levels of botrytis in plots with alyssum groundcovers. Alyssum ground covers beneath vine rows on the well drained site reduced the number of bunches affected by lightbrown apple moth to a mean of approximately 1.5 compared with approximately 5 in control plots that had weedy groundcover. On the less well-drained site, alyssum still reduced lightbrown apple moth damage to a mean of approximately 2 per plot compared with approximate 5 in the control plots. These reductions can be attributed to the flowers of alyssum providing nectar that attracts and nourishes beneficials such as parasitic wasps that then attack the pests. Evidence for this comes from laboratory experiments in which female parasitic wasps (*Trichogramma pretiosum*) were caged with alyssum and these lived long enough to each parasitise an average of approximately 9 host insects compared with only 3 when they were caged with water only (and no nectar source). It is important that any ground cover vegetation added to a vineyard does not have unanticipated negative effects such as providing nectar to lightbrown apple moth. This risk was assessed in laboratory studies and alyssum flowers were found not to increase egg laying by the moths compared with a control treatment with water and no nectar source.

Future effects of alyssum will vary according to site and year.

From a practical perspective, growers need to weigh-up the time and expense involved in establishing groundcover vegetation against the types of benefits that are possible. To suppress pest insects, it may be sufficient to plant only every 10th vine row. This is because beneficial insects such as *Trichogramma* wasps are able to fly so are able to move from vine rows with a ground cover strip and easily reach other rows. In the case of achieving suppression of lightbrown apple moth, this potentially has a flow-on effect of reducing botrytis. In contrast, if a grower is more concerned with suppressing weed growth and improving air flow to address fungal disease or frost risk, establishing ground covers beneath a larger proportion of the vineyard can be expected to maximise benefit.

Acknowledgement: This information arises from a Wine Australia-funded project “Functional biodiversity solutions for Australian vineyards: harnessing groundcovers, vineyard surrounds and native plants to deliver key ecosystem services” conducted by Charles Sturt University.

Photo caption: Alyssum growing as an undervine groundcover.

Photo credit: Jian Liu.



Material for Cover Crop Finder species fact sheets.

Buckwheat (*Fagopyrum esculentum*)

Buckwheat is an exotic but commonly used crop species that grew rapidly under well drained vineyard conditions, occupying approximately 30% of the area in sown mid-row plots by mid-summer and this helped suppress weeds. The area of ground occupied by weeds in mid-row plots of buckwheat was reduced to about 60% compared with close to 100% in the control pots in which the original vegetation was retained. The height of buckwheat (typically 40-80cm) precludes its use as an undervine groundcover since it would impede air flow. Shorter growing species such as alyssum and Myoporum are better suited for undervine use.

General experience of buckwheat in field trials indicates that the crop grows very rapidly if sown into a warm seed bed. It is, however, frost tender so needs to be sown in spring after the risk of frost is reduced. The rapidity with which buckwheat flowers offsets the need for late sowing and leads to flowers being available to beneficial insects reasonably early in the summer. The duration of flowering is extended by spontaneous self seeding and growth of a second flush of plants later in the summer. Flower availability to beneficials can also be promoted by slashing sections of the flowering crop so that fresh shoots are produced which will rapidly produce flowers.

Buckwheat ground covers between vine rows reduced the number of bunches affected by lightbrown apple moth to a mean of 1 on the well drained sites compared with approximately 4 in control plots that had weedy groundcover. On the less well-drained site, buckwheat still reduced lightbrown apple moth damage to a mean of approximately 2 per plot compared with approximate 8 in the control plots. These reductions can be attributed to the flowers of buckwheat providing nectar that attracts and nourishes beneficials such as parasitic wasps that then attack the pests. Evidence for this comes from laboratory experiments in which female parasitic wasps (*Trichogramma pretiosum*) were caged with buckwheat and these lived long enough to each parasitise an average of approximately 23 host insects compared with only 3 when they were caged with water only (and no nectar source). Benefit to a second species of wasp (*Trichogramma carverae*) were less strong but each of these females parasitised an average of approximately 7 host insects. It is important that any ground cover vegetation added to a vineyard does not have unanticipated negative effects such as providing nectar to lightbrown apple moth. This risk was assessed in laboratory studies and buckwheat flowers were found not to increase egg laying by the moths compared with a control treatment with no water and no nectar source.

Future effects of buckwheat will vary according to site and year.

From a practical perspective, growers need to weigh-up the time and expense involved in establishing groundcover vegetation against the types of benefits that are possible. To suppress pest insects, it may be sufficient to plant only every 10th vine row. This is because beneficial insects such as *Trichogramma* wasps are able to fly so are able to move from vine rows with a ground cover strip and easily reach other rows. In contrast, if a grower is more concerned with suppressing weed growth and improving air flow, establishing ground covers is a larger proportion of the vineyard can be expected to maximise benefit. Buckwheat is among the most economical cover crops to establish because seed is relatively inexpensive, readily available and emerges as a dense, vigorous sward. It does however need to be resown each season unlike alternative species such as alyssum and Myoporum that persist from year to year.

Acknowledgement: This information arises from a Wine Australia-funded project “Functional biodiversity solutions for Australian vineyards: harnessing groundcovers, vineyard surrounds and native plants to deliver key ecosystem services” conducted by Charles Sturt University.

Photo caption: Buckwheat growing as a mid-row groundcover.

Photo credit: Jian Liu.

