Hort Innovation

Final Report

The IPM program for the macadamia industry – BioResources inter row project

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Summary

The objective of this project was to provide macadamia growers with practical experience with inter row insectary options, which may improve conservation biological control on-farm. This activity was accompanied by monitoring to quantify potential risks and benefits. This project was complex, examining a specifically focussed research question via field experiments and field trials, within the context of eleven every-day working farms. The project team and growers, who were based across all major growing regions, worked together to find practical ways of incorporating insectaries into macadamia orchards.

The most significant finding for this project was that insectaries in the inter row can increase species diversity of arthropod communities. This in turn created a more complex food web, benefiting the health of the macadamia orchard. It did so without any corresponding increases in pests of macadamias.

More specifically, it was observed that an inter row insectary was associated with an increase in parasitoid and predator abundance and diversity. There was an expansion of specialised feeding niches, with relatively diverse parasitoid and predator families present in the insectary. It was found that there was a numerical increase in beneficial insects without corresponding increases in herbivores or macadamia pests. By contrast it was also found that blocks managed with a regular complete close mow had increased peaks of thrips abundance in the macadamia tree at three out of four **Case Study** farms.

Reduced mowing in the inter row is a simple starting point for most growers to trial an insectary and the use of that area for conservation biological control. This is achievable on many macadamia farms. Seeding and cover cropping in the inter row are other options. These involve greater management complexity but also considerably greater conservation biological control benefit.

An inter row insectary option should be selected on a farm-by-farm basis, but it is important to note that cover cropping was associated with substantially better results. Here parasitoids were on average three times more abundant in the cover crop inter row and more than double in number in the cover crop macadamia trees, as compared to the close mow treatment and corresponding inter row and trees, respectively. Similarly, predators were on average were almost three times as abundant in the cover crop block, and close to double in number in the cover crop macadamia trees. Conversely thrips were on average four times more abundant in the close mow block in the macadamia tree.

The benefits of changed inter row management for the purposes of an insectary and conservation biological control are further amplified when the potential for multiple ecosystem services are taken into consideration. Beyond insect services, managed vegetative diversity can improve soil structure, soil microbiology, nutrient cycling, water storage, carbon sequestration, and biodiversity, and this has been quantified in other studies.

The project recommends that an inter row insectary can be incorporated into existing orchard inter row management on most farms. We found that with basic monitoring and management this will not lead to other challenges such as rats, weeds and/or an insect pest reservoir. The project further recommends that inter row insectaries can be produced via reduced mowing and where suitable, seeding and cover cropping. Decisions to include insectaries in the inter row must be accompanied by planning and strategies for managed vegetative diversity and considerations of individual farm variations.

Growers will need to evaluate their orchards on a case-by-case basis for row width, available suitable machinery, available suitable light, and tree age. Inter row insectaries must be managed with clear objectives, planning, and management strategies.

This project has developed practical options for inter row insectaries that are compatible with the seasonal demands of macadamia orchard management and can be selected on a farm-by-farm, season-by-season and site-by-site basis. It has also developed information on likely associations between insectaries and the potential for increased rat, invasive weed, and/or arthropod pest presence, which can be used by industry and growers to help with decision-making for managing insectaries. In the specific case of rats, which has been of particular interest to many of this project's stakeholders, the project has found that rats must be managed as a stand-alone issue and irrespective of any decisions made in terms of an inter row insectary; and a poorly managed insectary may shelter rats, while a well-managed insectary is very unlikely to. Finally, the project has

quantified association between changes in inter row vegetation management and changes in orchard biodiversity for vegetation and arthropods.

Future R&D should consider: the role of seeding and cover cropping in the macadamia inter row for conservation biological control and other ecosystem services; the impact of increased biodiversity and natural enemies on pest suppression; the economic value of conservation biological control; the contribution of flies as potential pollinators of the macadamia crop; quantification of changes to arthropod abundance and diversity in insectaries at 3 years and beyond.

The BioResources project team

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Keywords

Alternate row mow, Beneficial insects, Conservation biological control, Cover crop, Inter row, Insectary, Mohawk, Natural enemies, Seeding, Reduced mow, Food web

Abbreviations and Glossary

Alternate row mow - Mow every second row on a rotating schedule, allowing all rows to "grow out" somewhat across the year and all rows to be mowed alternately for management, maintenance and rejuvenation.

Arthropod – An invertebrate animal with an exoskeleton and segmented body which includes insects, arachnids, myriapods and crustaceans.

Arthropod feeding guild - a guild is any group of species that exploit the same resources and is a functional classification pertaining to the life stages or strategies used by a group of individual organisms rather than their evolutionary based taxonomic classification.

Conservation biological control – Adopting and sustaining on-farm non-crop managed vegetative diversity specifically to enhance beneficial arthropods and the food web.

Cover crop – A crop grown for multiple ecosystem services including insectary and protection and enrichment of the soil.

Critical density sampling - A method to establish economic thresholds to know whether the population density of an insect pest exceeds a critical level at which some treatment should be applied for economic reasons.

Family taxon surrogates – In an estimation of species richness, counting higher ranked taxa (family) can be used as a measure of diversity of arthropods and is therefore a surrogate measure that is also well placed to determine the feeding guild structure of arthropods.

Food-web – Represents feeding relationships within a community via a system of interlocking food chains in an ecosystem.

Inter row – The ground area existing between macadamia tree rows.

Integrated Pest Management (IPM) (*Program definition*) IPM is a sustainable approach to pest control meeting the social, economic and environmental expectations of stakeholders. Successful IPM is reliant on regular monitoring. It utilises a combination of methods including biological suppression, cultural control and targeted chemistry.

Integrated Pest Management (IPM) (*Project definition, which extends the program definition to incorporate additional terms consistent with the specific focus and objectives of this project*) IPM is an ecosystem approach that aims for more sustainable pest control or suppression while meeting the social, economic and environmental expectations of stakeholders. Successful IPM is reliant on regular monitoring to establish critical densities. It utilises a combination of methods including biological control (conservation and augmentative biological control), cultural control and minimal targeted chemistry that is least harmful to biological control.

Insectary – An area of vegetation dedicated to the conservation of beneficial arthropods and the broader food-web.

Managed vegetative diversity – Managing vegetation in the inter row to encourage plant ecological diversity (in terms of species, floral characteristics, and habitat types) for an insectary for conservation biological control, while discouraging rats, weeds or pest reservoir, with selective and targeted mechanical and chemical treatments. Seeding may be incorporated into the inter row to further improve vegetative diversity in the insectary.

Mohawk - Reduced mowing leaves a central mohawk strip down the row, with more regular mowing down the drip-line of the trees.

Participatory Action Research (PAR) – an approach to research in communities based on participation and action and targeting practice change.

Reduced mowing – for this project this relates specifically to the macadamia orchard inter-row and is a management decision to reduce mowing frequency and/or areas and/or seasons there. This contrasts with the industry standard for regular complete close mow year-round.

Seeding – Selection of seed and seed mixes for seeding the inter row to improve vegetative diversity.

Yellow sticky traps (YSTs) – a commercially available sticky insect trap, yellow in colour, to attract a range of flying insects.

Introduction

Conservation biological control is a key strategy for integrated pest management (IPM). It is, however, currently substantially under-investigated and under-utilised in the macadamia industry. This project has provided a first-time opportunity to trial the implementation of conservation biological control and evaluate the results on working farms.

Conservation biological control is an insect pest management strategy that takes into consideration management practices of on-farm non-crop vegetation.[1] [a] The objective is to provide an environment that can secure and enhance the performance of beneficial arthropods – pollinators, predators and parasitoids – specifically, and the food-web generally.[2] This strategy seeks to reverse adverse trends in agricultural areas where biological diversity has declined with increasing landscape change, pesticide use and mechanisation, in favour of large and uniform production units.[3] In agricultural landscapes, the associated loss and fragmentation of non-crop semi-natural habitats has led to a reduction in species richness and abundance.[4–6]

The structure of food webs can be closely tied to biodiversity. Increased biodiversity can create more complex food webs and tends to provide more stable and better functioning ecosystem services i.e. pollination or pest suppression. The spatial and temporal patterns of orchard-associated resources such as adjacent non-crop habitats can be critical to the survival of beneficial arthropods.[7] For this reason, in this project, the potential for conservation biological control arising from insectaries located in the macadamia inter row is investigated. Insectaries are areas with relatively higher plant species diversity, year-round floral resources, reduced physical disturbance and improved habitat complexity. Thus characterised, they will provide shelter, nectar, alternative prey and hosts, and pollen for beneficial arthropods. (The acronym SNAP [for Shelter, Nectar, Alternate prey/hosts, and Pollen] is used to describe the intention behind management decisions associated with insectaries.)[8,9]

A well designed and managed insectary will thus in the first instance serve as a habitat – or shelter – for beneficial arthropods. It is here that a physical environment provides them with over-wintering areas, a green bridge, and even potentially a refuge and recovery area after spraying. Furthermore, the insectary provides necessary resources and stability for beneficial arthropods to breed and complete their often-complex lifecycle.
Floral resources located in an insectary will provide food in the form of nectar and pollen for many beneficial arthropods. There is good evidence that bloom abundance, floral characteristics, year-round availability and diverse species availability are important determinants of the presence, diversity, fecundity and activity of beneficial arthropods. It is this habitat that is also more likely to host alternative prey (non-economic insects) for the "natural enemies" of macadamia pests (natural enemies are the predators and parasitoids that naturally prey on (consume) pests). It is estimated that for every herbivorous pest there are at least five species of insect parasitoid, which may attack various stages of the host's lifecycle.[10] The majority of insects in the world are not harmful in any way: less than 1% of insect species are what would be classified as a pest. Prey diversity can have a powerful effect on the nutrition, reproduction and survival of natural enemies.

At a coarse scale, natural enemies can be considered to be either feeding specialists or generalists (although this is not always clear). Both can play important roles in biological control. A specialist feeds on a narrow range of prey. Specialist enemies have the advantage of close inter-relationships and specific adaptions to the pest and have historically been the focus of most research. Parasitoids such as the egg parasitoid genus *Trichogramma* (including *Trichogrammatoidea cryptophlebia* (MacTrix)) are a good example of success in this endeavour. They generally can be considered to have a weakness of inflexibility as they are fairly habitat specific. Although most other *Trichogramma* can parasitise moth eggs of different species, their cues for finding host eggs are primarily habitat based (forest/tree type).[11] Once in that habitat they then utilise finer cues such as moth scales and eventually host eggs.

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[a] This topic has been extensively reviewed in this project's literature review, *Insectaries in the macadamia inter-row – opportunities for maximising the presence and action of beneficial insects for the suppression of pest arthropods (MC16008)*, which is available from Hort Innovation (www.horticulture.com.au), and also from www.bioresources.com, and www.researchgate.net. The majority of references provided in this report have been published subsequent to the aforementioned literature review and serve as an update on the latest research.

Generalist predators by comparison feed on a broader range of prey. They can more readily adjust to the conditions that the environment provides them with and can take advantage of whatever prey or resources are available. But knowledge and understanding of these complex reticulated food web interactions is often difficult to visualise and manage. Generalist predators for instance are capable of prey switching or having alternating preference for different types of prey as their relative density changes. This allows generalist predators to subsist on alternative prey in times when pest populations are low and then switch to consuming the pest when it becomes abundant. Thus, alternative prey will maintain generalist predator populations, promoting a "lying-in-wait" strategy for pest suppression.[12] This ready "army" of beneficial insects in close proximity to the macadamia tree are in place to reduce the build-up of pests and may ensure that pest numbers remain below the economic threshold where chemical control might be used. This delay may provide enough time for the crop to grow out of a particular and vulnerable stage, or for the specialist enemies to establish and effect biological control.[13] For example, in macadamia, lacebug may be suppressed below economic thresholds by generalist beneficial arthropods such as robberflies, spiders, lacewing larvae etc, until nut set, at which time lacebug becomes less of a threat to production.[14]

In systems where there is only one predator, the habitat not utilised by the predator can become a refuge for the pest. However, when there are more predators, over a wider area, there is less area for the pest to hide, resulting in greater pest suppression. There is also the multiplier effect whereby the action of one predator increases exposure of the pest to another predator (e.g., when trying to escape). With multiple predators, this accumulation is greater than the combined impacts of the individual species on their own. Such positive effects of increasing diversity are the goal of conservation biological control programs.[13]

With this in mind, this project has sought to investigate conservation biological control options via modification of the current recommended industry standards for management of the macadamia orchard inter row. Industry standards promote regular, complete close mowing/slashing of the orchard floor. This typically produces low diversity ground-cover approaching a monoculture and thus a decline in species diversity of plants and beneficial insects and alternative prey.

"Reduced mowing" is a simple management starting point for moving away from low plant diversity in the inter row for the purposes of an insectary for conservation biological control. This is achievable on many macadamia farms where there is groundcover. Seeding and cover cropping in the inter row are other options, which involve greater management complexity but also potentially greater conservation biological control benefit.[8]

The objective of this project has been to provide growers with practical experience in trialling "managed vegetative diversity" in the inter row. This involves managing vegetation in the inter row to encourage plant ecological diversity (particularly in terms of species, floral characteristics, and habitat types) for an insectary for conservation biological control, while discouraging rats, weeds and/or pest reservoir, with selective and targeted mechanical and chemical treatments. Seeding or cover cropping may be incorporated into the inter row to further improve vegetative diversity in the insectary.

BioResources first worked with growers to consider practical options for reduced mowing, including mohawk, alternate row mow, and tree-to-tree reduced mow, as well as options for seeding and cover cropping, which are compatible with the seasonal demands of orchard management. BioResources then collected observations on any relationship between these options and the potential for increased rat, invasive weed and/or arthropod pest presence. Finally, BioResources sought to monitor association between changes in inter row vegetation management and changes in orchard beneficial/pest arthropod ecology.

The project hypothesis is that managed vegetative diversity in the macadamia inter row will lead to improved arthropod abundance and diversity in the inter row and macadamia trees. The following questions are out of scope in this project (but there are encouraging results in many other recent studies): specific contributions made by beneficial arthropods to pest control in the orchard;[15] specific reductions to crop damage associated with inter row insectaries;[16] specific improvements in yield linked to conservation biological control as investigated in this project.[17,18]

The project used yellow sticky traps (YSTs) to sample insects in a control block and a treatment block with an inter row insectary for comparison of estimated arthropod abundance and diversity. This was particularly useful for capturing winged insects such as flies and wasps, many of which are beneficial insects. Utilising this method, we did not directly collect macadamia pest data which requires inspection of flower (racemes) and nut. However, we did capture several pests of macadamia on YSTs including; thrips, lacebug, aphids, leafhoppers and other Hemiptera, which gave some indication of their relative populations in the standard mow (control) verses increased vegetative diversity (treatment).

The project has found that the most significant benefit of insectaries in the inter-row is an increase in species richness (diversity) of arthropod communities particularly those that are known to benefit the health of the macadamia orchard. Distinct trends in higher relative numbers of parasitoids and predators were observed on several farms. Predators and parasitoids are ecosystem regulators providing virtually free pest control. This increase in predators and parasitoids is likely to lead to not only the reduction of pest control inputs but in some cases pollination, as well, leading to enhanced productivity overall. At the same time, the control (industry standard) had a higher presence of sap sucking insects (potential pests such as tree thrips and leafhoppers) and a lower overall diversity of arthropod families, both herbivorous and beneficial.

The benefits of changed inter row management for the purposes of an insectary and conservation biological control are further amplified when the potential for multiple ecosystem services are taken into consideration. While specific quantification of these services has been beyond the scope of this project, it is worth noting that managed vegetative diversity in the inter row, and other areas on-farm, can contribute to ecosystem services specific to insects including pollination, food provisioning, recycling organic matter, and other services from lesser studied functional and taxonomic groups.[19] Beyond insect services, managed vegetative diversity can improve soil structure, soil microbiology, nutrient cycling, water storage, carbon sequestration, and biodiversity, and this has been quantified in other studies.[20]

The project demonstrated that an inter row insectary can be incorporated into existing orchard inter row management on most farms and recommends doing so to increase the food web and overall farm diversity. We found that with basic monitoring and management this will not lead to other challenges such as rats, weeds and/or an insect pest reservoir. The project further showed that inter row insectaries can be produced via reduced mowing and where suitable, seeding and cover cropping. Decisions to include insectaries in the inter row must be accompanied by planning and strategies for managed vegetative diversity and considerations of individual farm variations.

As a note of personal thanks, the project team would like to acknowledge the important and influential role that a number of industry consultants (most notably Alan Coates) have had in developing practices for conservation biological control. It is these people that have led the way, advising growers for many years now to allow the inter row to grow out to flowering to provide resources for beneficial insects.

This project is part of the larger IPM Program for the Australian Macadamia Industry [Horticulture Innovation Australia (Hort Innovation)].

Methodology

Introduction

The BioResources team worked with eleven participating macadamia growers, located in the Bundaberg region, Gympie, the Sunshine Coast, northern NSW, and the NSW mid-north coast (**Table 1**). The trials ran from early 2017 to mid 2019. Data collected from these eleven trial sites informs this report's results and recommendations in relation to the practical management of inter row insectaries and any potential risks arising there in connection with rats, weeds, and/or arthropod pest reservoir. Of the eleven participating trial farms, four are discussed in detail, below, as **Case Studies** of four different options for inter row insectaries with a presentation of associated results for changes in arthropod ecology.

Table 1: All farms participating in this project: farm name; location; treatment type; where in this report this trial site is discussed.

Farm	*Location*	*Reduced mow treatment type*	*In this report*
Alloway	Bundaberg, Qld	Mohawk	Appendix 7
Baldwin & Ranking	Mid-north coast NSW	Mohawk, seeding	**Case Study 3** Appendix 7
Bevan & Willemse	Northern NSW	Mohawk, Alternate row	**Case Study 1** Appendix 7
Bundaberg Sugar	Bundaberg, Qld	Mohawk	Appendix 7
Bundaberg North	Bundaberg, Qld	Tree-to-tree reduced mow, Alternate row	**Case Study 2**
Elanora	Mid-north coast NSW	Mohawk	Appendix 7
Hotson	Northern NSW	Mohawk	Appendix 7
Philp	Sunshine Coast, Qld	Mohawk	Appendix 7
Piccadilly Park	Northern NSW	Cover cropping	**Case Study 4** Appendix 7
Thomas	Gympie, Qld	Mohawk, Alternate row	Appendix 7
Wiley	Northern NSW	Mohawk, Tree-to-tree reduced mow, alternate row	Appendix 7

The objective of the trial was to provide growers with practical experience with inter row management options, which may improve conservation biological control on-farm, accompanied by monitoring to quantify results. Reduced mowing, as defined in this project, relates specifically to the macadamia orchard inter-row and is a management decision to reduce mowing frequency and/or areas and/or seasons. This contrasts with the convention for regular complete close mowing of the entire inter row year-round. Project participants trialled a number of different approaches for reduced mowing: mohawk, alternate row mow and tree-to-tree reduced mow. Additionally, seeding or cover cropping for improved vegetation ecology was also trialled on some sites. Detail of each approach is provided in **Field trials: treatment protocols**, as listed below.

Project activity was broken into three areas of investigation. First BioResources worked with growers to consider practical options for inter row management that encourage conservation biological control that are also compatible with the seasonal demands of orchard management. Second, BioResources collected observations on any relationship between changed inter row management and the potential for increased rat, invasive weed, and/or arthropod pest presence. Third, BioResources monitored association between changes in inter row vegetation management and changes in orchard arthropod abundance and diversity and their respective ecological function.

Experimental design

Two different and inter-related methods were applied in this project: 1. Field trials of inter row insectaries based on Participatory Action Research (PAR), and 2. Field experiments with biodiversity sampling of inter row vegetation and arthropods.

Field trials of inter row insectaries: Participatory Action Research (PAR)

Field trials were rolled out on eleven farms located across all growing regions (**Table 1, above**). This maximised opportunities for extension, investigating and recording the practicalities and challenges of different options for managed vegetative diversity options for the inter row. The team structured their engagement and extension with participating growers using PAR methods. They spent time with growers during each site visit discussing the trial and any observations or issues that the grower had in relation to rats, weeds, insect pests in the inter row vegetation and/or any challenges with reduced mowing. This was an iterative opportunity for feedback between the BioResources team and the grower, following on from which alterations to reduced mowing protocols that were compatible with standard farm operations and the trial and experimental objectives were made. (See **Appendix 1** for further information on PAR).[21] In this way, the BioResources team and participating growers investigated options for managed vegetative diversity in the macadamia inter row including, mohawk, alternate row mow, tree-to-tree reduced mow (young tree block), seeding and cover cropping.

Field trials: treatment protocols

Treatment protocols for the **mohawk** were trialled on eight out of eleven participating farms. The over-arching proposition for this approach was that targeted reduced mowing would encourage an increase in plant species diversity, an increase in floral resources, reduced physical disturbance and improved habitat complexity for beneficial arthropods. The decision to reduce mowing by leaving a 'mohawk' was made by the growers. It was especially appealing given its practical combination of regular mowing under the drip-line of the trees allowing for ground-cover management in conjunction with a central mohawk area where mowing was greatly reduced for an insectary. This strategy relied on naturally present weed, grass and native species that was likely to establish in the absence of regular mowing. There is a longstanding body of work linking this plant assemblage with ecosystem services including conservation biological control.[22,23]

Treatment protocols for **tree-to-tree reduced mow** were trialled on two out of eleven participating farms. This was selected specifically for a block with young trees, where harvest would not be occurring for a number of years. As with the mohawk, the over-arching proposition for this approach was that targeted reduced mowing would encourage an increase in plant species diversity, increased floral resources, reduced physical disturbance and improved habitat complexity for beneficial arthropods. A limited number of selective mows were conducted during the life of the trial to mulch aging vegetation, to encourage new growth and flowering, facilitate access, and manage any potential weediness. Through time this approach transitioned into alternate row tree-to-tree reduced mow, as will be discussed in further detail in **Guidelines** (below). This strategy relied on naturally present weed, grass and native species likely to establish in the absence of regular mowing.

Treatment protocols for **mohawk with seeding** were trialled on one out of eleven participating farms. This trial site focussed on incorporating seeding in the mohawk in conjunction with a mohawk reduced mow. The over-arching proposition for this approach was that targeted reduced mowing with targeted seeding would encourage an increase in plant species diversity, an increase in floral resources, reduced physical disturbance and improved habitat complexity/species richness for beneficial arthropods. This strategy relied first on naturally present weed, grass and native species likely to establish in the absence of regular mowing. It also incorporated seeding in April of every year that the trial was in the field (three times in total). These mixes included *Green Harvest* "*Good Bug Mix*"™ every year; plus, parsley and Brome 'Leona' (2017), buckwheat and Lucerne 'Sequal' (2018), and; Lucerne 'Hunter River', red clover, and Wynn Cassi (2019). These seed mixes were selected on the basis of their suitability for the relatively cooler conditions of the NSW mid-north coast and because they are conventionally and widely recommended for insectaries in relation to flower phenology in European studies, which dominate the worldwide literature.[24–26] The objective for seeding was to improve the plant species assemblage with high value characteristics that attract beneficial arthropods in contrast to regular management and a treatment: in particular, higher volumes of floral architecture providing quality nectar and pollen.

Treatment protocols for **cover cropping** were investigated on one out of eleven participating farms. This was selected specifically for a farm with macadamia tree row removal underway and interests already in place for multiple ecosystem services. According to Rex Harris (pers.com. 6 April 2020), "in August 2017 the Harris Family at Piccadilly Park Bangalow commenced a 7-year program to convert their monoculture orchard into a multi-species orchard incorporating seasonal multi species cover crops/insectaries and permanent insectaries. Each year, 1,000 trees (every second row) are being removed from their connected canopy orchard of 7 x 5 spacings to an open 14 x 5 spacings orchard, incorporating 6m wide centre strip inter-row cover crop/insectaries. The main reasons for the tree removal was the total loss of ground cover (thus loss of top-soil), the loss of macadamia nut production (dead centres) due to lack of sunlight and the opportunity to change from conventional practises of using chemical fertilisers, insecticides, fungicides and herbicides to regenerative agriculture practices." Intensive re-seeding of the inter row occurred seasonally, with a diverse mix of plant species with high value for cover-cropping. Plant species included and was not limited to sunflower, millet, sorghum, cow pea, mung bean, lablab, flax, chicory, plantain, tall fescue, smart radish, tillage radish, red clover, crimson clover, sunn hemp, oats, rye-corn, buckwheat, vetch, and many more. This is a specialised management system, discussed in further detail below in **Attachment 7 Piccadilly Park Final Report**.

For all eleven trial farms, inter row vegetation was evaluated for its value as an insectary with data collected on plant species identification, availability of floral resources, height and other features. Inter row vegetation was also assessed as a potential rat habitat, for weediness, and/or as a potential pest reservoir. Finally, inter row vegetation was evaluated for its general maintenance and management requirements (eg., suitable machinery, management schedules and so on) within the context of standard operations on a working farm. (See Methods **Appendix 1** for further information on inter row vegetation methods).

Field experiment with biodiversity sampling

In conjunction with field trials of inter row insectaries BioResources conducted a parallel field experiment on all eleven trial farms to quantify the results of changed vegetation management in the inter row in terms of conservation biological control. This was achieved by evaluating the impact of inter row management decisions on arthropods in the orchard using biodiversity (plant and arthropod) sampling methods. There were two blocks on each of the eleven participating farms. A control block was managed with complete close regular mowing, year-round. A treatment block was managed with a treatment option for conservation biological control for the trial period (**Table** 1 above, **Diagram 1**, below). Arthropods were sampled in both the inter row and the macadamia tree as they represent different "habitats" in ecological terms and the response of arthropods utilising these habitats.

Site visits to each of the eleven farms were scheduled for every 3 months. This aligned with the major annual seasonal events in the orchard: pre-harvest clean-up, harvest, flowering, and early nut-set as well as seasonality of arthropod abundance. With each site visit the BioResources team sampled each block for arthropods in three separate rows using yellow stick traps (YSTs) over a week period (**Diagram 1,** below), placing one YST in the inter row and one YST in a tree – six YSTs in total for each block approximately 10 metres apart. The three data collection points were at least 30m apart, and 50m from any block edge to avoid edge effects (See **Appendix 1** for further information on arthropod sampling methods).

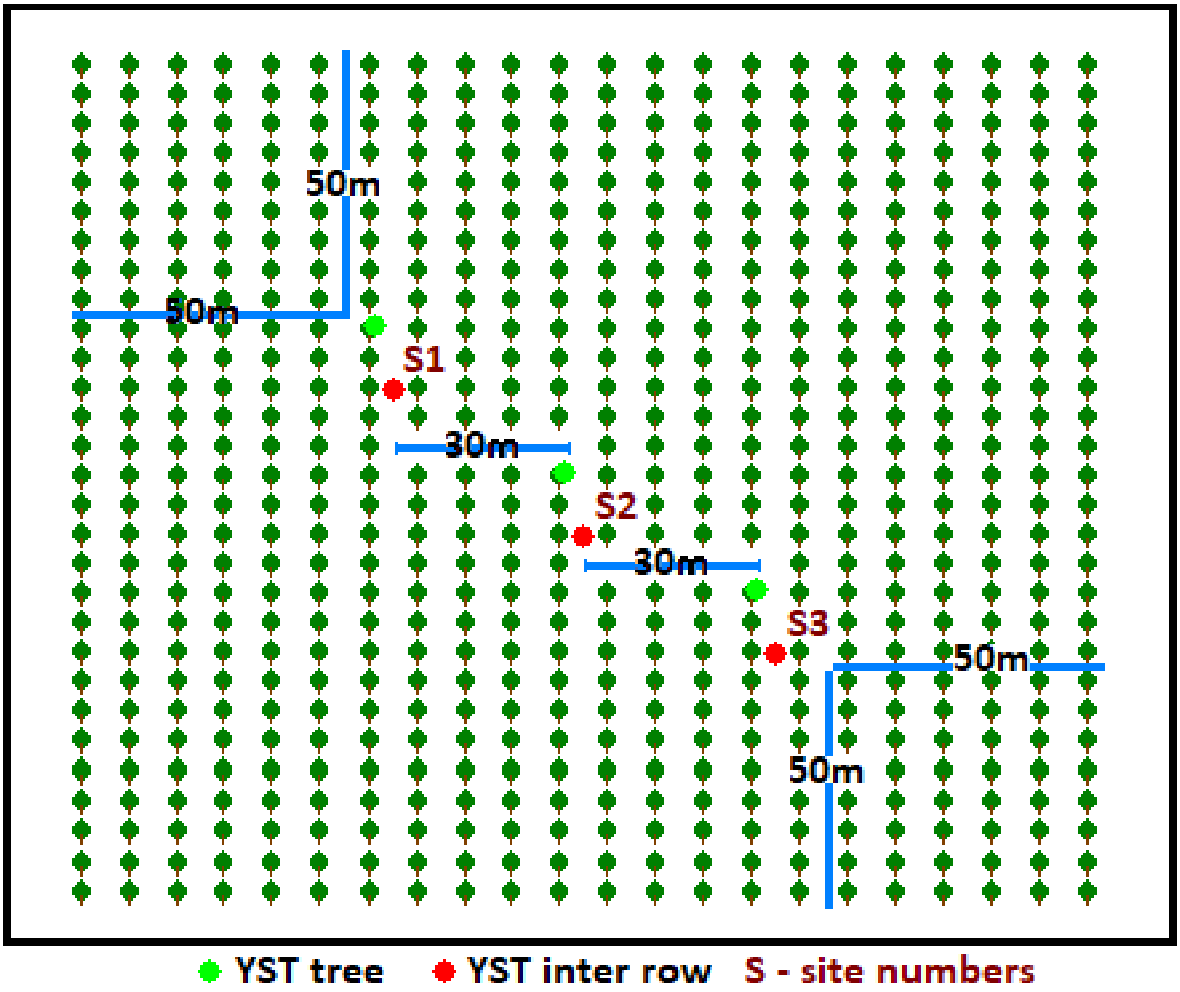


Diagram 1: Schematic of the experimental design. This design was used on each of the eleven participating trial farms in a control block (1ha), which was managed with regular complete close mow; and in a separate treatment block (1ha) with an inter row conservation biological control option specific to each participating farm.

Data pertaining to inter row vegetation at each of the three sampling sites was collected in a 10m by 20m quadrant (approximately, as based on row width on a farm-by-farm basis).

Environmental events were recorded including weather extremes, spray dates and product details, fertiliser and compost products and dates, mow and pruning/hedging/mulching dates. The control and treatment had the same environmental events before and during the sampling period.

Data analysis for the field experiment of the food web in four case studies

The project hypothesis was that managed vegetative diversity in the macadamia inter row will lead to increased arthropod abundance and diversity and a more complex functioning food web within the orchard ecosystem. For the purposes of this report, this is examined in detail in four **Case Studies**, below. Additional information is also available for each of the eleven participating trial farms in **Appendix 7**.

The project investigated the influence of a number of vegetation management options ("treatment protocols", above) in the inter row on vegetation ecology and arthropod ecology. Inter row vegetation ecology was evaluated for: plant species diversity, floral resources, and reduced habitat disturbance and increased habitat complexity. Arthropod ecology was evaluated for: abundance and diversity via higher taxon family surrogacy and feeding guild structure (**Table 2**).

Table 2: Independent and dependent variables: data, measure and indicator used to test the project hypothesis.

Variable	*Data*	*Measure*	*Indicator of*:
Independent variable			
Inter row vegetation	Plant species ID	count	Vegetative diversity
	Biomass of flowering	percent	Availability of floral resources
	Height	cm	Reduced disturbance and increased complexity
Dependent variable			
Arthropods	Abundance	count	Relative population size
	Family ID	count	Diversity/trophic guild
	Feeding guild	count	relevance of ecosystem services provided

In this study the independent variables of inter row vegetation relate to the trial and experimental conservation biological control protocols, and ultimately, farm vegetation management decisions. They are not the focus of discussion here. Inter row vegetation management is discussed at length below in **Case Studies**, **Guidelines Table 5** and **Appendix 2.**

The dependent variables in this study relate to arthropod ecology. Evaluation of this data was broken into a consideration of their abundance and diversity. To better understand the nature of food webs on macadamia farms the project identified most major insect orders caught to family level classification (except thrips and springtails), to describe the functional unit of feeding guild structure of arthropod assemblages. The guild concept has been widely utilised by ecologists; a guild is any group of species that exploit the same resources and is a functional classification. For instance, most insect herbivores are selective feeders, they may be specialised as leaf chewers, sap suckers, stem borers, root borers, gall formers, leaf miners etc. Beneficial insects highlighted by the project feed as predators and parasitoids. Another important beneficial arthropod feeding group highlighted was potential pollinators via nectar feeding (nectarivores). This allowed for an examination of species richness (via functional family higher taxon surrogacy) and how it relates overall to farm food webs.[27,28] (**Appendix 1**).

For the purposes of this report, arthropod results and analysis is based on four **Case Studies** (four out of the 11 participating trials farms). In the dataset for the four case studies reported on below, we first simplified feeding guilds as prey, nectarivore, predator and parasitoid, displaying them proportionally with respect to treatment for each farm.

Almost all of the wasp families we identified were parasitoids. They attack different stages of their host's lifecycle (i.e. egg, larvae, pupae etc.) and can be classified as either generalist or specific in targeting their hosts. Although numerous, the hymenopteran family *Trichogrammatidae* were excluded from the analyses at the family level because our samples of this family comprised mostly of *Trichogrammatoidea cryptophlebia* (MacTrix) which was released on all four **Case Study** farms during the survey. Placement of any grower-released MacTrix would have influenced abundance counts beyond treatment effects, however they were included in the diversity indices along with other chalcids. We examined wasps in terms of their abundance and diversity at the family level for each of the four case studies. Wasps from superfamily Chalcidoidea are minute and often numerous wasps and because of this the Chalcidoidea samples at Bundaberg North and Baldwin & Ranking were not classified to family level in 2017 and 2018, however, 2019 samples were classified to family for Chalcidoidea, because it was deemed such an important group and we then could adequately apply feeding guild and diversity measures to this group (*). At Bevan & Willemse, wasps from superfamily Chalcidoidea were classified to family for 2018 and 2019 data, and at Piccadilly Park all wasps from superfamily Chalcidoidea were classified to family level.

Most adult flies require only nectar or pollen as their primary food source and only recently have flies been recognised for their importance as pollinators. As more fly behaviour observations are studied it is likely we will better understand their specific roles in pollination. As part of a wider food web they are also an important food source for beneficial insects such as spiders and vertebrate animals.[29] We examined flies in terms of their abundance and diversity at the family level for each of the four case studies.

In this project we did not identify thrips to family (taxa) level identification, as these insects have highly diverse feeding strategies (i.e. herbivores, fungivores, predators etc), so higher taxa classification was limited for surrogacy measures. In this study we evaluate all thrips as potential "prey" and see their value within the food web as alternate prey for natural enemies of macadamia pests. This project did not specifically identify herbivorous thrips, but we also note that herbivorous thrips can be a pest of macadamia trees and their relative abundance in the macadamia tree is relevant. Thus, we examined thrips in terms of their abundance at the order level (Thysanoptera) for each of the four case studies. Tree and row were compared with equal YST traps so that effects of the inter row vegetation on abundance and diversity of arthropods in the macadamia tree could be measured within farms and across case study sites.

Each trial farm was treated as a stand-alone case study and its data was analysed separately. Site variations (geographical range/management practices/soil and other physical features as well as phenotypic variation in macadamia) and many other confounding factors (especially the timing of extreme weather events) required analysis and interpretation as a unit without these factors influencing experimental outcomes beyond which could be measured effectively.

YSTs have been utilised in several orchard and other farming systems worldwide to measure diversity and abundance of aerial arthropods. We sampled seasonally four times a year to get a "snapshot" of relative abundance and diversity of arthropods in the macadamia tree and inter row vegetation for comparative purposes. We were unable to directly measure pest pressure as this requires detailed observations of the raceme and nut over time. However, in our "snapshot" comparing row and tree in the treatment and control, we were able to observe the general presence of insects that were caught on YSTs some of which are pests of macadamia. This included thrips, lacebug, aphids, leafhoppers and other Hemiptera. By comparing insects caught in the inter row verses trees we were able to infer if these groups of insects were utilising both row and tree habitats. In this respect we observed differences in generalist predators (which utilise both row and tree) compared to more specialist insects that are habitat specific (e.g herbaceous aphids vs tree aphids)

There were three sample sites for vegetation and arthropods on each block. Data collected from each of these sample sites is not strictly independent because they are samples from a single and interconnected experimental unit (the control and the treatment block, respectively). Separation of treatment effects in the same management system is difficult when taking into account geographical and phenological differences of macadamia. Thus these samples taken within sites of a defined area are pseudo replicate, rather than an independent replicate.[30] This is a common limitation of field experiments (trial sites of a size and uniformity, management, phenology and topography able to accommodate true replicates were beyond the capability of this project) (this is discussed further in **Appendix 1**). The consequence of this is that statistical tests of data and results are not suitable in rigorous statistical sense, however the nested design of sites is often performed in agricultural experiments on a single field level as we have conducted.

As indicated on a case-by-case basis in **Case Study** charts below, data is presented as "inter row", "tree" or "pooled" (combing both inter row and tree data between sites); and as counts, averages (mean), and/or time series. Where appropriate, data is presented with standard error (±SE) with error bars on charts to show variance of sampled individuals that were recorded, which is useful to understand population changes (spread) and their relative change over time. In the absence of statistical tests, this report's analysis and interpretation relies entirely on mean and change through time with comparison of control against the treatment.

Results

Practicalities of inter row insectary – something every macadamia grower can or should consider?

The project found that trialling changed management practices for the purposes of an insectary was achievable on all participating trial farms (refer to **Case Studies** and **Individual Grower Reports (Appendix 7)** for details).

An inter row insectary was most suitable in orchards with the following:

- Row width ideally of 10m, but down to 8m depending on tree size and age and available machinery.
- Available machinery, including mower, slasher and harvester that can manage the required reduction to mowing/harvesting area.
- Low gradient of slope because where there is higher gradient nut is likely to roll and get caught in insectary areas and contribute to other management difficulties.
- Good available light to the orchard floor for plant photosynthesis and other soil characteristics such as decomposition/nutrient flow

It is very important to note that there are particulars involved in managing an inter row insectary. At the outset of the project, "reduced mowing" was trialled as a complete cessation of all mowing. At around 12 months we found that this was producing sub-optimal vegetation for the purposes of insectaries (decreasing plant species diversity, reducing rates of flowering, dominance by low-value grass species) and producing minor inter row management issues relating to heavy catch-up mowing loads, weediness and rat activity. "Managed vegetative diversity" is the key and guiding principle, with farm-specific monitoring and management necessary for insectaries. This experience is documented extensively, below in **Guidelines**.

Rats, weeds and pest reservoir – will an inter row insectary lead to other problems?

The project found that an inter row insectary can be incorporated into existing orchards with basic monitoring and management without leading to other problems. This was the case on all participating trial farms. This is discussed in detail in **Appendix 2**.

Observations of rat behaviour and populations in association with the trial varied farm-by-farm dependant on concerns of individual growers. At the outset of the trial five of the eleven participants had a pre-existing rat problem. Four of these five were "worried" about their rat problems and the possibility that the trial might make management more difficult and rat populations increase. For two of these five, rats were *not* thereafter observed as a problem emerging out of inter row management changes. At some point in the life of the trial (a period of 2.25 years), a total of four out of eleven participants observed that rat activity had increased in some of their trial area. These participants took prompt and targeted action and reported that increases in rat activity in the trial area were resolved. This involved standard rat management approaches combined with intermittent spot mowing and spot herbicide spraying of the inter row where deemed appropriate as part of their regular treatment of rats.

Weeds or weediness requiring some intervention was observed on around half of the participating trial farms at some point in the life of the trial. In each of these cases either one locally present species became very dominant, or there were several very limited instances of woody weeds. In all cases this situation was easily managed with either intermittent mowing/slashing and/or spot herbicide applications. This is discussed in further detail in **Appendix 2** and **Table 5: Guidelines** and **Appendix 3**.

Negligible observations were recorded for plant species in the inter row hosting any of the major pests of macadamias (This is discussed in further detail in **Appendix 2**).

Case studies: the food web and conservation biological control

The project investigated a number of different options for conservation biological control suitable for inclusion in the macadamia orchard inter row. These were mohawk, tree-to-tree reduced mow (young tree orchard), seeding and cover cropping. Results for these options are presented below as four case studies (summarised in **Table 14 Appendix 2**):

1. **Case Study 1**: mohawk (Bevan & Willemse) northern NSW,
2. **Case Study 2**: tree-to-tree reduced mow young tree orchard (Bundaberg North) Bundaberg Qld,
3. **Case Study 3**: mohawk with seeding (Baldwin & Ranking) the NSW mid-north coast, and
4. **Case Study 4**: cover cropping (Piccadilly Park) northern NSW.

Arthropod abundance

We compared relative abundance of insects that are attracted or incidentally caught on YSTs in the inter row and tree in the standard block (control) and increased vegetative diversity (treatment) firstly as pooled abundance numbers (tree and inter row YST specimens total from all sites) over the entire sampling period in each of our four case **Case Study** trial farms (**Chart 1**).
On each of the four case study farms there was increased overall arthropod abundance in the treatment blocks. This means there is more insects in the food-web. To examine what this increased number of arthropods are we examined their diversity.

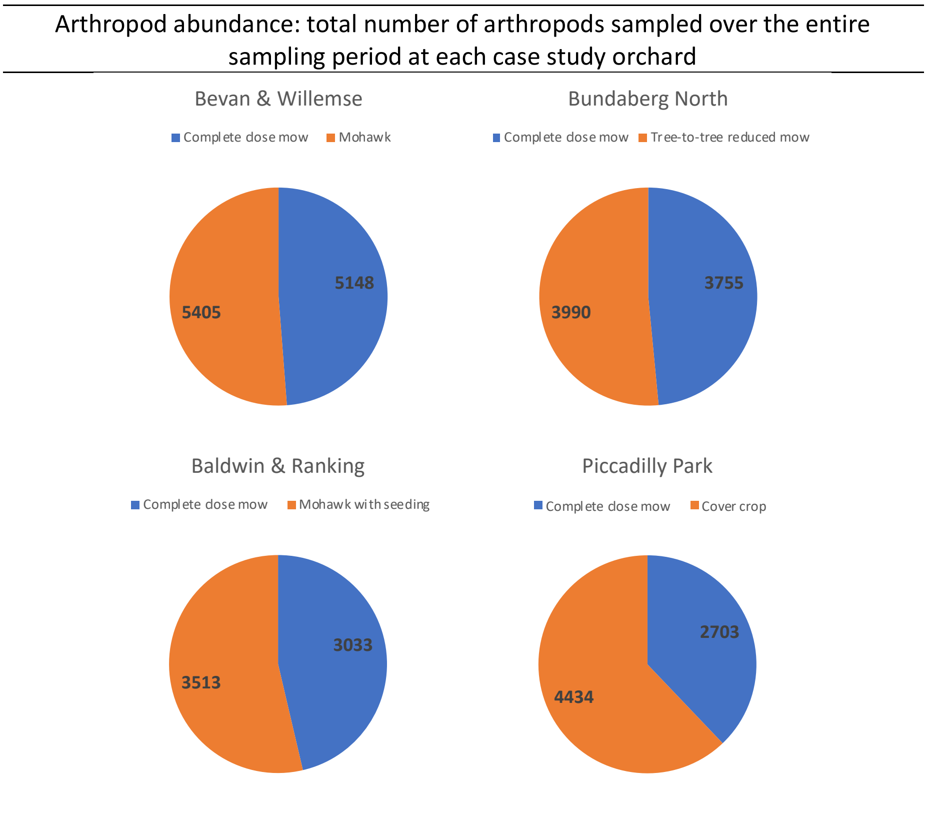


Chart 1: Arthropod abundance (pooled from row and tree) at each of the four case study orchards across the total sampling period. Orange segments within each of pie chart shows the total number of arthropods sampled within the four differently managed increased vegetative diversity treatment blocks, whilst the blue segments display the total number of arthropods sampled within each of the complete close mow blocks.

Arthropod diversity

The diversity of arthropods was measured by comparing their respective hierarchical groups (orders) Here, we can see results for some of the more detailed changes that emerge in the food web in response to the provision of "SNAP": shelter, nectar and pollen, and alternative prey/hosts.

Where there was increased vegetative diversity in the inter row, we see a corresponding increase in diversity of insect groups, most notably the wasps and flies, across all farms when abundance in row and tree specimens was pooled (**Chart 2**). **Chart 2** presents the total number of insect families from the commonly collected groups, flies (Diptera), beetles (Coleoptera), true bugs (Hemiptera) and wasps (Hymenoptera), sampled in the control and treatment blocks at each farm. For all farms, flies (mostly potential pollinators but also predators/parasitoids) and wasps (mostly parasitoids) had higher diversity in the insectary treatment block. Thus this increase in plant heterogeneity within the inter row means that beneficial insects have more resources available for them to thrive, which might lead to stronger pest suppression via complementary feeding niches (discussed further in **Appendix 2** under **Feeding Guilds**). The increase in arthropod abundance was because there was more beneficial insects and prey (non-economical species that are potential food source for beneficial insects) that are not macadamia pests. Whilst we did not measure pest pressure, we did have several macadamia pests that were caught on YSTs including aphids, thrips, lacebug and leafhoppers. By comparing tree and inter row separately we were able to determine that the thrips, leafhoppers, and aphids of the inter row (herbaceous) were different to those found on the tree which we detail in each of the farm case studies in the following sections.

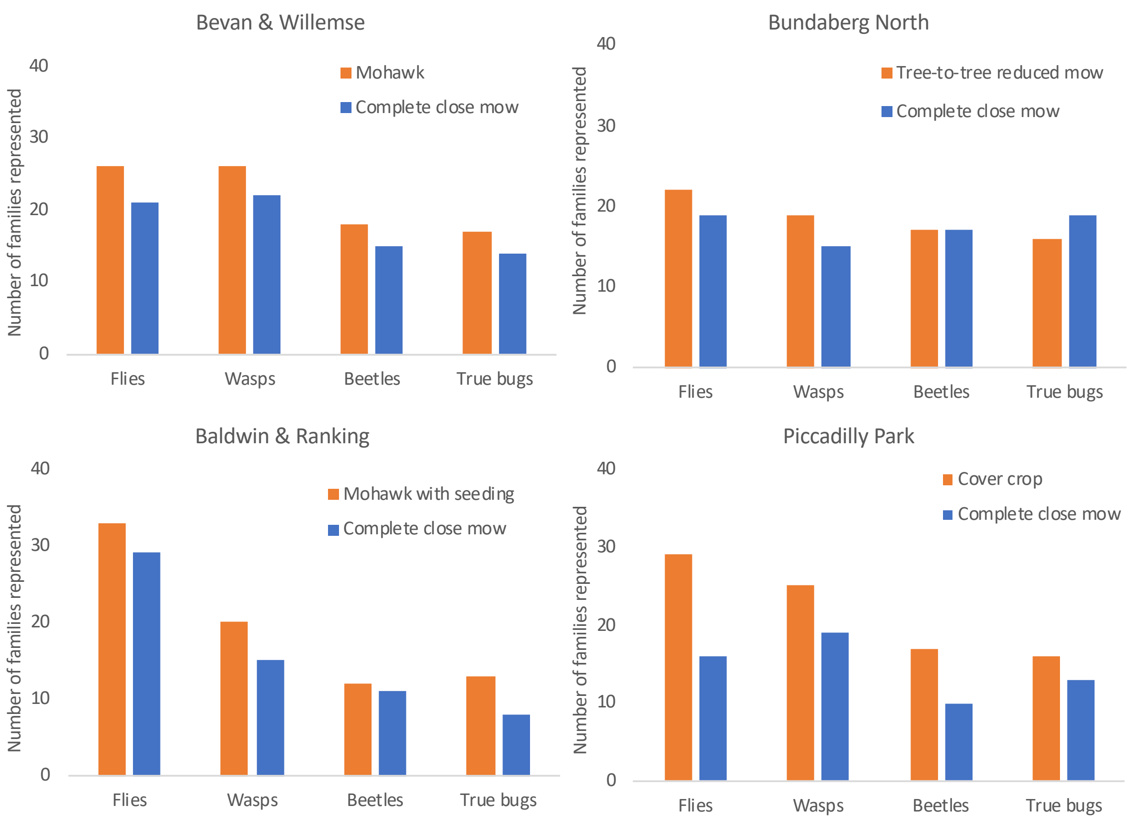


Chart 2: Comparison of insect diversity between control and mohawk treatment blocks, pooling total abundance in the inter row and tree over the entire sampling period, using the commonly identified insect groups (flies, wasps, beetles and true bugs). Diversity is measured as a function of the number of insect families (taxa) identified.

Case Study 1: mohawk (Bevan & Willemse) northern NSW

Case Study 1 (Bevan & Willemse) featured a mohawk in the treatment block. This was sustained year-round, including during harvest. Photos, below, show the inter row in the control (**Photo 1a**) and treatment (**Photo 1b**) blocks.

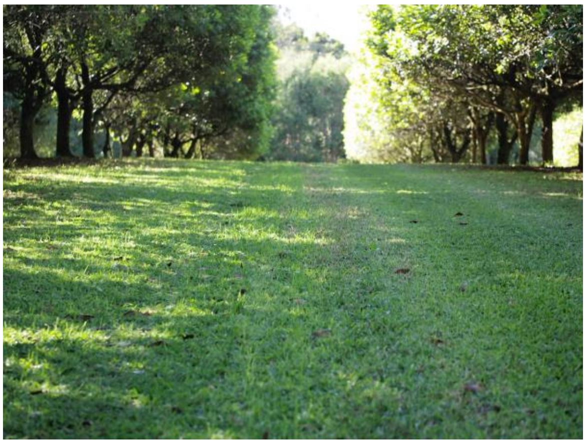


Photo 1a: Control - complete close mow May 2017

Photo 1b: Treatment - mohawk May 2017

When we compared inter row vegetation sampled in the complete close mow (control) block against the mohawk (treatment) (**Photos 1a & 1b**; **Chart 3**), we found that the count of plant species in the mohawk block was around double that of the control for each assessment year. The percentage of biomass as floral resources in the mohawk block was many orders of magnitude higher against a value of zero for the control for each assessment year. Minimised habitat disturbance and improved habitat complexity, evaluated as height, was a value in the order of five times more than that of the control for each assessment year.

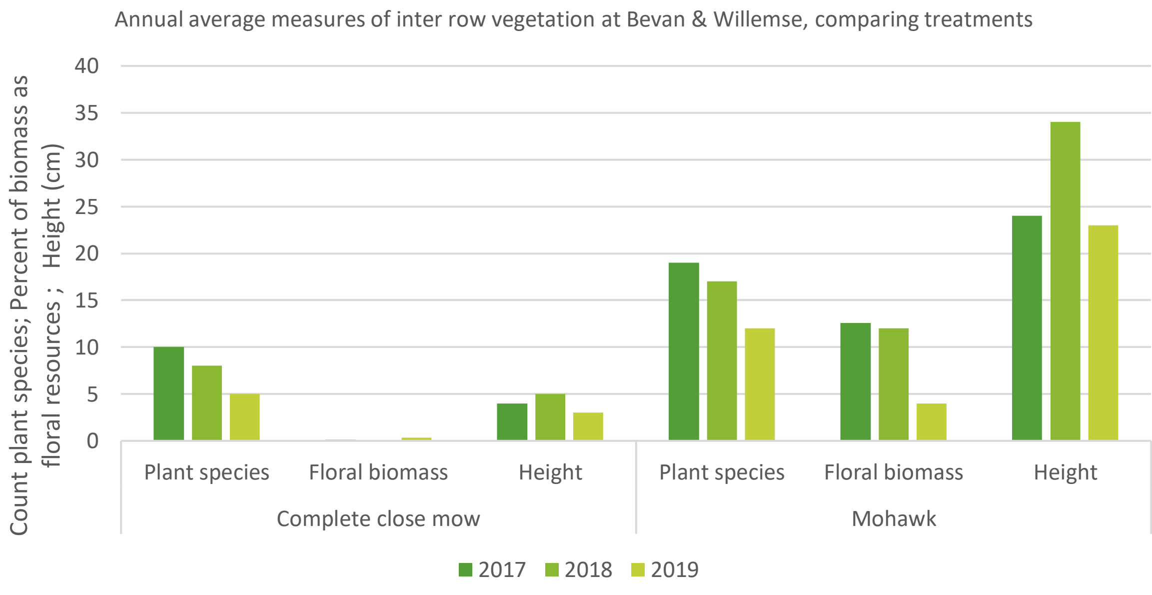


Chart 3: Mohawk average annual insectary measures by treatment: count of plant species, the percentage of biomass as floral resources, and the height of vegetation (cm).

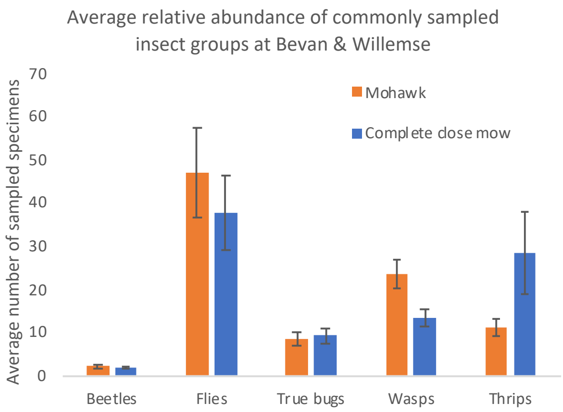
In the final months of this trial (just prior to the final sample collection), alternate row mowing (of the mohawk itself) was also incorporated into reduced mowing for rejuvenation of mohawk vegetation and grower initiated intermittent clean-up for any potential rat or weed areas (refer to **Guidelines** in **Table 5** and **Appendix 3).**

Confounding factors for the food web experiment

The influence of confounding factors (physical and/or temporal) or in-field problems with the independent variables were negligible at this trial site and we propose that arthropod data quality for the food web experiment results will reflect this. We were able to sustain a strong distinction between the control and the insectary treatment for the life of this trial site. The experimental protocols were consistently systematically and appropriately applied. There were no major disruptive farm management, environmental or weather events.

Arthropod results for mohawk (Bevan & Willemse)

We identified 10,553 arthropod specimens using YST catches from the inter row and tree within two treatment blocks at Bevan & Willemse over 10 sampling occasions between 2017 and mid 2019. Most of the arthropods were flies (4748 specimens), thrips (2200 specimens) and parasitoid wasps (2076 specimens), followed by true bugs (993 specimens) and beetles (239 specimens). When comparing average relative abundance in these groups (orders) combining both row and tree specimens there is a clear difference in wasp and thrips with no overlapping variance between the control and treatment (**Chart 4L**).
When we examine at each of the two sampling locations (**Chart 4R**), inter row (darker colour shades) and tree (lighter colour with lattice), wasps were more than twice as abundant in the trees of the mohawk treatment compared to the control and conversely thrips were nearly double in abundance in the tree of the control compared to the treatment. True bugs and beetles that are not known to be economic pests of macadamia were twice as abundant in the treatment than in the control in both tree and row. There was only a small difference in fly populations between the control and treatment in either tree or row locations (**Chart 4R**).



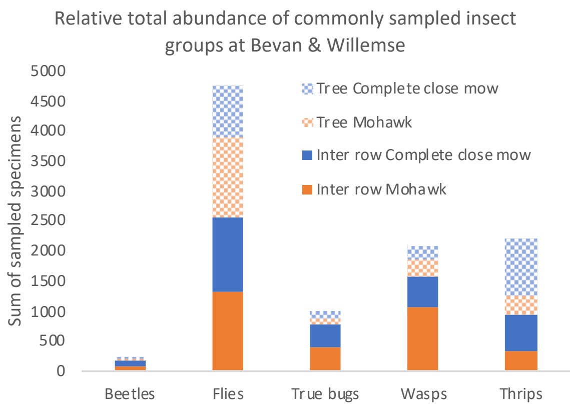


Chart 4: Left (L) Relative average abundance of the most sampled insect groups (orders) (± SE) at Bevan & Willemse in the control and mohawk treatment over the entire sampling period. **Right (R)** The relative total abundance of the dominant insect groups at Bevan & Willemse in the control and mohawk treatment and location over the entire sampling period. Mohawk results are displayed in orange (lattice = tree specimens) and complete close mow results are displayed in blue (lattice = tree specimens).

Feeding guilds at Bevan & Willemse

Differences between the control and insectary treatment were seen in the nectarivore, parasitoid and predator feeding guilds (**Chart 5**). The biggest treatment differences were in the beneficial insects where there were double the number of parasitoids (1347 specimens) and predators (155 specimens) in the mohawk block compared to the complete close mow block (733 parasitoid specimens, 85 predatory specimens).

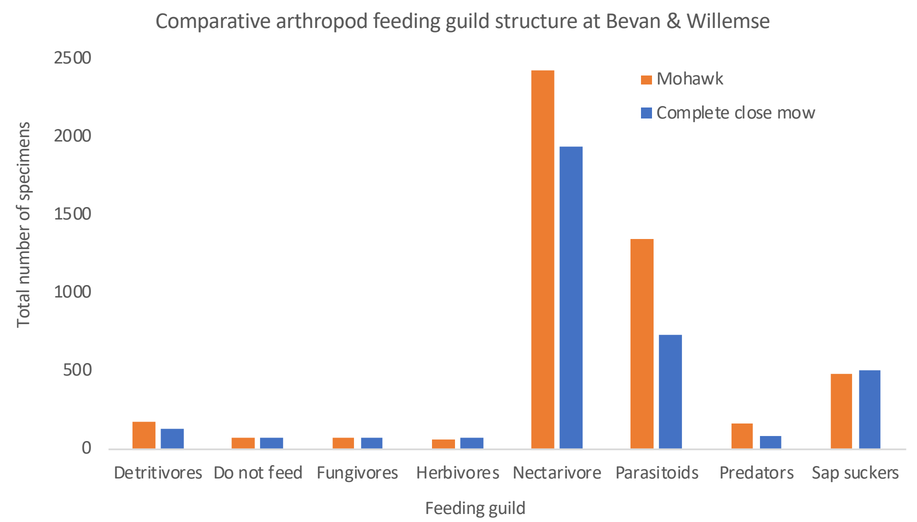


Chart 5: Comparative arthropod feeding guild abundance in the control and mohawk treatment at Bevan & Willemse. Data includes all arthropods captured on YSTs, excluding thrips (as we were unable to accurately assign feeding guild), over the entire sampling period and combines row and tree specimens.

To simplify our results, we classified all insects as prey and then separated nectarivores (potential pollinators), predators, parasitoids and prey as four broad categories. We then compared treatment and control proportionally. When we combined tree and inter row abundance counts within the treatment and control blocks, we see a greater proportion of prey in the mohawk (57%) (**Chart 6**). The proportion of predators and parasitoids in the mohawk block was far greater (63%) than in the complete close mow block (37%). Nectarivores were modestly greater in the mohawk (55%) compared to the complete close mow block (45%). This combined inter row and tree data can be seen as a whole-of-farm view, and we found that there were more beneficial insects present when an insectary was available within the farm landscape.

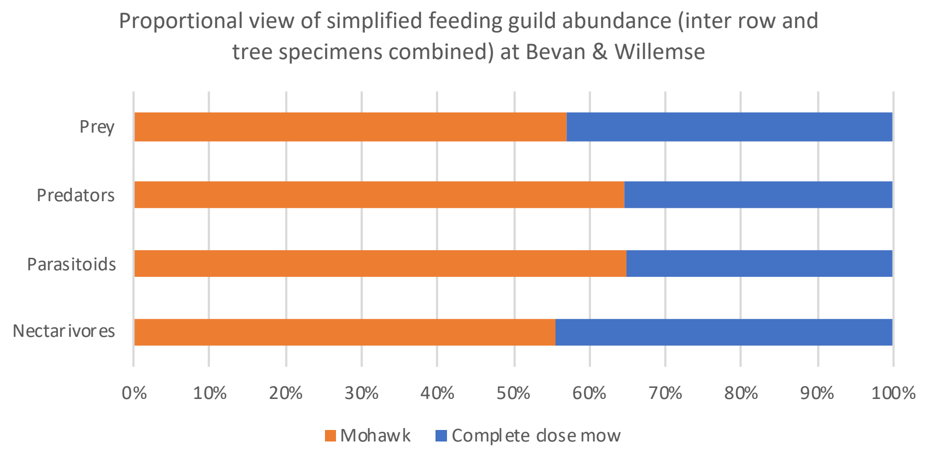


Chart 6: Proportional view of simplified feeding guild abundance at Bevan & Willemse. Data includes all arthropods captured on YSTs from both inter row and tree, over the whole sampling period (2017-19).

Taking a more detailed look, we would then expect to see more beneficial insects in the relatively more favourable environment of the inter row mohawk. When we examine this ratio comparing the inter row habitat in mohawk block and complete close mow block (**Chart 7L**), nectarivores have similar proportions (51% and 49% respectively). There was, however, proportionally greater abundance of prey in the mohawk (56%). This may account for the greater proportions of predators (65%) and parasitoids (67%) in the mohawk block compared to the complete close mow block.

But do we see the SNAP of the inter row insectary also translating into increased numbers of beneficial insects in the macadamia tree? In the macadamia tree we found a higher proportion of all broad feeding guild groups in the mohawk block compared to the complete close mow block (**Chart 7R**). The prey ratio in the mohawk was 59% to that of the complete close mow (39%), and this was similar for the nectarivores. In the mohawk block predators and parasitoids had higher proportional ratios (64% & 56% respectively). In considering these ratios, we can speculate that the mohawk its likely contributing to increased pest suppression in the macadamia trees.

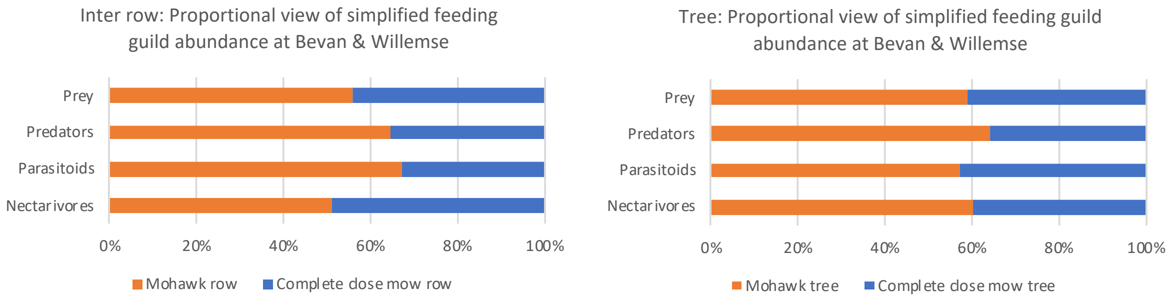


Chart 7: Left (L) Proportional view of simplified feeding guild abundance in the inter row at Bevan & Willemse in the and mohawk treatment. **Right (R)** Proportional view of simplified feeding guilds in the tree at Bevan & Willemse in the control and mohawk treatment. Data from both charts includes all arthropods captured on YSTs over the whole sampling period (2017-19).

A focussed look at wasp parasitoids at Bevan & Willemse

A total of 2076 individual wasps were identified in the control and insectary treatment blocks over the entire sampling period at Bevan & Willemse; 1552 were sampled from the inter row and 524 from the tree. The vast majority of the wasps collected were parasitoids. Details of the diversity and abundance of the wasp parasitoids sampled within inter rows and trees of the treatment blocks at Bevan & Willemse can be found within **Table 7 Appendix 2.**

At Bevan & Willemse, one super-family of parasitoids (Chalcidoidea) and two families within it (Eulophidae and Encyrtidae) dominated both the mohawk block inter row and all tree samples: (**Charts 8 L&R**). Chalcidoidea is a superfamily of tiny parasitic wasps that are extremely important in biological control of major pests around the world and includes the well-known family Trichogrammatidae (this family includes MacTrix). Eulophidae and Encyrtidae are two of the other most economically important families within Chalcidoidea. Eulophidae are mostly parasitoids of concealed larvae, such as leafminers, whilst Encyrtidae are endoparasitoids of scale, as well as the eggs or larvae of species within almost every major insect order.

Indeed, only three of the most common families shown in **Chart 8L** are outside the superfamily Chalcidoidea (Braconidae, Bethylidae and Diapriidae), whilst five of the families are included within Chalcidoidea (Aphelinidae, Mymaridae, Eupelmidae, Encyrtidae and Eulophidae).

Chart 8 displays all wasp parasitoid families sampled within the inter row (**L**) and tree (**R**) at Bevan & Willemse where there were 20 more individuals collected (excluding Trichogrammatidae due to the release of MacTrix) over the entire sampling period.

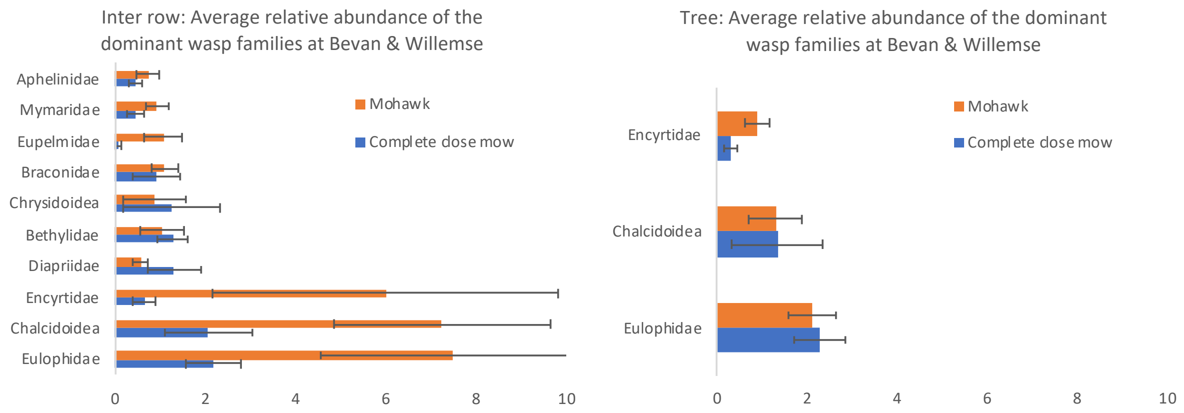


Chart 8: Left (L) The relative average abundance of the dominant parasitoid families/groups within inter rows (± SE) at Bevan & Willemse in the control and mohawk treatment over the whole sampling period. **Right (R)** The relative average abundance of the dominant parasitoid families within trees (± SE) at Bevan & Willemse in the control and mohawk treatment over the whole sampling period.

The temporal change in wasp parasitoid abundance at Bevan & Willemse over the sampling period shows that parasitoid populations fluctuated between seasons and years, with distinct differences occurring between control and treatment block in the inter row (**Chart 9 L&R**). For the majority of sampling dates, parasitoids were decisively more abundant within inter row of the mohawk block compared to the complete close mow block (**Chart 9L**). In 2017 the inter row within the mohawk block had more than double the number of wasp parasitoids (644 specimens) than the complete close mow treatment (248 specimens). In 2018, 523 wasp parasitoids were sampled from the treatment block and 374 from the control block. In 2019 there were almost double the abundance of wasp parasitoids within the inter row in the mohawk block (232 specimens) compared to the complete close mow block (122 specimens). In the trees, average number parasitoids were relatively even taking into consideration the variance in the mohawk block compared to the complete close mow block (**Chart 9R**). Most of the commonly sampled wasp parasitoid families were better represented in the mohawk block inter row. Although their overall abundance was low, the family Ichneumonidae were on average four times more abundant in the mohawk macadamia trees compared to the complete close mow trees. The Ichneumonoids are large wasps that commonly parasitise the larvae and pupae of Coleoptera (beetles), Hymenoptera (bees & wasps), and Lepidoptera (moths & butterflies) and they play an essential role in most ecosystems.

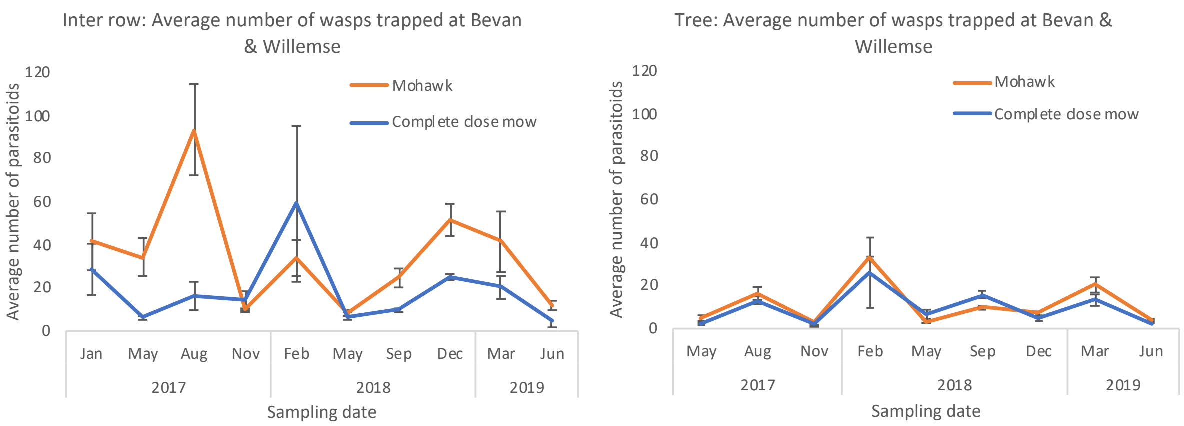


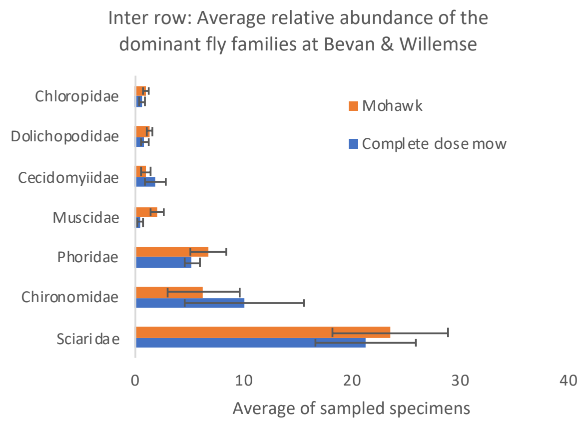
Chart 9: Left (L) The relative average abundance of parasitoids within inter rows (± SE) at Bevan & Willemse in the control and mohawk treatment over the entire sampling period. **Right (R)** The relative average abundance of parasitoids within trees (± SE) at Bevan & Willemse in the control and mohawk treatment over the entire sampling period.

A focussed look at flies (potential pollinators/prey/parasitoids/predators) at Bevan & Willemse

Of the 4748 individual flies sampled within the two treatment blocks over the entire sampling period at Bevan & Willemse, 2545 were sampled from the inter row and 2203 from the tree (the large majority of which were in the mohawk block). Inter rows within the mohawk block had a higher abundance of flies compared to the complete close mow block. Details of the diversity and abundance of flies sampled within inter rows and trees of the treatment block at Bevan & Willemse can be found within **Table 6 Appendix 2.**

Within both inter rows and trees at Bevan & Willemse, three fly families dominated the specimen counts: Sciaridae, Chironomidae and Phoridae. All three fly families are extremely species-rich, and individual flies are small in size. Because the families are so species-rich, the ecology within each family is diverse. Sciaridae, or 'fungus gnats', which dominated the inter rows, most likely breed within the moist mulch in the inter row because the larvae primarily feed on fungi and organic matter in the soil. Some adult Sciaridae have been discovered to be pollinators in certain habitats. Chironomidae, or 'non-biting midges', which dominated the trees, mostly feed on nectar as adults and may play an important role as pollinators. The third most abundant group, Phoridae or 'scuttle flies', mostly feed on nectar as adults and play an important role in pollination, although some species are aphid predators and other Phoridae species have been identified as parasitoids of macadamia seed weevil and fruit spotting bug. The predatory Dolichopodidae (long legged flies) were on average more abundant in the inter row (**Chart 10L**), and more than twice as abundant within trees of the mohawk block compared to the complete close mown block.

Chart 10 displays the average abundance of all fly families sampled within the inter row (**L**) and tree (**R**) where there were 20 or more individuals collected over the entire sampling period. There were more flies present in the mohawk inter row for five out of seven families; and more present for all families in trees of the mohawk block when compared to the control.



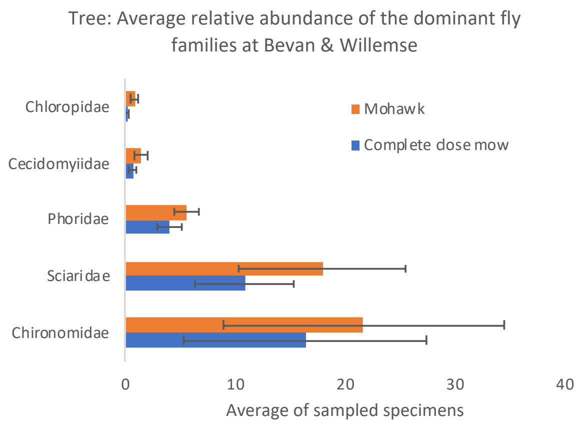
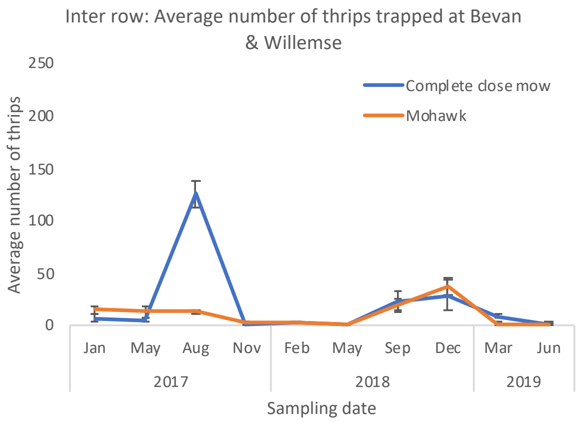


Chart 10: Left (L) The relative average abundance of the dominant fly families within inter rows (± SE) at Bevan & Willemse caught on YSTs in the control and mohawk treatment. **Right (R)** The relative average abundance of the dominant fly families within trees (± SE) at Bevan & Willemse in the control and mohawk treatment.

A focussed look at thrips at Bevan & Willemse

Thrips were present at relatively low levels throughout the sampling period in the mohawk block at Bevan & Willemse, with fluctuations in their population over time in both the inter row and tree (**Chart 11 L&R**). Within the control block, thrips population abundance generally followed a similar pattern to thrips within the mohawk block; however, there was a sharp peak in the thrips population in the control block in August 2017 in particularly in the tree samples (**Chart 11 L&R**). There was a smaller peak in thrips abundance within the inter row of both treatment blocks in December 2018 and within the tree of the complete close mow block, though not within trees of the mohawk block. It should be noted that thrips had not been an issue on this farm even in August 2017 and any insecticide treatments for any other pests were applied on both the control and treatment blocks evenly. Overall, thrips abundance was relatively low at Bevan & Willemse.



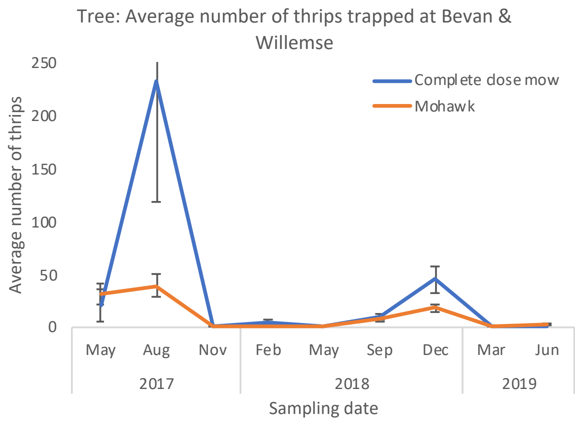


Chart 11: Left (L) The relative average abundance of thrips within inter rows (± SE) at Bevan & Willemse in the control and insectary treatment over the entire sampling period. **Right (R)** The relative average abundance of thrips within trees (± SE) at Bevan & Willemse in the control and insectary treatment over the entire sampling period (2017-19).

Case Study 2: tree-to-tree reduced mow – young tree orchard (Bundaberg North) Bundaberg

Case Study 2 (Bundaberg North) experimented with tree-to-tree reduced mow in the entire treatment block in a young tree orchard. The treatment was sustained year-round. There was at least one mow per year during the life of the trial, as management and access required. Photos, below, show the inter row in the control (**Photo 2a**) and treatment (**Photo 2b**) blocks.

Photo 2a (left): Control – complete close mow December 2017 **Photo 2b** (right): Treatment - tree-to-tree reduced mow December 2017.

When we compared inter row vegetation sampled in the complete close mow (control) block (**Photo 2a**) against the tree-to-tree reduced mow (treatment) block (**Photo 2b**; **Chart 12**) we found that the count of plant species in the tree-to-tree reduced mow block was around 1.5 times greater than that of the control for each assessment year. The percentage of biomass of floral resources in the tree-to-tree reduced mow block was around 2-3 times higher than the control block for each assessment year. Minimised habitat disturbance and improved habitat complexity in the tree-to-tree reduced mow block (evaluated as height) was between 4 and 12 times greater than that of the control for each assessment year.

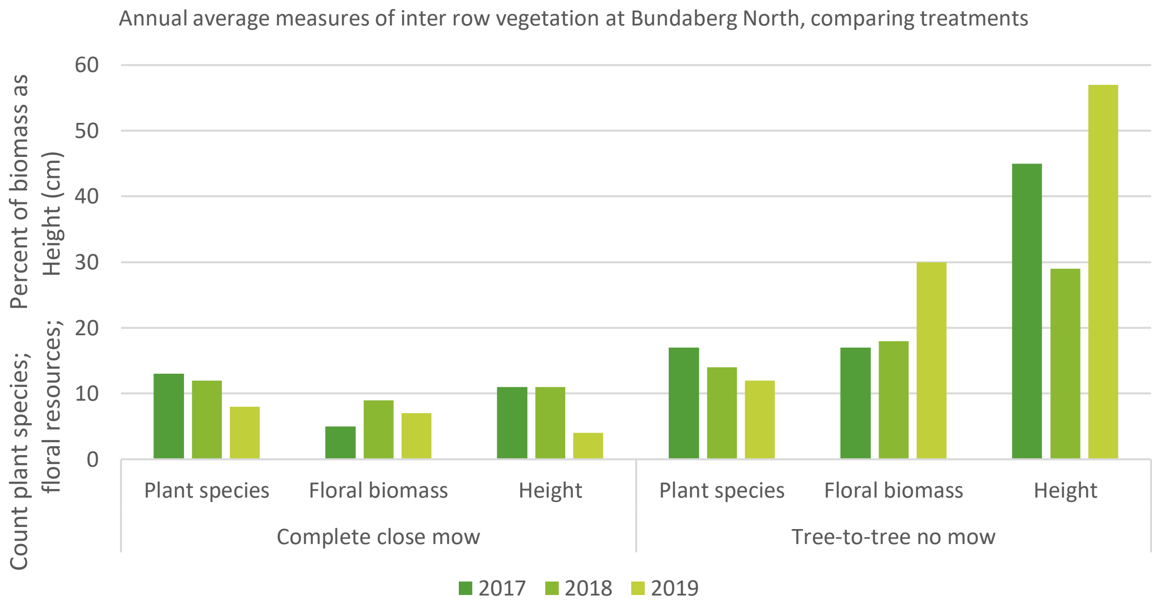


Chart 12: Tree-to-tree reduced mow average annual insectary measures by treatment: count of plant species verses the percentage of biomass as floral resources, and the height of vegetation (cm) comparing sampling years.

This trial site incorporated alternate row mow from April 2019 (**Photo 3a, Photo 3b & Photo 3c**).

Photo 3a: Tree-to-tree alternate row reduced mow April 2019.

Photo 3b: Tree-to-tree alternate row reduced mow April 2019 (left) mown; **Photo 3c** (right) unmown.

Confounding factors for the food web experiment

We propose that arthropod data in the food web experiment will be reflected by influencing confounding factors and in-field problems with the independent variables at this trial site. We were not entirely able to sustain a strong distinction between the control and the insectary treatment for the life of this trial site. The natural diversity already present in the seed bank across the entire trial site was very high relative to many other trial farms. This is valuable from a farm management perspective; but for our experiment it meant that the control and the insectary treatment were often somewhat similar (as compared to Bevan & Willemse and Piccadilly Park). Furthermore, there were some minor issues with experimental protocols – the reduced mow block was accidently mowed in autumn 2018 and did not recover for several months owing to the dry weather. There were no major disruptive farm management, environmental or weather events.

Arthropod results for tree-to-tree reduced mow

A total of 7,745 arthropod specimens were captured using YSTs from the inter row and tree within two treatment blocks at Bundaberg North over 9 sampling occasions between March 2017 and May 2019. The majority of specimens were thrips (2848 specimens), wasps (2009 specimens), flies (1297 specimens), true bugs (767 specimens) and beetles (306 specimens)**.** When these insect groups (orders) were compared between the tree-to-tree reduced mow and complete close mow blocks, average abundance of flies and wasp parasitoids were slightly higher within the tree-to-tree reduced mow block over the entire sampling period (**Chart 13L**).

When we look at each of the two sampling locations, inter row (darker colour shades) and tree (lighter colours with lattice), insects from all groups were more abundant within the inter row compared to the tree (**Chart 13R**).

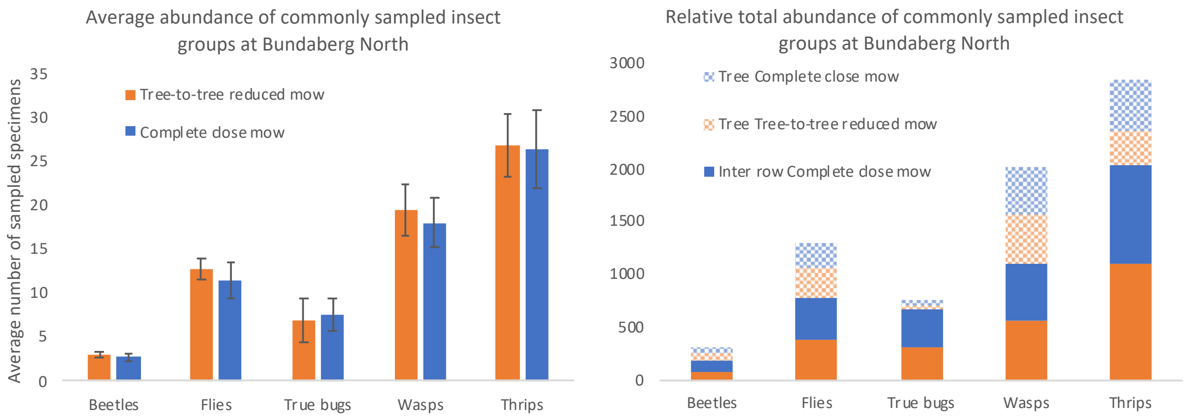


Chart 13: Left (L) Relative average abundance of the most sampled insect groups (orders) (± SE) at Bundaberg North in the control and tree-to-tree reduced mow treatment over the entire sampling period. **Right (R)** The relative total abundance of commonly sampled insect groups at Bundaberg North; for each insect group comparing control and treatment and row and tree. Tree-to-tree reduced mow results are displayed in orange (with lattice for tree specimens) and complete close mow results are displayed in blue (with lattice for tree specimens) over the entire sampling period (2017-19).

Feeding guilds at Bundaberg North

Overall, both the treatment and control show similar feeding guild structure abundance trends, though there were subtle differences within key beneficial groups (**Chart 14**) which provide an important indication of the emergence of a more complex food web in the insectary. For instance, there were more detritivores, parasitoids and predators in both the inter row and macadamia trees in the tree-to-tree reduced mow block when compared to the complete close mow block (**Chart 14**). By contrast, in the complete close mow treatment, we found slightly more nectarivores, herbivores, and sap suckers in the inter row. The sap suckers consisted mainly of aphids which are not the same species of aphid that feed of macadamia. Rather these aphids are an important food-source for beneficial insects such as lacewing and ladybeetle larvae. Sap suckers were slightly higher in abundance in the tree within the complete close mow block (**Chart 14**) which are minor pests of macadamia and were predominantly the black citrus aphid. These findings for the complete close mow block suggest that there was less consumption there from parasitoids and predators on potential pest herbivores and sap suckers.

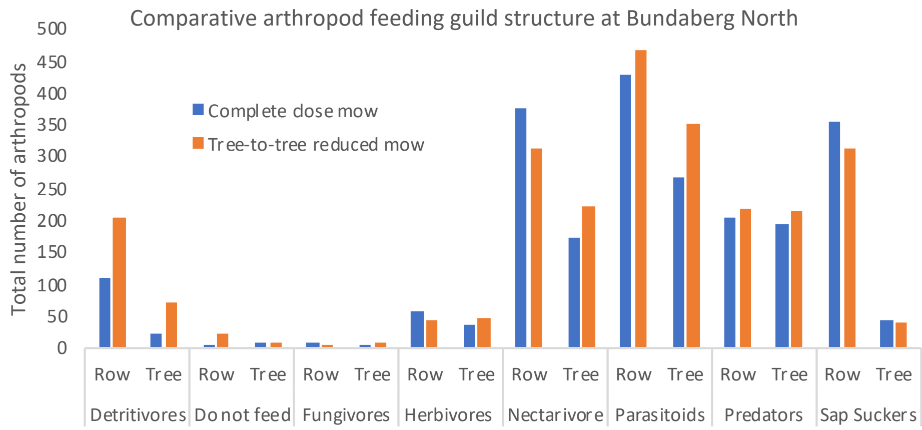


Chart 14: Comparative arthropod feeding guild abundance in the control and tree-to-tree reduced mow treatment and habitat (tree and inter row) at Bundaberg North. Data includes all arthropods captured on YSTs, excluding thrips, identified over the entire sampling period (2017-19) and combines row and tree specimens.

When we combined tree and inter row abundance counts within the treatment and control blocks there were slightly less nectarivores in the tree-to-tree reduced mow block (49%) compared to the close mow block (51%) (**Chart 15**). There was some increase in parasitoids in the tree-to-tree reduced mow block (54%) compared to the close mow block (46%). When we looked at prey and predator abundance in the tree-to-tree reduced mow block (both 52% and 48% respectively) we saw a favourable shift in response to the tree-to-tree reduced mow treatment: there was less prey in the tree-to-tree reduced mow treatment, which suggests suppression from predators and parasitoids. Consistent with this, there were more predators and parasitoids in the tree-to-tree reduced mow treatment.

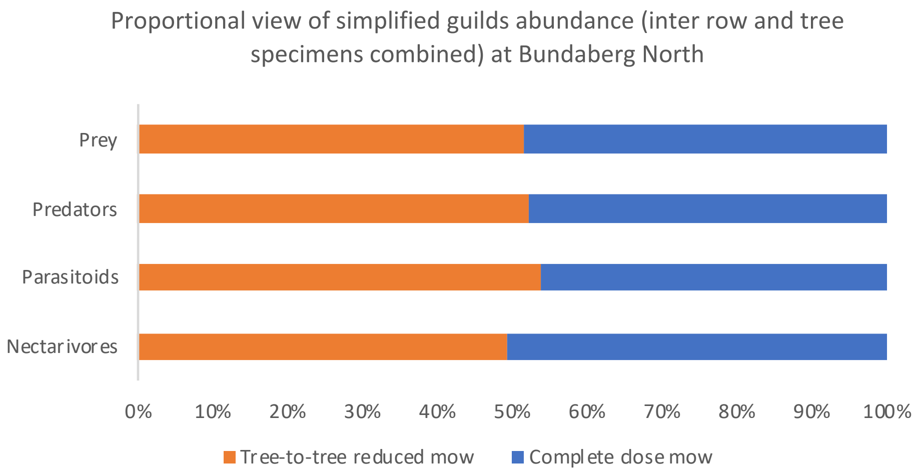


Chart 15: Proportional view of simplified feeding guild abundance at Bundaberg North. Data includes all arthropods captured on YSTs from both inter row and tree, over the whole sampling period (2017-19).

Taking a more detailed look, we would then expect to see more beneficial insects in the relatively more favourable environment of the inter row tree-to-tree reduced mow. When comparing the abundance of feeding guilds proportionally in the inter row; prey, predators and parasitoids were only slightly higher in the tree-to-tree reduced mow (52%), and there was a greater proportion of nectarivores (55%) in the complete close mow block (**Chart 16L**).

In the macadamia tree there were proportionally greater nectarivores in the tree-to-tree reduced mow block (56%) and prey (56%) as well as parasitoids (57%), and to a small degree, predators (52%) than the complete close mow treatment block **(Chart 16R)**. In considering these proportions, we can speculate that the mohawk its likely contributing to more pest suppression in the macadamia trees

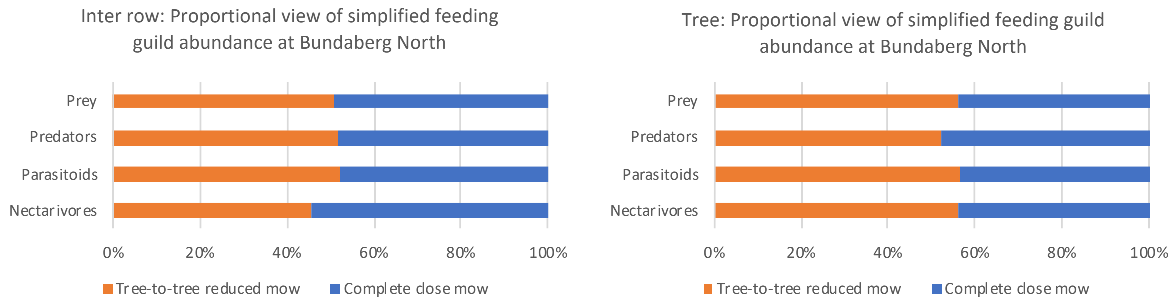


Chart 16: Left (L) Proportional view of simplified feeding guilds in the inter row at Bundaberg North in the control and tree-to-tree reduced mow treatment. **Right (R)** Proportional view of simplified feeding guilds in the tree at Bundaberg North in the control and tree-to-tree reduced mow treatment. Data from both charts includes all arthropods captured on YSTs over the whole sampling period (2017-19).

A focussed look at wasp parasitoids at Bundaberg North

A total of 2009 wasp specimens were caught on YSTs in the two treatment blocks over the sampling period at Bundaberg North; 1105 were sampled from the inter row and 904 from the tree. Within the inter row, the diversity of wasp parasitoid families was higher in the tree-to-tree reduced mow block when compared to the complete close mow block (19 vs 14 families respectively). Within the tree, both wasp parasitoid diversity and abundance were similar between treatment and control blocks (**Table 9 Appendix 2).**

The majority of wasp parasitoids sampled at Bundaberg North were from the superfamily Chalcidoidea (approximately 70%). When Chalcidoidea was identified to family from the 2019 samples, nine families were present: Agaonidae, Aphelinidae, Encyrtidae, Eulophidae, Eupelmidae, Eurytomidae, Mymaridae, Pteromalidae and Trichogrammatidae. Within both inter row and trees, Chalcidoidea were on average more abundant within the tree-to-tree reduced mow block (**Charts 17 L&R**).

Chart 17 displays the average abundance of the most commonly sampled wasp parasitoid superfamilies sampled within the inter row (L) and tree (R) at Bundaberg North.

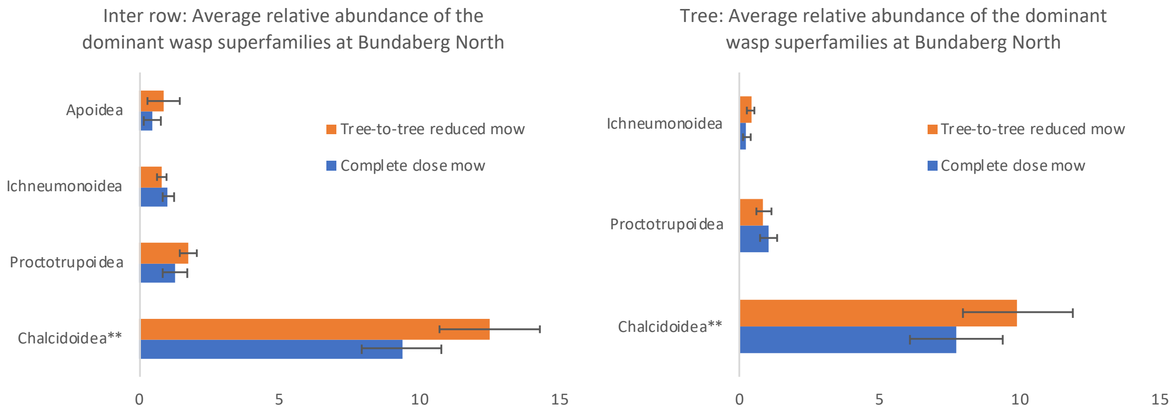


Chart 17: Left (L) The relative average abundance of the dominant wasp parasitoid superfamilies within inter rows at Bundaberg North in the control and tree-to-tree reduced mow treatment. **Right (R)** The relative average abundance of the dominant wasp parasitoid superfamilies within trees at Bundaberg North in the control and tree-to-tree reduced mow treatment. This chart excludes wasp parasitoids from the family Trichogrammatidae, because releases of Mactrix had the potential to confound the abundance counts depending on their release points.

In the other parasitoid wasp families, there was very little difference in terms of their abundance between treatments (**Chart 18**). There were, however, some wasp parasitoid families that were present in the tree-to-tree reduced mow block but not in the complete close mow; this included the families Platygastridae (parasitoids of cecidomyiid flies), Pteromalidae (leafminer parasitoid) and Agaonidae (fig parasite) (**Chart 18**).

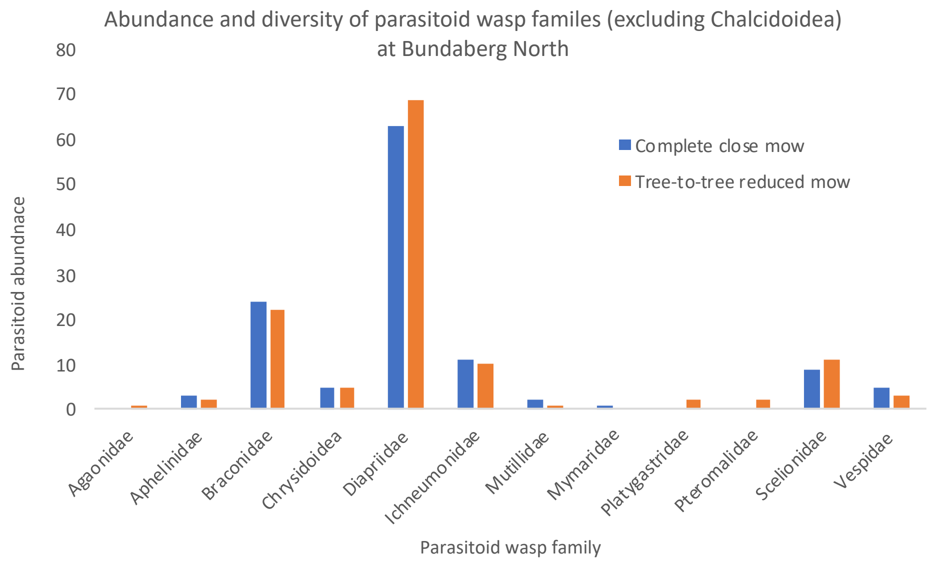
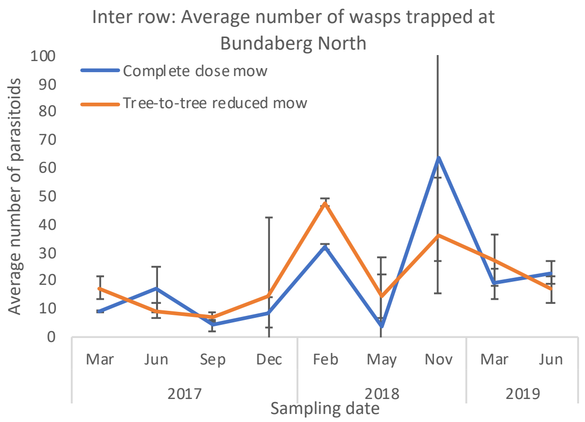


Chart 18: Abundance and diversity of wasp parasitoid families (excluding superfamily Chalcidoidea) at Bundaberg North. Specimen counts from both inter row and tree were combined as well as the three collection sites.

The temporal change in wasp parasitoid abundance at Bundaberg North over the sampling period shows that on average parasitoid populations increased in abundance both within the inter row and tree through 2018 and early 2019 (**Chart 19 L&R**). With regards to treatment, parasitoid wasps were not consistently more abundant in either the tree-to-tree reduced mow treatment or control block over the sampling period; instead there were peaks and troughs in the average abundance of parasitoid populations in both blocks (**Chart 19 L&R**).



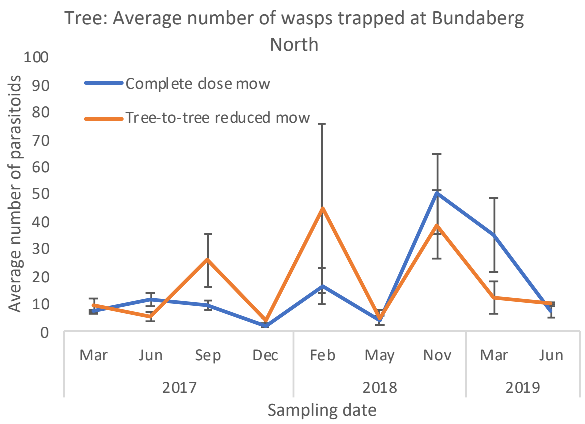


Chart 19: Left (L) The relative average abundance of parasitoids within inter rows (± SE) at Bundaberg North in the control and tree-to-tree reduced mow treatment over the entire sampling period. **Right (R)** The relative average abundance of parasitoids within trees (± SE) at Bundaberg North in the control and tree-to-tree reduced mow treatment over the entire sampling period (2017-19).

A focussed look at flies (potential pollinators/prey/parasitoids/predators) at Bundaberg North

A total of 1297 individual flies were sampled within the two treatment blocks over the entire sampling period at Bundaberg North; 780 specimens were sampled from the inter row YST and 517 specimens from the tree YST. Because this a young tree trial site, potential pollinators are of less interest here than other fly feeding guilds (fungivores, predators and parasitoids). Thus, if we exclude the fly families that we caught on YSTs that are primarily nectarivores in their adult life, the next most abundant feeding guild were parasitic flies. The tree-to-tree reduced mow block had almost double the number of parasitic flies in the inter row (74 specimens) when compared with the complete close mow block (44 specimens) (**Chart 20**). Numbers of parasitic flies were also slightly higher in the tree within the tree-to-tree reduced mow block (23 vs 16 specimens). There were also more predatory flies (from the families Asilidae and Dolichopodidae) in the inter row and trees within the tree-to-tree reduced mow block (55 specimens) compared to the complete close mow block (33 specimens). There were no fungivores (family Mycetophilidae) in the close mow block in either the inter row or tree samples, and this provides some indication of differences in blocks in terms of soil health ecosystem services. Detritivores were relatively even among treatments and habitats (**Chart 20**).

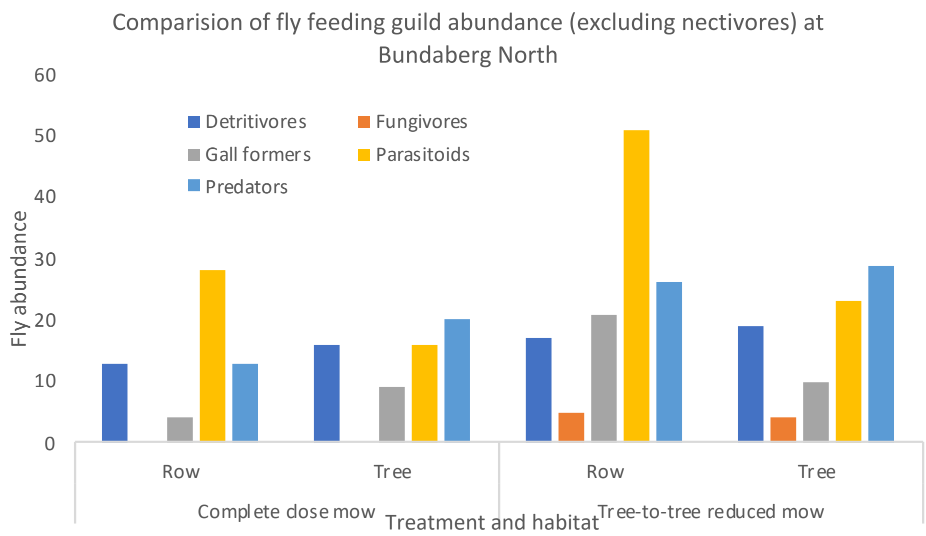
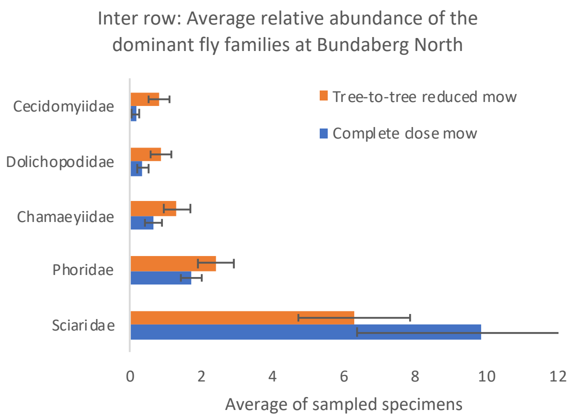


Chart 20: Comparison of fly feeding guild abundance (excluding nectarivores) in the control and tree-to-tree reduced mow treatment and habitat in the row and tree across the entire sampling period.

The fly family Sciaridae (fungus gnats) dominated both inter rows and trees at Bundaberg North (**Chart 21 L&R**), The second most abundant family, Phoridae (scuttle flies) are a large and diverse group in terms of their ecology. The majority of adult Phoridae may play an important role in pollination so we have listed them primarily as nectarivores, however, some specific species are aphid predators and other Phoridae species have been identified as parasitoids of macadamia seed weevil and fruit spotting bug. The next most commonly caught fly families, Dolichopodidae and Chamaeyiidae, are both mostly predatory and some are parasitic. Dolichopodidae, or 'long legged flies' are predators as adults on a range of soft bodied invertebrates (hence serve to keep the numerous sap sucking arthropods at lower levels). Chamaeyiidae are an important family for macadamia as the larvae are predators of coccids and psyllids which may benefit young trees in particular. Chamaeyiidae have been used as biological control agents in other crops. All of the dominant fly families, with the exception of Sciaridae in the inter row, were sampled in greater abundance within inter row and trees of the tree-to-tree reduced mow block compared to the complete close mow block (**Chart 21 L&R**). Family Chamaeyiidae, although not numerous, did not show much treatment difference in 2017, however, in 2018 there were on average twice as many in the row and three times as many in the tree of the tree-to-tree reduced mow treatment compared to the control (**Chart 22**). Chamaeyiidae were absent in the complete close mow block in 2019 in both the tree and row (**Chart 22**).



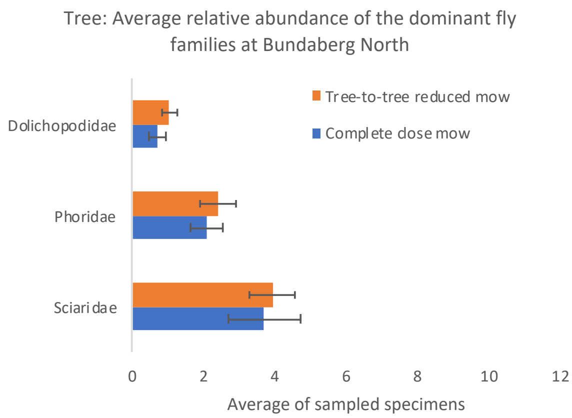


Chart 21: Left (L) The relative average abundance of the dominant fly families within inter rows (± SE) at Bundaberg North in the control and tree-to-tree reduced mow treatment, over the whole sampling period **Right (R)** The relative average abundance of the dominant fly families within trees (± SE) at Bundaberg north in the control and tree-to-tree reduced mow treatment over the whole sampling period (2017-19).

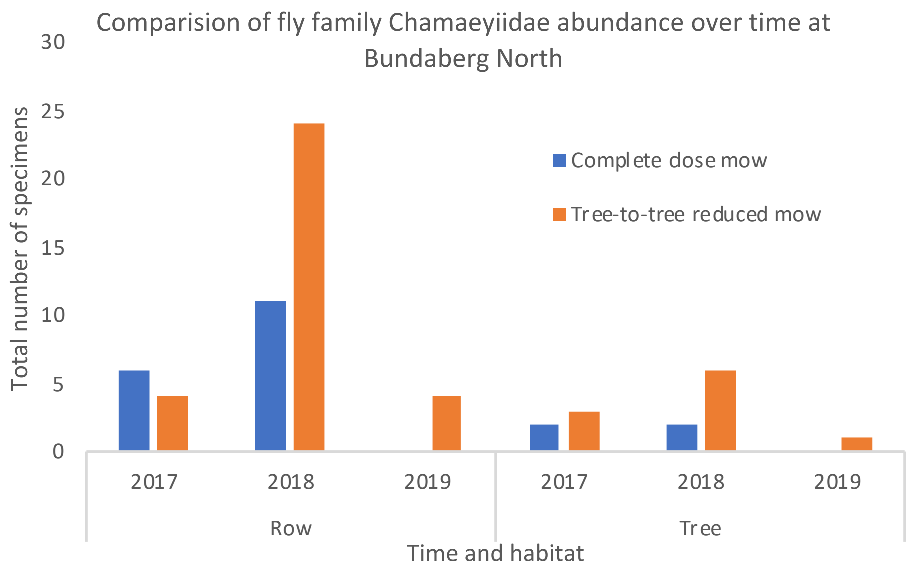
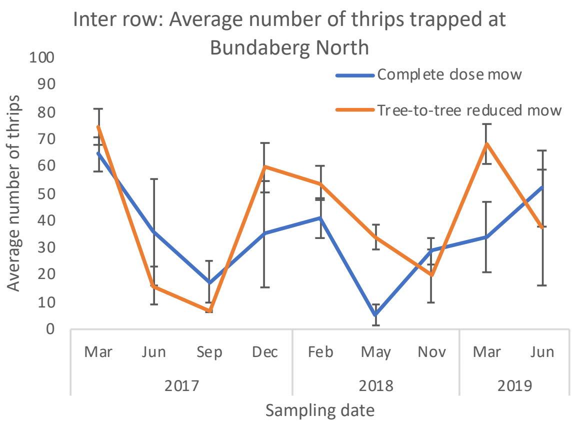


Chart 22: Comparative abundance of fly family Chamaeyiidae, that includes species that are predators of macadamia pests coccids and psyllids, in the control and tree-to-tree reduced mow treatment over the sampling period within both inter row and tree habitats across sites.

A focussed look at thrips at Bundaberg North

There was a relatively low abundance of thrips in both the inter row and tree of both the tree-to-tree reduced mow treatment and control block at Bundaberg North (**Chart 23 L&R)**. Within the inter row, thrips abundance followed a similar pattern in the two blocks (**Chart 23L**). Within the tree, thrips abundance followed a similar pattern except during September 2017 when there was a sharp peak increase the average abundance of thrips in the macadamia tree of the complete close mow treatment (**Chart 23R**). It is interesting to observe that for sampling dates when thrips were on average in higher numbers in the tree-to-tree inter row we do not see this in the corresponding trees. By contrast, when average numbers of thrips were recorded in peaks in the complete close mow trees, we do not see high numbers in the corresponding inter row. We can speculate that the more complex food web in the insectary may be contributing to the suppression of thrips in trees. Overall thrips were not reported to be a pest issue during the trial on this farm.



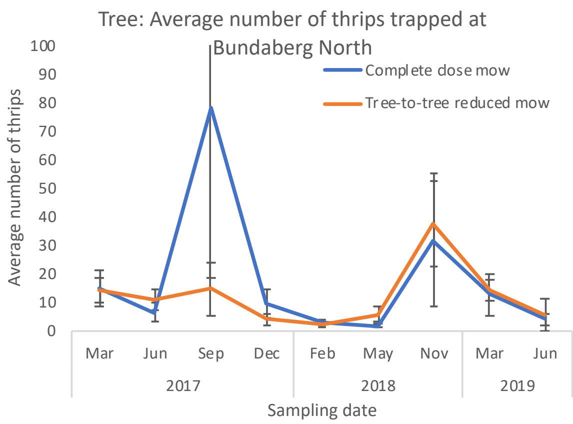


Chart 23: Left (L) The relative average abundance of thrips within inter row (± SE) at Bundaberg North in the control and tree-to-tree reduced mow treatment over the entire sampling period. **Right (R)** The relative average abundance of thrips within trees (± SE) at Bundaberg North in the control and tree-to-tree reduced mow treatment over the entire sampling period.

Case Study 3: mohawk with seeding (Baldwin & Ranking) NSW mid-north coast

Case Study 3 (Baldwin & Ranking) experimented with mohawk with seeding in the treatment block. The original intention was to retain the mohawk during harvest, however, it was found to cause some complexities with harvest operations and was removed for the harvest period. The mohawk was seeded with a seed mix in April of every year (see protocols, above) that the project was in the field (three times in total). Photos, below, show the inter row in the control (**Photo 4a**) and treatment (**Photo 4b**) blocks.

Photo 4a: (left) Control – complete close mow October 2018 **Photo 4b** (right): Treatment – mohawk with seeding October 2018 including a mix of broad-leafed parsley, Queen Anne's lace, marigold, calendula, phacelia, cosmos, buckwheat, Lucerne, red clover, dill.

When we compared inter row vegetation sampled in the complete close mow (control) block (**Photo 4a**) against the mohawk with seeding (treatment) block (**Photo 4b**; **Chart 25**) we found that the count of plant species in the mohawk with seeding block was around 1.5 times higher than that of the control for each assessment year. The percentage of biomass as floral resources in the mohawk with seeding block was many orders of magnitude higher against a very low value for the control for two out of three assessment years (2018 was the exception with relatively similar results in the control (19 species) against the treatment (14 species) and this result was likely associated with heavy rain preventing mowing of the control block and poor establishment of seeded species in the treatment block). Minimised habitat disturbance and improved habitat complexity in the mohawk with seeding block (evaluated as height) was in the order of 3 times greater than the control block for each assessment year.

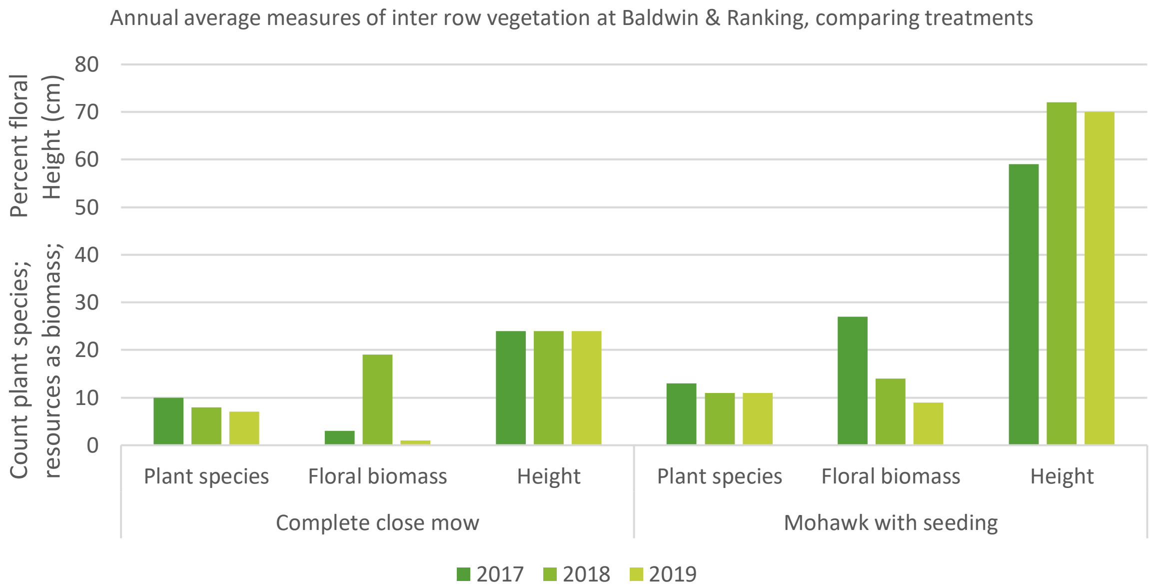


Chart 24: Comparison of the treatment (Mohawk with seeding) as average annual insectary measures (y count of plant species, percentage of biomass as floral resources, and the height of vegetation (cm)) over time.

Confounding factors for the food web experiment

We propose that arthropod data for the food web experiment will be reflected by some minor influences from confounding factors and in-field problems with the independent variables at this trial site. There were some minor difficulties in sustaining a strong distinction between the control and the insectary treatment for the life of this trial site. The natural diversity already present in the seed bank across the entire trial site was relatively high. From a farm management perspective this is valuable; but for our experiment it meant that the control and the insectary treatment were more similar than ideal for the experiment (and as was achieved experimentally at Bevan & Willemse and Piccadilly Park). Furthermore, there were some minor issues with experimental protocols in relation to machinery breakdowns and very heavy and prolonged rainfall, both of which prevented mowing of the control block.

Arthropod results for mohawk with seeding

A total of 6,546 arthropods specimens were captured by YSTs from the inter row and tree in the two experimental blocks at Baldwin & Ranking over nine sampling periods between March 2017 and July 2019. The majority were flies (2143 specimens), wasps (1432 specimens), thrips (1199 specimens), true bugs (812 specimens) and beetles (361 specimens). When these insect groups (orders) were compared between the mohawk with seeding and complete close mow blocks, all insect groups were slightly more abundant within the mohawk with seeding block (**Chart 25L**). Importantly, wasp parasitoids were in greater abundance within the mohawk with seeding treatment block when compared to the control block.

When each treatment was divided into the inter row (darker colour shades) and tree (lighter colour shades with lattice), insects from all groups had higher abundance in the inter row compared to the tree (**Chart 25R**).

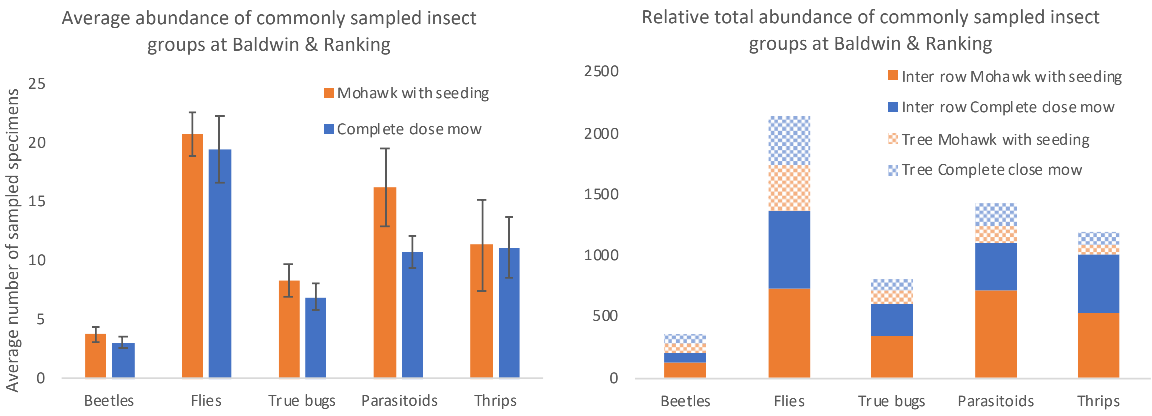


Chart 25: Left (L) Relative average abundance of commonly sampled arthropod groups (± SE) at Baldwin & Ranking in the and mohawk with seeding treatment over the sampling period. **Right (R)** The relative total abundance of commonly sampled insect groups at Baldwin & Ranking in the treatment and location over the sampling period. Mohawk with seeding results are displayed in orange (lattice = tree specimens) and complete close mow results are displayed in blue (lattice = tree specimens).

Feeding guilds at Baldwin & Ranking

Chart 26 summarises the total number of arthropods (excluding thrips) grouped by feeding guild in terms of their abundance with respect to control and mohawk with seeding treatment. The mohawk with seeding treatment block had higher numbers of nectarivores, parasitoids and predators compared to the complete close mow block (**Chart 26**).

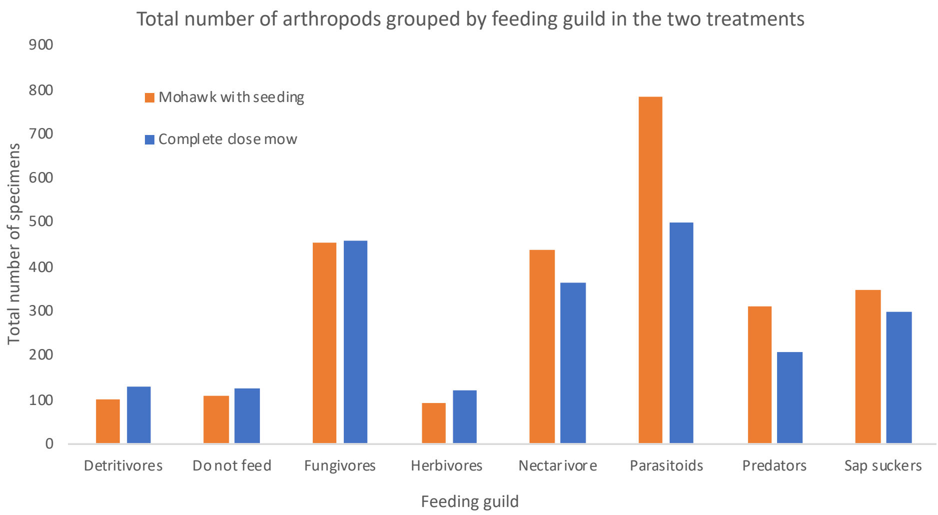


Chart 26: Comparative arthropod feeding guild abundance in the control and mohawk with seeding treatment at Baldwin & Ranking. Total numbers of specimens include all arthropods captured on YSTs, excluding thrips, identified over the entire sampling period (2017-19) and combines row and tree specimens across sites.

To simplify our results, we classified all insects as prey and then separated nectarivores (potential pollinators), predators, parasitoids and prey (all arthropods) as four broad categories. We then compared treatment and control proportionally. When we combined tree and inter row abundance counts within the treatment and control blocks, there was a slightly greater proportion of prey in the seeded mohawk block (54%) (**Chart 27**). The proportion of predators and parasitoids in the seeded mohawk block was also greater (60 and 61% respectively) than in the complete close mow block. Nectarivores were modestly greater in the seeded mohawk block (55%) compared to the complete close mow block (45%) (**Chart 27)**.

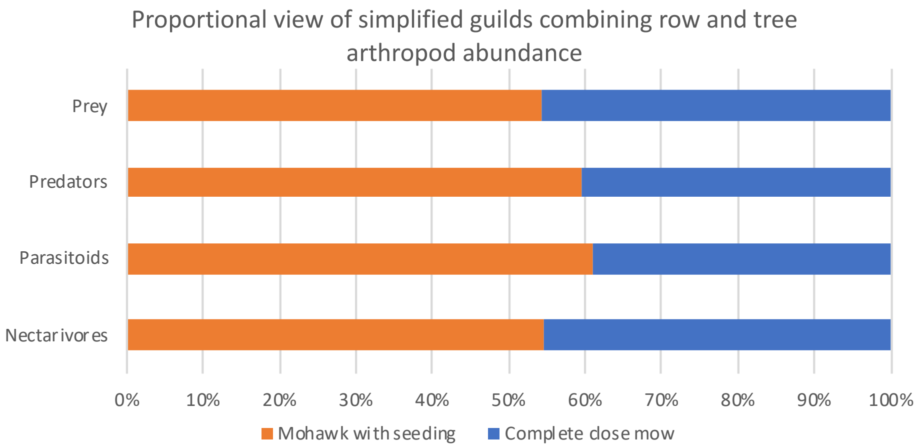
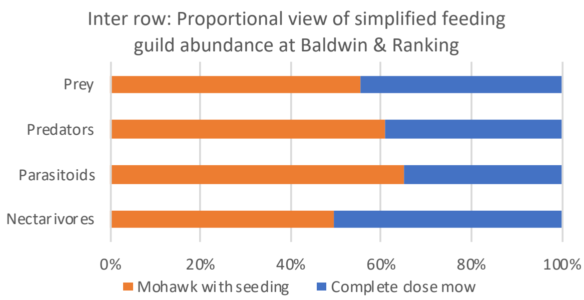


Chart 27: Proportional view of simplified feeding guild abundance at Baldwin & Ranking. Data includes all arthropods captured on YSTs from both inter row and tree, over the whole sampling period (2017-19).

When we compared the abundance of arthropod feeding guilds proportionally in the inter row comparing control and mohawk with seeding treatment, nectarivores had similar proportions in the treatment (51% in seeded mohawk block and 49% in complete close mow block) (**Chart 28L**). Prey was in proportionally greater abundance in the inter row within the seeded mohawk block (55%) which may account for the greater proportions of predators (61%) and parasitoids (65%) in the inter row within the seeded mohawk block compared to the complete close mow block (**Chart 28L)**.

In the macadamia tree we found a slightly higher prey ratio in the mohawk with seeding (53%, 1890 specimens) to that of the complete close mow (47%, 1702 specimens), and conversely slightly less parasitoids in the mohawk with seeding block (46%, 131 specimens) compared to the control block (54%, 153 specimens) (**Chart 28R**). Predators (including species from flies, beetles and true bugs) were higher in trees within the mohawk with seeding block (57%) compared to that of the complete close mow block (43%). In consideration of these ratios, we can with a degree of confidence speculate that the mohawk its likely contributing to more pest suppression in the macadamia trees. Nectarivores (potential pollinators) were much higher in trees within the mohawk with seeding block (61%) compared to that of the complete close mow block (39%) (**Chart 28R**).



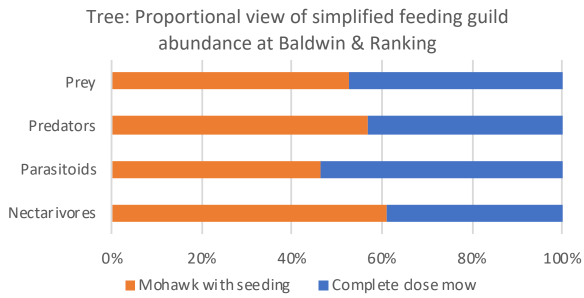


Chart 28: Left (L) Proportional view of simplified feeding guild abundance in the inter row at Baldwin & Ranking in the control and mohawk with seeding treatment. **Right (R)** Proportional view of simplified feeding guilds in the tree at Baldwin & Ranking in the control and mohawk with seeding treatment. Data from both charts includes all arthropods captured on YSTs over the whole sampling period (2017-19).

A focussed look at wasp parasitoids at Baldwin & Ranking

A total of 1402 wasp specimens were caught on YSTs in the two treatment blocks over the entire sampling period (2017-19) at Baldwin & Ranking; 1083 were sampled from the inter row and 319 from the tree. Most of the wasps collected were from parasitoid families. Within the inter row, the mohawk with seeding treatment block had a higher diversity of wasp parasitoids (21 vs 17 families) and almost double the number of individual specimens collected**.** Within the tree, both diversity of wasp parasitoid families and abundance of individual specimens was more similar (**Table 11 Appendix 2**).

The large majority (approximately 90%) of wasp parasitoids sampled at Baldwin & Ranking were from the superfamily Chalcidoidea. When Chalcidoidea was identified to family from the 2019 samples, seven families were present: Aphelinidae, Encyrtidae, Eulophidae, Eupelmidae, Eurytomidae, Mymaridae and Trichogrammatidae. Within the inter-row, Chalcidoidea were on average approximately twice as numerous within the mohawk with seeding block compared to the complete close mow block (**Chart 29L**), though there was less treatment difference within the tree (**Chart 29R)**.

Chart 29 displays the four most abundant wasp parasitoid superfamilies sampled within the inter row (**L**) and tree (**R**) at Baldwin & Ranking.

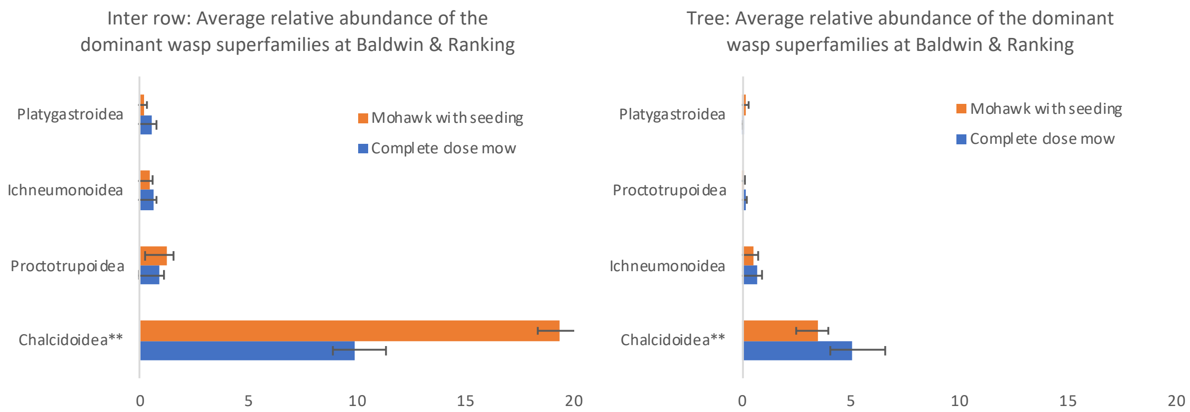


Chart 29: Left (L) The relative average abundance of the dominant wasp parasitoid superfamilies within inter rows (± SE) at Baldwin & Ranking in the control and mohawk with seeding treatment across the sampling period (2017-19). **Right (R)** The relative average abundance of the dominant parasitoid superfamilies within trees (± SE) at Baldwin & Ranking in the control and mohawk with seeding treatment across the sampling period (2017-19). **Excludes wasp parasitoids from the family Trichogrammatidae, which were released for biological control at Baldwin & Ranking.

In **Chart 30** we compare wasp families excluding superfamily Chalcidoidea sampled during 2017 and 2018 so as to better compare less numerous families. The families identified from Chalcidoidea in 2019 were Encyrtidae, Eulophidae, Eupelmidae, Eurytomidae and Mymaridae. Encyrtidae was the most numerous in the mohawk with seeding block (82 specimens) compared to the complete close mow block (28 specimens). The next most numerous family was Diapriidae; these wasps typically parasitise larvae and pupae of a wide range of insects, especially flies. Diapriidae were generally more numerous in the insectary treatment block (34 specimens) than the control block (28 specimens). There were several wasp families absent from the complete close mow block (Figitidae, Pergidae, Tenthredinidae and Torymidae) that were present in the mohawk with seeding block. No unique families were found only in the complete close mow block.

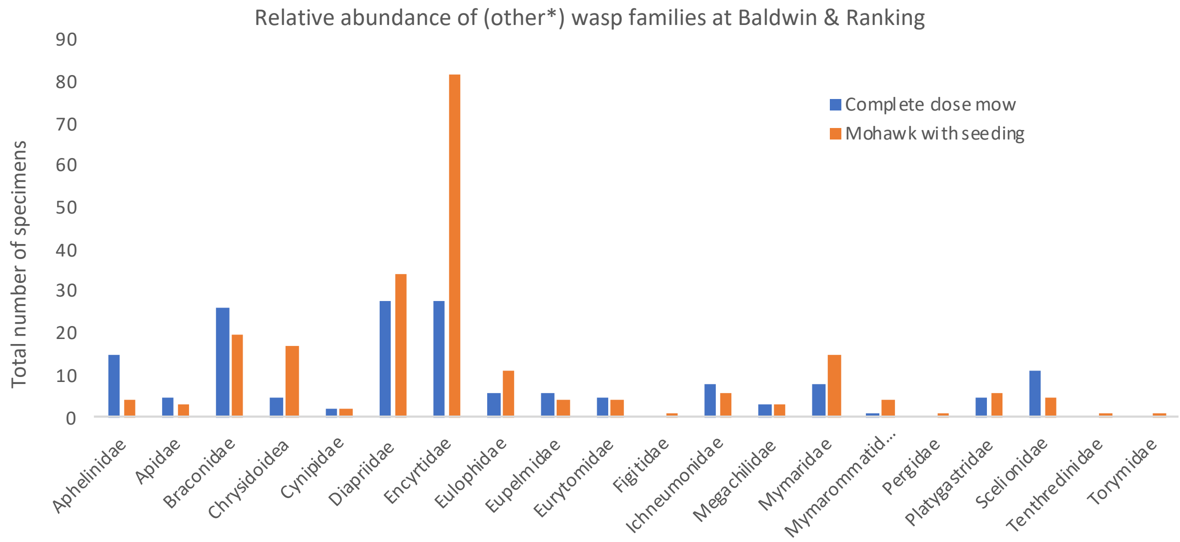


Chart 30: Relative abundance of wasp families (* other than Chalcids) at Baldwin & Ranking from March 2017 to July 2019. Data from both inter row and tree are combined and excludes the superfamily Chalcidoidea from 2017-18 samples to better compare less numerous families. Family Trichogrammatidae were also excluded because they were released for biological control at Baldwin & Ranking.

The temporal change in wasp parasitoid abundance at Baldwin & Ranking over the sampling period shows a large peak in parasitoid abundance in October of 2018 in the inter row of the mohawk with seeding block (**Chart 31L**) and to a much lesser degree in the trees within the 'complete close mow' block (**Chart 31R**). For the majority of sampling dates, parasitoids were similar in abundance in both the mohawk with seeding treatment and control blocks.

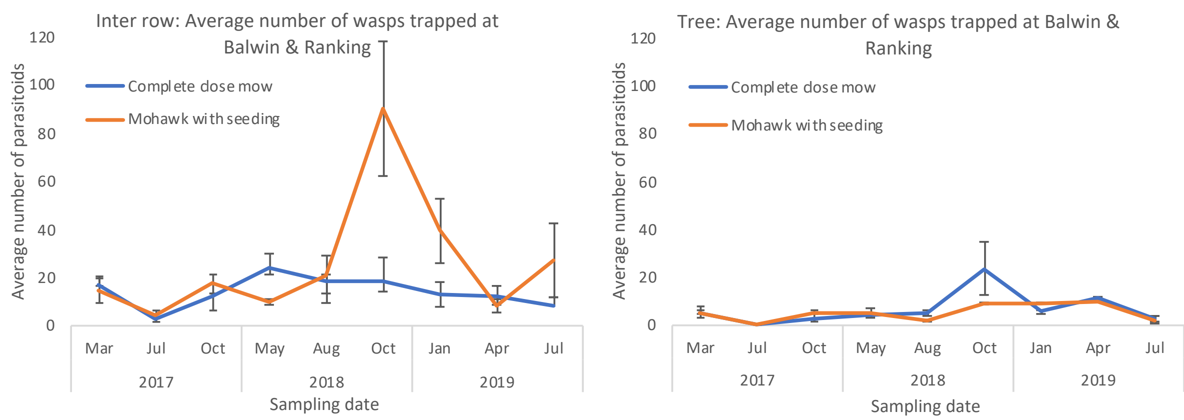


Chart 31: Left (L) The relative average abundance of wasp parasitoids in the inter row (± SE) at Baldwin & Ranking in the control and mohawk with seeding treatment over the sampling period (2017-19). **Right (R)** The relative average abundance of parasitoids within the tree (± SE) at Baldwin & Ranking in the control and mohawk with seeding treatment over the sampling period (2017-19).

A focussed look at flies (potential pollinators/prey/parasitoids/predators) at Baldwin & Ranking

A total of 2143 flies were sampled within the two treatment blocks over the entire sampling period at Baldwin & Ranking; 1368 from the inter row and 775 from the tree. Inter rows within the mohawk with seeding treatment block had a greater diversity of fly families (28) than the control block (22), and the abundance of individuals was also modestly more (723 specimens vs 645 respectively). Within the trees, diversity and abundance of the fly assemblage was similar (**Table 10 Appendix 2).**

The mohawk with seeding block had a higher diversity of flies, with nine extra families (**Chart 32**). Of these families four are predators (Anthomyiidae, Asilidae, Empididae, Micropezidae) and another four are nectarivores (Micropezidae, Sciomyzidae, Stratiomyidae, Therevidae); the final family does not feed (Bibionidae). In the complete close mow, there are two parasitoid fly families that were not in the mohawk with seeding block (Conopidae and Pyrgotidae), one fungivore family (Keroplatidae), one nectarivore family (Tabanidae) and one detritivore family (Heleomyzidae). These families only appeared in the control block in 2018 and may be a reflection on experimental protocol modifications in that year/season.

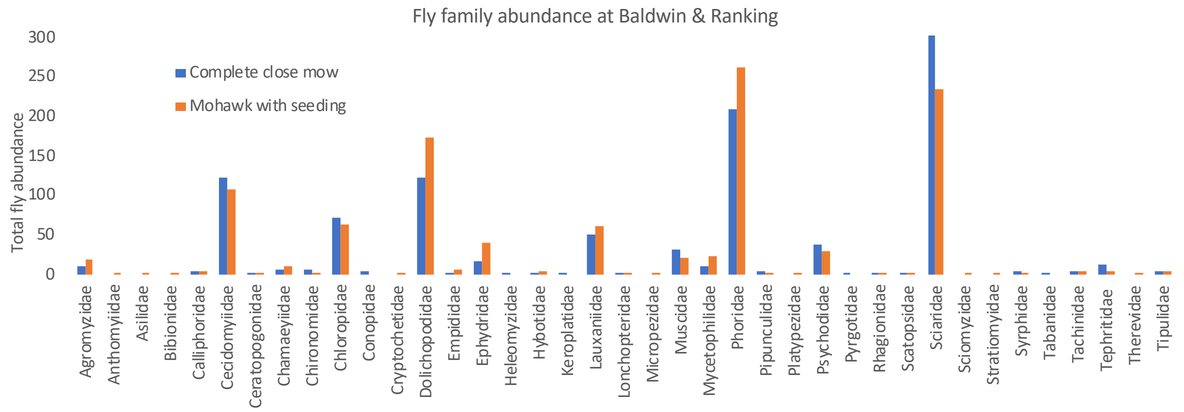


Chart 32: Fly family abundance at Baldwin & Ranking in the control and mohawk with seeding treatment. Specimens counts from both inter row and tree are combined over the entire sampling period (2017-19).

Chart 33 displays the average abundance of all fly families sampled within the inter row (L) and tree (R) where there were 20 or more individuals collected over the entire sampling period. Inter rows within the mohawk with seeding treatment block had a greater number of most commonly sampled fly families, including the predatory Dolichopodidae (**Chart 33**). Within the macadamia tree, the mohawk with seeding treatment block had greater numbers of the family Phoridae, which are nectarivores and may play a role in crop pollination as well as some family members being parasitoids. There was a reverse trend in the trees of the complete close mow control in the scaridae, which are potential pollinators in their adult stage and fungivores in their larval stage.

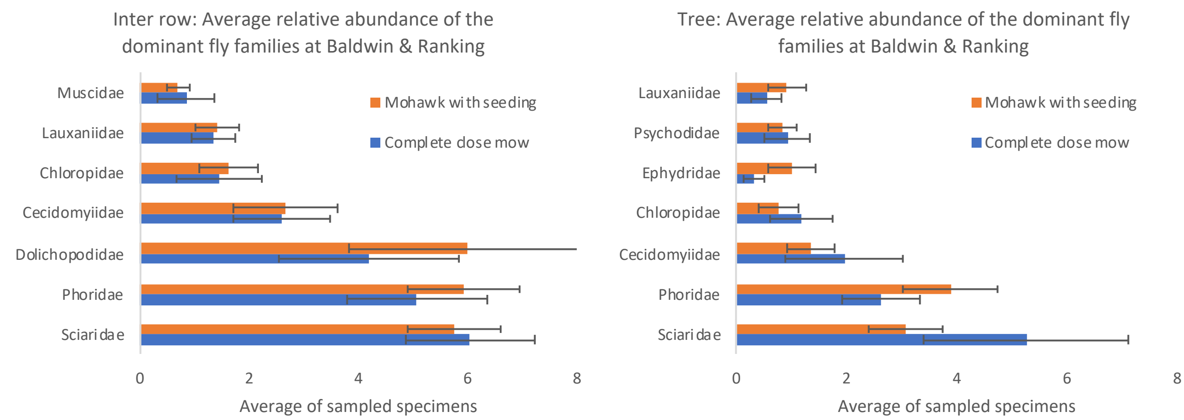
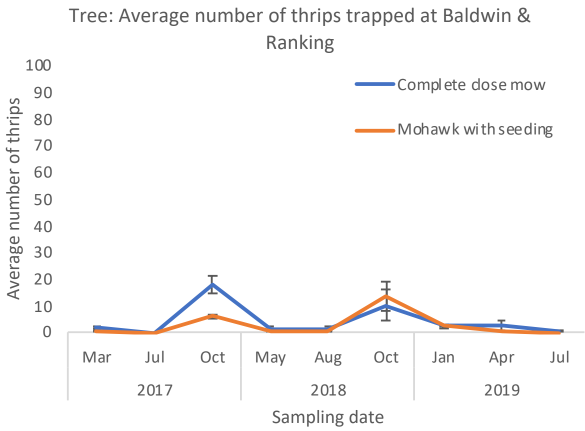


Chart 33: Left (L) The relative average abundance of the dominant fly families within the inter row (± SE) at Baldwin & Ranking in the control and mohawk with seeding treatment across the entire sampling period (2017-19). **Right (R)** The relative average abundance of the dominant fly families within the tree (± SE) at Baldwin & Ranking in the control and mohawk with seeding treatment over the entire sampling period (2017-19).

A focussed look at thrips at Baldwin & Ranking

Overall, there was a low abundance of thrips in both treatment blocks and thrips were not a reported issue on this farm during the sampling period. **Chart 34 L&R** show the average number of thrips recorded at each sampling period with respect to treatment at Baldwin & Ranking, highlighting any variations in their abundance over time. Within the inter row there were two peaks in thrips abundance (October 2017 and August 2018) in the mohawk with seeding block and a smaller size peak in the complete close mow inter row in January 2019 (**Chart 34L**). Within the tree, thrips maintained low abundance in both treatment blocks throughout the sampling period (**Chart 34R**).



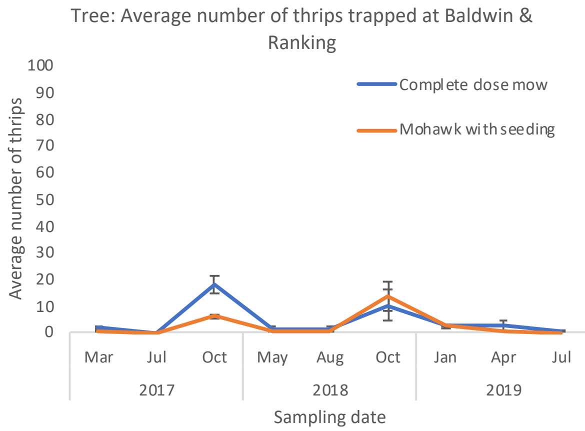


Chart 34: Left (L) The relative average abundance of thrips within inter rows (± SE) at Baldwin & Ranking in the mohawk with seeding treatment and control over the entire sampling period (2017-19). **Right (R)** The relative average abundance of thrips within trees (± SE) at Baldwin & Ranking in the mohawk with seeding treatment and control over the entire sampling period (2017-19).

Case Study 4: cover cropping (Piccadilly Park) northern NSW

Case Study 4 (Piccadilly Park) is cover cropping in the treatment block. This was sustained year-round, including during harvest, in the treatment block. Cover crops were seeded and terminated three times while the trial was in the field (12 months). Photos, below, show the inter row in the control (**Photo 5a**) and treatment (**Photo 5b**) blocks.

Photo 5a (left): Control – complete close mow June 2019 **Photo 5b (right):** Treatment – cover crop June 2019 including tillage radish, perennial ryegrass, millet, vetch.

When we compared inter row vegetation sampled in the complete close mow (control) block (**Photo 5a**) against the cover cropping (treatment) block (**Photo 5b**; **Chart 35**) we found that the count of plant species in the cover crop block was around 5-6 times greater than the control for each assessment year. The percentage of biomass as floral resources in the cover cropping block was many orders of magnitude higher against a value of zero for the control for each assessment year. Minimised habitat disturbance and improved habitat complexity (evaluated as height) was between 8-10 times greater in the treatment than that of the control for each assessment year.

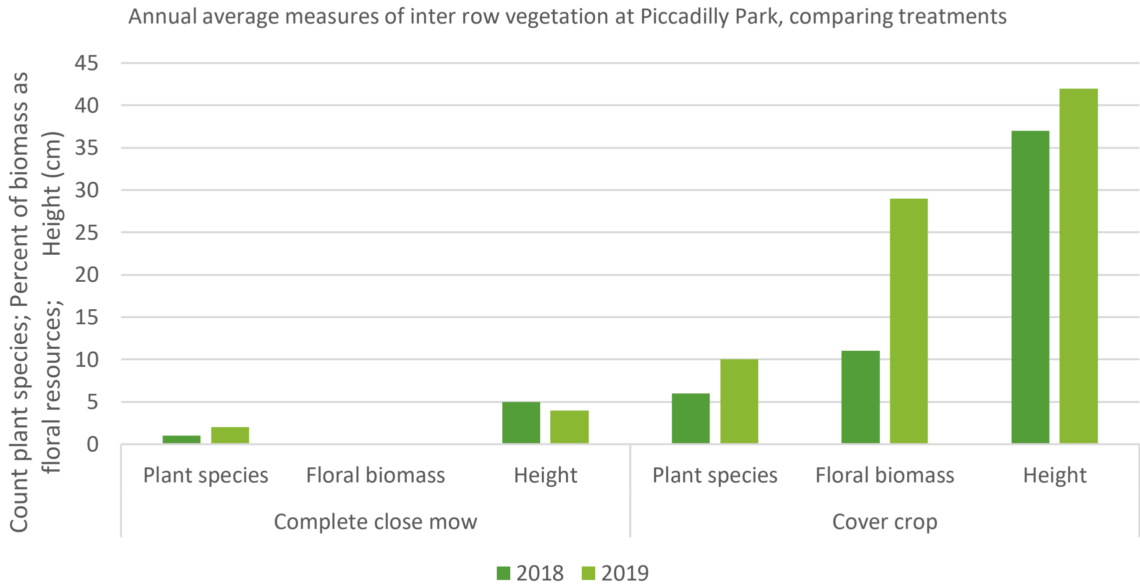


Chart 35: Comparison of the treatment (cover cropping) as average annual insectary measures (count of plant species, percentage of biomass as floral resources, and the height of vegetation (cm)) over time.

As will be discussed in and **Guidelines** in **Table 5** and **Appendix 3** below, cover cropping in the inter row is a specialised and dedicated system. In **Photos 6a-6e**, below, we can see a portion of the range of various cover crop species selection choices and re-seeding activities that occurred during the life of the trial at various locations around the farm.

Photo 6a: Piccadilly Park – smart radish and vetch (left) **Photo 6b**: (right) millet and smart radish October 2018.


Photo 6c: Piccadilly Park – (left) emerging cover crop re-seeded August 2019 including smart radish **Photo 6d:** (right) alternate adjacent row with cover crop at maturity September 2019 including smart radish, ryecorn, oats, chicory, red clover.

Photo 6e: Piccadilly Park – mature cover crop (sunflowers and tillage radish) December 2018. This row was retained as an "alternate row" for an insectary, while adjacent rows were terminated and reseeded.

Recommendations for specific design elements and management requirements are beyond the scope of this project. Cover cropping in macadamia orchards is the focus of two new projects being run by BioResources (funded by Landcare) in 2020-22. A detailed report on this farm is available in **Appendix 7**.

Confounding factors for the food web experiment

There is one major data limitation for this trial site: we were able to sample only once each season for a year. As a result, we are unable to report on the emergence of trends that would be anticipated to be associated with such a comprehensive change to the orchard and inter row environment and management systems.

The influence of confounding factors or in-field problems with the independent variables were negligible at this trial site and we propose that arthropod data quality for the food web experiment will reflect this. We were able to sustain a strong distinction between the control and the insectary treatment for the life of this trial site. The experimental protocols were systematically and appropriately applied. There were no major disruptive farm management, environmental or weather events.

Arthropod results for cover cropping

A total of 7,137 arthropod specimens were captured using YSTs from both inter row and tree within the cover crop treatment and control blocks at Piccadilly Park over 4 sampling occasions between December 2018 and September 2019. The most abundant group (order) of insects were flies (2510 specimens), followed by wasps (1891 specimens), thrips (1368 specimens), true bugs (875 specimens) and beetles (109 specimens). When these groups were compared between the cover crop and complete close mow blocks, all insect groups showed a noticeable difference between the blocks in terms of their abundance (**Chart 36L**). Beetles, flies, true bugs and wasp parasitoids were appreciably more abundant within the cover crop block, whilst thrips were more abundant within the complete close mow block (**Chart 36L**).

When each treatment was divided into the two sampling habitats (**Chart 36R**), (inter row: darker colour shades and tree: lighter colour shades with lattice), beetles, flies, true bugs and wasp parasitoids were on average all more abundant within the two habitats in the cover crop block when compared with their counterpart habitat in the complete close mow block.

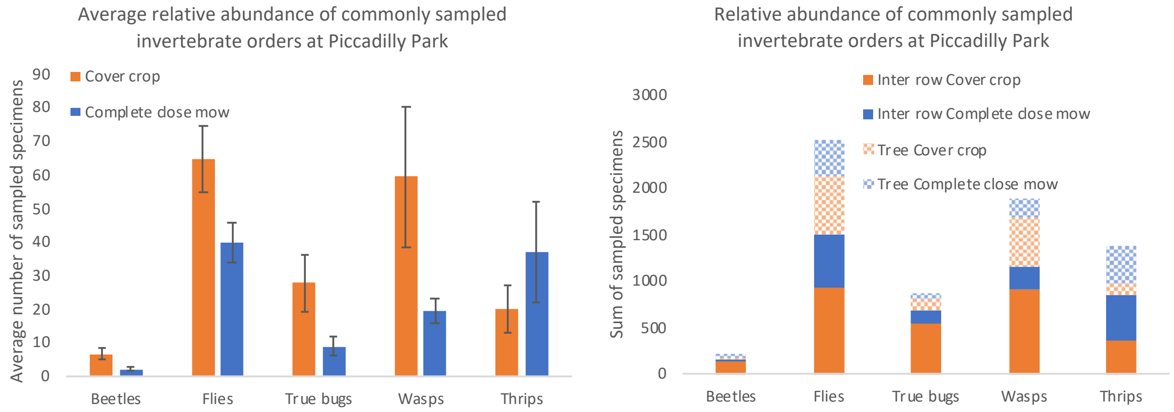


Chart 36: Left (L) Relative average abundance of commonly sampled arthropod groups (± SE) at Piccadilly Park in the control and cover crop treatment over the entire sampling period (2018-19). **Right (R)** The relative total abundance of commonly sampled insect groups at Piccadilly Park in the treatment and location over the entire sampling period (2018-19). Cover crop results are displayed in orange (lattice = tree specimens) and complete close mow results are displayed in blue (lattice = tree YST specimens).

Feeding guilds at Piccadilly Park

Chart 37 summarises the total number of arthropods (excluding thrips) grouped by feeding guild in terms of their abundance with respect to control and cover crop treatment. There are several other feeding guilds including borers, blood suckers, gall formers, omnivores and pollen-only feeders that were omitted from analysis and the graph as they were too few in number and did not show any difference between treatments. Seed feeders (family Lygaeidae) and non-specialist herbivores (grasshoppers) were also similar in abundance within both blocks and had low overall abundance. An interesting phenomenon was seen in the sap sucking guild when comparing their abundance in inter row and tree habitats between the cover crop treatment and control blocks. Within the complete close mow block, total sample numbers of sap suckers were 133 in the inter row and 48 in the tree, while within the cover crop block, where inter row numbers of sap suckers were higher than in the control (594 in the cover crop inter row), the trees within the cover crop block only had 13 individual sampled sap sucker specimens (**Chart 37**). The sap suckers consisted mainly of leafhoppers, and the higher leafhoppers in the cover crop inter row did not increase abundance in the trees indicating that these leafhopper species were unlikely to feed on macadamia.

Within the macadamia trees, nectarivores (nectar feeders and potential pollinators) and parasitoids were approximately twice as abundant in the cover crop block compared to the complete close mow block and predators were also in higher overall abundance (**Chart 37**).

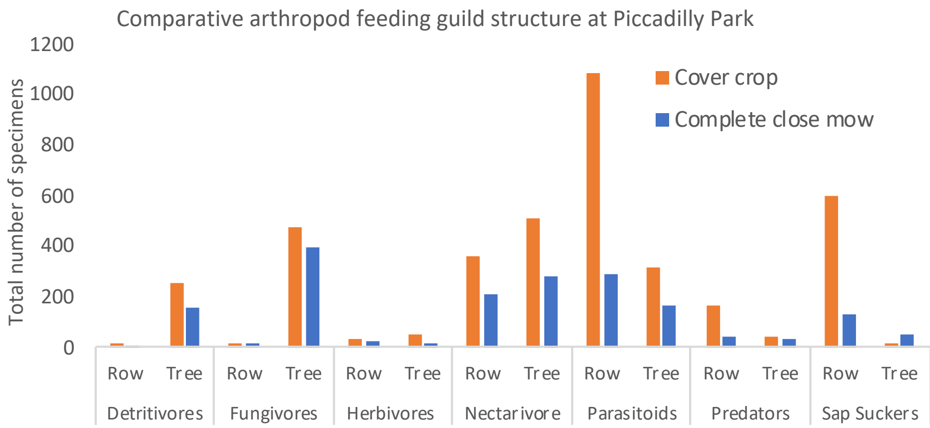


Chart 37: Comparative arthropod feeding guild abundance with respect to treatment and habitat at Piccadilly Park. Total specimen counts include all arthropods captured on YSTs, excluding thrips, sampled over the entire sampling period (2018-19) and combines row and tree specimens over the three sites.

To simplify our results, we classified all arthropods as prey and then separated nectarivores (potential pollinators), predators, parasitoids and prey, as four broad categories and compared their abundance proportionally with respect to treatment. When tree and inter row abundance counts were combined and compared between cover crop treatment and control blocks we observed high proportions of parasitoids (76%) and predators (74%) in the cover crop block (**Chart 38)**. Potential prey and nectarivores were also proportionally much higher in the cover crop treatment block (62% and 61% respectively) (**Chart 38)**.

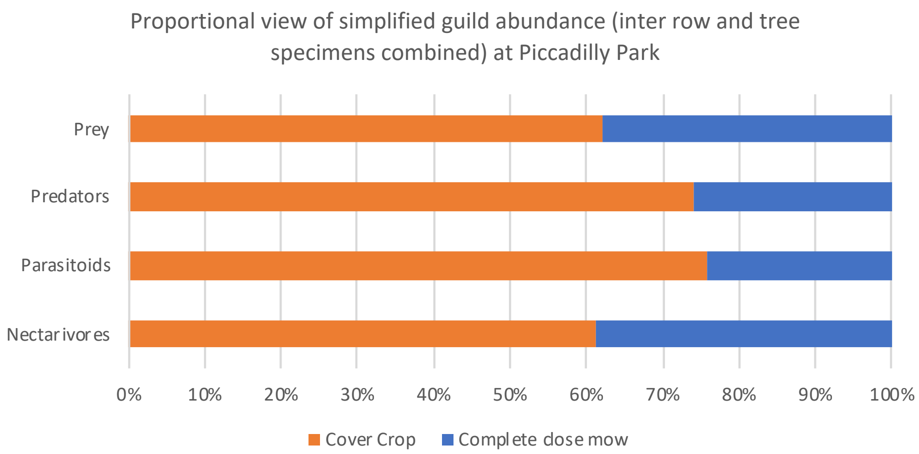
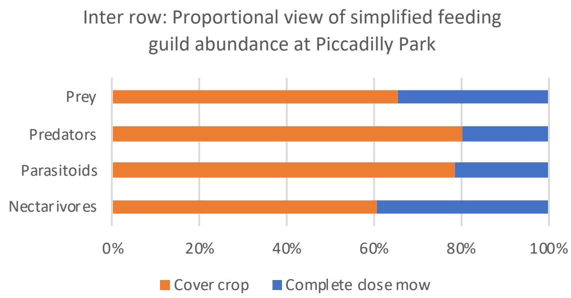


Chart 38: Proportional view of simplified feeding guild abundance at Piccadilly Park. Data includes all arthropods captured on YSTs from both inter row and tree across sites, over the whole sampling period (2018-19).

These proportions are much higher when we compare arthropod feeding guild abundance in the inter row between the cover crop treatment and control blocks (**Chart 39L**). There were very high proportions of parasitoids (79%) and predators (80%) in the cover crop block when compared to the control (**Chart 39L**). Potential prey and nectarivores were also proportionally more abundant in the cover crop block when compared with the complete close mow block (65% and 61% respectively) (**Chart 39L**).

As we can see from **Chart 39L**, this cover crop environment was particularly attractive to beneficial arthropods because it provided shelter, breeding areas, nectar, alternative hosts/prey and pollen. But does this transfer to higher numbers of beneficial arthropods in the macadamia tree? **Chart 39R** shows that there was a proportionally greater abundance of predators and parastioids in the macadamia trees within the cover crop block (71% and 63% respectively) compared to the complete close mow block. Overall prey and nectarivores were also higher in the macadamia trees within the cover crop block (57% and 62% respectively) (**Chart 39R**).



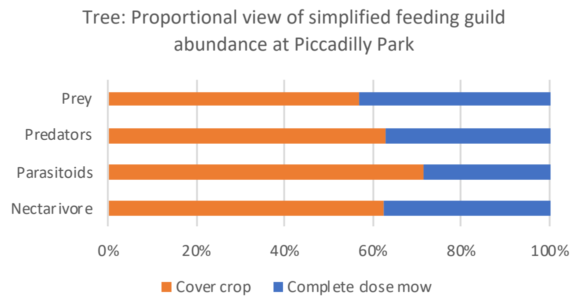


Chart 39: Left (L) Proportional view of simplified feeding guild abundance in the inter row at Piccadilly Park in the control and cover crop treatment. **Right (R)** Proportional view of simplified feeding guilds in the tree at Piccadilly Park in the control and cover crop treatment. Data from both charts includes all arthropods captured on YSTs over the whole sampling period (2018-19) across sites.

A focussed look at wasp parasitoids at Piccadilly Park

A total of 1889 wasp specimens were sampled within the two treatment blocks over the entire sampling period at Piccadilly Park; 1159 were sampled from the inter row and 729 from the tree. There was a large contrast in the diversity and abundance of the parasitoid assemblage between the cover crop block and the complete close mow block (**Table 13 Appendix 2**). Wasp parasitoid diversity and abundance was higher in the cover crop block when compared to the complete close mow block for both the inter row and tree samples.

Chart 40 compares the total abundance of parasitoids in both the inter row and trees in the cover crop treatment and control blocks. The cover crop inter row had more than three times as many parasitoids (886 vs 243 specimens) and almost that ratio in the cover crop trees (505 specimens) compared to the close mow trees (205 specimens).

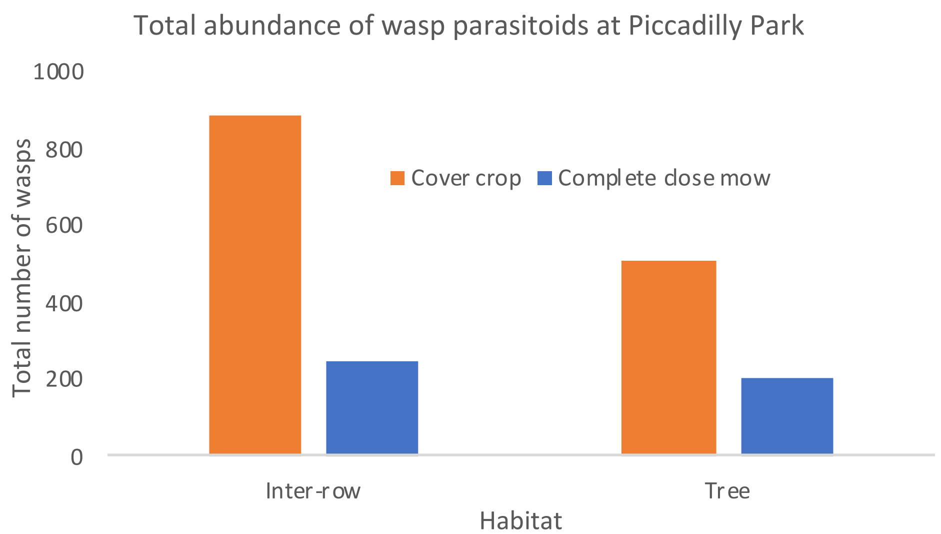


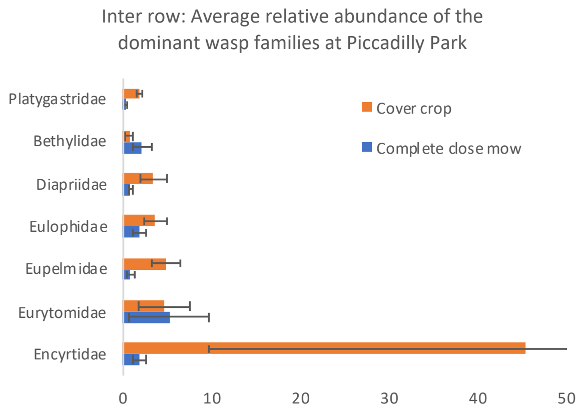
Chart 40: Comparison of the total abundance of wasp parasitoids in both inter row and tree in the control and cover crop treatment block over the entire sampling period (2018-19).

The cover crop block was dominated by one family, Encyrtidae (superfamily Chalcidoidea), both within the inter row and the trees (**Chart 41 L&R**). Encyrtidae is a large family that are important in biological control; a lot of the species in this family are parasitoids of true bugs (including aphids, coccids, psyllids, whiteflies, leaf hopper etc). Encyrtidae were most numerous in the cover crop inter row (546 specimens), however, they were five times more abundant in the cover crop macadamia trees (121 specimens) than in the close mow block (23 specimens) (**Chart 41**).

In the inter row, other commonly sampled wasp parasitoid families that were at least twice as abundant within the cover crop block compared to the complete close mow block were Eupelmidae (58 vs 10 specimens), Eulophidae (44 vs 23 specimens), Diapriidae (41 vs 10 specimens respectively) and Platygastridae (22 vs 4 specimens) (**Chart 41L**). Both Eulophidae and Eupelmidae belong to the superfamily Chalcidoidea and play an important role in biological control. Eulophidae is a large family that are mostly primary parasitoids of concealed larvae such as leafminers. Eupelmidae is another large family that are often parasitoids of the larvae of wood-boring Coleoptera. Only 1 sampled wasp parasitoid family (Bethylidae) was considerably more abundant within inter rows of the complete close mow block compared to the cover crop block (26 vs 9 specimens respectively) (**Chart 41L**).

Within the tree, other commonly sampled wasp parasitoid families that were on average at least twice as abundant within the cover crop block compared to the complete close mow block were Bethylidae (27 vs 2 specimens respectively), Braconidae (27 vs 4 specimens), Diapriidae (26 vs 7 specimens) and Platygastridae (24 vs 5 specimens) (**Chart 41R**). Eurytomidae were the only family of wasp parasitoids that were on average more abundant within trees of the complete close mow block compared to the cover crop block (**Chart 41R**). Eurytomidae is also from the superfamily Chalcidoidea. While most Chalcidoidea are parasitoids of insects that undergo complete metamorphosis, Eurytomidae are often phytophagous (feed on plant tissue) to some degree and those that are parasitic are mostly parasitoids of concealed larvae within plant tissue, such as stems, galls and seeds. There were 39 individual Eurytomidae sampled from ‘complete close mow’ trees compared to 4 individuals from ‘cover crop’ trees.

Chart 41 L&R display the average abundance of all wasp parasitoid families sampled within the inter row (L) and tree (R) at Piccadilly Park where there were 20 or more individuals collected (excluding Trichogrammatidae) over the entire sampling period.



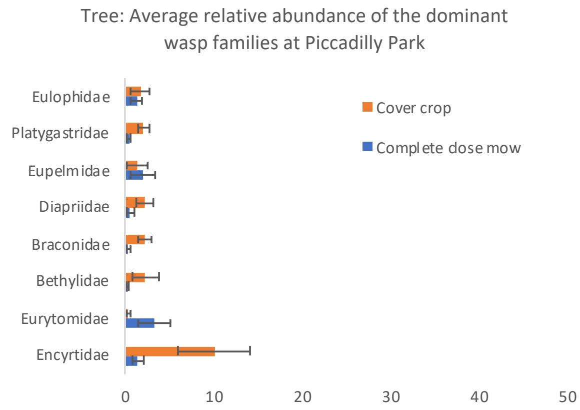


Chart 41: Left (L) The relative average abundance of the dominant wasp parasitoid families within inter rows (± SE) at Piccadilly Park in the control and cover crop treatment. **Right (R)** The relative average abundance of the dominant parasitoid families within trees (± SE) at Piccadilly Park in the control and cover crop treatment. Data from both charts are over the entire sampling period (2018-19) and excludes wasp parasitoids from the family Trichogrammatidae, which were released for biological control at Piccadilly Park as they were in the other case study sites (see **appendix 3** for further detail).

The less commonly sampled wasp parasitoids at Piccadilly Park were also found in higher abundance within the cover crop treatment block compared to the control (**Chart 42**). Parasitoid families that were found within the cover crop treatment block but not in the control block were Agaonidae, Eucharitidae, Figitidae, Pompilidae and Pteromalidae (**Chart 42**).

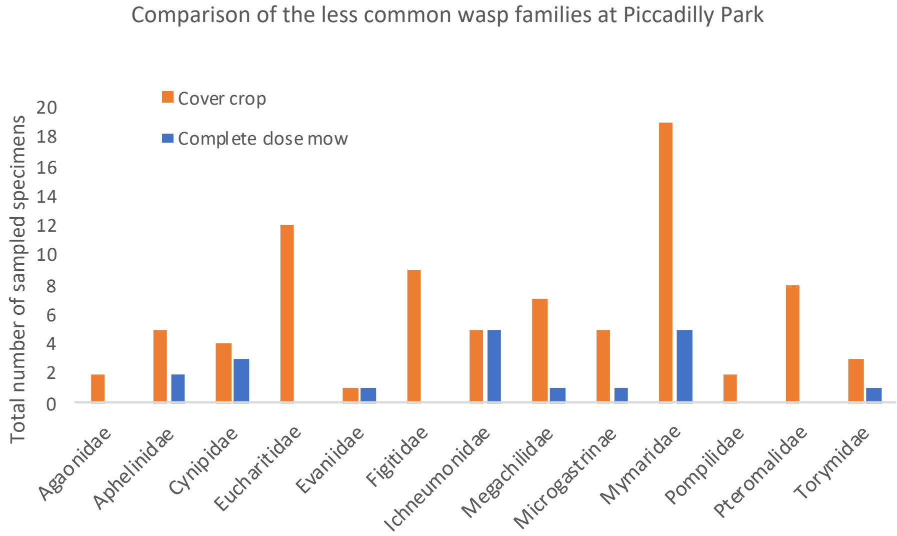


Chart 42: Comparison of the less commonly sampled wasp parasitoid families at Piccadilly Park in the cover crop treatment and control. Specimen counts from inter row and tree were combined over the entire sampling period (2018-19).

The temporal change in wasp parasitoid abundance at Piccadilly Park in the cover crop treatment and control blocks show a similar trend in the fluctuation of wasp parasitoids over the sampling period (**Chart 43 L&R**). There was a notable increase in wasp parasitoid abundance within the inter row of the cover crop block in September 2019 (**Chart 43L**). Over the entire sampling period in both the inter row and trees, parasitoid wasps were on average consistently more abundant within the cover crop block compared to the complete close mow block (**Chart 43 L&R**).

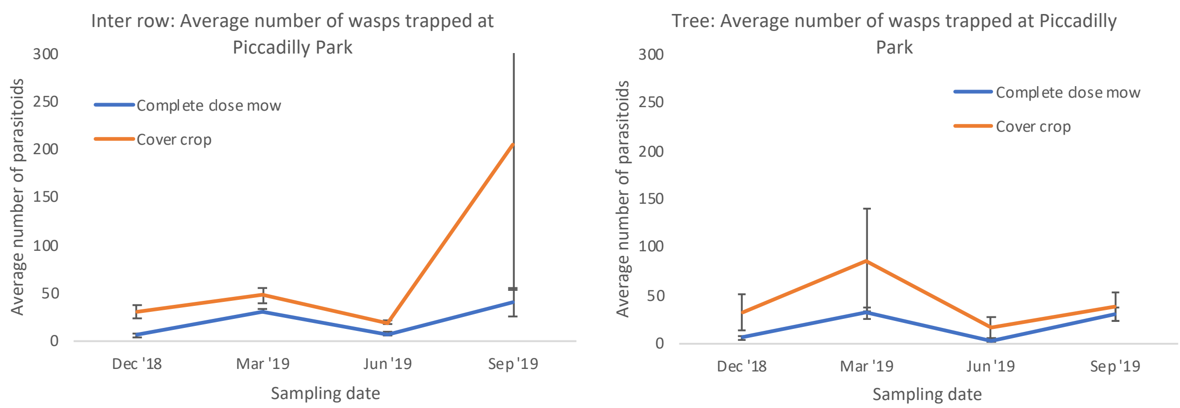


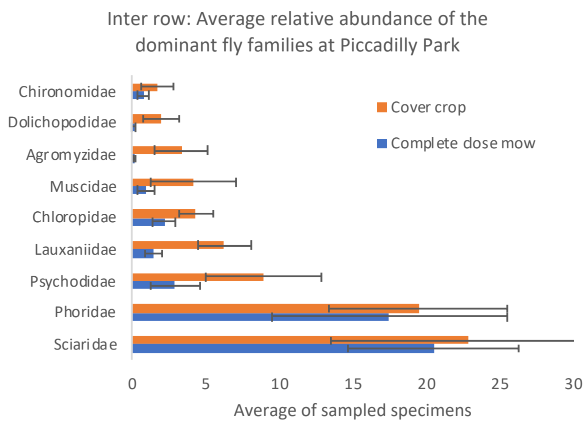
Chart 43: Left (L) The relative average abundance of wasp parasitoids within inter rows (± SE) at Piccadilly Park in the control and cover crop treatment over the sampling period. **Right (R)** The relative average abundance of parasitoids within trees (± SE) at Piccadilly Park in the control and cover crop treatment over the sampling period (2018-19).

A focussed look at flies (potential pollinators/prey/parasitoids/predators) at Piccadilly Park

A total of 2510 flies were sampled using YSTs in the two treatment blocks over the sampling period at Piccadilly Park; 1502 from the inter row and 1008 from the tree. The difference in flies between the cover crop treatment and control blocks was substantial in terms of the diversity and abundance in both the inter row and tree. The cover crop block had appreciably greater diversity and abundance of flies within both inter row and trees (**Table 12 Appendix 2**).

The assemblage of flies was very different between the cover crop and the complete close mow block at Piccadilly Park (**Chart 44**). Within the inter row, the two dominant families, Sciaridae (fungus gnats) and Phoridae (scuttle flies) were on average slightly higher in abundance within the cover crop treatment block, and the average abundance of the other dominant fly families within the cover crop inter row was greater, whilst in the complete close mow inter row these same fly families were scarce (**Chart 44L**). Within the trees, there were on average approximately five times the average number of flies from the family Phoridae within the cover crop block compared to the complete close mow block (**Chart 44R**). Family Agromyzidae were common within the macadamia trees in the cover crop block but scarce within trees of the complete close mow block. Conversely, Chironomidae were a fly family that dominated the trees within the complete close mow block but were not abundant in trees of the cover crop block (**Chart 44R**).

Chart 44 displays the average abundance of all fly families sampled within the inter row (L) and tree (R) where there were 20 or more individuals collected over the entire sampling period.



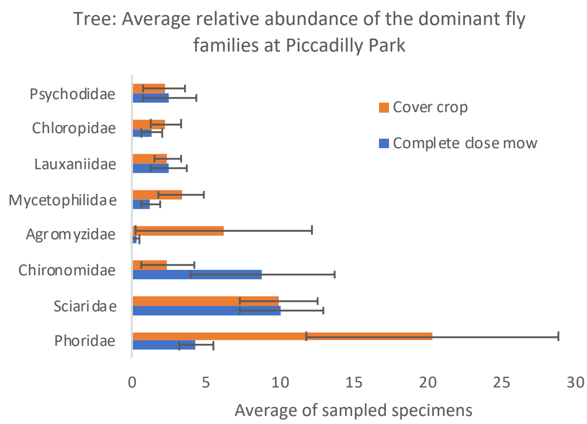


Chart 44: Left (L) The relative average abundance of the dominant fly families within inter rows (± SE) at Piccadilly Park in the control and cover crop treatment. **Right (R)** The relative average abundance of the dominant fly families within trees (± SE) at Piccadilly Park in the cover crop treatment and control. Both charts are specimens caught over the entire sampling period (2018-19).

Nectarivores were more abundant in the cover crop inter row than the inter row of the complete close mow block (439 vs 266 specimens respectively), and there was a similarly large difference in the trees (407 specimens in cover crop vs 208 specimens in complete close mow) **Chart 45.** Detritivore flies were three times more abundant in the cover crop inter row than in the complete close mow inter row, although there was minimal difference in the trees between treatment blocks. Of the predatory flies sampled (family Dolichopodidae), 24 specimens were sampled from cover crop inter row vs 1 specimen within complete close mow inter row **Chart 45**. There were very few parasitic flies sampled at Piccadilly Park.

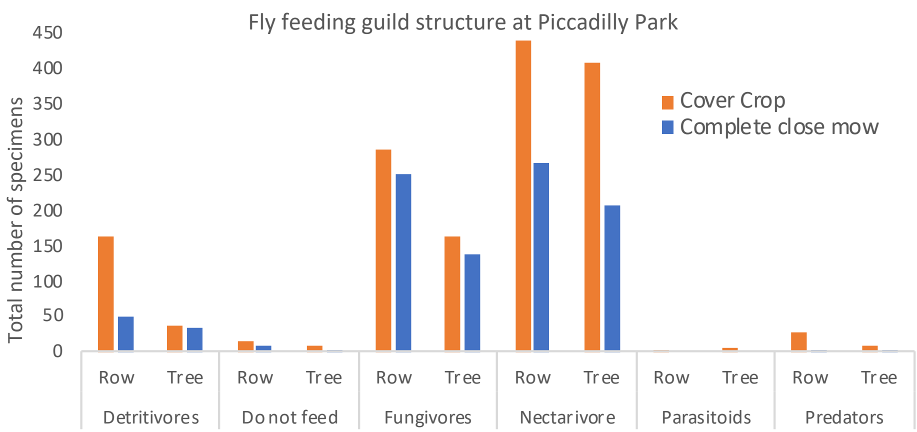


Chart 45: Fly feeding guild abundance comparing treatment and habitat at Piccadilly Park. Total specimen counts of all fly specimens identified over the entire sampling period (2018-19) at Piccadilly Park.

Several fly families within the nectarivore (potential pollinator) feeding guild such as Bibionidae, Anthomyiidae, Ephydridae, Drosophilidae, Ceratopogonidae and Syrphidae were present within macadamia trees in the cover crop treatment block, but absent within trees of the complete close mow block (**Chart 46**). Similarly, detritivores that recycle nutrients (Heleomyzidae) and parasitoids (Cryptochetidae and Tachinidae) were also present within trees in the cover crop treatment block but absent from trees within the complete close mow block (**Chart 46**).

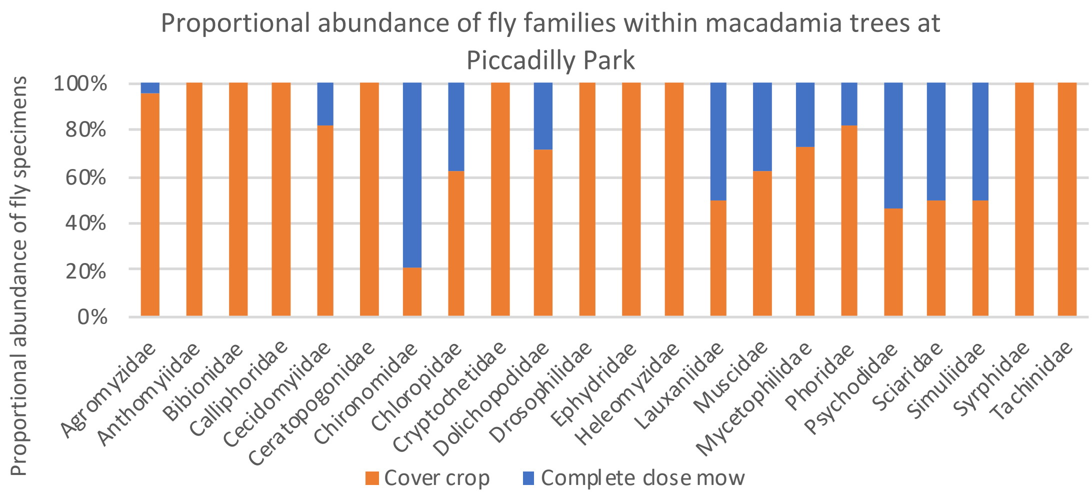
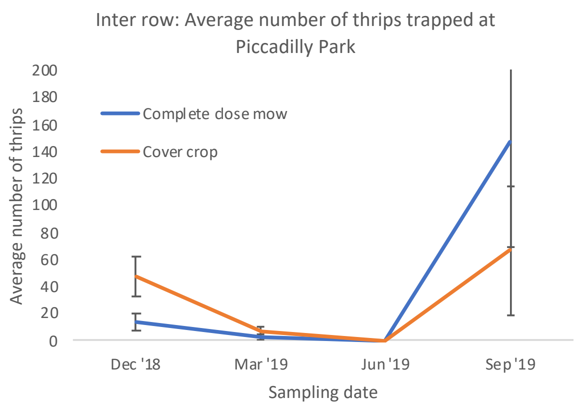


Chart 46: Proportional abundance of fly families within macadamia trees at Piccadilly Park comparing the cover crop and control over the entire sampling period (2018-19).

A focussed look at thrips at Piccadilly Park

Overall, there was a low abundance of thrips in both treatment blocks and there were no reported problems with thrips damage during the sampling period at Piccadilly Park. **Chart 47 L&R** show the average number of thrips recorded at each sampling period in the cover crop treatment and control at Piccadilly Park; this highlights any variations in their abundance over time. In September 2019 there was a peak in thrips abundance in both inter row and tree habitats, however, the scale of the peak was much less in the cover crop treatment block compared with the complete close mow block (**Chart 47 L&R**).



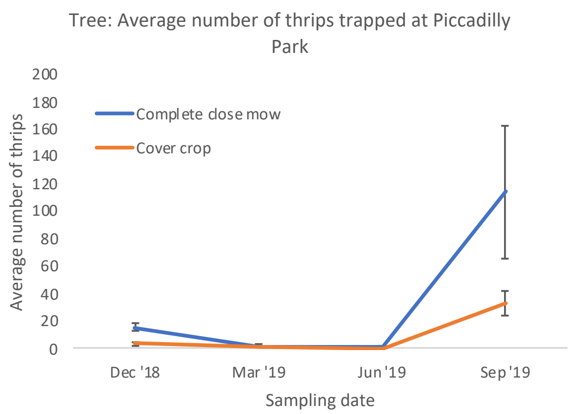


Chart 47: Left (L) The relative average abundance of thrips within inter rows (± SE) at Piccadilly Park in the control and cover crop treatment over the sampling period (2018-19). **Right (R)** The relative average abundance of thrips within trees (± SE) at Piccadilly Park to control and cover crop treatment over the sampling period (2018-19).

Discussion of case study results

Our results confirm the project hypothesis that improving inter row vegetational characteristics with a plant-based insectary will in turn increase the abundance and diversity of arthropods in both the inter row and macadamia tree. Higher *abundance* of arthropods in an insectary inter row means that there is more food source availability. Higher *diversity* of prey provides better nutrition, reproduction, and survival for beneficial insects as well as other important predators such as birds and bats, increasing the food web complexity further and strengthening ecological functioning. This increase in overall biodiversity and food web complexity provides more stable and better functioning ecosystem services such as soil health through nutrient recycling, pollination services and natural pest suppression.

Higher trophic levels such as predators and parastioids are more sensitive to changes in the environment by virtue of being dependant on lower trophic groups, hence they are more adversely affected by intense inter row management than, for example, herbivorous insects. To measure this, we used feeding guild structures to better realise the overall food web structure and complexity. In each case study we found that both predators and parasitoids had a higher abundance and diversity in all the insectary treatment blocks.

Nectarivores that feed primarily on nectar and pollen as adults (potential crop pollinators) were found to have increased abundance and family taxa diversity in all insectary treatment blocks. The role of flies as potential crop pollinators is poorly understood and under-appreciated; their potential to pollinate or visit macadamia flowers was not assessed in this project, however it warrants further investigation.

The increase in overall arthropod biodiversity particularly in the inter row did not increase pests of macadamia in the insectary blocks. Thrips were sampled in abundance from both the insectary treatment and control inter rows, however, their abundance was low within trees in all insectary treatment blocks though not within trees in all control blocks (i.e., complete close mow blocks). This suggests that thrips in an insectary inter row *do not tend to move into the adjacent macadamia trees* as they are most likely different species than those in the macadamia tree. Conversely there were more thrips and leafhoppers across case study farms in the macadamia tree of the complete close mow blocks. This warrants further investigation, though none of the case study farms reported any issues with thrips in either control or treatment blocks throughout the study.

In this project, various approaches to reduced mowing were trialled on a total of ten farms out of eleven. Of these ten, five had a pre-existing seedbank for grasses, herbaceous naturalised weeds, and local natives that provided measurable improvements in inter row vegetation for the purposes of an insectary where mowing was reduced. Five farms had a less favourable seedbank and reduced mowing alone was unable to generate an insectary. As the reduced mowing trials conducted by this project indicate, some but not all farms will have a seed bank with plant species likely to create an insectary. This is discussed extensively in detailed farm reports available in **Appendix 7**. It is also covered in more detail in **Guidelines in Table 5 and Appendix 3.**

Case study 1: Mohawk (Bevan & Willemse)

The experimental method used for this project required recording all plant species observed in the inter row of the respective trial blocks. Because of these records we can see for example that the average number of plant species recorded at Bevan & Willemse in 2017 was 10 in the control block, while in the mohawk block it was 19. This representation is more conceptually understood when we consider plant species observed as a percentage of biomass: we found that the dominant species in the complete close mow block was smother grass (*Dactyloctenium australe*) at an annual average of 95-99% of the biomass (**Photo 1a).** Smother grass has been incorporated and promoted in the inter row of many orchards precisely because of its growth habit in response to complete, close and regular mowing[31] as it is very dominant, shade tolerant and carpet-forming. Beyond erosion control, the provision of ecosystem services from regularly mowed smother grass is limited and this is not taken into consideration by many macadamia growers. When we reduced mowing in the mohawk at this farm, we found that already present plant species (grasses, herbaceous naturalised weeds, local natives), had characteristics suitable for an insectary and were able to establish and thrive. At the same time, with regular mowing under the trees, the smother grass habitat was sustained because it out-competed other species, allowing for year-round access and management, including harvest.

When compared to most other trial farms in this project, the pre-existing seedbank at this trial site consistently included a relatively high diversity of plant species (grasses, herbaceous naturalised weeds, local natives) with valuable floral traits and a capacity for good habitat complexity and limited disturbance. This trial site stands out particularly as one that makes the case for reduced mowing alone (without seeding or cover cropping), providing measurable benefits from an insectary where there is the right mix of conditions (seed bank, climate, weather, available light, life stage of the orchard).

Arthropod results for this farm have shown that arthropod abundance is clearly higher in the mohawk block than in the complete close mow. The mohawk was not shown to increase any macadamia pests. At the same time, we found double the abundance of parasitoids and predators in the mohawk and greater species richness in terms of arthropod families represented both in the row and trees. There was also a small increase in the presence of parasitoids and predators in the macadamia trees as a result of the mohawk vegetation compared to the complete close mow area of the orchard (particularly the Ichneumonoids). By contrast, there was a major peak in thrips abundance within trees of the complete close mow block on one particular sampling date, and another small peak in the same (control block) trees later in the study. No such peak in thrips abundance was found in trees within the insectary (mohawk) block, which remained at low abundance throughout the study. Thrips were not reported as an issue under management on this farm during our site visits and in information from bug checking by consultants.

Case study 2: Tree-to-tree reduced mow (Bundaberg North)

Tree-to-tree reduced mowing was selected for this block specifically because it was a young tree orchard. The pre-existing seedbank at this trial site consistently included a relatively high diversity of plant species ranging from 12 to 17 species over the life of the trial (grasses, herbaceous naturalised weeds, local natives) with valuable floral traits and a capacity for good habitat complexity and limited disturbance. In comparison to the mohawk trial in northern NSW (**Case Study 1**), this inter row vegetation was subject to the more demanding seasonal weather of Bundaberg, particularly the dry winters. The combination of the plant species mix and the seasonal weather conditions at this site meant that the availability of floral resources was inconsistent. The real benefit of this reduced mow approach under these conditions came from the insectary's capacity for vegetative biomass, and by extension an area of reduced disturbance. Over the life of the trial, an average of 95% of inter row ground surface was covered by vegetation at a height of up to 120cm, and often for periods of several months.

Options for inter row vegetation irrigation for farms in the Bundaberg area were reviewed and proposed by trial participants as possible future directions. These options included additional central drip lines or switching from drippers to sprinklers under trees to bring about a more consistent year-round inter row ground cover and insectary as a result.

Overall, both the control and the insectary treatment had similar arthropod abundance and diversity trends in the measures we assessed. There were, however, subtle changes in the arthropod assemblage, consistent over time, that indicate improvements in beneficial arthropods within the tree-to-tree reduced mow block. We found that there was a numerical increase in beneficial insects without corresponding increases in herbivores or macadamia pests in the insectary treatment block. For example, the increase in the beneficial fly family, Chamaeyiidae, within the tree-to-tree reduced mow block is potentially important for macadamia trees as the larvae are predators of coccids and psyllids. In the inter-row, the fly parasitoid/predator families Chamaeyiidae, Dolichopodidae and Tachinidae were twice as abundant in the tree-to-tree reduced mow block compared to the complete close mow block. There were also several wasp parasitoid families that were present in the tree-to-tree reduced mow block but not in the complete close mow and proportionally more nectarivores (potential pollinators) in the macadamia trees of the insectary block compared to the control.

These results are discussed extensively in detailed farm reports available in **Appendix 7**. They are also covered in more detail in **Guidelines in Table 5 and Appendix 3**.

Case study 3: Mohawk with seeding (Baldwin & Ranking)

The pre-existing seedbank at this trial site was relatively and consistently high in diversity of plant species (grasses, herbaceous naturalised weeds, local natives) with characteristics of value for an inter row insectary. Conservation biological control is particularly valued in certified organic operations and the improvement of plant species with more targeted and desirable insectary characteristics was a valuable area of investigation for this trial site.

The plant species selected for seeding at this trial site did not establish well and despite annual re-seeding throughout the trial, proportionally they could not sustain increases in the number of plant species present or related floral resources. An investigation into reasons for this result were outside the scope of this project. On the basis of climate suitability, many of the species included in promoted commercial “beneficial insect mixes” are not well suited or specific to temperate macadamia orchards, nor to sub-tropical zones where the majority of orchards residing in Queensland and northern NSW are. This is further realised by the much more promising results of the cover crop species selection, which is discussed below. By evaluating seeding and cover cropping trial sites independently, we have found further enhancements that could aid in future mohawk with seeding trials.

Overall there were nine extra fly families in the mohawk with seeding, with half of these being predatory fly families. Given the modest increase in prey as well as less competition from parasitoid wasps, the changes in inter row vegetation increased the higher fly trophic guilds in this block. In 2018 there was a slight change in experimental protocols in the control, which then increased the diversity of flies (two extra parasitic families) in that block for that period only. The results thus would suggest, even with subtle changes in the inter row vegetation, a pool of beneficial predators and parasitoids in the fly group (Family taxa) are being attracted/recruited and overall contributing to more complex feed webs in this orchard system. We expect over time with consistent vegetation improvement in the inter row, more abundance and diversity given our result with the recruitment of rare species that we calculated using family taxon surrogacy measures.

When this farm was compared to the other trial farms, there was a relatively high diversity of flies. We also saw reasonable diversity of beetles and true bugs. For flies, abundance and diversity was very good (better than northern orchards) and many fly families that are predators and parasitoids were represented and had much higher populations in the mohawk with seeding block. Many other fly families had lower abundance however were not present in the control block. Mohawk with seeding is increasing the diversity of flies, and with subsequent years of monitoring would be expected to show higher abundances as well.

However, compared to the other case study sites, there was also a relatively lower abundance and diversity of parastioid wasps. This was unusual and unexpected, especially for an organic farm (wasps are sensitive to pesticides so an organic orchard should be a favourable environment) especially when considering results for other insect groups present on the farm. This presents a case for the consideration of measures to increase parasitoid wasp diversity particularly by increasing the availability of suitable floral resources. While the trial of a “beneficial insect” seed mixes did not achieve strong results in terms of establishment at this site, the results for wasps indicate that it would be worthwhile trialling other plant species, and particularly those noted to be favourable to wasps.[15,32]

A detailed report on this farm is available in **Appendix 7**. It is also covered in more detail in **Guidelines in Table 5 and Appendix 3**.

Case study 4: Cover cropping (Piccadilly Park)

A review of the results for cover cropping return strong results when compared against that farm’s control. The average percentage of vegetation biomass as floral resources was between 10% and 30% year-round. Furthermore, not only were there more flowers, but there were also more flowering species. By contrast, we found that for the control the dominant species was smother grass (*Dactyloctenium australe*) at around 99% of the biomass and this was without flowers year-round as a result of complete close mowing. This is especially apparent in **Photo 5a**, above, where we can also see that the capacity for smother grass to provide ground cover is diminished with bald areas as light to the orchard floor is low. For this grower, the gradual reduction in ground cover provided by smother grass, along with its limited capacity for ecosystem services, was one trigger for farm-wide orchard row removal, which commenced in 2017, and has incorporated the implementation of a comprehensive cover cropping system.

Cover cropping was also associated with substantially stronger results when compared to other insectary treatments trialled in this project (as will be discussed in **Guidelines in Table 5 and Appendix 3**, an inter row insectary option should be selected on a farm-by-farm basis). Although only sampled on four occasions, we found the highest rate of arthropod abundance and diversity in the cover crop compared to the complete close mow and the highest ratio of beneficial arthropods when compared to prey. This provides an insightful demonstration of a surprisingly rapid restoration of arthropod biodiversity at a time when several influential studies argue that there is a global decline in arthropod biodiversity as a result of habitat destruction and the intensification of agriculture.[5]

At Piccadilly Park, unlike all the other case study farms, the benefits seen in terms of arthropod abundance and diversity in the inter row also translated strongly into the macadamia tree. Predator and parasitoid abundance within trees in the insectary block at Piccadilly Park were double that found within trees in the complete close mow block. There are several farm features at Piccadilly Park that may have contributed to this. The first is the selection of species in the cover crop seed mix and associated available floral resources. At Piccadilly Park the cover crop mix consisted of species selectively bred for flowers that are abundant (brassica) and/or large (sunflower) and hence highly attractive to insects (this relates to the floral architecture of species with associated attractiveness to insects and available pollen and nectar in quality and quantity). Furthermore, this vegetation was rejuvenated (terminated and reseeded) three times over the life of the trial (which was 1 year at Piccadilly Park), serving as a well provisioned habitat year-round. In comparison, plant species present at Bevan & Willemse, Bundaberg North and Baldwin & Rankin generated an insectary under conditions of reduced mowing, but they flowered intermittently and opportunistically as seasonal conditions permitted and with fewer and smaller flowers as linked to phenotype and genotype for locally occurring grasses, weeds and natives.

The second feature that differentiated Piccadilly Park from the other case study sites was reduced disturbance of the inter row vegetation. Termination of cover crops occurred in alternate rows to ensure an insectary was always present in the orchard and hence disturbance to arthropods was limited. The other case study sites had more overall disturbance during the trial.

A third point of difference between Piccadilly Park and two of the three other case study sites was chemical use. Bundaberg North at times applied insecticides to treat twig girdler and scale; Bevan & Willemse treated lacebug, macadamia seed weevil and fruit spotting bug at different times. Baldwin & Ranking being organic had no insecticide use. Piccadilly Park did control for macadamia seed weevil (using Indoxicarb) in both treatments between September and December sample dates, however, was relatively chemical free otherwise (including fungicides and herbicides).

Finally, the sheer scale of the inter row insectary vegetation at Piccadilly Park is noteworthy. Following on from row removal, Piccadilly Park had large (14m) inter rows with 3m to 6m inter row cover crop centre strips. There were also cover crops seeded more selectively to fit around harvest under the drip-lineThe sheer number of insects for alternative prey from the cover crop may have contributed to increased predator and parasitoid abundance and diversity in the macadamia tree.

Although there was an increase in leafhoppers in the cover crop inter row compared to the control, *they did not impact on the macadamia tree*. Conversely there were lower numbers of leafhoppers in the control block inter row, but there were four times as many leaf hoppers in the tree of the complete close mow block as compared to trees in the cover crop block. Generally, these are minor pests of mature macadamia trees, however we suspect that the increased predators and prey (proportionally 80:20) may be reducing the numbers of herbivorous pests in trees. This prey shifting by generalist predators and parasitoids (e.g robber flies, syrphid larvae etc) seems to be reducing the impact of macadamia pests. We did not directly measure this; however, it would be an exciting experiment to conduct on this farm and in cover crops generally. A concurrent study of lacebug in August-September 2019 on this farm had preliminary results indicating through branch taps of the macadamia tree, that there was four-fold increase in spider abundance and three times as many adult lacewings in the cover crop block compared to the complete close mow treatment.[14] Further studies on the impact of beneficial insects on pest suppression is highly warranted in this system.

Selecting an inter row insectary option and management plan is discussed in detail below within **Guidelines in Table 5 and Appendix 3**.

This project was in-field for a total of 2.25 years for the mohawk, tree-to-tree reduced mow, and mohawk with seeding case studies; and 1 year for the cover cropping case study. Similar studies find that improvements in arthropod abundance and diversity using insectaries for the purposes of conservation biological control are best understood as cumulative and as developing trends through time. These studies are typically in the field for a minimum of 3 years[8,33,34] and they find that their results become pronounced at around 5 to 6 years.[17,35,36] On this basis, the results for this project are very promising indeed. In this project we propose that as management decisions are iteratively developed and improved for the macadamia inter row insectary, the abundance and diversity of beneficial arthropod populations will increase, while the food web will become more ecologically complex and self-regulating for conservation biological control and other ecosystem services.[15] Given the lack of macadamia pests in the inter row at all case study farms, we suspect that inter row vegetation might offer some protection for prey and beneficial arthropod diversity in the event that chemical controls in the crop are needed, allowing populations of beneficial arthropods to quickly re-establish. It would be pertinent for future studies could address this.

Outputs

Introduction

This project has developed practical options for inter row insectaries that are compatible with the seasonal demands of macadamia orchard management and can be selected on a farm-by-farm, season-by-season and site-by-site basis. It has also developed information on likely association between insectaries and the potential for increased rat, invasive weed, and/or arthropod pest presence, which can be used by industry and growers to help with decision-making for managing insectaries. Finally, the project has quantified association between changes in inter row vegetation management and changes in orchard biodiversity for vegetation and arthropods.

The project has delivered the following high-level outputs:

- Macadamia industry-specific review and study of the impact of management practices in the inter row on plant and arthropod biodiversity.
- Macadamia industry-specific trialling of new options for inter row management, providing guidelines for setting new industry standards.
- Promotion and championing of new industry conservation biological control management systems using reduced mowing, seeding and/or cover cropping in the inter row.

Table of project deliverables

Project deliverables are listed below in further detail **Table 3**:

Table 3: Itemised project deliverables.

Output	***Date***	***Description***
Literature review	22/05/2017 Milestone 102	This review provides the first opportunity for the consideration of "managed vegetative diversity" and insectaries within the specific context of macadamia orchards. http://www.bioresources.com.au/inter_row_project/publications.html and https://www.horticulture.com.au/growers/help-your-business-grow/research-reports-publications-fact-sheets-and-more/insectiaries-literature-review/ 198 reads on Dr Abigail Makim's profile on researchgate.net (15 May 2020)
11 trial sites	The trials ran from early 2017 to mid 2019	Located in the Bundaberg region, Gympie, the Sunshine Coast, northern NSW, and the NSW mid north coast. The objective of the trials was to provide growers with practical experience in reduced mowing on-farm with monitoring to quantify results.
Experimental data	Collected from early 2017 to mid 2019	Collected from the 11 trial sites (including the 4 Case study sites): inter row vegetation assessments; arthropod samples; environmental and site conditions; participant observations of rats, weeds, pest reservoir, management issues. Refer to **Appendix 4**
Presentations	June 2017 September 2017 February 2018 February 2018 June 2018 November 2018	Mac consultants conference Mac group poster (**Appendix 6**) Mac Society groups, Glass House Mts, Gympie Macadamia IPM program annual researcher meeting Mac consultants conference Macadamia IPM program annual researcher meeting
Reports	August 2018 2018 2020	Mac Bulletin NSW Macadamia Plant Protection Guide 2018-19 NSW Macadamia Plant Protection Guide 2020-21
Video	2019-20	http://www.bioresources.com.au/videos/interrow_part_1.mp4 http://www.bioresources.com.au/videos/Direct_drill_seeder.mp4
www		http://www.bioresources.com.au/inter_row_project/
Grower reports	February – March 2020	Individual final reports to participating growers **Appendix** 7 Individual detailed photographic reports on plant ID and inter row condition.
Case study reports	April 2020	1-page case study report for participating growers and other industry professional **Appendix 6** www.researchgate.net Case study trial results, "cover cropping" **Appendix 7** www.researchgate.net 213 reads on 16 May 2020 @drexharris on Twitter 30 click throughs on 1 May 2020 http://www.bioresources.com.au/inter_row_project/publications.html Case study trial results, "mohawk" **Appendix 7** www.researchgate.net

Outcomes

New practices for conservation biological control in macadamia orchards

Reduced mowing is a simple starting point for most growers to trial a move away from low vegetation diversity and towards use of the inter row for the purposes of an insectary for conservation biological control. This is achievable on many macadamia farms.

Seeding and cover cropping in the inter row are other options. These involve greater management complexity but also considerably greater conservation biological control benefit, in conjunction with multiple other valuable ecosystem services[37] including those associated with soil health,[38] erosion control,[39] soil water storage and conservation,[40] adaptive management for climate change[41] and carbon sequestration.[42]

This project provides detailed recommendations and guidelines for selecting and managing each of these options, as suits specific farm, season and site conditions. These recommendations and guidelines are provided in **Appendix 3**.

Cover cropping is a dedicated and specialised management practice, which is beyond the scope of this project. It is the subject of further development and extension in two new BioResources projects to be rolled out in 2020-21 (funded by Landcare).

The project recommends insectaries in the inter row on the basis of low to no risk of associated problems with rats, weeds and/or insect pests *where there is basic monitoring and management of the inter row*.

This is discussed in **Appendix 2**.

Behavioural changes reported by participating growers

On the basis of their participation in this trial, growers provided the following feedback via completion surveys regarding behavioural changes in industry standard inter row management:

- Identification of farm-specific ways to reduce mowing in the inter row of their orchard – changes to mowing schedules, changes to areas mowed (e.g., leaving strips, alternate row mow).
- Awareness of other areas on their farm with the potential for insectary, including headlands and fence-lines.
- Consideration of logistics of reduced mowing operations for planning and purchasing future machinery.
- Seeking information and advice on conservation biological control and management decisions for insectary areas.
- Seeking information and advice on seeding and cover cropping.

Adoption and uptake reported by participating growers

In **Table 4: Completion Survey**, below, we see participant reflections on adoption and uptake for themselves and industry.

Table 4: Completion survey: individual participating grower responses to the questions "What is the future for inter row insectaries on your farm?"; and "What is the future for conservation biological control for the macadamia industry?"

Question	*Response*
What is the future for inter row insectaries on your farm?	Currently taking opportunities around the farm in some areas to reduce mowing occasionally, as possible. Seeding is a big consideration in future plans. There are 12m blocks where reduced mow and seeding very practical and valuable. Looking at seed mixes. Not currently continuing reduced mowing farm-wide but thinking about future management approaches, such as mowing scheduling and training, and new machinery purchases (slasher, harvester) over the next few years specifically to incorporate inter row insectaries.
	Now keeping a mohawk but not letting it get too long: mower 1.8m deck, leaving a 1.5m mohawk. Mow in traveling mode. Fairly regularly mown, leaving at 300-200mm high. This seems to encourage more flowering than when we let it grow longer. And hard to put machinery through if it gets much longer so keeping it at a manageable height. More round-up, targeted spot spraying of *Setaria* grass to

	prevent dominance. Looking for areas to create some vegetative diversity. Considering seeding options and mixes. The canopy is closing-over so the orchard is getting darker, which limits future opportunities.
	Very relevant for young trees, new blocks, where limited management is necessary. Prefer 500m herbicide under trees as too much grass competition around young trees not desirable, especially crows foot grass. Mowing beside trees rather than herbicide too difficult with current management system: need the right machine. Let inter row go, monitor vines etc., make sure they're not getting into trees. Powdery mildew knocks vines out in cooler months, so reduced mow is good definitely in cooler months. Mowing provides mulch in dry conditions, maintains moisture, saves irrigation, best of both worlds.
	Ongoing reduced mowing in 11m rows will be easy into the future. There are blocks with 8m rows and there will come a time when a mohawk will not be possible. But alternate mow will definitely be done there. Overall, already looking at areas and ways to reduce mowing and improve vegetation and insects farm-wide. 8m rows especially worrisome area with low vegetation diversity in the general area. Considering plantings of perennials on headlands and hedgerows, especially anywhere harvester doesn't need to turn. During harvest mow with side-delivery back under trees. Using this approach don't get build-up of mulch in centre trapping nut, so not a problem for harvester.
	Ongoing row removal and cover cropping: 2 summer, 1 winter. Centre strip 6m wide, always terminate and reseed alternate row approximately 1 month apart, more thought yet. 25 different species now seeded into the dedicated "meadow" insectary area. Looking for more opportunities for permanent insectaries, rows of perennials shrubs (*Buddleia)* strips for seeding.
	Reduced mowing was typical for us pre-weevil and we should be able to return to it now with better weevil control available. Outside of harvest a 2-monthly rotation of mowing, depending on time and staff availability. The canopy is closing over so that will start to limit future opportunities in the inter row.
	With the row width we found that we couldn't keep a mohawk once primary orchard floor clean up began. We've started alternate row mowing outside of harvest. We are looking for ways to do things differently. We developed an idea for a "mobile flower-hub" last year and have started to put them out in the orchard. These are 1000l shuttles and we drive them around to different areas in the orchard. There's some fine-tuning on how to water, weed etc. We have started a new venture in our operation; a dedicated organic farming system block. In some ways this is a romance, but we are also very serious about making this venture viable, sustainable. It will be a beacon for what we can do as an industry. We want all of the different experts, entomologists and so on involved from the outset, so that we get the whole farm set up to be self-sustaining with pest suppression, pollination, water and soil conservation, and so on.
	Stopped mowing outside of harvest, has helped. What are plant species that are softer and easier? - Green panic was a problem. It used a lot of horse-power when taking machinery through. What are the type of crops that will give best bang for buck - cover cropping, inter row - shade, slope. Limb removal underway. What type of machine will do it? double disc. Very interested in specifics of set up. Inside or outside the tractor wheels. Seed mixes specific our area. Sow dry in flat country, in areas with compaction etc, want to plant into moisture. Depends on soil type, moisture, in a given season, might need to get chisel plough in. Might be unlucky with heavy rain and loose soil. Would need to plan for inter row - reduce tree height, limb removal, get more sunlight, staged planning, so many different characteristics in the orchard. Staff information and education, to understand some of these management practices.
	Committed to mohawk. Looking for advice on seeding options, and necessary machinery. As organic growers we value the contribution of beneficial insects. In high pressure years we might lose a bit, but in other years we get the same yields as other growers without using chemicals. We know there's more pressure from FSB in our old dark orchard where there's no inter row. In our young orchard with inter row there is much less pressure. We need to keep working at the best management approach for our farm. Alternate row seems like a really good next step. How to keep a mohawk during harvest with the machinery we currently have? What to do as trees grow and canopy closes over?
What is the future for conservation biological control for the macadamia industry?	Very confident of the benefits and practicalities of including reduced mow. So much so that looking at reduced mow and seeding on "own" farm (this correspondent managed the relevant trial farm). Needs to be done, be open-minded, make the commitment and it's not hard to see the benefits far outweigh and problems. This is an important consideration for optimising future yields in the face of softening prices on the international market. Something we should push for, we have to do it. there is "no added pressure" to incorporate insectaries into the orchard.

	Love to think it would become integral and essential. After a spray program how will you restore biological control? Insectaries are where this can happen. And consider biocontrol releases. Leave veg strips. This project will help get the message out. There should be a real discussion on how to design new orchards; and what to do with older orchards. Dedicated areas for biodiversity. Continue to develop management approach for insectaries. It's about finding opportunities around the farm for insectaries. Enough light in the rows is the biggest issue and "dark orchards" are a major consideration. Communicate the benefits of insectaries and the problems of dark orchards, skirting and hedging, limb removal, the angle of tree - cone and vase are first line of defence. But a lot of growers should be looking at every second row pulled out and then new plantings. So many orchards too tight and dark for this to be effective. Consider varieties of trees that allow more light. A38s A16s much better for letting filtered light through. Daddow by contrast extremely dense.
	Huge benefit especially if the harvest period can be shortened up.
	Change ideas on the value of "messy" orchards. Don't be afraid to let grass and weeds grow out a bit.
	Improve understanding and knowledge of multiple ecosystem services of cover crops, not just for insectaries: photosynthesis of plants in inter row is producing exudates, which are valuable for soil biology. Also, the cover crop is creating a water reservoir; so far soil health management and cover crop has increased soil carbon on my farm from 4% to 8-10%. That's equivalent to 140, 000L of water per ha. Growers should use twitter, follow hashtags, use facebook, youtube. Watch webinars. Follow innovators. Currently not any no-till cover crop conferences in Australia, unlike America, where there is a lot of opportunity for learning, extension etc.
	Important part of IPM practice that everyone will need to adopt. This is a strategy to resilience. Drill down into the data. Rats are the only real impact to be considered when rolling out a reduced mow program and we found that we managed that easily.
	Industry needs to explore the options out there. It should be reducing its environmental footprint where it can. Keep looking for alternatives and don't go back to what we already know and old ways of doing things because there are lots of ways we can change for the betterment of the industry.
	Definitely is promising if we can use these things. It might give us another way to stay on top of over-wintering for pests. Bigger context includes issues like Acephate to be withdrawn. Look at out of orchard insectaries, buffer zones, where don't have to harvest. Insectaries outside of harvest. Orchard design, row width. What's the optimal distance for insectaries? Unsprayed and active. Long term future that could work. An unproductive area could be targeted for row removal, leave irrigation in there for insectary preserve chemistry as much as possible by using these methods. Have to consider all possibilities, it's important. This project has opened up the management scenarios for different growers, from bench-marking look at break down of middle 50%, top 25%- this is where there's interest and capacity. Let the smaller growers observe. Who has attention to detail and can roll out new management approaches? New BioResources project looking at cover cropping is great natural progression. Always interested in helping with betterment of industry. Keeping experts such as BioResources in the industry is important.
	Mohawk worked for encouraging beneficial insects on our farm. It's a positive and something to aim for others.

Access to new information

The project has provided participating growers and industry with access to new information on the design, management and results arising from conservation biological control:

- Existing vegetation biodiversity in the inter row. Changes to vegetation biodiversity in response to trialling treatments.
- Arthropod biodiversity in the orchard. Changes to arthropod biodiversity in response to trialling treatments.
- "Reduced mow" protocols and strategies for the inter row.
- Seed mixes suitable for the macadamia inter row; proof of concept of seeding to improve inter row vegetation for the purposes of insectary.
- Cover cropping for the inter row. New systems for realising the potential and value of this area in the orchard landscape in terms of productivity, profitability and sustainability.

Pathway to conservation biological control

The project has established a pathway with achievable milestones and quantifiable results for the consideration of individual growers and industry at large (see **Guidelines Table 5 and Appendix 3** for details):

- Step 1: Audit orchard for tree age, row width, available light to the orchard floor, available machinery for inter row management, current rat and weed management program. Set conservation biological control objectives.
- Step 2: Select and implement inter row insectary option as suits capacity and objectives:
  - Option 1: Reduced mowing option (**Case Studies 1 & 2**)
  - Option 2: Reduced mowing option with seeding (**Case Study 3**)
  - Option 3: Cover cropping (**Case Study 4**)
- Step 3: Monitor and evaluate:
  - Inter row vegetation growth rates, flowering
  - Changes in rat activity or weeds
  - Ease of incorporation into standard orchard operations for harvest, clean up and so on.
  - Consider opportunities and capacity for progression.
    - Reduced mow progresses to reduced mow with seeding
    - Reduced mow with seeding progresses to cover cropping
- Step 4: Select and implement inter row insectary option as suits improved capacity and revised objectives. And so on.

Seeding and cover crops

"Reduced mowing" was initially identified as the focus for this project because it provides an achievable and simple starting point within reach of many growers. But preliminary field work and stakeholder feedback revealed that existing vegetation in the inter row of many orchards was frequently insufficient to the task. Knowledge and extension on the topic of plant species suitable for ground cover in the macadamia inter row has not been revised since 2003.[43]

Since that time a number of major changes have occurred:

- The macadamia industry has been on a growth trajectory with many new orchards planted yearly and expansion into new climatic areas in Queensland;
- Many orchards in NSW are aging and becoming "dark" and developing associated problems requiring new cultural controls;[44]
- Precision and other agriculture technologies have become more specialised and affordable with specific application for cover cropping and conservation biological control;[45]
- Expertise, experience and success with cover cropping in many industries has emerged in Australia and internationally;[9,46]
- There is good supporting evidence based on farmer practice and trials applying longstanding ecological and agricultural propositions to support adoption of seeding and cover cropping to create insectaries for beneficial insects (as covered in this project's literature review);
- Multiple ecosystem services is an emerging area of research and knowledge (as discussed above);
- Seed varieties, availability and expertise has expanded;[47]
- Stewardship of biodiversity, soil health, soil carbon and so on, are at the centre of major federal and state government initiatives;[48,49]
- Producers from many industries are seeking and providing peer-to-peer support and this dialogue is expanding rapidly via social media (#covercrop, #soilhealth, #soilbiology); and finally,
- As is reflected in this project, ideas and practices relating to the functional capacity and value of the macadamia inter row have changed to incorporate insectaries and other ecosystem services.

On the basis of this revised scope, Bioresources Pty Ltd has become a major co-investor in the project, along with Hort Innovation. To incorporate this change of scope, Bioresources has invested in the order of an additional $160k over the life of the project (this figure excludes administration costs such as insurance and in-kind time from the project lead). This allowed:

- Inclusion of a "cover cropping" case study in this project. As the results presented above indicate (**Case Studies**), cover cropping increases the abundance and diversity of beneficial arthropods present in both the inter row and the macadamia trees, and hence the orchard's potential for self-regulating conservation biological control. Building on these results, the cover cropping case study provides growers and industry with sign-posts and a pathway to changed management practice for IPM. To progress this, Bioresources are undertaking two new studies of cover cropping in the macadamia inter row as part of the Landcare Smart Farms Small Grants program (2020-22).
- Purchase and trialling of new technology including seeders and crimp roller (discussed below).
- Purchase and trialling of seed mixes.
- Engagement with the seed supply industry to develop knowledge, understanding and capacity for servicing macadamia growers.
- Identification of arthropods to family level, which was crucial to the investigation of changes in food web complexity, this was time and resource intensive.

Protocols

The project developed protocols for trials of applied on-farm conservation biological control insectaries in the macadamia inter row (see **Methods and Results**); and **Guidelines in Table 5 and Appendix 3)** for working farms are based on these protocols.

Monitoring and evaluation

This study has been complex, examining a specifically focussed research question via field experiments and field trials within the context of every-day working farms. The project team and growers have worked together to find practical ways of incorporating insectaries into macadamia orchards. The project has relied heavily on participants reviewing, revising and communicating their inter row management changes (PAR). This has been done principally via "narratives" (an unstructured interview conducted during site visits), followed up with emails, phone calls and texts.

- The M&E plan specified "Narratives" for the life of the project.
- 50 individual narratives were recorded.
- Narratives were taken from all participating growers (owners or managers, as appropriate), and a number of other interested growers, and industry consultants, who were not directly involved in the trial.
- The narratives cover all project phases: conception and initiation, planning, execution, monitoring and evaluation, and project completion.
- This method of M&E was selected as consistent with the project's focus on PAR and field trials.
- Narratives were used inside and outside the project for M&E.

Positive and negative experiences with regards to the practicalities of insectaries in the inter row were recorded for the 11 participating growers. In recording these results, the project team and participating growers undertook iterative modifications of trial protocols for management of insectary areas. By the end of the trial this method had produced recommendations for insectary options in the macadamia inter row suitable for standard orchard operations and also suitable for insectaries (see **Guidelines in Table 5 and Appendix 3**).

In this way, participating growers, who had self-selected with their interest in the project's objectives, were working with the project team to develop and implement a new technique for orchard management. Through the life of the project this method also helped to identify the following key themes:

- *Intensive seeding and cover cropping*. This was outside the original scope of the project but stakeholder interest in this was very strong. This, rather than reduced mowing, became the principal interest for the project and its participants through grower-initiated trials.
- *Insectaries*. There are particulars involved in managing an inter row insectary. See **Guidelines in Table 5 and Appendix 3 and Individual Grower Reports (Appendix 7**).
- *Rats*. Prior to commencement of the trial grower concerns about rats, their confidence in managing rats and the presence of a rat problem varied significantly farm-by-farm. This was an issue over and above the inter row insectary trial.

Recommendations

Growers

- The insectaries trialled in this project can support a more complex food web, and this is a prerequisite for conservation biological control. In this study we have found that predators and parasitoids can increase in abundance and diversity with the provision of SNAP. It is on this basis that pest suppression is possible and conservation biological control can be recommended as a valuable tool for IPM systems.
- An inter row insectary can be incorporated into existing orchard inter row management and with basic monitoring and management will not lead to other problems. (This is discussed at length in **Methods: Analysis and interpretation** and **Appendix 1**).
- Reduced mowing is a simple starting point achievable for most growers, to trial and test the practicalities of an inter row insectary on their farm (see **Table 5**, below, and for further details refer to **Appendix 3**).
- Growers will need to evaluate their orchards on a case-by-case basis for row width, available suitable machinery, available suitable light, and tree age.
- Inter row insectaries must be managed with clear objectives, planning, and management strategies, which should be considered on a farm-by-farm basis (see **Tables 15 & 16**, for recommendations in **Appendix 3**).
- Commitment to farm space and dedicated management will realise the true potential of insectaries and conservation biological control. Furthermore, there are multiple ecosystem services and multiplier effects.
- Seeding and cover cropping can yield very high value insectaries and this project finds these insectaries will substantially increase the numbers of beneficial insects – predators, parasitoids and potential pollinators - present in the orchard. Additionally, there are multiple ecosystem services and multiplier effects associated with seeding and cover cropping (**Image 1: Food Web**, below).

Table 5: Guidelines for inter row insectary options – mohawk, alternate row mow, reduced mowing with seeding, and cover cropping. Refer to **Appendix 3** for further detail.

MOW OPTION	DESCRIPTION
MOHAWK	*Reduced mowing leaves a central mohawk strip down the row, with more regular mowing under the drip-line of the trees.*
	A mohawk can be retained year-round, including throughout harvest. Row width of minimum 10m. Mohawk strip width to be calibrated against width of harvester, slasher and mower.
ALTERNATE ROW MOW	*Mow every second row on a rotating schedule, allowing all rows to "grow out" somewhat across the year and all rows to be mowed alternately, outside of harvest.*
	This approach provides opportunities to more regularly encourage rejuvenation and flowering of vegetation in the inter row while managing dominant vegetation and areas of potential rat activity.

	A good option for young tree blocks where there is very limited ongoing access and management. Also a good option where row width less than 10m and during non-harvest.
REDUCED MOWING WITH SEEDING	*Decide on a preferred reduced mowing strategy. Incorporate seeding into the inter row to improve vegetative diversity.*
	Intermittent seeding with seed mixes suitable specifically for the macadamia inter row to improve quality of the insectary and other ecosystem services.
COVER CROPPING	*Intensive management of the inter row with cover crops that improve multiple ecosystem services including insect pest suppression and crop pollination, nutrient cycling and soil health, carbon sequestration, and water and erosion control.*
	This is a dedicated system and detailed recommendations are beyond the scope of this project. Further information with be available from Bioresources in 2020-21. A valuable management approach for new blocks, young tree blocks, and blocks where row removal is underway. Also suitable in mature orchards where row width is greater than 10m and good light is available.

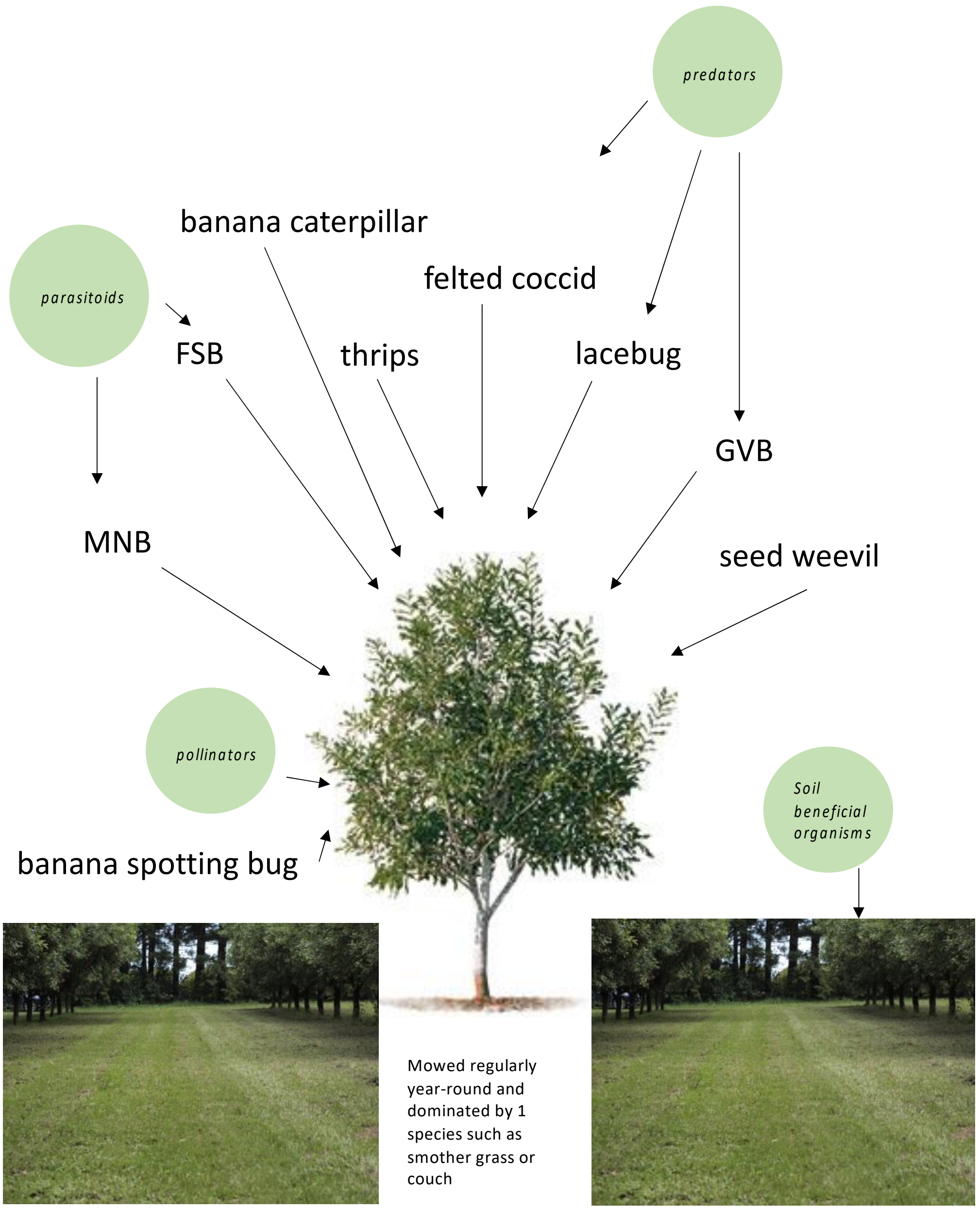


Image 1: Generalised representation of the food web in a conventional orchard with regular, complete close mowing. Based on data collected by this project, we find that a conventional orchard has relatively modest counts for abundance and diversity of beneficial arthropods - predators, parasitoids and pollinators - when compared to the cover cropping block (below). Overall there were fewer insect families represented in the inter row and tree, and specifically fewer natural enemies. We can speculate that this comparatively simple food web has a limited number of interactions between natural enemies and pests and hence limited potential for biological control. This not only limits self-regulating pest control, but also limits nutrient recycling, pollination and other ecosystem services. Note: the list of pests presented here is neither exhaustive nor universal: there are further recorded pests and we would not find all of these pests on any one farm or even in any one growing region.

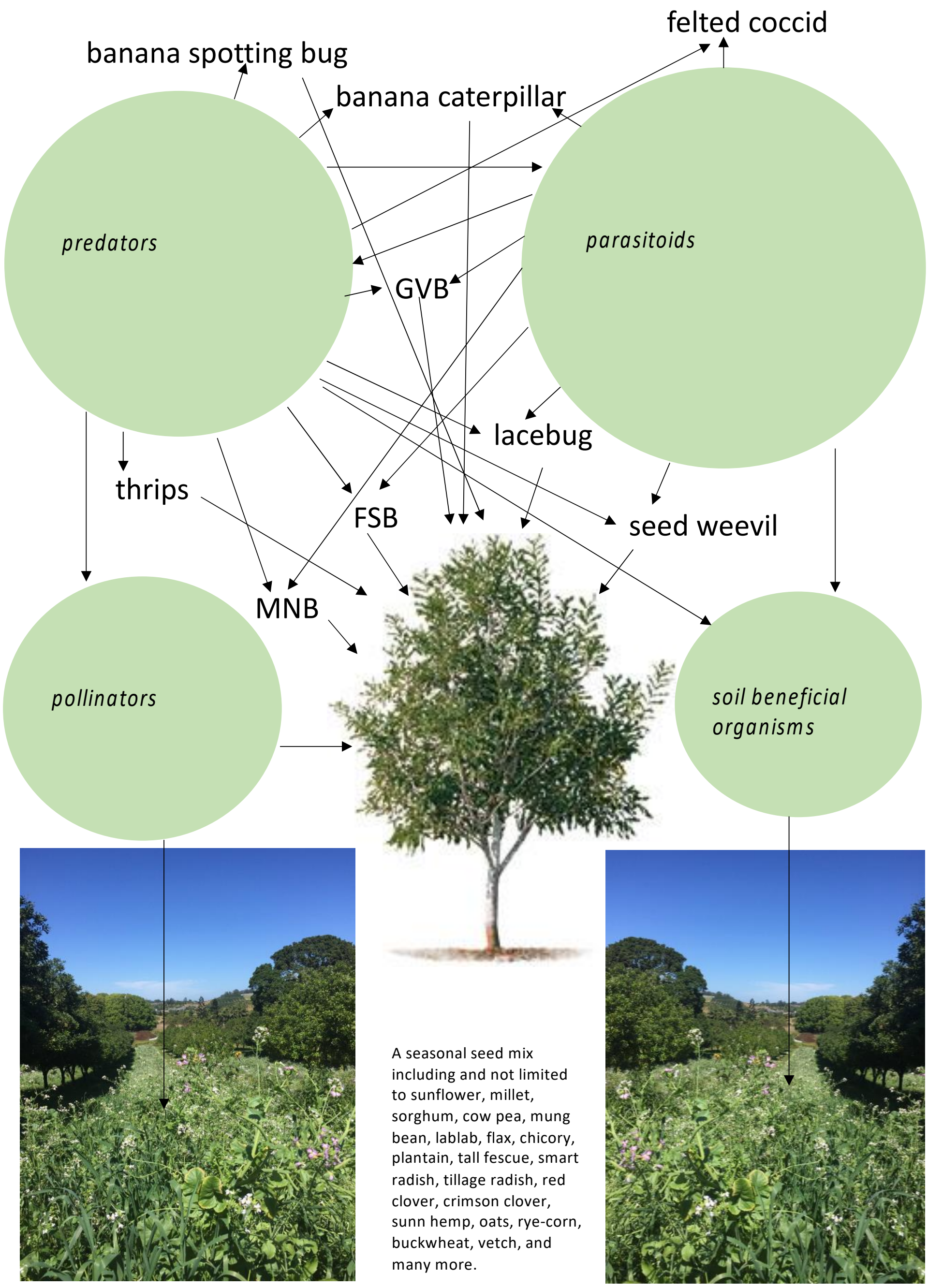


Image 2: Generalised representation of the food web in an orchard with cover cropping in the inter row. Based on data collected by this project, we find that this orchard has relatively greater abundance and diversity of beneficial arthropods. Compared to the conventional block (above), there were on average approximately three times more parasitoids in the inter row and more than twice the number in the macadamia trees. There were close to an average of three times the number of predators in the inter row and nearly twice as many in the trees. There were an average of around twice as many potential pollinators in the trees. Overall there were more insect families represented in the inter row and tree, and specifically more natural enemies. We can speculate that this increased food web has a greater number of interactions between natural enemies and pests and hence greater potential for biological control. This not only provides self-regulating pest control, but also benefits in nutrient recycling, pollination and other ecosystem services. Note: the list of pests presented here is neither exhaustive nor universal: there are further recorded pests and we would not find all of these pests on any one farm or even in any one growing region.

Industry

- Use material provided in this report to progress and develop understanding and discussion via professional associations, field days, and other supports for growers and consultants of:
    - 1) Conservation biological control (**Introduction**, above; **Results**, above);
    - 2) Insectaries in macadamia orchards and IPM programs (**Image 2** above);
    - 3) Seeding (**Case Study 3**); and,
    - 4) Cover cropping (**Case Study 4**).
- Use material provided in this report to deliver extension support, training and information modules for growers to establish and maintain insectaries capable of conservation biological control and compatible with standard farm operations (**Pathway to conservation biological control**, above; **Appendix 3 Guidelines**, below; **Appendix 7 Individual Grower Reports**, below).
- Use material provided in this report to guide growers in investment decisions for future machinery, training and development of personnel, and orchard development (new orchards; dark orchards).
- Invest in ongoing education for growers on general rat management planning, strategies and technologies (**Appendix 2 Findings**).
- Adoption and uptake of conservation biological control in the Australian macadamia industry presents a new opportunity to develop a distinctive Australian product and brand for key markets in Japan and Europe within the context of softening prices and growing trade competition.

These recommendations should be considered within a broader context facing all agricultural and horticultural industries within Australia, macadamias included, where there are numerous pressures in regarding management decisions related to productivity, profitability and sustainability. Some of the pressures include:

- Reducing pesticide use due to consumer and environmental pressure, as well as the withdrawal of existing insecticides and the higher costs of new selective insecticides
- Reducing chemical fertiliser use due to consumer and environmental pressure
- Dealing with water runoff and topsoil loss as a result of the 'dark farm' phenomenon seen in a large portion of Australian macadamia orchards
- The likely arrival of varroa mite (*Varroa destructor*) at some stage in the future and its impact on crop pollination
- Reducing on-farm carbon emissions and increasing carbon sequestration
- Changing weather patterns and climate change; and coping with severe weather events and increased temperatures.

On-farm insectaries and cover cropping are set to be important tools in helping to alleviate these pressures for Australian macadamia growers. These technologies are new to macadamias and need to be tailored to suit individual farm situations, but with the understanding and support of innovative growers and consultants this change in management practices will flow through the industry and become standard practice in years to come.

Key messages

- Overall there can be more insect families represented in the inter row and tree, and specifically more natural enemies. We can speculate that this increased food web has a greater number of interactions between natural enemies and pests and hence greater potential for biological control. This not only provides self-regulating pest control, but also benefits in nutrient recycling, pollination, reduces chemical inputs and other ecosystem services. By contrast, in an orchard with regular mowing there may be a higher presence of herbivorous pests such as thrips, which may be four times more numerous in the orchard.
- Compared to a regularly mowed orchard (**Image 1** above), an orchard with reduced "mohawk" mowing (**Image 2** above) where weeds, grasses and local natives grow out somewhat, may have double the number of predators and parasitoids. There may also be a moderate increase in nectivorous (pollinator) insects such as flies, wasps and beetles. Furthermore, there may be a higher diversity (species richness) of arthropods in a mohawk orchard with an overall increase of approximately 30% in the amount of arthropod families represented. By contrast, in an orchard with

regular mowing there may be a higher presence of herbivorous pests such as thrips, which may be three times more numerous in the macadamia trees.

- "Clean orchards" do not, by virtue of intensive mowing, have better management and/or suppression of arthropod pests. In this project we found that clean orchards are more likely to have poor plant and poor beneficial arthropod biodiversity. Data collected from a number of trial farms indicate that regular mowing may be creating an environment more favourable to herbivorous pests such as thrips and leafhoppers in the trees. By contrast, project data indicates that orchards that incorporate inter row insectaries will have greater abundance and diversity of natural enemies.
- Intensive mowing in the inter row will not manage rats. Selective mowing of observed problem areas in conjunction with ongoing baiting and other rat management strategies is advised.
- The plant species typically found in the inter row (grasses, herbaceous naturalised weeds, local natives) will create a macadamia pest reservoir (potential exceptions are discussed in **Appendix 2**).
- There are a number of achievable options for insectaries in the inter row to be considered on a farm-by-farm basis.

R&D decision makers

This study and many others establish that improved vegetation mixes and plant species selections are likely to substantially improve on-farm ecosystem services including natural pest control and pollination.[15,16,50] Optimising these systems requires ongoing work,[51] and will be the subject of further research being rolled out by BioResources in 2020-21. Recommendations on seed mixes selected for various climates, soil types, orchard types (amount of light to the orchard floor, in particular), economic and cost considerations, available machinery (seeders), targeted focus on ecosystem services, and mitigating pest reservoir risk is very important.[52] Likewise, recommendations on cover cropping seeding and management schedules (e.g., alternate row management) to maximise cover crop and associated conservation biological control potential and avoid any potential unintended consequences is also crucial.[15,53,54] Finally, the provision of appropriate extension and support for growers to develop systems suitable for their farms and to guide them in investment decisions for future machinery, orchard development and so on, is vital for achievable and practical on-farm results at an industry level.

Conservation biological control is one tool to be incorporated into an IPM system. Its relative place and influence must be monitored and is still being understood alongside other system decisions. For example, decisions to use pesticide will be the single biggest limiting factor for the efficacy of conservation biological control.[55] Although pesticides can remove the threat of insect attack, it is not always an economically sound strategy.[56] The routine use of pesticides can lead to "pest resurgence" where, after pesticide application, insect pests can return to their former abundance.[57,58] Additionally, secondary insect pests previously suppressed by natural enemies or competition may then increase, creating further insect pest recurrence and requiring repeated insecticidal control.[59] Human and animal health, food quality and safety and environmental quality may all be compromised.[3] Barbosa has called these effects a global crisis, because whilst they contribute to high productivity, they may be too perilous for the environment, too risky for the consumer, and too problematic for the farmer.[7] Likewise, decisions in other areas of farm management can substantially influence the presence of crop pests - e.g., high numbers of grain aphids in cereals are most influenced by the use of nitrogen fertiliser rather than the farm system's capacity for biological regulation.[60] In macadamias, this project's data indicates that on several farms thrips were more abundant in the macadamia trees of the close mow control block. In theory, given the recorded increase in predators and parasitoids in the treatment blocks (mohawk and cover crop), we can hypothesise that this may help decrease thrips populations in these blocks.

Work should also begin on an evaluation of the role of non-crop perennial and woody habitats for conservation biological control in macadamia orchards. Temporal changes in resource availability and insect population sizes are a feature of agricultural landscapes. Non-crop habitats are generally stable and crop habitats are generally unstable.[61] This is due to harvest activities, as well as periodic agricultural inputs including pesticides, herbicides, nutritional sprays and the like.[62] The result of these processes is that natural enemies and their hosts are subjected to frequent potential mortality events. However, persistent populations have traits that enable them to exist in ephemeral and disturbance-prone habitats such as short life cycles and the ability to move to refuges outside the crop.[63] Frequent disturbance may affect the abundance of natural enemies in crops, even when suitable prey or host densities are present. Insect communities and populations in ephemeral habitats depend on large-scale regional exchange between populations. There are several reviews that examine the role of biological control at the field and landscape scale.[64] Schellhorn et al highlighted the limited knowledge of natural enemies in Australia and stressed the importance of future research to include (1) identifying habitats that act as sources of natural enemies and their pests; (2) understanding dispersal from habitat sources into crops, and (3) acquiring quantitative knowledge of the tipping points and spatial scales at which the key processes operate.[65,66]

Experimental design and methods

The project used YSTs for sampling; with economy, simplicity and efficiency in mind. Future investigators may consider adding in additional methods for more representative sampling and sampling of species not typically collected by YST (spiders, beetles, bees, moths), and to investigate proposed future research questions (e.g., DNA gut analysis of generalist predators to evaluate their feeding ratios and if they are consuming targeted pests of macadamia e.g. Lacebug).

Arthropod identification work and database management is especially time consuming. Project managers should be selective in allocating resources to highest priority tasks and objectives.

True replicates are difficult if not impracticable for this kind of research. Pseudo replicates are more likely. This will limit the statistical power available for analysis of results.

Future research questions and directions

This project has been able to establish that an inter row insectary can improve the abundance and diversity of beneficial arthropods, including predators, parasitoids and pollinators. A number of questions were outside the scope of this project, and should be considered for further study:

- Does the provision of insectaries encourage predators and parasitoids specifically of benefit to macadamia crop for the suppression of major pests?
- What is the impact of insectaries that increase predators and parasitoids on crop damage and/or yield?
- What are the economic costs and benefits of inclusion of insectaries as a key tool of IPM farm management?
- What are the multiple ecosystem services available with “managed vegetative diversity” in the inter row? What is the multiplier effect of these services’ benefits?
- What area of insectary refuge, be it inter row or native vegetation, is needed to maintain adequate beneficial insect populations to reduce insect pest populations in macadamia orchards?
- Investigate the effects of climate change on beneficial insects and macadamia pest interactions in the landscape, and how they might be mitigated.
- Integrate a multi-disciplinary approach to beneficial insect utilisation in IPM by assessing impacts on multiple pests in the landscape.

Utilising more sustainable and ecological practices to safeguard vital ecosystem services is needed now more than ever. A recent comprehensive review by Sanchez-Bayo & Wyckhuys highlighted the world-wide decline of insect species and the possibility that 40% of the world’s insect species over the next few decades may well become extinct.[5] Consequently, pest species may increase due to lack of predators and parasitoids. Sanchez-Bayo & Wyckhuys found that the main drivers are pesticides and fertilisers, pathogens and introduced species, and finally, climate change.

Refereed scientific publications

None to date.

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Intellectual property, commercialisation and confidentiality

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Field trial support and IPM advice	Eddie Dunn

Appendices

Appendix 1. Methods

Participatory Action Research (PAR) methods

Theoretical framework

While the project sought to investigate the proposed benefits in terms of beneficial arthropods in an inter row insectary in the macadamia orchard, it also sought to do so in a manner that addressed fundamental industry concerns in the context of working farms. Changes to inter row vegetation management needed to be practical and achievable for conventional farms. The methods of PAR were applied in order to allow the project team and growers to work together in this endeavour.[21,67,68] While the project team designed and delivered the project in terms of data collection and interpretation, growers led the implementation of the field trial and provided iterative feedback where farm-specific adjustment was necessary.[69]

Field work

Unstructured interview conducted by project manager with farm manager during every site visit to review any issues or concerns with rats, invasive weeds, inter row vegetation hosting crop pests, practicalities of reduced mow protocol for that orchard.[70]

Out-of-field work

Follow-up by project manager with farm manager by email and telephone to review results or requirements for further change to protocols. Recording of all feedback for analysis, interpretation and further iteration.[71]

Vegetation assessment methods

Theoretical framework

Extant vegetation present in the macadamia inter row typically combines regional and site-specific mixes of naturalised weeds, introduced grasses and annuals for ground cover and erosion control, and endemic local natives. Mowing, slashing and/or herbicide are employed to variously eradicate, limit and/or manage this vegetation to what is described as a "carpeting" ground cover on an industry standard orchard. This also produces something approaching a monoculture in terms of ground cover species. This project proposes a change to this standard practice, which is described as "managed vegetative diversity".[b] The project has first promoted the idea that under managed reduced mowing conditions, "weeds" can provide a number of valuable ecosystem services including insectaries for conservation biological control.[3,72,73] Beyond this, the project has also pursued ideas linking seeding and cover cropping to superior vegetative diversity in terms of conservation biological control.[15] The project has investigated these ideas via a field experiment with an industry standard control (regular complete close mow) and managed vegetative diversity treatment. The objective is to measure the characteristics of the vegetation present in the control and the treatment for potential benefits as an insectary; plant species diversity, provision of habitat, and food resources for beneficial arthropods.[25,74]

Materials

- Record sheet
- Pen, clipboard, tape-measure
- Field guides, websites, apps – for grass, legume, herb, weed, native vegetation species ID
- Smart phone, camera

Field work

A quadrant of approximately 10m x 20m was assessed. This varied farm-by-farm depending on row width. For example, on a farm with 8m rows, the quadrant would be 8m x 20m. All vegetation in the quadrant was noted if observed during a 10-minute walk-about of the quadrant.
The following were recorded for each quadrant:

[b] This idea is explored extensively in the project's literature review.

- individual plants species ID,
- plant species ID with floral resources at the time of the site visit,
- height of vegetation measured at 5 equidistant points in a transect across the inter row,
- estimated % of vegetation ground cover,
- dominant plant species ID,
- observations and photos of beneficial arthropod-plant interactions,
- observations of any "weediness" – invasiveness or woody growth habit,
- observations of any presence of major macadamia arthropod pests on inter row plant hosts (green veggie bug, fruit spotting bug, macadamia nut borer, lacebug, macadamia seed weevil),
- photographs parallel and perpendicular to the row of inter row vegetation,
- photographs of anything that cannot be identified or otherwise documented.

Out-of-field work

Confirm and finalise all plant IDs.

Arthropod assessment methods

Theoretical framework

Focused site arthropod assessment

Arthropods caught on YSTs consisted of the following recorded orders; flies (Diptera), wasps/ants/bees (Hymenoptera), true bugs (Hemiptera), beetles (Coleoptera), thrips (Thysanoptera), moths (Lepidoptera), springtails (Collembola), lacewings (Neuroptera), grasshoppers (Orthoptera), woodlice (Pscoptera), cockroaches and termites (Blattodea), snails (Gastropoda) and Protura. Of these orders, the majority (50 + specimens) that were captured were Diptera, Hymenoptera, Hemiptera, Coleoptera, Thysanoptera, Neuroptera and Lepidoptera. Considering that these are the most biologically diverse insect orders and the most abundant in most ecosystems[77], YSTs despite their biases are satisfactory for sampling biological diversity. We also trialled suction sampling of the row and tree at all of the farms, however the additional resources required to replicate periods across all sites and process samples was deemed out of budget for this project. Instead YST catches were identified further so that all of the above main insect orders except for thrips were classified to family level identification. Thrips identification was deemed too time consuming and difficult to determine to family level classification in the sticky gel of YSTs.

Tree and row were compared with equal YST traps so that effects of the inter row vegetation on abundance and diversity of arthropods in the macadamia tree could be measured within farms and across case study sites.

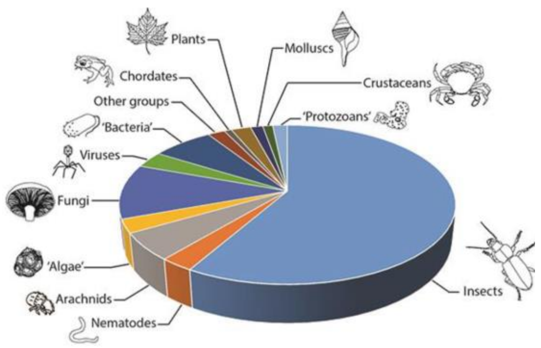
True bugs (Hemiptera) is an order of insects that has over 6000 species in Australia and includes species such as cicadas, aphids, scale insects and planthoppers. YSTs are not an ideal trapping method for population estimates and overall, this group is poorly represented by this technique. We have included this group in abundance and diversity calculations and have documented their abundance graphically in some farm reports (appendix). This was also the case for beetles (Coleoptera). Even though they are one of the most diverse groups of insects, they are poorly represented by YST. We did however include this group in abundance and diversity calculations with the species that we did catch using YSTs.

The Trichogrammatidae (egg parasitoids) are also chalcids and include mostly *Trichogrammatoidea cryptophlebiae* (MacTrix) a highly successful parasitoid in controlling macadamia nut borer. We separated them from the analyses as they were released on all of the focus farms in this study. The release points of MacTrix in summer would have confounded the results in both treatments during this period. We can also assume that there should be little difference in abundance between treatments if the releases are spread evenly, however as we did not monitor this, we cannot infer directly what is influencing the population in either treatment.

All specimens were identified using a Nikon SMZ-1B stereo microscope.

Insect Abundance

Abundance is the total counts of individual organisms. Insects are the most abundant species of organism compared to any other species on earth (Fig 1a). Within the insects, beetles are the most diverse with 420,000 species, followed by moths and butterflies (157,000 species), flies (153, 000 species), wasp, bees and ants (150,000).



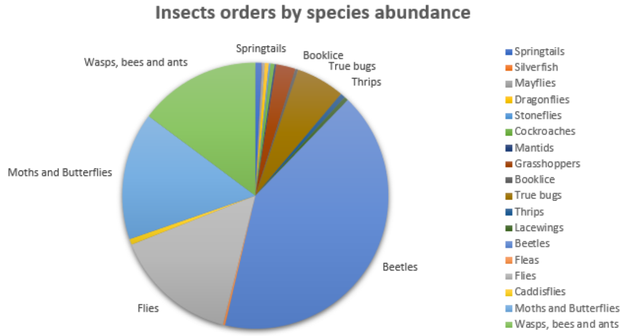


Figure 1a(left) Estimated proportions of different groups of organisms on earth today. (Chordates are vertebrate animals).[75] **1b (right)** Total number of species within each insect order (Adapted from species counts from Zborowski and Story, 2017).[76]

Insect Diversity measures

Conventionally, biological diversity has components of genetic, organismic and ecological diversity, and functionally could be separated into compositional, structural and functional levels.[77] Biodiversity in a broad sense cannot be measured directly, it is a relative measure. Genetic diversity in practical terms cannot be measured for whole communities or biotypes.[77] Thus, estimates of populations have been widely used in ecological studies to determine relative biodiversity and surrogates (the number of species in a particular taxon in a particular area) have been proposed.[78] One potential surrogate is the number of higher taxa, and this may be as a valid a measure of biodiversity as many others.[79] Following broadly similar patterns of geographic variation and community structure, positive correlations can be drawn between the number of species and numbers of higher taxa.[80] Several studies have reported a significant positive relationships between numbers of species and numbers of higher taxa[27,81] and particularly when in the same community/ecological type.[82] Surrogates require the identification of relative levels of richness, and higher taxa perform well in this regard. Balmford et al. observed that they appear noticeably better than the relationships between the numbers of species of different taxonomic groups.[27] Heino and Soininen found that for macroinvertebrates in streams, the assemblage structure (taxon richness) remained the same irrespective of taxonomic level from species – genus and family level.[83] In certain studies, such as palaeontology, due to the lack of preserved specimens, family level identification is standard to determine species richness. However, there is no clear consensus on the appropriate taxonomic resolution and performance of higher taxon surrogates in conservation biology.[84] Ultimately there is a trade-off between choosing the best predictor of species richness and the functional taxonomic level that is cost effective.[79] Neeson et al. used modelling to show that family taxon surrogates performed well in communities in which a few common species were most abundant which is the case in our studies, but would not work as well where dominant species were relatively even or low (such as a tropical rainforest).[84] In this study we are comparing a similar ecological type, a macadamia orchard, but are assessing the variation in arthropod species based on increasing inter row plant complexity (both structurally and genetically) to a standard ecological unit, macadamia tree and complete close mow. Given the time and resources available for this study we have determined that family level surrogacy can give us a good indication of species richness of comparable management practices on the same farm. It is also useful for understanding functional diversity i.e how ecosystems work. To examine this in more detail we have used higher taxon level (family) to determine groups of species that exploit the same resources or their feeding guild structure for comparative purposes. Therefore, using higher taxa surrogates at the family level can be as justified for guild classification.[81]

Feeding guilds

Guilds are the life stages or strategies used by a group of individual organisms (functional group) that are predictable according to taxonomic level however are grouped and related to their traits rather than their evolutionary based taxonomic classification. To understand the impact of multiple species within a macadamia orchard, the assessment of functional group richness (such as feeding guilds) is more useful to make management decisions instead of simply measuring species richness which may not relate to the capacity of the individual organism to provide a specific ecosystem service.[85]

We classified herbivores as either sap sucker, leaf miners, stem borers, gall former, seed feeders or omnivores. The other functional categories were fungivores, parastioids, predators, detritivores and scavengers. Because we caught the adult lifecycle stage mostly using YST, we only determined the feeding guild in that stage of their lifecycle, as we would be only speculating its role in the macadamia orchard in other life stages. This was a limitation that could be best integrated in future studies with other arthropod assessment techniques for a better picture of their role within the orchard. Several taxonomic groups have multiple feeding strategies which also complicated groupings. However, when examining changes in cultural controls such as mow frequency, higher trophic levels (such as predators and parastiods) are more sensitive to changes in the environment by virtue of being dependant on lower trophic groups.[81] Thus, feeding guild structures are very useful for understanding food web structure and complexity.

Yellow Sticky Traps

Comparison of arthropod biodiversity in regularly mown and less mown (mohawks) were assessed in macadamia orchards by yellow sticky traps (YST) across eleven farms (Nambucca heads to Bundaberg) once each season for 2.5 years. YST were placed in the inter-row and in the macadamia tree at three sites within each treatment ("more" and "less" mow), with at least a 50m buffer between treatments. Twelve YST (6 in the interrow and 6 in the tree) were collected each season at each farm for assessment of arthropod biodiversity. Like all sampling methods, YSTs have biases, and are designed to sample winged arthropods during flight (though non-winged arthropods do get caught occasionally). Their colour, yellow, is particularly attractive to wasps, flies, winged aphids and thrips, which were well sampled during this project. Arthropod groups such as spiders and ants are seldom captured using YSTs. The arthropod families captured during this project and the data presented within this report provides a partial snapshot of the food web within each orchard. Suction sampling was trialled (below) but deemed too time consuming for this project. Most of the results presented within the arthropod section of this report focus on wasp (parasitoids), flies and thrips and as they were the main groups captured on the YSTs. Important groups like lacewings were seldom caught on YSTs. The only times we present data using all the arthropods collected on YSTs are within the 'Arthropod Abundance' section, and then again within each of the 'feeding guild' sections for each case study. Diversity was calculated for the four most abundant insect groups that were captured on YST and identified to family level (flies, wasps, true bugs and beetles). Tree and inter row were sampled using equal numbers of YST traps so that the effects of the inter row vegetation on abundance and diversity of arthropods in the macadamia tree could be measured within farms and across case study sites.

The YST were sourced from Bugs-For-Bugs^{tm} (Toowoomba, Qld), a standard, commercially available sticky trap with two 11.5cm x 7.5cm grids. Within the inter-row, the YST were placed on a wooden stake at the height of the inter-row vegetation. In the trees YST were attached to a lower branch within the canopy. In both the inter-row and tree, YST were folded at the midway point to capture insects from both directions. After one week in the field the traps were collected by stapling the two far edges in a loop to protect the insects. Once in the laboratory, the cards where assessed under a stereo microscope to identify the arthropods to order (for grower sites) or family level of the main insect orders (detailed sites) for feeding guild comparisons, with only one side (11.5cm x 7.5cm grids) taxonomically recorded, which was deemed to have the most insects on them.

Traps based on the attraction response of arthropods have been widely used in integrated pest management programs in a diverse range of crops.[86–88] Similarly, terrestrial biodiversity surveys, due to the high costs and large numbers of arthropods, typically rely on a single technique.[89,90] Different coloured traps will attract different types of arthropods selectively. Schellhorn et al.[91] found for instance that yellow colour sticky traps had a wavelength range of 556– 892 nm and reflectance of 110%, whereas green leaves have a wavelength range of between 500– 600 nm and energy reflected was less than 20%. The high reflectance of yellow compared with other colours permits catches with the highest species richness.[92,93]

YST have been used extensively to trap whitefly[94], thrips,[95] leafhoppers[96] and aphids[97] in the field and glasshouse environments. YST have also been used to collect a range of beneficial insects including hoverflies,[98] ladybeetles,[99] lacewings,[88] parasitoids[11] and is generally regarded as the best coloured trap to capture beneficial insects.[98,100,101]

Vacuum sampling

As the YST are selective in capturing certain groups and types of insects (e.g. aerial arthropods) aspiration sampling was also used once at each site in spring at the time of placing out the YST for comparison. A commercial garden two-stroke engine-powered leaf blower (Stihl[tm] SH 85) was reversed and a 1 metre long suction pipe (Diameter 7cm) was fitted with voile and elastic bands to capture the insects. Within each treatment site, arthropods were vacuumed for 10 sweeps separately for lower tree canopy and the inter-row treatments in an area of approximately 20 metres. Samples were taken between 10am and 2pm to maximise insect catch. The voile was replaced for each sample and placed in a labelled cylindrical take away container and placed in the esky until they could be stored in the freezer before arthropods were identified under a stereo microscope to family level or further to species level.

Suction sampling has been used since the 1960s[102] in a variety of habitats and has the purpose of collecting arthropods from a defined area. Whilst vacuum sampling has inherent bias, previous studies showed suction sampling to be reliable for abundance and diversity assessments of certain arthropod groups.[103] Monzo et al. found that suction sampling was particularly good for detecting sparse populations of arthropods.[104] As suction sampling is not attracting it provides a useful comparison to compare to the YST in estimating the abundance and diversity of arthropods.

Suction sampling was done once at each of the three sample sites to capture the insects directly on vegetation at a specific time. Unfortunately, the suction sampling was deemed too time consuming for this project relative to scope and budget priorities. In the field, it was very difficult to standardise sampling across multiple sites (time of day etc) and it was time and labour intensive. From there, the insects were difficult to separate from the incidental vegetation also captured. Suction samples have been kept for potential reference in future trials.

In the final analysis, YST sampling was sufficient to the sampling task necessary for investigation of this project's hypothesis.

Data processing and statistics

Arthropod results for wasps and flies were analysed in terms of their abundance and diversity at the family level. Families within the orders Hymenoptera (wasps) and Diptera (flies) that were sampled in an abundance of 20 or more individuals over the sampling period were termed 'commonly sampled' and their family abundance displayed graphically. This number, 20, was chosen arbitrarily, but based on the median for the sampled specimens within each family (**Tables 6-13** below in **Appendix 2 Findings**). Any wasp or fly family sampled in lower abundance that was of particular interest in terms of their role in providing insights into changes in diversity in response to the insectary treatments; or biological control (predator or parasitic) was analysed separately, because certain species/families can play an important role biologically without being numerous in their presence.

Data was processed with Excel. Key results were evaluated for variance using Standard Error of the Mean (SE). Beyond this, it was decided that the project data was subject to a number of standard field trial limitations in terms of statistics: pseudo-replicates, confounding factors, and multiple complex ecological processes. T-tests were considered in order to develop analysis of statistical significance of differences between the control and the insectary treatments in terms of arthropod abundance and diversity for each individual case study. The case studies could not be paired to produce replicates (climatic and geographic differences), and the data within each farm site was highly sensitive to outlier values. T-test results were produced but it was decided that, given the many associated caveats, the results could not meaningfully illuminate findings in terms of significance or assistance in the interpretation of associated trends. Further data processing and statistical assessment in “R” was considered, but it was decided that it was not a suitable use of project time and resources in terms of project objectives.

The project team consulted regularly with Stephen Morris, biometrician, NSW DPI, with regards to data processing and statistics.

Appendix 2. Results

Rats, weeds and pest reservoir – will inter row insectaries lead to other problems?

The project found that an inter row insectary can be incorporated into existing orchard inter row management and with basic monitoring and management will not lead to other problems. This was the case on all participating trial farms. Please note that methods and data are highly qualitative, and these results must be understood as such, thus being subjective and specific to each individual grower's perception of these issues.

Rats

The perceived risks of rat damage and the demands of its management are clearly a major concern for many (but not all) growers. Putting the necessary management of the orchard floor for harvest operations to one side, rat risk reduction can be a major driver of decisions to regularly mow the inter row.

The project team noted varying degrees of confidence amongst participating growers in their capacity for rat management. In this context, heavy inter row mowing was understood to be a manageable and definitive control strategy by many growers. Given the limits of this project's capacity to further investigate this issue, there is no evidence to suggest that regular mowing consistently delivers the desired result. This is evidenced by the number of growers with a pre-existing rat problem at the commencement of the trial in areas that were historically mowed regularly and their anecdotal perspective on change in rat pressure with an inter row treatment. From this approach, no clear relationship between rat issues and reduced mowing was identified.

This project has consistently made the case for "managed vegetative diversity" as the principal concept for informing decisions on reduced mowing in the inter row. This means that in areas where reduced mowing is applied, there are always options for mechanical and/or chemical vegetation management if that vegetation is hindering monitoring or providing habitat or food for rats. Where participating growers found that they were in a position requiring intervention for rat management, they were satisfied with these options and the results.

Weeds and weediness

For six out of eleven participating farms, weeds or weediness was observed at some point in the life of the trial. In each of these cases either one locally present species became very dominant (Setaria grass, Kikuyu grass, Rhodes grass, or Cobbler's Pegs); or there were very limited instances of woody weeds (Noogoora bur, Paddy's Lucerne, Wild Tabaco). In all cases this situation was easily managed with either intermittent mowing/slashing and/or spot herbicide applications.

For completeness it is noted here that one participant withdrew from the trial after 12 months, citing reduced mowing as too disruptive to standard farm operations. The grower had a range of concerns regarding clumping grasses and a lack of row width (8m) for mohawk. This grower was a small/family-operator and the requirements for adherence to experimental protocols and schedules were, quite reasonably, too demanding on his time and farm management priorities. He remained interested in the objectives of the trial in principle.

The potential benefits in terms of an insectary for most of the plant species growing under conditions of reduced mowing in the inter row far outweighed their risks as weeds. Unlike issues associated with rats, ten out of eleven participating growers indicated that they were confident in their options and choices for weeds and weediness management prior to and during the trial. Through this lens, "managed vegetative diversity" saw growers confidently identifying and managing the very limited instances of weed species that were of concern to them.

When we consider the specific task of an insectary (an area with plant communities characterised by qualities of benefit to beneficial arthropods) the trial provided growers and the project team with important opportunities to develop skills and knowledge of best practice. The challenge in this instance became one of managing for diversity and preventing dominance of one plant species through time. Conventional mechanical and chemical management were up to this challenge. However, as is discussed elsewhere (**Guidelines**), diversity that incorporates plant characteristics that are especially attractive to beneficial arthropods is best served by seeding and/or cover cropping.

Pest reservoir

An exceedingly small number of observations were recorded by the project team for plant species in the inter row hosting any of the major pests of macadamias. To further contextualise this, the project recorded in the order of 220 plant species distributed across 11 farms over 2.5 years. Of these records, there was one observation of lablab hosting Green Vegetable Bug (GVB). Another plant species is noted in the literature to be a potential host of GVB and Fruit Spotting Bug is blackberry nightshade.[105] The project team did not observe either of these pests on that species.

The methods applied to this issue were modest and while they were appropriate to the focus, scheduling, and budget of the project, it is possible to claim that they were not comprehensive or robust. However, the project team argues that based on evidence to date there is no current case for further investigation of this issue.

In the very limited range of instances where inter row plant species (*Lablab*, blackberry nightshade) were hosts of pests, growers participating in the trial were unconcerned by this issue when discussing it with the project team and in fact took no mitigating action. In the event that they perceived a potential risk, they noted that they had an extensive range of management options including herbicide spot spraying and mechanical removal.

Arthropods

All the data represented below is pooled across the entire sampling period at each case study farm.

Bevan & Willemse: flies

Table 6: Details of the diversity and abundance of the flies found within inter rows and trees of the control and insectary treatment blocks at Bevan & Willemse.

Location	Treatment Block	Number of fly families recorded (diversity)	Number of individual flies collected (abundance)
Inter row	Mohawk	22	1332
	Complete close mow	21	1213
Tree	Mohawk	20	1337
	Complete close mow	13	866

Bevan & Willemse: parasitoids

Table 7: Details of the diversity and abundance of the wasp parasitoids found within inter rows and trees of the control and insectary treatment blocks at Bevan & Willemse.

Location	Treatment Block	Number of wasp parasitoid families recorded (diversity)	Number of individual wasp parasitoids recorded (abundance)
Inter row	Mohawk	24	1041
	Complete close mow	21	511
Tree	Mohawk	15	297
	Complete close mow	19	227

Bundaberg North: flies

Table 8: Details of the diversity and abundance of the flies found within inter rows and trees of the control and insectary treatment blocks at Bundaberg north.

Location	Treatment Block	Number of fly families recorded (diversity)	Number of individual flies collected (abundance)
Inter row	Tree-to-tree reduced mow	19	391
	Complete close mow	17	391
Tree	Tree-to-tree reduced mow	19	287
	Complete close mow	17	230

Bundaberg North: parasitoids

Table 9: Details of the diversity and abundance of the wasp parasitoids found within inter rows and trees of the control and insectary treatment blocks at Bundaberg North.

Location	Treatment Block	Number of wasp parasitoid families recorded (diversity)	Number of individual wasp parasitoids recorded (abundance)
Inter row	Tree-to-tree reduced mow	19	566
	Complete close mow	14	539
Tree	Tree-to-tree reduced mow	14	469
	Complete close mow	13	435

Baldwin & Ranking: flies

Table 10: Details of the diversity and abundance of the flies found within inter rows and trees of the control and insectary treatment blocks at Baldwin & Ranking.

Location	Treatment Block	Number of fly families recorded (diversity)	Number of individual flies collected (abundance)
Inter row	Mohawk with seeding	34	723
	Complete close mow	24	645
Tree	Mohawk with seeding	22	374
	Complete close mow	22	401

Baldwin & Ranking: parasitoids

Table 11: Details of the diversity and abundance of the wasp parasitoids found within inter rows and trees of the control and insectary treatment blocks at Baldwin & Ranking.

Location	Treatment Block	Number of wasp parasitoid families recorded (diversity)	Number of individual wasp parasitoids recorded (abundance)
Inter row	Mohawk with seeding	21	701
	Complete close mow	17	382
Tree	Mohawk with seeding	16	135
	Complete close mow	14	184

Piccadilly Park: flies

Table 12: Details of the diversity and abundance of the flies found within inter rows and trees of the control and insectary treatment blocks at Piccadilly Park.

Location	Treatment Block	Number of fly families recorded (diversity)	Number of individual flies collected (abundance)
Inter row	Cover crop	23	929
	Complete close mow	14	573
Tree	Cover crop	22	626
	Complete close mow	13	382

Piccadilly Park: parasitoids

Table 13: Details of the diversity and abundance of the wasp parasitoids found within inter rows and trees of the control and insectary treatment blocks at Piccadilly Park.

Location	Treatment Block	Number of wasp parasitoid families recorded (diversity)	Number of individual wasp parasitoids recorded (abundance)
Inter row	Cover crop	26	905
	Complete close mow	14	254
Tree	Cover crop	18	520
	Complete close mow	17	212

Case study ID	Location	Photos of 'less mown' inter rows	Sampling dates	Number of sampling occasions	Number of yellow sticky traps collected	Total number of arthropods identified	Proportions of predators and prey in each treatment	Number of insect families (wasps, flies, true bugs and beetles only) in treatments
1. Mohawk, alternate row mow (Bevan & Willemse)	northern NSW		2017: January, May, August, November 2018: February, May, September, December 2019: March, June	10	112	10553	*Mohawk* 65% predators 65% parasitoids Close Mow 35% predators 35% parasitoids	Mohawk - 84 families Close mow 72 families
2. Tree-to-tree reduced mow and alternate row mow – young tree orchard (Bundaberg North)	Bundaberg, QLD		2017: March, June, September, December 2018: February, May, November 2019: March, June	9	107	7745	*Tree-to no mow* 52% predators 54% parasitoids Close mow 48% predators 46% parasitoids	Tree-to-tree reduced mow – 75 Families Close Mow – 73 Families
3. Mohawk with seeding (Baldwin & Ranking)	Mid-North coast NSW		2017: March, July, October 2018: May, August, October 2019: January, April, July	9	107	6546	*Mowhawk* 60% predators 61% parasitoids *Close Mow* 40% predators 39% parasitoids	Mohawk with seeding – 78 families Close mow – 63 families
4. Cover cropping (Piccadilly Park)	northern NSW		2018: December 2019: March, June, September	4	48	7137	Cover crop 74% predators 76% parasitoids Close mow 26% predators 24% parasitoids	Cover crop – 89 families Close mow – 58 families

Table 14. The four case study orchards with details of location, sampling dates, numbers of sampling occasions and yellow sticky traps analysed, total number of arthropods recorded, proportional percentages of predators and parasitoids recorded with insectary treatment and control to treatment and numbers of insect families recorded with respect to insectary treatment and control.

Appendix 3. Guidelines – options and management strategies for inter row insectaries

Table 15: Options for inter row insectaries.

MOW OPTION	DESCRIPTION
MOHAWK	*Reduced mowing leaves a central mohawk strip down the row, with more regular mowing under the drip-line of the trees.*
	A mohawk allows for an area of greatly reduced mowing for an insectary down the centre of the inter row in conjunction with more intensive ground-cover management under trees. A mohawk can be retained year-round, including throughout harvest. • This helps to keep beneficial arthropods active in the orchard year-round, and especially leading into flowering when pest pressure will start to increase. • It also keeps insectary vegetation viable in the inter row throughout drier winter months. It can take many months for this vegetation to recover during long dry periods if it is mowed out. Row width of minimum 9-10m. Mohawk strip width to be calibrated against width of harvester, slasher and mower. Mohawk strip to be monitored: • Is nut getting caught in the mohawk? Take action to reduce mohawk width or remove mohawk altogether for harvest period. • Is mohawk vegetation getting "ropey" or "thatchy" and likely to cause problems for
ALTERNATE ROW MOW	*Mow every second row on a rotating schedule, allowing all rows to "grow out" somewhat across the year and all rows to be mowed alternately, outside of harvest.*
	This reduces the overall disturbance of beneficial arthropods that conventional mowing creates. At any one time, only half of the orchard is disturbed by mowing. Inter row vegetation has an opportunity to grow out and flower, providing food and habitat for beneficial arthropods. A refuge remains in place at all times somewhere in the orchard. This approach provides opportunities to more regularly manage: • Heavy, clumping grasses and woody weeds and dominating species. • Rejuvenation of vegetation for new growth and flowering. • Any areas where rats are observed to be active. Alternate row mow is only suitable outside of harvest.
MOWHAWK OR ALTERNATE ROW MOW?	*Ultimately this is a decision to be taken on a farm-by-farm, season-by-season and also site-by-site basis, given the following considerations:*
	Mohawk can be a better fit where:

- Width is available. 9-10m row minimum.
- Machinery is compatible.
- Retaining insectary vegetation throughout harvest and winter is a priority.
- Time, resources and/or capacity for basic monitoring and management of the mohawk during harvest is available.

Alternate row mow can be a better fit where:

- Width is a constraint. In this trial, mohawk worked best in 9-10m rows.
- In relation to width, machinery operation is a constraint. Configuration of existing machinery may not be optimal in conjunction with a mohawk.
- Time, resources and/or capacity for basic monitoring and management is limited.
- Dominating, clumping plant species, and/or woody weeds are present (eg., setaria, rhodes grass, kikuyu, cobblers' pegs, noogoora bur and so on) and require regular mechanical mangment.
- New blocks and orchards with young trees where the more intensive management of the mohawk is not necessary. The entire inter row can be dedicated to ecosystem services including insectary and soil health until trees begin to set nut.

"Mohawk" and "alternate row mow" described here provide basic templates, which you can trial and innovate for your own farm

Reduced mowing must be conducted with clear objectives, planning, and management strategies, which should be considered on a farm-by-farm basis (see **Table 16**, for recommendations below).

The strategies presented below are listed in order of increasing management commitment and increasing insectary value.

Table 16: Management strategies for inter row insectaries.

MOW STRATEGY	DESCRIPTION
CURRENT INDUSTRY STANDARD	*<u>Action</u>: Complete close mow of the entire inter row, under the drip-line and down the centre of the inter row.* *<u>Objective</u>: The entire inter row is managed for ground cover to harvest standards and requirements.*
	The inter row is managed with heavy regular mowing, slashing and/or herbicide year-round with ground cover principally for erosion management and orchard floor suitable for harvest requirements. A monoculture of densely-packed, carpet-forming grass (eg., smother grass, broad-leafed carpet grass, or couch) is maintained. Monitor and manage rats in the inter row, as appropriate.
REDUCED MOW - CALENDAR	*<u>Action</u>: Mowing is reduced in the inter row using either a mohawk or alternate row mow and scheduled against major orchard activities including pre-harvest clean-up and harvest.* *<u>Objective</u>: Reduce frequency of mowing to allow for growth of diverse species in inter row vegetation, which will flower and provide habitat for beneficial insects.*

	Reduce mowing to approximately 1-2 month intervals outside of harvest. Suitable for any orchard (most row widths, and moderate available light). Existing machinery for current industry standard will be suitable. Monitor and manage rats in the inter row, as appropriate.
REDUCED MOW - MONITORING	*Action: Mowing is reduced in the inter row using either a mohawk or alternate row mow and scheduled on the basis of monitoring and major orchard activities including pre-harvest clean-up and harvest.* *Objective: Reduce frequency of mowing based on simple monitoring of vegetation to allow for growth of diverse species in inter row vegetation, which will flower and provide habitat for beneficial insects.*
	Some farms have good existing mixes of naturalised weeds, grasses and natives, which perform well in low mow insectaries. Observe and monitor for desirable characteristics. Base decisions to mow on basic monitoring of inter row vegetation during the growing season and seasonal extremes. For example: • Reduce mowing during prolonged dry periods. • Reduce mowing to allow flowering of grasses. • Increase mowing - during wetter periods if growth rates produce large volumes of vegetation that can tangle harvester mechanisms; if one grass species or naturalised weed becomes too dominant; if you observe an increase in rat activity. Suitable for most orchards (row width, available light). Existing machinery for current industry standard will be suitable. Consider configuration and settings for stream-lined operation of reduced mowing operations for future machinery purchasing decisions. Monitor and manage rats in the inter row, as appropriate.
INTERMITTENT SEEDING	*Action: Mowing is reduced in the inter row using either a mohawk or alternate row mow and scheduled on the basis of monitoring and major orchard activities including pre-harvest clean-up and harvest. There will be seeding of the inter row with seed-mixes prepared specifically for macadamia orchards (annually or biannually, as required).* *Objective: Seed to improve plant species diversity in the inter row, selecting species with characteristics attractive to beneficial arthropods including flowers and habitat.*
	Some farms do not have good existing mixes of naturalised weeds, grasses and natives. Observe and monitor for dominance, weediness, low value plants. Seeding may be necessary to improve the overall mix. Some farmers will be interested in simple but targeted and selective improvements of the inter row with seeding. It is strongly recommended that seed mixes are specifically selected for suitability in the macadamia orchard:

- A number of seed suppliers can provide advice and pre-mixed selections suitable for your orchard and local area.
- Do not use "good bug mixes" that are often recommended for gardeners and temperate climate horticulture. They do not represent value for money in this application and in our trials did not establish or perform well in the field.

Target specific areas of the inter row. For example:

- Shade tolerant, carpet forming species mixes can be selected for under the drip-line, and these will be especially compatible longer-term with harvest.
- Annual species that flower heavily, grow vertically and vigorously and are easily mowed out can be seeded into the mohawk.

Most suitable for orchards with row width of 9-10m and/or good available light.

Existing machinery for current industry standard will be suitable to get started. Consider configuration and settings for stream-lined operation of reduced mowing operations for future machinery purchasing decisions. You can hand broadcast seed but eventually access to a seeder will be preferable.

Monitor and manage rats in the inter row, as appropriate.

COVER CROPPING	*Action: Multiple annual and/or seasonal re-seedings of the inter row with cover crops selected specifically for macadamia orchards, with mowing to support and improve cover crops and major orchard activities including pre-harvest clean-up and harvest.* *Objective: Intensive management of the inter row with cover crops that improve multiple ecosystem services including insect pest suppression and crop pollination, nutrient cycling and soil health, carbon sequestration, and water and erosion control.*

Major opportunities for cover cropping exist during the development of new orchard blocks, in blocks with young trees, and following the removal of macadamia tree rows. Cover cropping can also be incorporated into the inter row of orchards with sufficient row width (9-10m minimum) and good available light on the orchard floor year-round; and where growers will invest in managing and maintaining a dedicated cover-cropping system to realise the potential of high-value returns for multiple ecosystem services.

This project has collected data from one farm with cover cropping (See **Methods** and **Appendix** x). The results are very impressive and warrant industry-wide consideration.

These results come with careful long-term farm planning, prudent investment in appropriate machinery, education and training, and commitment to evidence-based decision-support (various crop consultants).

Provision of further advice on this very promising management strategy is beyond the scope of this project.

Appendix 4. Table of data produced for this project

The following data sets are available in .csv format, upon request to BioResources Pty Ltd.

Table 17: Table of data produced for this project.

Data area		
General project information		
	Trial farm details	Location Mow/slasher and harvest machinery specifications used during the trial Tree varieties Tree age Tree and row spacing Manager/owner contact details
	Farm mow and spray records	Date Action taken (eg, pesticide selection)
	Extreme weather and environmental events	Date Type of event (eg, flash flood)
Inter row vegetation		
	Plant ID 217 records	Common name(s) Scientific name Photos Flower colour Type (herbaceous, grass, legume, perennial) Origin (native, naturalised weed, cover crop) Regional location Trial site location
	Plant assessment 593 records	Trial farm ID Assessment date Plant species ID in assessment Count of plant species Height of vegetation at 5 points across inter row Height average % vegetation as ground cover Dominant species (> 50%) Dominant species (>25%) Plant ID of flowering at time of assessment % vegetation biomass as floral resources Photos Site notes Treatment method Assessment site ID
Arthropod	YST samples Farm/Total specimens/number of YSTs Alloway: 9329 specimens, 120 YSTs Bundaberg Sugar: 9354 specimens, 95 YSTs Elenora: 9479 specimens, 107 YSTs Hotsons: 13718 Specimens, 120 YSTs Thomas: 6377 specimens, 96 YSTs Wiley: 11860 specimens, 120 YSTs Bevan and Willemse: 10553 specimens, 112 YSTs Bundaberg North: 7745 specimens, 107 YSTs Baldwin and Ranking: 6546 specimens, 107 YSTs Piccadilly Park: 7137 specimens, 48 YSTs	Order level ID all specimens *Non focused sites*; ID to Order then to beneficial/ parasitoid/ predator/ mac pest *Focused Sites*; ID to Order then; Lepidoptera, Diptera, Coleoptera, Hemiptera, Hymenoptera, Neuroptera to; Suborder, Superfamily, Family, Feeding Guild and any macadamia pest specimens to genus/spp.
Participatory action research (PAR)		

	Rat observations	Site notes from project team Unstructured interview notes taken by project team when talking with trial farm manager/owner
	Weed observations	Site notes from project team Unstructured interview notes taken by project team when talking with trial farm manager/owner
	Inter row vegetation pest reservoir observations	Site notes from project team Unstructured interview notes taken by project team when talking with trial farm manager/owner
Narratives (M&E)	Narrative records 50 records	Unstructured interview notes taken by project team when talking with trial farm manager/owner, during site visits, emails and telephone conversations. Project completion survey.

Appendix 5. Mac group poster

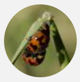
INSECTARIES IN THE MACADAMIA INTER-ROW

Authors: Abigail Makim and Richard Llewellyn

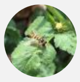
PROJECT AIMS

This project reviews and trials insectaries established in the macadamia orchard inter-row, which are designed to encourage beneficial arthropods.

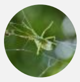
- The inter-row is currently an under-utilised resource in macadamia orchards.
- It can make a valuable contribution as an insectary where selective vegetative diversity is cultivated.
- The macadamia industry is looking for new pest control options, given new pests, emerging arthropod resistance, withdrawals, and community concern with chemistry.
- Pests of macadamias are unlikely to live or thrive in inter-row vegetation.



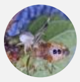
Insectaries provide generalist predators such as ladybugs with additional food resources so that they can complete their life-cycle and remain active in the orchard year-round.



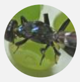
It is often the larvae of familiar beneficials such as the hoverfly or ladybug that are most active as predators.



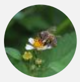
Spiders will thrive and be most effective in undisturbed habitat – fruit spotting bug (FSB) caught in spider web.



Spiders are important generalist predators of many macadamia pests - spider dispatching banana spotting bug nymph.



Biocontrol adult parasitoids including MacTrix (parasitoid of nut borer) and Anastatus (parasitoid of FSB) will be more fecund and long-lived if they have access to food sources such as flower nectar.



Insectaries in the orchard will also attract and shelter pollinators.

PROPOSED BENEFITS

increased yield

reduced crop damage

suppression of pests

increased numbers of beneficials

selective vegetative diversity

Literature review available at: www.bioresources.com.au

REDUCED MOWING FIELD TRIALS

- 10 farms over 2 years - Bundaberg region, south east Queensland, NSW northern rivers, and Nambucca Heads region.
- Trialling reduced mowing practices that allow greater vegetative diversity and bulk.
- Assessing changes in vegetation and arthropod populations in relation to changes in mowing.
- Recommendations on row width, tree spacing, mowing programs, machinery set up, cover-crops.

Above, reduced mowing practices such as this mohawk provide an insectary, with habitat and food resources for beneficials throughout harvest. This means beneficials are established in the crop before flowering and ahead of pests.

INDUSTRY APPLICATION

- Insectaries can conserve beneficials in macadamia orchards, which can in turn contribute to the suppression of a range of pests.
- Insectaries can be designed into many different kinds of farms, providing consultants and growers with options for the suppression of pests.
- Insectaries work in conjunction with biocontrol and insecticides.

This project is funded by Horticulture Innovation Australia (HIA) with in-kind contributions from BioResources Pty Ltd and Coates Horticulture.

Appendix 6. 1-page summary cover cropping & mohawk

Case study of cover cropping - prepared for trial participants in the BioResources macadamia inter row project
This document was prepared by Dr Abigail Makim and Dr Christopher M. Carr

Conservation biological control in the macadamia orchard – insectaries in the inter row

Case Study – cover cropping and beneficial insects, northern New South Wales

Row width - 14 m
Centre strip width - 6m
Excellent light to the orchard floor.

Plant species ID – seasonal seed mixes combining cover crops suitable for the macadamia orchard (vetch, smart radish, millet, crimson clover, sorghum, sunflower, flax, sunn hemp, rye corn, and many more). Different seed mixes for under the drip-line and the centre strip.

Comments – Dedicated cover cropping system with specialised machinery and long-term soil health management. Specific planning and scheduling of seasonal reseeding year-round. Reseeding alternate rows to limit disturbance of insectary. In conjunction with conservation biocontrol, there are strong ecosystem services for soil microbiology, water storage, carbon sequestration, and more.

This is a specialised system and further details and grower recommendations will be available from BioResources in 2020-21.

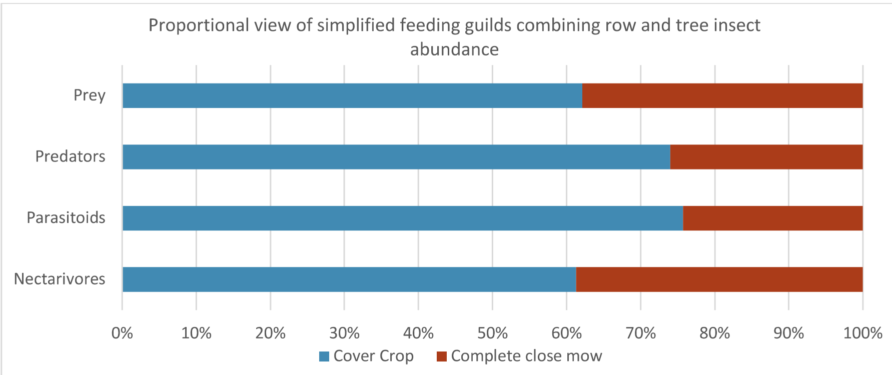


Chart 1: Comparison of simplified feeding guilds of beneficial insects – prey, predators, parasitoids and nectarivores (potential pollinators). More beneficial insects were caught in the cover crop.

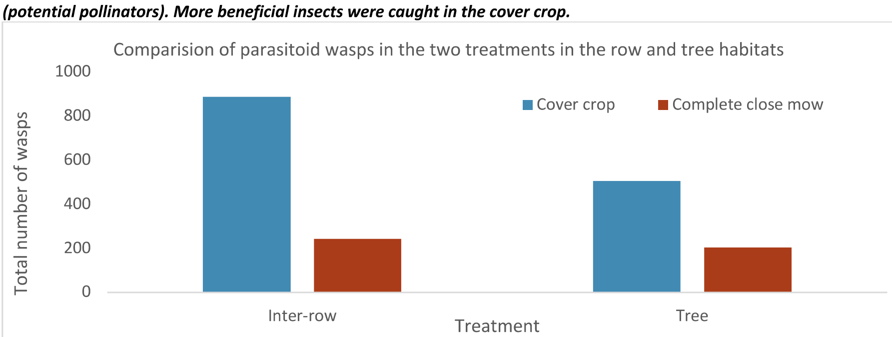


Chart 2: Comparison of the number of parasitoids caught in the inter-row and trees by treatment. The cover crop environment supports more parasitoids in both the inter-row and tree. Parasitoids are crucial beneficial insects in macadamia IPM.

April 2020 Hort Innovation MC16008

This project has been funded by Hort Innovation using the macadamia research and development levy and funds from the Australian Government. For more information on the fund and strategic levy investment visit horticulture.com.au

Case study of mohawk reduced mow - prepared for trial participants in the BioResources macadamia inter row project
This document was prepared by Dr Abigail Makim and Dr Christopher M. Carr

Conservation biological control in the macadamia orchard – insectaries in the inter row

Case Study – mohawk reduced mow and beneficial insects, northern New South Wales

Row width - 10 m
Mohawk width - 1m

Good to moderate light to the orchard floor.
Mohawk sustained throughout harvest. Occasional alternate row mow for management.

Plant species ID - naturalised weeds, grasses, local natives.

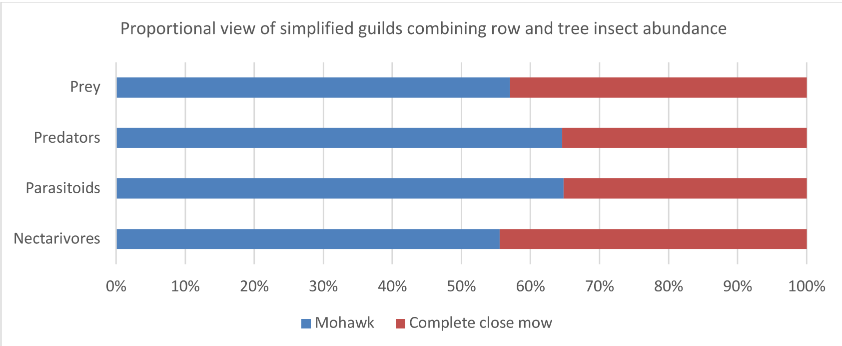


Chart 1: Comparison of simplified feeding guilds of beneficial insects – prey, predators, parasitoids and nectarivores (potential pollinators). More beneficial insects were caught in the mohawk.

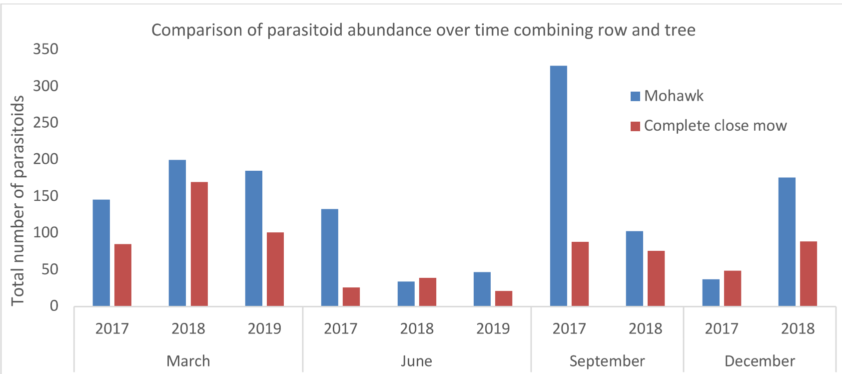


Chart 2: Comparison of the number of parasitoids caught in assessment month and year. More parasitoids were caught more often in the mohawk. Parasitoids are crucial beneficial insects for macadamia IPM.

April 2020 Hort Innovation MC16008

Appendix 7. Individual farm reports

Case study farms

1) Bevan & Willemse, mohawk, northern New South Wales
2) Baldwin & Ranking, mohawk with seeding, New South Wales mid-north coast
3) Piccadilly Park, cover cropping, northern New South Wales

Other participating farms

4) Alloway, mohawk, Bundaberg
5) Bundaberg Sugar, mohawk, Bundaberg
6) Elanora, mohawk, New South Wales mid-north coast
7) Hotson, mohawk, northern New South Wales
8) Thomas, mohawk, Gympie
9) Wiley, mohawk, northern New South Wales

Final Report

"Mohawk trial farm" – Macadamia Inter-row Trial Results

Hort Innovation program title: The IPM program for the macadamia industry – BioResources

Hort Innovation project code: MC16008

Date: April 2020

This report was prepared by Dr Abigail Makim and Dr Christopher M. Carr

This report was produced as part of the MC16008 extension program for participating macadamia growers and other industry professionals. It is not intended for peer review or publication. Further work is underway, processing data for statistics and additional analysis.

Summary

This project investigates the potential for the development of insectaries through vegetation changes in the inter-row via reduced mowing. Adoption of reduced mowing where possible is expected to increase the abundance and diversity of beneficial arthropods by creating more complex food-webs that are vital to pollination and pest suppression. Our aim is to optimise macadamia orchards for the self-regulation of pests by supporting beneficial arthropods with shelter, breeding areas, nectar, alternative hosts/prey and pollen.

The “mohawk trial farm” worked with the BioResources Pty Ltd team to investigate these ideas from early 2017 to mid 2019.

The mohawk trial farm reduced mowing trial has provided several useful insights into the practicalities of reduced mow options in macadamia orchards. Industry has been particularly concerned that reduced mowing of the inter-row may lead to significant problems such as increased rat activity, invasive weeds and/or increased insect pests. This trial gives other growers reassurance that a mohawk can be incorporated into existing orchard inter-row management and with basic monitoring and management will not lead to other problems.

The most significant benefits to having a mohawk vegetation inter-row in this trial is an increase in species richness (diversity) of arthropod communities particularly those that benefit the health of the macadamia orchard. The most distinct trend we observed overall was double the number of parasitoids and predators in the block where there was mohawk vegetation. In comparison the block with no mohawk had lower diversity of arthropods and higher presence of herbivorous insects such as thrips which were three times more numerous in the macadamia trees. Predators and parasitoids are ecosystem regulators providing virtually free pest control. The increase of predators and parasitoids on the farm is providing an economic benefit in terms reduced pest control inputs but also may be increasing other ecosystem services such as pollination via flies, wasps and beetles, leading to enhanced productivity overall.

The results for this trial are likely to be enhanced farm-wide and into the future where the owners maintain a commitment to insectaries throughout the entire orchard. This farm has developed innovative strategies for harvesting and inter-row management, which are compatible with standard orchard operations while allowing retention of some vegetation year-round. The farm enjoys an unusually diverse mix of naturalised weeds and natives in the inter-row with desirable characteristics for an insectary and that are also reasonably easily managed for weediness. The owners can consider some seeding with cover crops if they wish to use their features for more targeted benefits from the inter-row including improved seasonally-specific resources for pollinators and parasitoids, along with other ecosystem services (see below).

The BioResources final report for the *Macadamia IPDM Program - Inter-row Project (MC16008)*, is available via *Hort Innovation*. Here the reader will find out more on the benefits of insectaries for macadamia orchards and also the experiences of other trial farms in implementing and managing insectaries. There is also an exploration of the multiple ecosystem services known to flow from reduced mow inter-row management practices along with improved arthropod biodiversity, including benefits for soil organic matter, nutrient cycling, water management, erosion control, weed suppression, soil carbon storage, soil microbiology and more.

Introduction

This project proposes that reduced mowing in the macadamia inter-row may increase vegetative diversity, increase floral resources and reduce habitat disturbance. This may in turn increase the presence of beneficial arthropods in the orchard. More broadly, the proposed changes in plant ecology may increase arthropod populations in general, leading to more complex food webs and better orchard self-regulation of economic pests. Furthermore, this enhanced nutritional food-web will benefit birds and micro-bats, which also have a role in pollination and pest suppression. In comparison it is estimated that beneficial insects provide 5-10 times the pest control in agricultural ecosystems compared to chemical applications[1], as these processes are occurring all the time. By encouraging more diverse ecosystems within the orchard the likelihood and/or intensity of pest outbreaks decreases.

The mohawk trial farm worked with the BioResources team in this investigation from early 2017 to mid 2019. We compared two (approximately) 1 Ha blocks. A control block was managed as industry standard with regular mowing (**Photo 1**, below). A treatment block was managed with reduced mowing, sustaining a centre mohawk for most of the trial period (**Photo 2**, below).

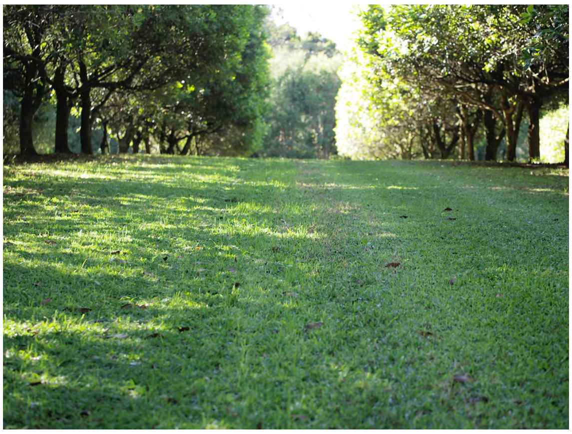


Photo 1: "Mohawk trial farm" complete close mow 1 May 2017

Photo 2: "Mohawk trial farm" mohawk 1 May 2017

With each site visit the BioResources team sampled each block for arthropods in three separate rows using yellow stick traps (YSTs), placing one YST in the inter-row and one YST in a tree. We assessed the vegetation in the inter-row at those three points (a quadrant of approximately 10m x 20m). The three data collection points were at least 30m apart and 50m from any block edge. We also spent time with the owner discussing the trial and any observations that they may have made in relation to rats, weeds, insect pests in the inter-row vegetation and/or any challenges with reduced mowing.

The objective of the trial has been to provide growers with practical experience in reduced mowing options on-farm with monitoring to quantify results.

BioResources first worked with growers to consider practical options for reduced mowing that are compatible with the seasonal demands of orchard management. It has then sought to provide information on any relationship between reduced mowing and the potential for increased rat, invasive weed and/or arthropod pest presence. Finally, the trial has sought to monitor association between changes in inter-row vegetation management and changes in orchard beneficial/pest arthropod ecology.

[1] Pimentel, D., Stachow, U., Takacs, D.A., Brubaker, H.W., Dumas, A.R., Meaney, J.J., Onsi, D.E., Corzilius, D.B., 1992. Conserving biological diversity in agricultural/forestry systems. BioScience 42, 354-362.

Reduced mowing in the inter-row at "Mohawk trial farm"

Reduced mowing and potential problems

	Throughout the trial, BioResources regularly monitored for and consulted with the owners on the following issues:
Rats	The project team did observe evidence of rat activity in the mohawk during one site visit. This was quite late in the life of the trial. The mohawk trial farm reported the same observations. Alternate row mowing was organised in response to enable monitoring and management and discourage the rats from continued digging of nests in the area. No further problems were reported after this.
Problem weeds	The project team did observe a potentially "woody weed" in the mohawk during one site visit. This was Paddy's Lucerne. The mohawk trial farm reported the same observations and it was decided to spot slash and spot spray this weed. No further problems were reported.
Major insect pests of macadamias	The project team monitored vegetation in the inter-row for the presence of major macadamia pests including Macadamia Seed Weevil, Macadamia Nut Borer, Green Veggie Bug and Fruit Spotting Bug. Plant species typically found in the inter-row trial blocks at this farm were not observed to host these pests. The mohawk trial farm did not report observations of insect pests in the inter-row vegetation.
Management of the inter row	No issues were observed by the project team during site visits. No issues were reported by the mohawk trial farm. A number of different machinery options were available for slashing and harvesting, which suited straightforward inclusion of a mohawk in the trial block year-round.

Outcomes

The mohawk trial farm has provided several useful insights into the practicalities of reduced mow options in macadamia orchards and especially the mohawk. Industry has been especially concerned that reduced mowing of the inter-row may lead to significant problems with increased rat activity, invasive weeds and/or insect pests. This trial gives growers reassurance that a mohawk can be incorporated into existing orchard inter-row management and with basic monitoring and management will not lead to other problems.

Management of the trial blocks for the life of this trial was very strong and consistent. Furthermore, inter-row management practices can be defined as "best practice" in both the complete close mow block (which is the current industry standard) and the mohawk block (which is a new proposed industry alternative). Unlike several of our other trial farms, these trial blocks were not adversely impacted by extreme weather or environmental events. For this reason, the results from this trial are especially robust.

The most profound change we observed in arthropod assemblages was double the number of predators and parasitoids in the mohawk block vs the complete close mow block. We also found a moderate increase in nectivorous (pollinator) insects such as flies, wasps and beetles, in the mohawk block. Furthermore, there was a higher diversity (species richness) of arthropods in the mohawk block with overall increase of approximately 30% in the amount of arthropod families represented. In comparison the block with no mohawk had lower diversity of arthropods and higher presence of herbivorous insects such as thrips which were three times more numerous in the macadamia trees.

Proportionally there was more food (prey) available for beneficial insects in the mohawk block and subsequently we observed more predators and parasitoids. This was more pronounced in the inter-row than in the macadamia trees.

Whilst thrips have not been an economic issue for this farm, we did find in the macadamia trees of the complete close mow block that there were three times as many thrips. Although the data on egg parasitoids is potentially confounded by releases of *Trichogrammatoidea cryptophlebiae* (MacTrix), we did record an increase in the presence of egg parasitoids in the mohawk row block. Subsequently this modestly increased egg parasitoid presence/visitation in the macadamia trees.

Results of reduced mowing in the inter-row

Vegetative diversity

Vegetative diversity refers to the number of plant species present. Changes to regular mowing can change plant species diversity. This can in turn be associated with diversity of arthropod species. **Chart 1** presents an average count of plant species observed in the inter-row by treatment through time.

In this trial we anticipated that reduced mowing will increase the number of plant species present in the orchard. As we can see in **Chart 1**, this is consistently the case for the life of this trial, where reduced mowing and the retention of a mohawk result in an inter-row with more plant species. This can be characterised as an area with "managed vegetative diversity".

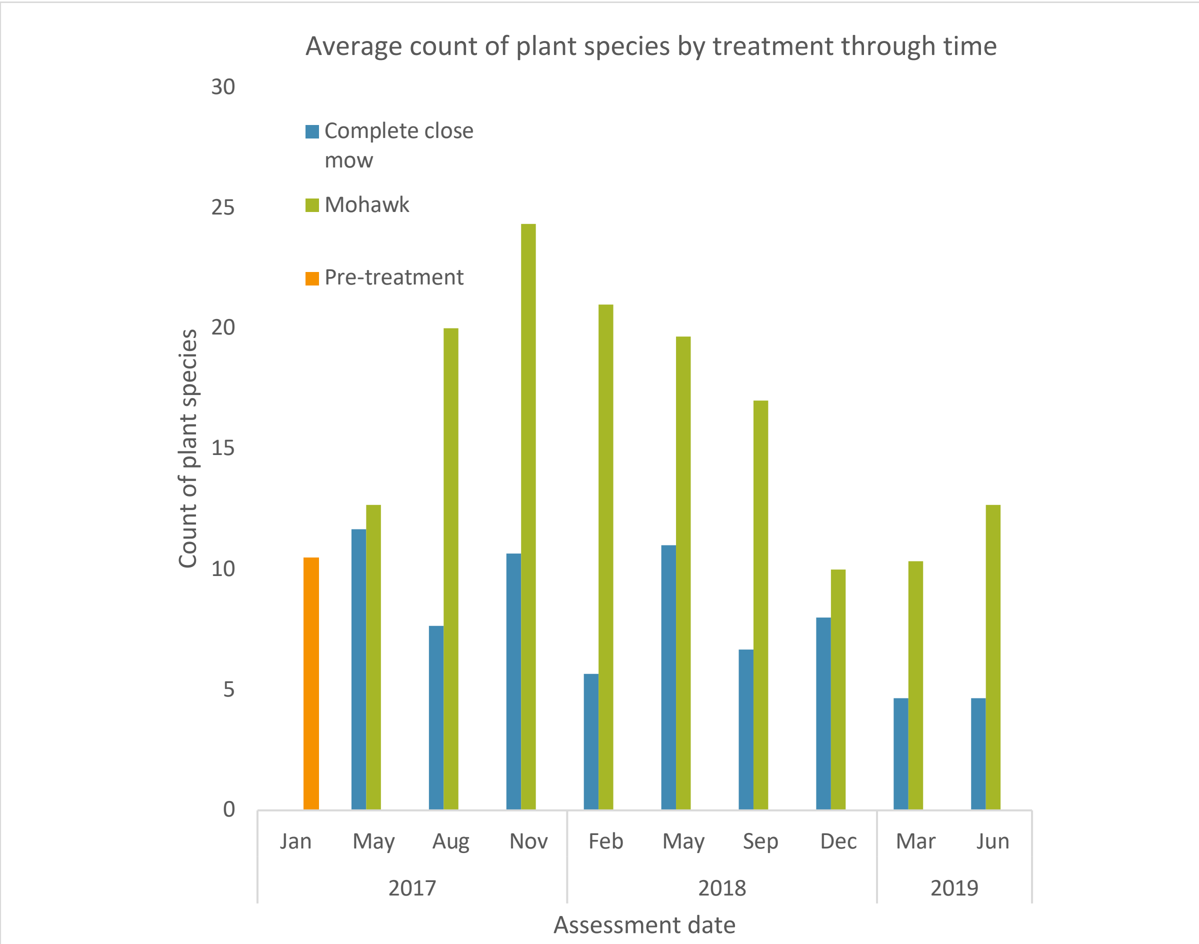


Chart 1: Average count of plant species by treatment through time. This is an average of counts taken at the three assessment points on each block.

Floral resources

Floral resources provide a food source for many beneficial arthropods and will encourage them to remain active in the orchard. **Chart 2** provides an average count of the plant species flowering at the time of the site visit. There were always flowering plant species in the mohawk block. In conjunction with this, we also see that these flowering species always produced a larger volume of flowers as a percent of biomass in the mohawk block as compared to the complete close mow block (**Chart 3**). These results are a consequence of the mix of "naturalised weed" species present in the trial block, which demonstrate a number of favourable characteristics for plants in an insectary. By contrast, the complete close mow block could sustain only occasional and very limited floral resources (**Charts 2 and 3**).

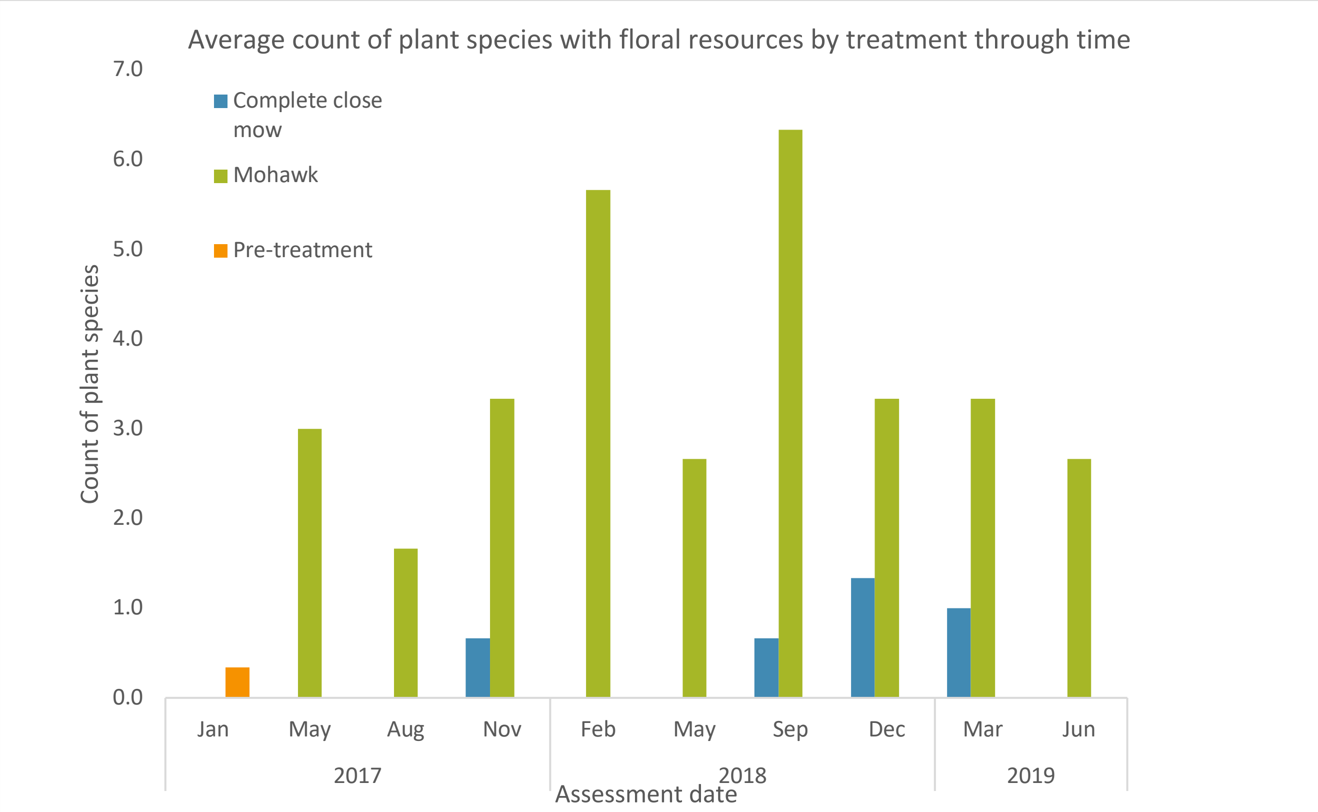


Chart 2: Average count of plant species with floral resources by treatment through time. This is an average of counts taken at the three assessment points on each block.

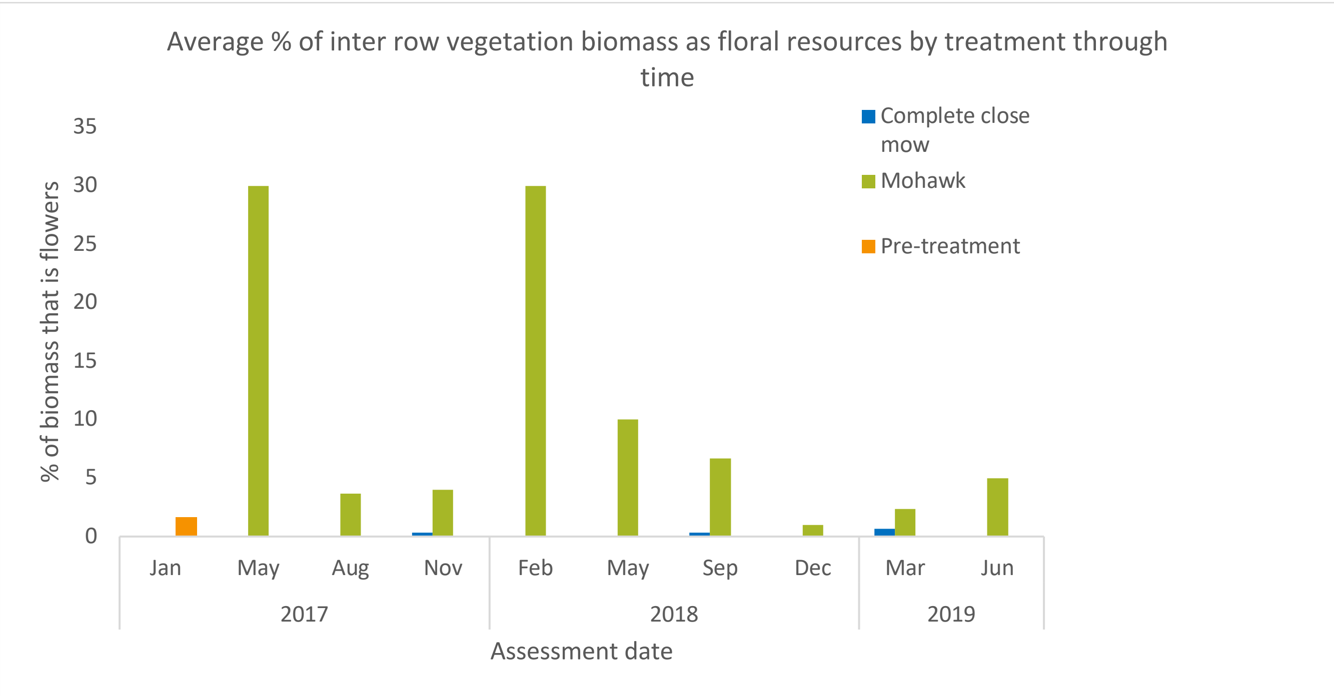


Chart 3: Average percentage of inter-row vegetation biomass as floral resources by treatment through time. This is an average of counts taken at the three assessment points on each block.

Habitat disturbance

Areas of reduced mechanical and chemical disturbance can serve as favourable habitat for beneficial insects. Undisturbed areas may also provide a refuge for beneficial arthropods for faster recovery after spraying. The measurement of height provides a good indication of rates of mechanical disturbance. **Chart 4** reports the height in centimetres (cm) of vegetation in the inter-row by treatment through time. Retention of a central mohawk on this farm allowed for greater height of vegetation, and hence less disturbance in the inter-row for the life of the trial. By contrast, the complete close mow block was regularly and heavily disturbed.

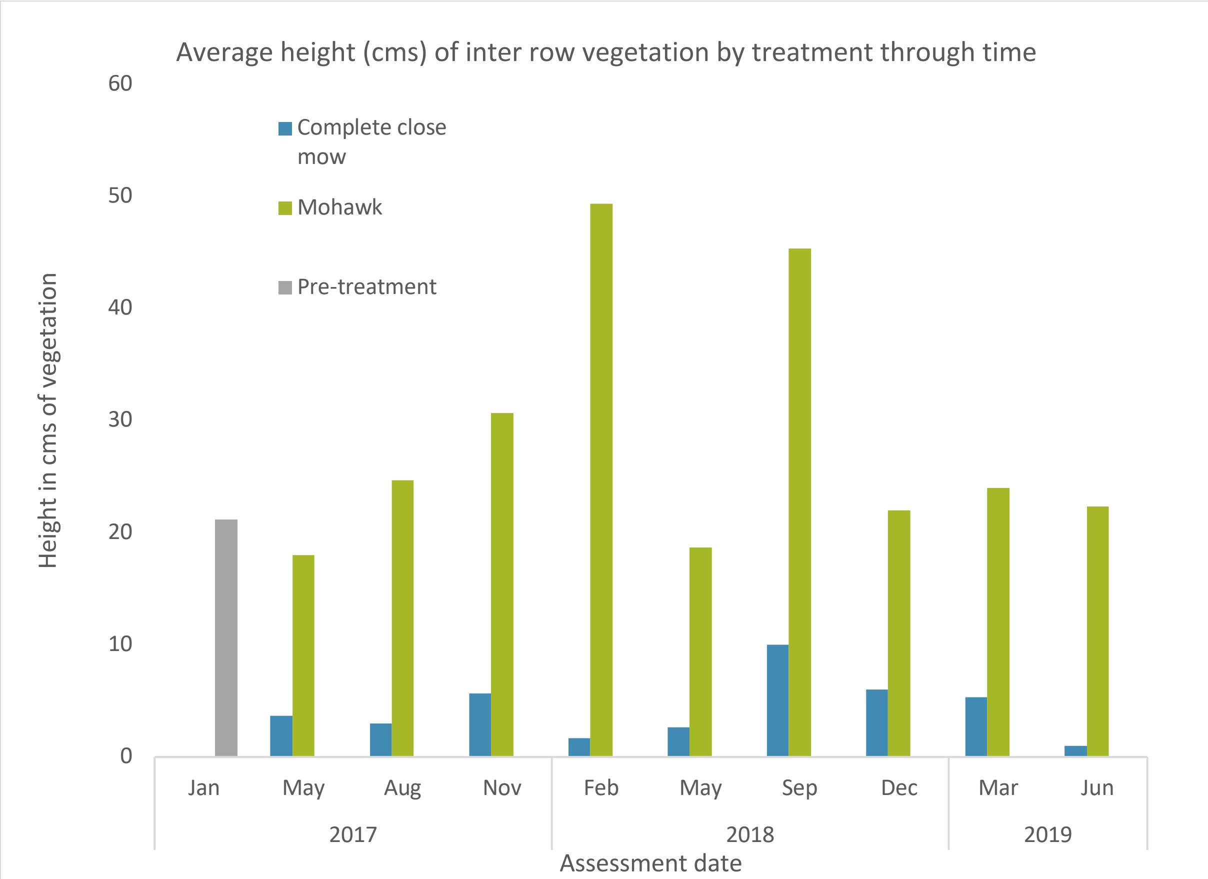


Chart 4: Average height (cm) of inter-row vegetation by treatment through time. This is an average of counts taken at the three assessment points on each block.

Results of arthropod evaluation

General arthropod abundance

From January 2017 to June 2019 we conducted 10 arthropod assessments (1 approximately every 3 months). In total, we collected and identified 10,553 arthropods using yellow sticky traps (YSTs). YSTs best capture flying insects such as flies, true bugs (including aphids), wasps and thrips. However non-flying insects and those not attracted to yellow are seldom caught (e.g. ants and spiders for instance). In **Chart 5** we have collated all the arthropods over the sampling period into broad order level classification. Both flies and wasps were more abundant in the mohawk treatment block than in the complete close mow block**.** Wasps were twice as likely to occur in the mohawk compared to the complete close mow block. Comparatively there are more thrips in the complete close mow block.

To examine more closely these broad arthropod order groupings, we identified the main arthropod groups (except thrips) to family level. We identified 4748 specimens of flies (Diptera) on this farm, comprising of 30 families out of 111 found in all Australian environments. Most adult flies require only nectar or pollen as their primary food source and only recently have flies been recognised in their importance as pollinators. As more fly behaviour observations are studied it is likely we will better understand their specific roles in pollination better. As part of a wider food web they are also important food source for beneficial insects such as spiders and vertebrate animals.

We identified 2133 specimens of wasps (Hymenoptera) on this farm, comprising of 28 families out of 77 families found in Australia, almost all of which were parasitoids. Consequently, this farm can be considered to have good biological diversity of this group.

In the complete close mow, we found nearly three times more thrips caught on the YSTs than in the mohawk (**Chart 5**). In the mohawk an even number of thrips were found in the row and trees (326 & 312 thrips respectively), as compared to the complete close mow area (617 & 945 thrips respectively). This three-fold increase of thrips in the trees could be further investigated as close mowing seems to have increased thrips in the trees and row compared to the mohawk block on this farm. It should be noted however, given the ubiquitous nature of this group, large numbers of thrips can be caught on individual YSTs traps leading to biases in population estimates. In theory given the increase in predators and parasitoids in the mohawk block we can hypothesize that this may help decrease thrip populations in macadamia trees on this farm.

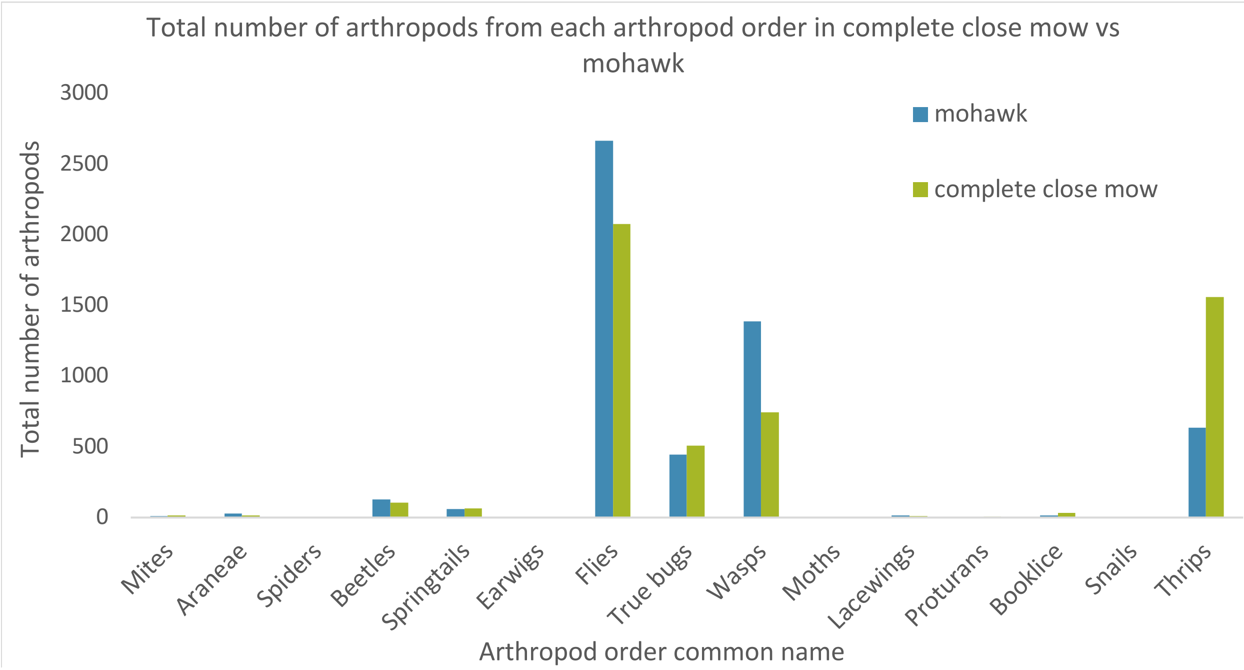


Chart 5: Total number of arthropods in order grouping caught in YSTs from January 2017 to June 2019 on the mohawk trial farm comparing mohawk and complete close mow treatments.

Overall insect abundance was higher in the mohawk than in the complete close mow in both the row and tree, except for in 2017 in the macadamia tree, when thrips dominated the complete close mow samples (**Chart 6**).

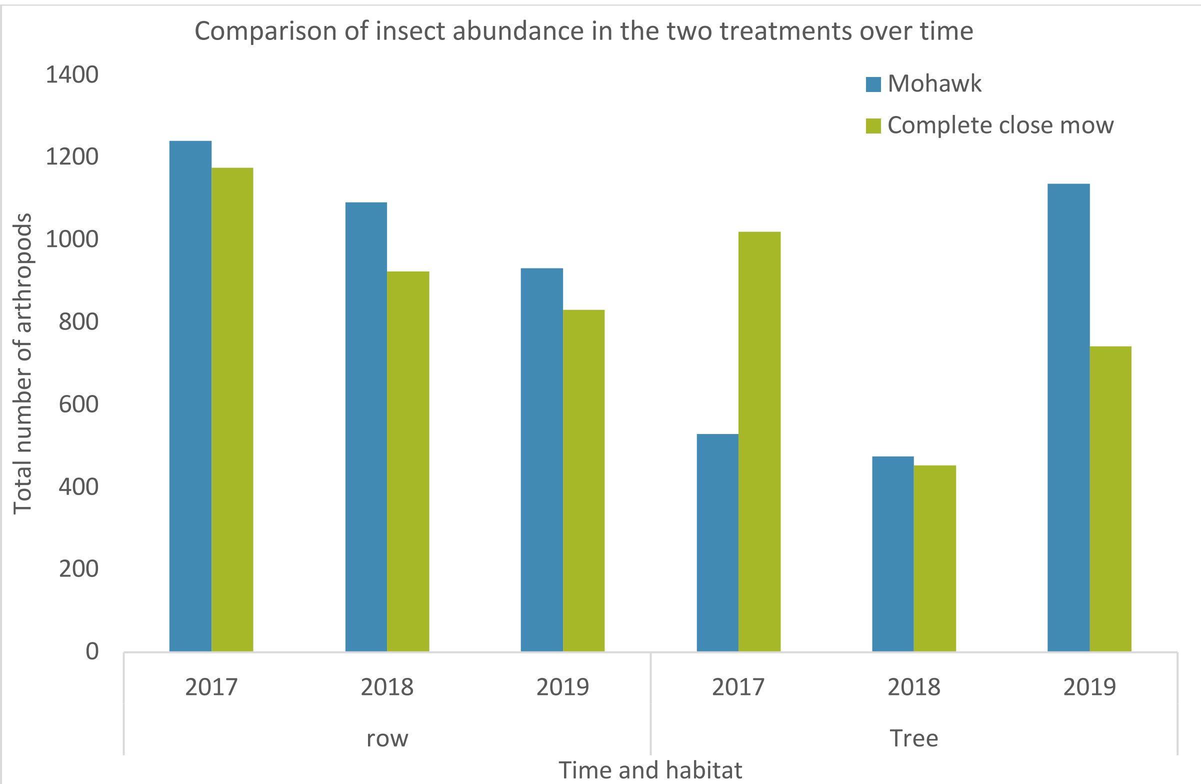


Chart 6: Number of arthropods identified on YSTs comparing treatments across time in the row and tree

Feeding Guilds

To better understand the nature of food webs on macadamia farms we have identified most insect species to family level classification, allowing us to determine the feeding guild structure of insect assemblages. The guild concept has been widely utilised by ecologists; a guild is any group of species that exploit the same resources. For instance, most insect herbivores are selective feeders, they may be specialised as leaf chewers, sap suckers, stem borers, root borers, gall formers, leaf miners etc. Beneficial insects feed as predators and parasitoids. Other important arthropod feeding groups are pollinators via nectar feeding (nectarivores). This is a good way of examining species richness and how it relates overall to farm food webs.

On the mohawk trial farm, the mohawk block had a comparatively greater number of nectarivores (primary food source - flower nectar) and twice as many predators and parasitoids when compared to the complete close mow block (**Chart 7**). Detritivores (which feed on dead plant and animal material) were almost double in number as well. However, in the close mow block, sap suckers (mainly thrips) were double as abundant when compared with the mohawk block. Other groups were less numerous as they are not as well represented by YSTs collection methods.

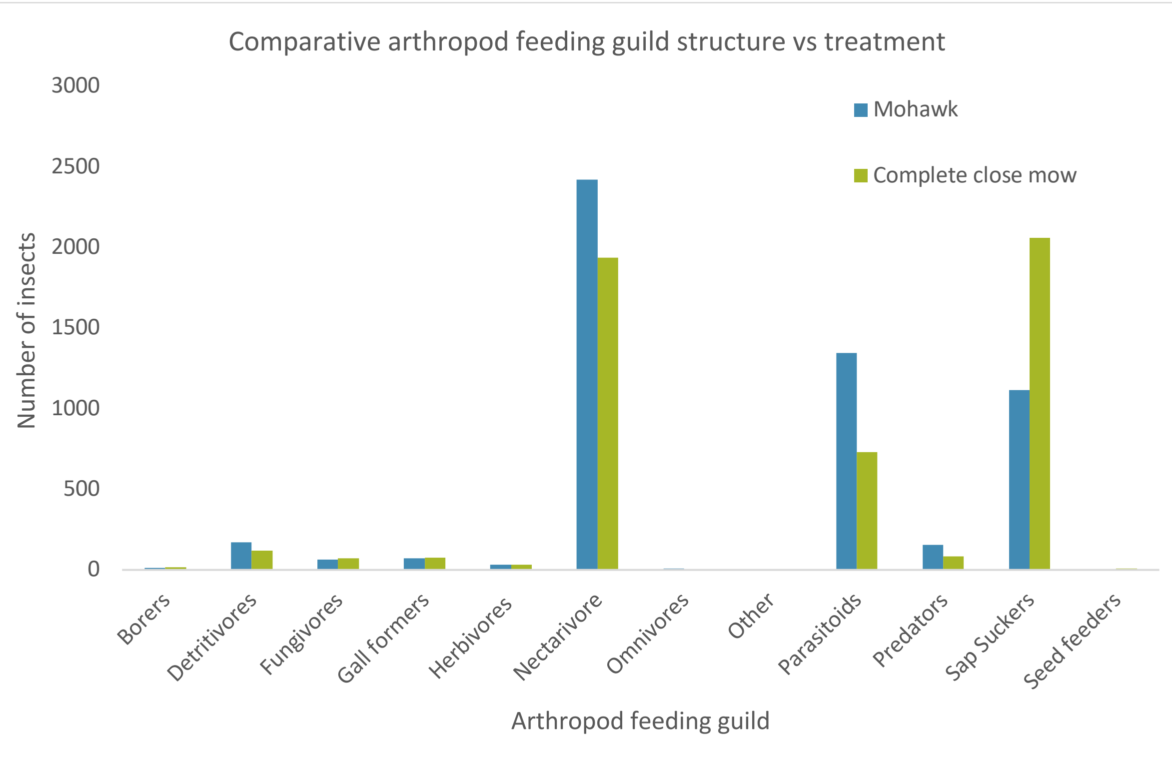


Chart 7: The number of insects and their respective insect assemblages (feeding guilds) caught on YSTs from January 2017 to May 2019.

To simplify our results, by classifying all insects as prey and then separating nectivores (potential pollinators), predators and parasitoids, as four broad categories, we can compare treatments comparatively in proportions. By combining tree and inter-row abundance counts between mohawk and complete mow treatments (**Chart 8**), there is a greater proportion of prey in the mohawk (57%). The proportion of predators and parasitoids in the mohawk block is far greater (63%) than in the complete close mow block (37%). Nectivores are only modestly greater in the mohawk (55%) compared to the complete close mow block (45%).

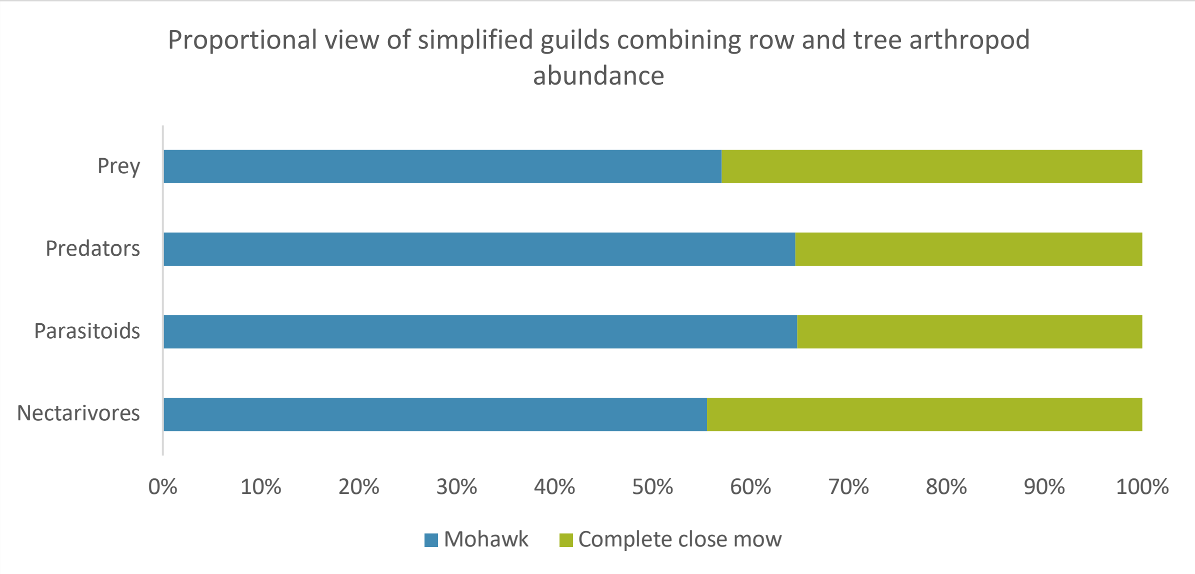


Chart 8: Representation of simplified feeding guilds in macadamia tree and inter-row habitats combining all abundance data.

When we examine this ratio comparing the row habitat in mohawk and complete close mow (**Chart 9**), nectarivores have similar proportions (51% and 49% respectively). There is however proportionally greater abundance of prey in the mohawk (56%). This may account for the greater proportions of predators (65%) and parasitoids (67%) in the mohawk compared to the complete close mow block.

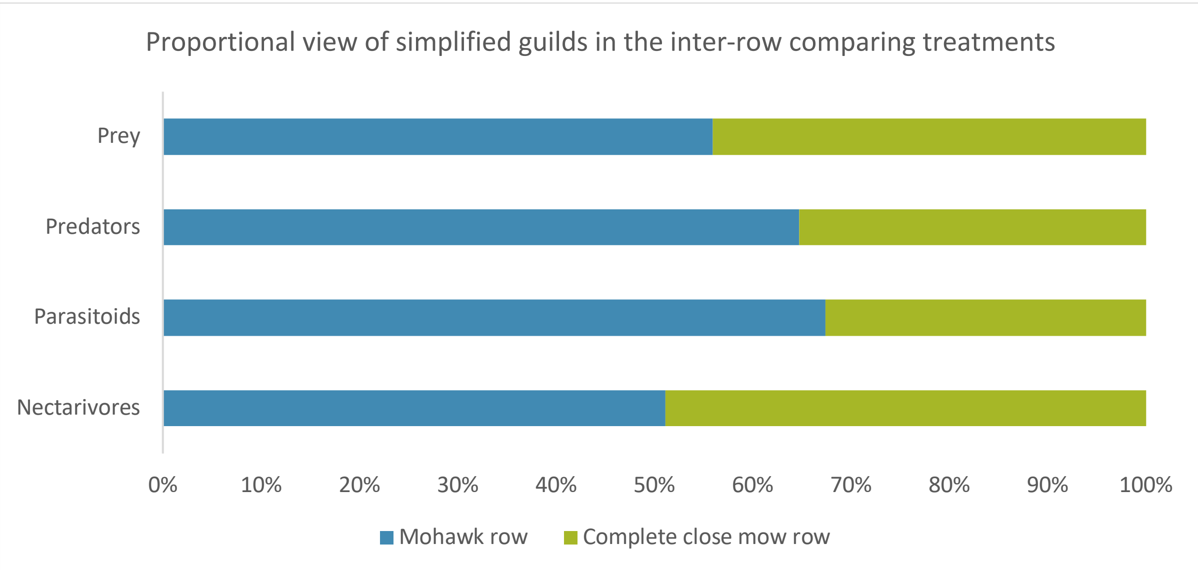


Chart 9: Representation of simplified feeding guilds in the inter-row comparing the mohawk and complete close mow treatments.

In the macadamia tree we found a higher proportion of all broad feeding guild groups in the mohawk (Chart 10). The prey ratio in the mohawk was 59% to that of the complete close mow (39%), and this was similar for the nectivores. In the mohawk predators and parasitoids had higher proportional ratios (64% & 56% respectively).

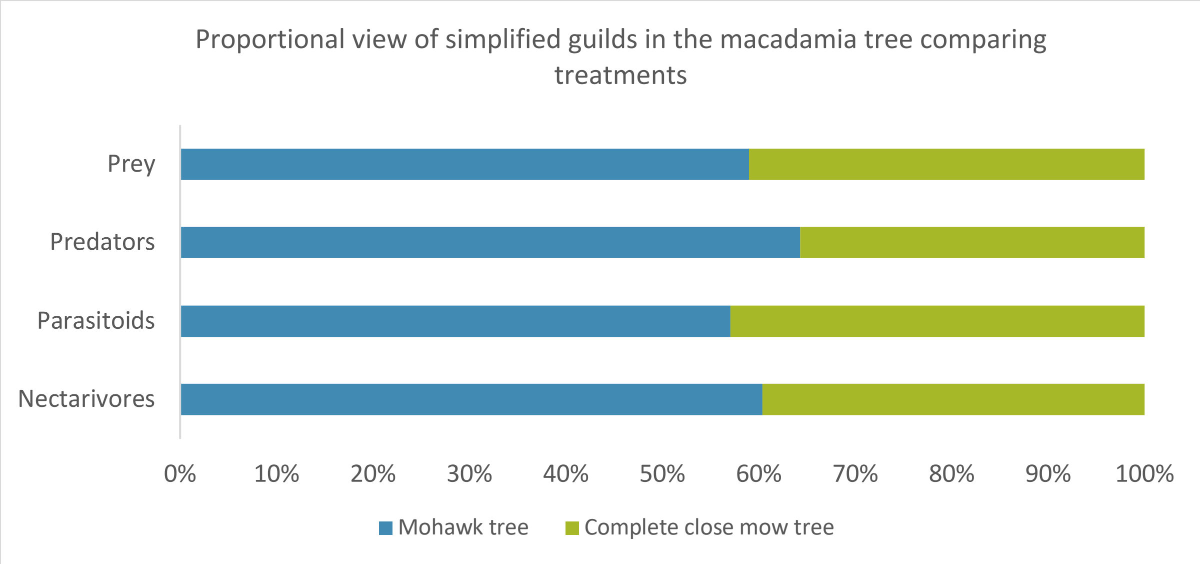


Chart 10: Representation of simplified feeding guilds in macadamia trees comparing mohawk and complete close mow treatments

Pollination

In many ecosystems, including agricultural ones, flies are very important pollinators. Of the 150 families of flies worldwide, almost half, 71, have been shown to feed from flowers (mainly nectar) and thus in principle transmit pollen from one plant to another. This is currently an expanding area of behavioural research as we discover more about their pollinating abilities. A famous example is that we would be a world without chocolate without pollination by the chocolate midge (family Certopogonidae). Of the fly families that dominate the nectarivores on this farm, they are from three main families: the Sciarids (fungus gnats), Chironomids (non-biting midges), and to a lesser extent Phorids (scuttle flies). Some Sciarid species are known to be pollinators however they are generally poorly studied in Australia, as they are particularly difficult to observe in the field, and thus their roles as pollinators are probably not fully appreciated. However, they are one of the most numerous specimens caught on YSTs on the mohawk trial farm. In certain environments like the artic, Chironomids are the most important pollinators of plants. Phorids are a very diverse family and many are important pollinators particularly in forest habitats. The most numerous Phorid genus on this farm was *Megaselia* which has over 1500 species worldwide. Some Phorids species are also known to be aphid predators. Phorid species have also been identified in northern NSW that parasitise macadamia seed weevil and fruit spotting bug.

The detritivores were substantially more dominant in the mohawk (**Chart 11**). They consist of the fly families Calliphoridae, Ephydridae, Psychodidae and Muscids. They are important for the recycling of nutrients back into the soil, as they feed on dead leaves, twigs and subsequent decaying mould.

The mohawk also had a greater number of predatory flies, mostly Dolichopodidae (long legged flies) and other families included Asilidae (Robber flies), Micropezidae (stilt legged flies) and Syrphids (hoverflies). Hover flies are second only to solitary bees in their value as commercial pollinators worldwide. Phorids where not collectively placed in the predatory guild as they are very diverse and occupy various feeding guilds as adults and larvae including scavengers, predators, herbivores, fungivores, parasitoids, and true parasites.

Fly parasitoids were absent from the complete close mow macadamia trees and in small number in the row. However, parasitoids were more abundant in the mohawk and at greater numbers in the adjacent trees than the row of the close mow block (**Chart 11**). A similar pattern was revealed in the fungivore guild. There was an increase in dipteran gall formers (family Cecidomyiidae) in the mohawk trees compared to the close mow trees (**Chart 11**). Overall, there was a greater diversity of family level flies and their feeding guilds in the mohawk trees.

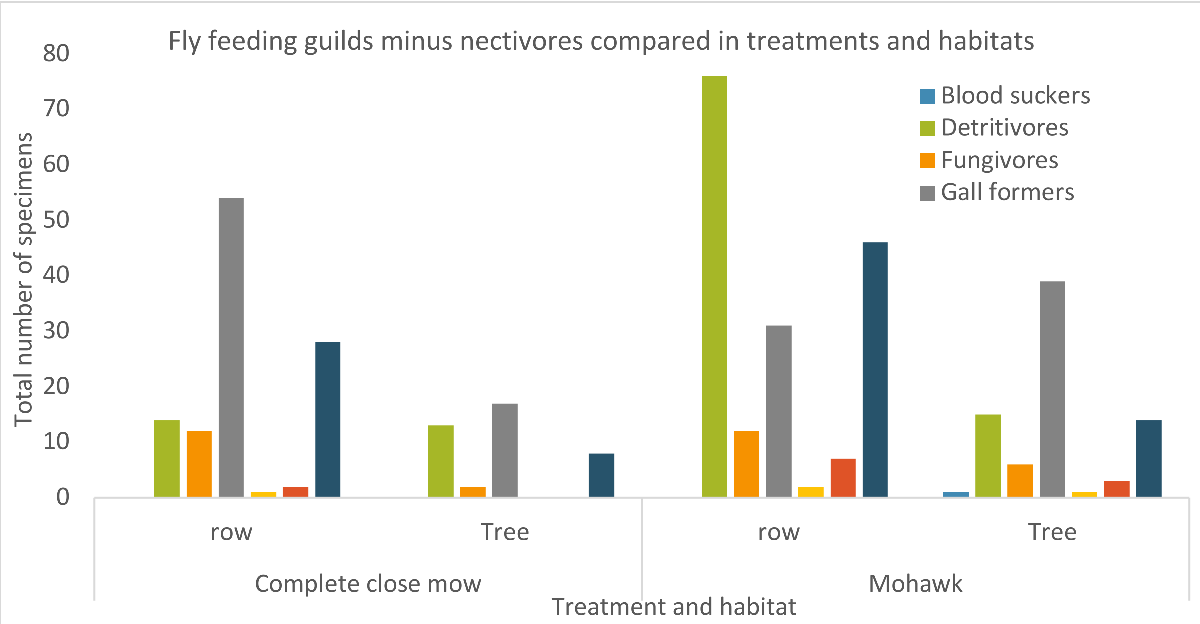


Chart 11: Dipteran (fly) feeding guilds with nectivores removed demonstrating smaller guild structure in mow treatments in the row and trees.

Parasitoids

One of the main treatment differences on the mohawk trial farm was a substantial increase in wasp parasitoids in the mohawk block compared to the complete close mow block in the three years of combined abundance data (**Chart 12**). When we examined differences between the row and tree, we found that there were less differences in parasitoid abundance in the tree, although mohawk trees had somewhat higher numbers.

The main parasitoid differences were recorded in the row, which had three times higher parasitoid abundance in the mohawk in the 2017 seasons and double as many parasitoids in 2019. If we examine more closely the families represented (**Chart 13**) we find that the mohawk has significantly more Chalcidoidea[2], Encyrtidae and Eulophidae. Chalcidoidea are very important in biological control of herbivorous crop pests because they are predominantly parasitoids of lepidoptera, aphids and beetles. Many other families were also better represented in the mohawk, with only the Diapriidae (parasitoids of flies) twice as high in the close mow treatment. Groups like the Ichneumonoids however, were four times more abundant in the mohawk macadamia trees. The Ichneumonoids are large wasps that commonly parasitise the larvae and pupae of Coleoptera (beetles), Hymenoptera (bees & wasps), and Lepidoptera (moths & butterflies) and they play an essential role in most ecosystems. Ichneumonids have been used

[2] It should be noted here that Chalcidoidea is a superfamily and was used for identification purposes in 2017 with only the Trichogrammatidae separated, but in 2018 and 2019 YST samples the Chalcidoidea was further identified to families within that group to better understand this significant group.

successfully as biocontrol agents however, not enough ichneumon species have been studied and further comprehensive research is needed.

Overall increased parasitoid abundance in the mohawk block fitted with our hypothesis as parasitoids need nectar to thrive. This may be better provided by the mohawk. Furthermore, the mohawk also provides more ecological niche space in terms of plant height/architecture, which is known to increase species richness.

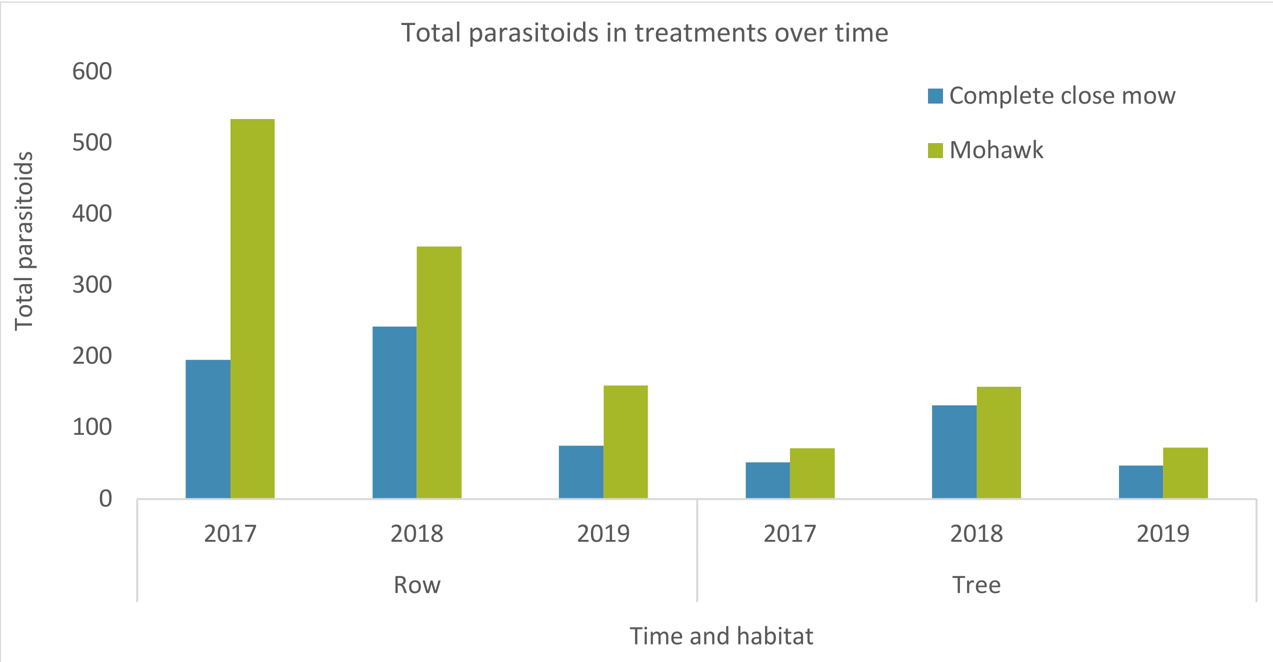


Chart 12: Comparison of the number of parasitoids caught on YSTs from January 2017 to May 2019 in row and tree.

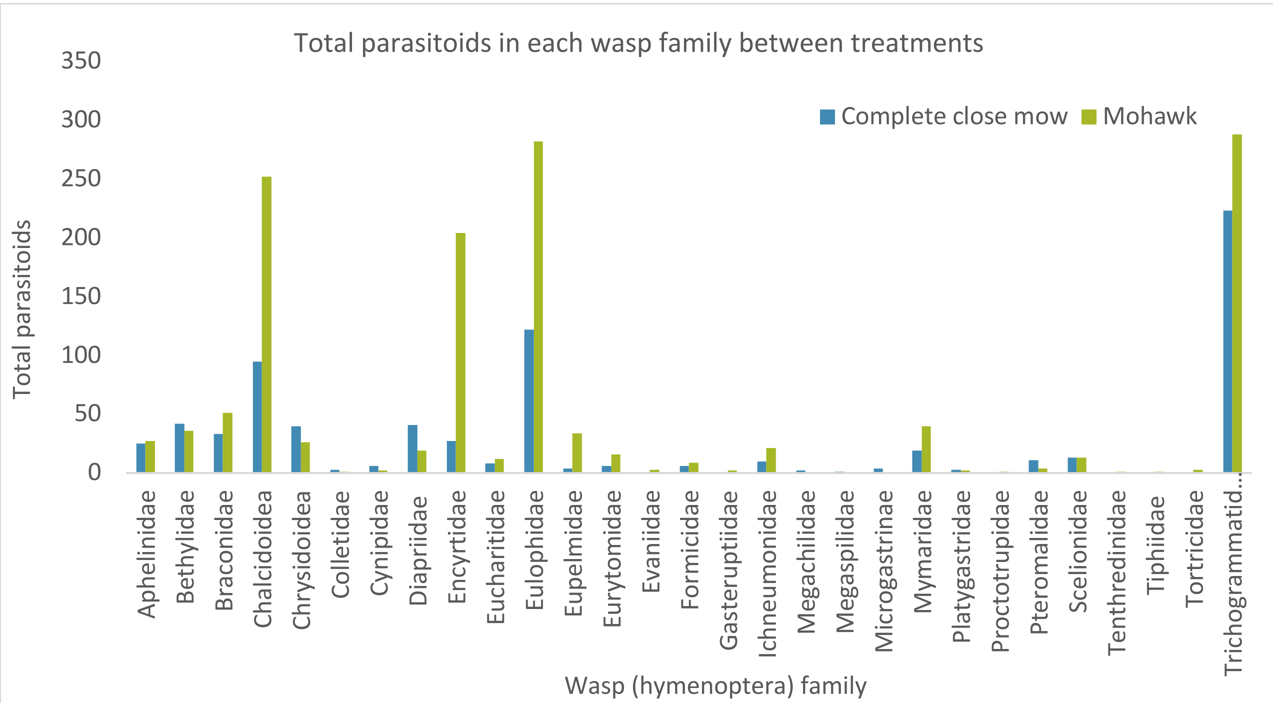


Chart 13: Numbers of Hymenoptera families (parasitoids) caught on YSTs from January 2017 to May 2019 comparing mow treatments.

Turning now to examine the parasitoids released on the mohawk trial farm, we saw interesting variations between treatments. **Chart 14** details the seasonal variation in tree and row habitats for each sampling period (e.g. May to June) that we took samples (10 consecutive seasons). The Trichogrammatidae (egg parasitoids) comprise mostly of *Trichogrammatoidea cryptophlebiae* (MacTrix) in summer when releasing them. However, there are also other egg parasitoids that parasitise moths and other arthropod eggs, which is why they can be found on this farm overwintering in small populations including *Trichogrammatoidea bactrae* and not *Trichogrammatoidea cryptophlebiae*. In 2018 there is approximately double Trichogrammatidae and triple the abundance in 2019 in the trees where there is a mohawk although there is little differentiation in 2017. Numbers are not so clear in the row habitat, with slightly more Trichogrammatidae in 2017 in the mohawk and three times more Trichogrammatidae in the complete close mow in 2018. In 2019, twice as many Trichogrammatidae are caught in the mohawk. However, the release points of MacTrix in summer will have confounded the results in both treatments during this period. Interestingly there is a small peak in 2018 in the complete close mow treatment in the tree habitat during winter. We can theorise there might have been a spike in moth egg laying by pyralids (grass moths) in the complete close mow that laid eggs in smother grass, to warrant this modest population increase.

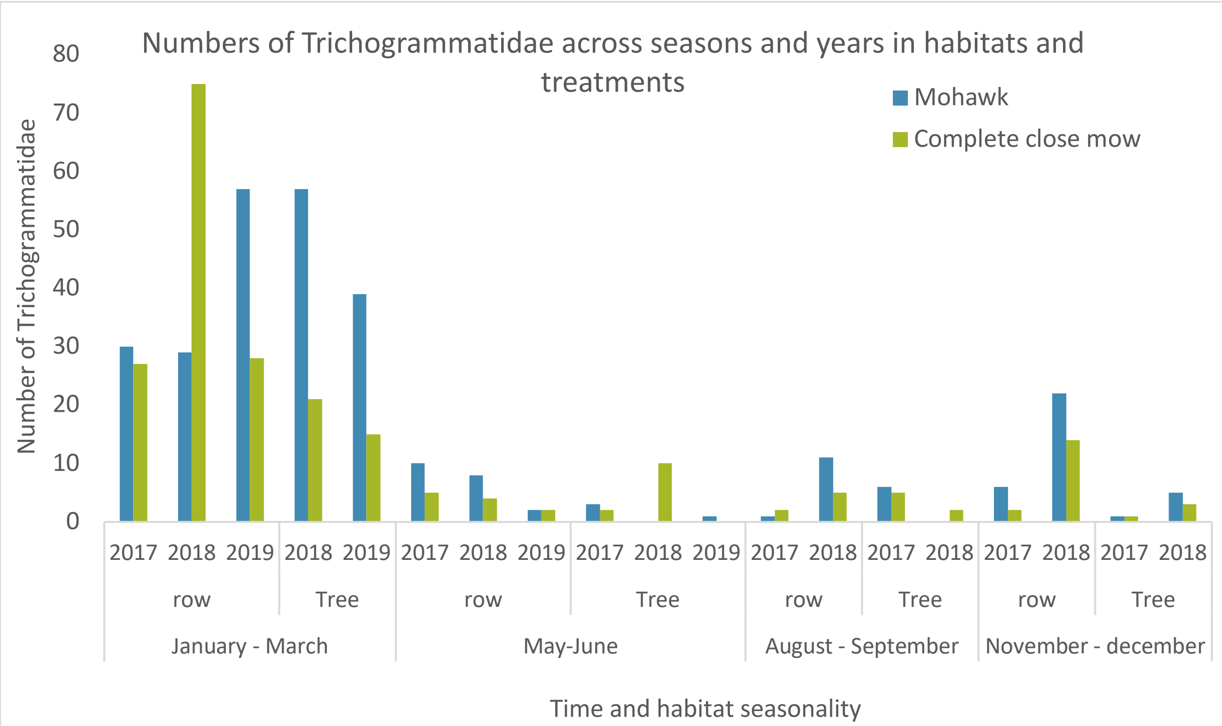


Chart 14: Seasonal abundance of Trichogrammatidae between habitats, treatments and time caught on YSTs from January 2017 to May 2019.

Findings and recommendations

Mohawk worked very well for the mohawk trial farm, given the 10m rows and availability of machinery of a suitable configuration. Retaining a mohawk year-round, including during harvest, proved to be relatively straight-forward. The principal advantage of the mohawk reduced mow approach is that it can be sustained during harvest. This can be especially advantageous during winter, and particularly in dry years, because it keeps an insectary viable during slow growth periods. Other trial farms that removed the mohawk during harvest took many months to re-establish insectary vegetation. Optimal benefits from insectaries are possible when they are in place ahead of macadamia flowering and the annual intensification of crop pest pressure.

It is worth noting that findings from other trial farms and other industries indicate that alternate row mow is another management strategy for consideration. This involves mowing every second row on a rotating schedule, allowing all rows to “grow out” somewhat across the year but providing opportunities for mowing and management as required. This reduces the overall disturbance of beneficial arthropods, ensuring a refuge remains in place at all times for them. It ensures that beneficial arthropods will always have undisturbed areas around the farm for habitat. But it also provides opportunity to schedule removal of vegetation for rat monitoring and management. Likewise, there is opportunity to monitor and manage any “weediness” or dominance of vegetation and encourage regrowth and flowering.

For the mohawk trial farm our results have shown that arthropod abundance is clearly higher in the mohawk area than in the complete close mow. The mohawk was not shown to increase any macadamia pests. However, we found double the abundance of parasitoids and predators in the mohawk and greater species richness in terms of arthropod families represented both in the row and trees. There was also small increase in the presence of parasitoids and predators in the macadamia trees as a result of the mohawk vegetation compared to the complete close mow area of the orchard (particularly the Ichneumonoids). We also found a three-fold increase in thrips compared to the mohawk block over the season sampling period in the complete close mow treatment in the macadamia trees. Thrips were not however reported as much of an issue on this farm during our site visits and in information from bug checking by consultants. However, with increased predators and parasitoids when having a mohawk of vegetation we anticipate a reduction overall pest numbers and coupled with increased pollination. The economic benefit of increased beneficial arthropods could be measured in future studies. It is worth noting that our trial was conducted over 2.25 years, if these practices continue its likely arthropod diversity will increase further.

When the findings from all of the farms that participated in this project are taken into consideration, it is clear that insectaries have meaningful influence on orchard ecology when growers can commit to inclusion of the insectary in the orchard in terms of space allocation and long-term management. The mohawk in the inter-row worked very well on this farm given row width. There are other areas on-farm worth considering, including headlands, field margins and so on where changes to management can allow for habitat suitable for beneficial arthropods. Decisions to improve plant diversity with seeding, well-timed seeding and mowing to limit dominance of one species while encouraging new growth and flowering and so on are also very influential.

Acknowledgements and thanks

The project team wishes to thank the Bevan & Willemse families for their participation, and particularly Jenny and Bob for their contributions and support in the field.

Hort Innovation
Strategic levy investment

MACADAMIA FUND

BioResources

Final Report

"Baldwin & Ranking" – Macadamia Inter-row Trial Results

Hort Innovation program title: The IPM program for the macadamia industry – BioResources

Hort Innovation project code: MC16008

Date: February 2020

Summary

This project investigates the potential for the development of insectaries through vegetation changes in the inter row via reduced mowing. Adoption of reduced mowing where possible is expected to increase the abundance and diversity of beneficial arthropods by creating more complex food-webs that are vital to pollination and pest suppression. Our aim is to optimise macadamia orchards for the self-regulation of pests by supporting beneficial arthropods with shelter, breeding areas, nectar, alternative hosts/prey and pollen.

You worked with the BioResources team to investigate these ideas from early 2017 to mid 2019.

Your reduced mowing trial has provided several useful insights into the practicalities of reduced mow options in macadamia orchards and especially the mohawk. Industry has been particularly concerned that reduced mowing of the inter row may lead to significant problems such as increased rat activity, invasive weeds and/or increased insect pests. Your trial gives other growers reassurance that a mohawk can be incorporated into existing orchard inter row management and with basic monitoring and management will not lead to other problems.

There were clear benefits associated with having a mohawk with seeding in the inter row on your farm. This included an increase in species richness (diversity) of arthropod communities, particularly those that benefit the health of your macadamia orchard. Insect family diversity was higher in the trial block with a mohawk with seeding when compared to the complete close mow block for all of the main groups of insects sampled including beetles, flies, wasps and true bugs. Flies were comparably more diverse with 38 families represented, many of which are potential pollinators. The most distinct trend we observed overall was an increase in the number of parasitoids and predators. Predators and parasitoids are ecosystem regulators providing virtually free pest control. By contrast, when it comes to potential secondary pests in the orchard, we found for example three times as many thrips in the macadamia tree of the complete close mow treatment block. We speculate that with lower numbers of predators and parasitoids, the complete close mow environment is more favourable to thrips.

The results for your trial are likely to be enhanced farm-wide and into the future where you can maintain a commitment to insectaries throughout your entire orchard. Your farm currently supports biodiversity given your organic management system, areas of native vegetation and relatively relaxed mowing schedules. Your farm enjoys a diverse mix of naturalised weeds, grasses and natives in the inter row with desirable characteristics for an insectary and that are also reasonably easily managed for weediness – with the exception of setaria grass. During the trial we explored seeding options and this and even cover crops can be incorporated into your orchard if you wish to use their features for more targeted benefits from the inter row including improved seasonally-specific resources for pollinators and parasitoids, along with other ecosystem services (see below).

The BioResources team encourages you to read the final report for the *Macadamia IPDM Program – Inter-row Project (MC16008)*, which is available via *Hort Innovation*. Here you will find out more on the benefits of insectaries for macadamia orchards and also the experiences of other trial farms in implementing and managing insectaries. There is also an exploration of the multiple ecosystem services known to flow from reduced mow inter row management practices along with improved arthropod biodiversity, including benefits for soil organic matter, nutrient cycling, water management, erosion control, weed suppression, soil carbon storage, soil microbiology and more.

Introduction

This project proposes that reduced mowing in the macadamia inter row may increase vegetative diversity, increase floral resources and reduce habitat disturbance. This may in turn increase the presence of beneficial arthropods in the orchard. More broadly, the proposed changes in plant ecology may increase arthropod populations in general, leading to more complex food webs and better orchard self-regulation of economic pests. Furthermore, this enhanced nutritional food-web will benefit birds and micro-bats, which also have a role in pollination and pest suppression. In comparison it is estimated that beneficial insects provide 5-10 times the pest control in agricultural ecosystems compared to chemical applications[1], as these processes are occurring all the time. By encouraging more diverse ecosystems within the orchard the likelihood and/or intensity of pest outbreaks decreases.

You worked with the BioResources team in this investigation from early 2017 to mid 2019. We compared two (approximately) 1 Ha blocks. A control block was managed as industry standard with regular mowing (**Photo 1**, below). A treatment block was managed with reduced mowing, sustaining a centre mohawk and seeding for most of the trial period (**Photo 2**, below).

Photo 1: "Baldwin & Ranking" – complete close mow October 2018 ***Photo 2: "Baldwin & Ranking" – mohawk with seeding October 2018 including a mix of broad leafed parsley, Queen Anne's lace, marigold, calendula, phacelia, cosmos, buckwheat, lucerne, red clover, dill.***

As you will recall, with each site visit the BioResources team sampled each block for arthropods in three separate rows using yellow stick traps (YSTs), placing one YST in the inter row and one YST in a tree. We assessed the vegetation in the inter row at those three points (a quadrant of approximately 10m x 20m). The three data collection points were at least 30m apart and 50m from any block edge. We also spent

[1] Pimentel, D., Stachow, U., Takacs, D.A., Brubaker, H.W., Dumas, A.R., Meaney, J.J., Onsi, D.E., Corzilius, D.B., 1992. Conserving biological diversity in agricultural/forestry systems. BioScience 42, 354-362.

time with you discussing the trial and any observations that you may have made in relation to rats, weeds, insect pests in the inter row vegetation and/or any challenges with reduced mowing.

The objective of the trial has been to provide growers with practical experience in reduced mowing options on-farm with monitoring to quantify results.

BioResources first worked with growers to consider practical options for reduced mowing that are compatible with the seasonal demands of orchard management. It has then sought to provide information on any relationship between reduced mowing and the potential for increased rat, invasive weed and/or arthropod pest presence. Finally, the trial has sought to monitor association between changes in inter row vegetation management and changes in orchard beneficial/pest arthropod ecology.

Reduced mowing in the inter row at "Baldwin & Ranking"

Reduced mowing and potential problems

	Throughout the trial, BioResources regularly monitored for and consulted with Sue Ranking, on the following issues:
Rats	The project team did make occasional observations of evidence of rat activity in the mohawk during some site visits late in the growing season. This included some shell or burrows here and there. It was noted that this block was especially susceptible to rat incursions because that end of orchard is adjacent to the bush on 3 sides (unlike the complete close mow block). Where setaria grass became very dominant it did provide some habitat. You reported regular concerns that the reduced mowing area may increase your rat issues in the orchard. You provided observations that leading into harvest for 2018 some nut was washing/rolling into the mohawk area and potentially attracting rats. You also observed that unmown areas may provide cover for rats. You observed more rat damage in the reduced mow area in 2018. You increased mowing in that area for harvest and then reduced mowing later in the year. You also reported that as an organic grower you were likely to have access to some additional methods for rat control in the foreseeable future and this provided much stronger rat management for you overall. Mowing more regularly resolved concerns relating to the trial. You also mowed areas specifically when you were managing rats using your Cheetah Rat Control machine. Towards the end of the trial you reported that during the life of the trial rat activity was generally much higher than usual in your area and on neighbouring farms.
Problem weeds	The project team did observe a couple of potential problems with setaria grass becoming dominant in reduced mow areas. Setaria limited the overall vegetative diversity of the trial block and created some additional mowing burden. It also had the potential to provide rats with habitat and shelter from predators. By the end of the third season it was noted however that the power harrowing and seeding was starting to reduce the dominance of setaria in the seeded mohawks. You reported that woody weeds were starting to establish in reduced mow inter rows and you consequently increased mowing frequency and were happy with the result.
Major insect pests of macadamias	The project team monitored vegetation in the inter row for the presence of major macadamia pests including Macadamia Nut Borer, Green Veggie Bug and Fruit Spotting Bug. Plant species typically found in the inter row trial blocks at your farm were not observed to host these pests. You did not report observations of insect pests in the inter row vegetation.
Management of the inter row	There were a number of iterations of the reduced mowing schedule in order to find periods of time that best allowed vegetation growth for insectary but also limited issues with difficult to manage growth-rates and volumes, and possible association with rats, and general pre-harvest clean-up. A combination of unusually wet weather and reduced mowing created some challenges for harvest (mostly because you could not get machinery on to the orchard), but you found a number of solutions including increased mowing as required and a more narrow mohawk for harvest. You noted additional future refinements including: leave the mohawks long until the nut shells harden, the Fruit Spotting Bug high risk time and wasp releases are past.

	Then mow and keep short for a month to two before pickup starts and to deter the rats. The seed mixes selected for your trial did not demonstrate especially strong establishment. As a result, we did not see strong increases in plant species diversity and floral resources. This provided a very useful insight because these plant species are widely recommended for insectaries. Your trial results have helped the project to identify other new and more promising seed mixes suitable for the macadamia inter row.

Outcomes

Your trial has provided several useful insights into the practicalities of reduced mow options in macadamia orchards and especially the mohawk and seeding. Industry has been especially concerned that reduced mowing of the inter row may lead to significant problems with increased rat activity, invasive weeds and/or insect pests. Your trial gives other growers reassurance that a mohawk can be incorporated into existing orchard inter row management and with basic monitoring and management will not lead to other problems.

Some trial farms, including yours, found through time that maintaining a mohawk in the orchard in parallel with standard orchard operations was difficult. This was a result of a combination of row width and available machinery and was particularly a problem leading into harvest. This is an important finding, and the project team and participating growers including you, formed the opinion that alternate row mow outside of harvest may be a more suitable reduced mow strategy in such circumstances.

Over the life of your trial there were a number of challenges to the consistent incorporation of a control and a reduced mow with seeding treatment option into the inter row. There were cumulative impacts from some irregular mowing; wet weather conditions especially in 2018 prevented you from mowing the control block, while management issues with the mohawk meant that you mowed this area out, all of which will have introduced confounding factors into the experimental data. Despite this, data collected for your trial in terms of the benefits of reduced mowing for beneficial arthropods in your orchard are promising and suggest that mohawks with seeding can complement your organic system and native vegetation areas in the promotion beneficial arthropods that can provide ecosystem services.

Abundance of arthropods was higher in the mohawk with seeding (3206 specimens) than in the close mow treatment (2771 specimens), with the most difference in abundance being in samples taken from the inter row and slightly higher in samples taken from the macadamia tree.

Insect family diversity was higher in the mohawk with seeding treatment for all the main groups of insects caught on YSTs (beetles, flies, wasps and true bugs). Flies were comparably more diverse with 38 families represented. The mohawk with seeding block had a higher diversity of flies, with nine extra families. The mohawk with seeding had a greater number of predatory flies both in the inter row and macadamia tree

The mohawk with seeding treatment block had higher nectarivores (potential pollinators), parasitoids (wasps and flies) and predators than the complete close mow block.

There were five parasitoid wasp families absent from the complete close mow block that were present in the mohawk with seeding block. No wasp families were found only in the complete close mow block.

There is not much difference in parasitoid abundance in the macadamia tree in the two treatments, However, parasitoid numbers were double and triple in the mohawk with seeding treatment block in 2018 and 2019 respectively. There were twice as many Trichogrammatidae (including MacTrix) in the mohawk with seeding, but only in the first period of 2019, so this might have been confounded by the release points of MacTrix In other sampling periods there was little difference of MacTrix between treatments.

True bug diversity is greater in the mohawk with seeding treatment block with seven families present there that are not present in the complete close mow block. True bug predators are higher in the row and tree of the mohawk with seeding treatment block.

We found three times as many thrips in the macadamia tree of the complete close mow treatment block. We speculate that it is possible that with lower numbers of predators and parasitoids in the complete close mow environment it could be more favourable to thrips.

For an overview of the potential for inter row insectaries in macadamia orchards, the BioResources team urges you to read the project’s final report, *Macadamia IPDM Program - Inter row Project (MC16008),* which will be available via *Hort Innovation*.

Results of reduced mowing and seeding in the inter row

Vegetative diversity

Vegetative diversity refers to the number of plant species present. Changes to regular mowing and the incorporation of seeding can change plant species diversity. This can in turn be associated with diversity of arthropod species. **Chart 1** presents an average count of plant species observed in the inter row by treatment through time.

In this trial we anticipated that reduced mowing with seeding will increase the number of plant species present in the orchard. As we can see in **Chart 1**, this is consistently the case for the life of your trial, where reduced mowing with seeding and the retention of a mohawk result in an inter row with more plant species. This can be characterised as an area with "managed vegetative diversity".

In experimental terms, you will note however that the distinction between the values recorded for the control and treatment is not strong on a number of the assessment dates – the mohawk with seeding has increased species to a maximum of 2-3 additional species on four out of eight assessment dates. This result is linked to the species selected for seeding, which project records indicate were not consistently strong in establishment. Likewise, reduced mowing was unable to consistently and substantially increase the number of plant species present. At the same time the plant species diversity in the control (complete close mow) was in fact reasonably good. This is good news for your farm, which has good existing plant diversity in the weeds, grasses and local natives already present. But the lack of distinction between the two blocks will have somewhat diminished the arthropod results discussed below, where we sought to investigate an experimental comparison between two different types of inter row management.

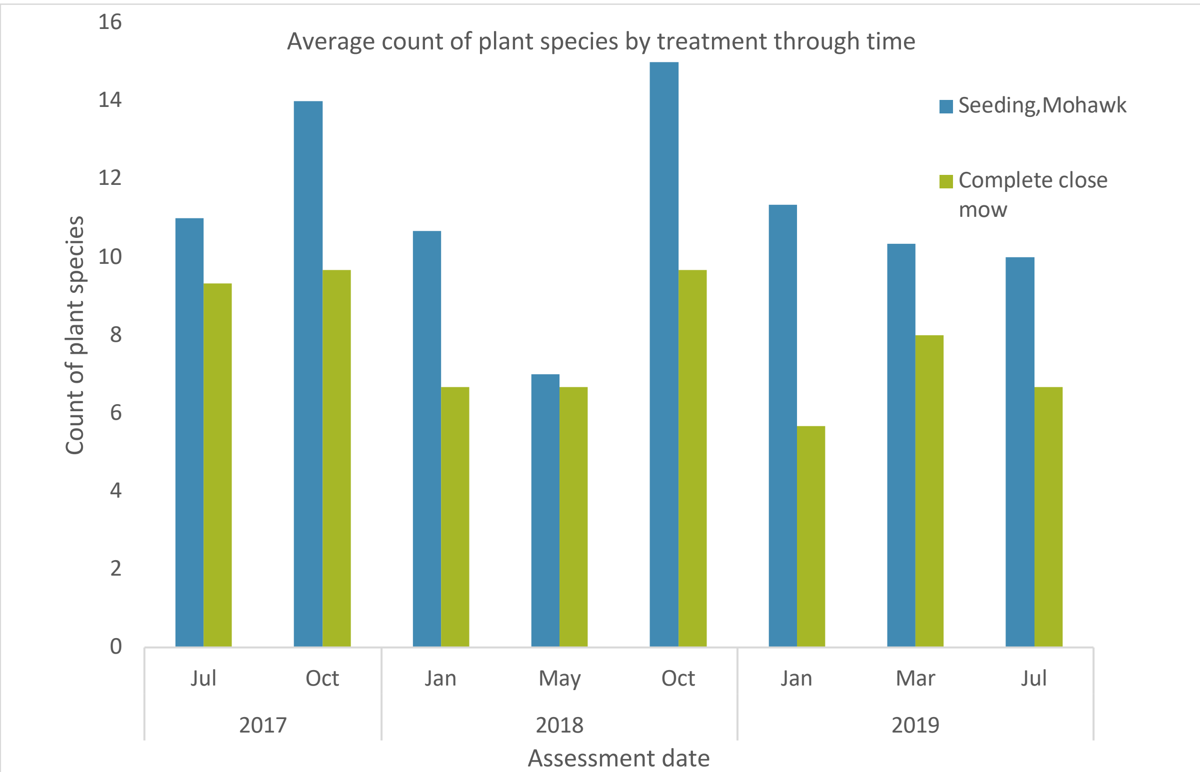


Chart 1: Average count of plant species by treatment through time. This is an average of counts taken at the three assessment points on each block.

Floral resources

Floral resources provide a food source for many beneficial arthropods and will encourage them to remain active in the orchard. **Chart 2** provides an average count of the plant species flowering at the time of the site visit. There were always flowering plant species in both blocks (with the exception of May 2018); but there was always a larger number of flowering species in the mohawk block. In conjunction with this, we also see that these flowering species produced a larger volume of flowers as a percent of biomass in the mohawk block as compared to the complete close mow block (with the exception of October 2018, when prairie grass was especially vigorously flowering in the control block (**Photo 1**)(**Chart 3**). These results are a consequence of the mix of plant species present in the trial block and seeding, which demonstrate a number of favourable characteristics for plants in an insectary. By contrast, the complete close mow block could generally only sustain occasional and very limited floral resources (**Charts 2** and **3**).

Again, in experimental terms, you will note however that the distinction between the values recorded for the control and treatment in **Chart 2** is not especially strong for a number of the assessment dates. The mohawk with seeding increases the number of flowering species in a range of 2 to 3 additional species in most cases. Despite this, in **Chart 3** we see that the flowering species in the mohawk with seeding have significantly increased the availability of floral resources for beneficial arthropods.

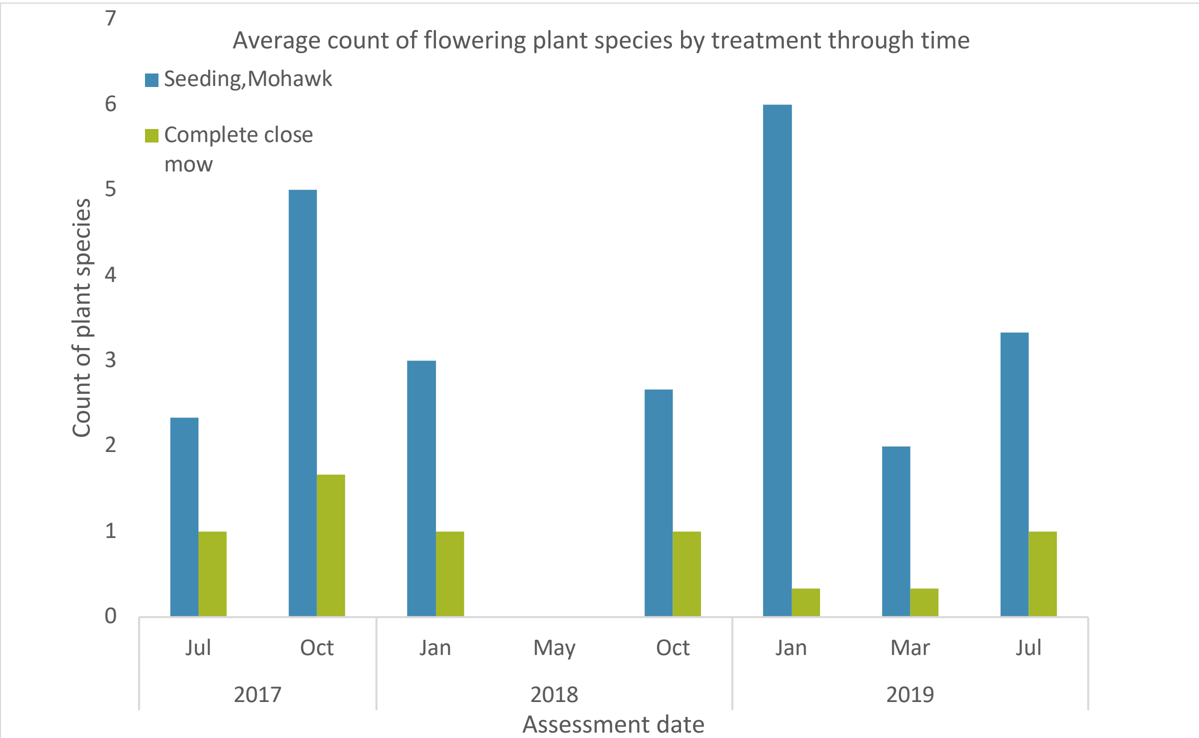


Chart 2: Average count of plant species with floral resources by treatment through time. This is an average of counts taken at the three assessment points on each block.

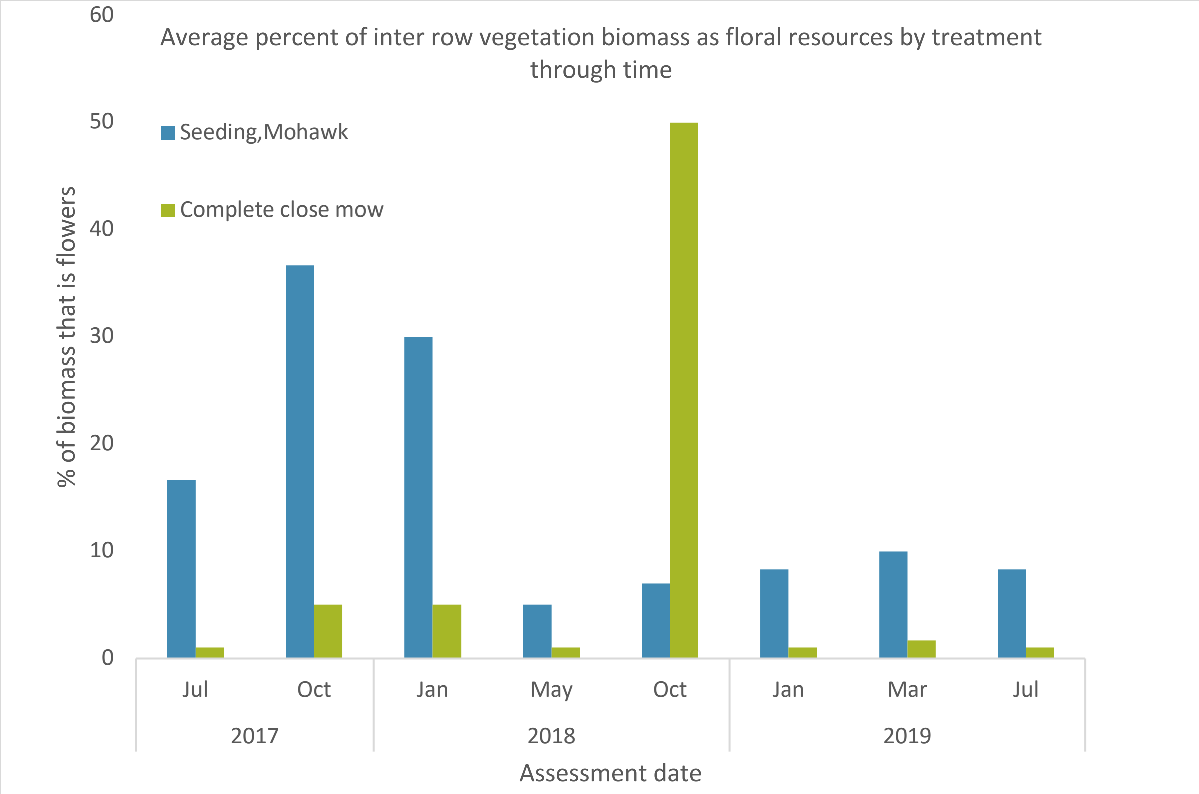


Chart 3: Average percentage of inter row vegetation biomass as floral resources by treatment through time. This is an average of counts taken at the three assessment points on each block.

Habitat disturbance

Areas of reduced mechanical and chemical disturbance can serve as favourable habitat for beneficial insects. Undisturbed areas may also provide a refuge for beneficial arthropods for faster recovery after spraying. The measurement of height provides a good indication of rates of mechanical disturbance. **Chart 4** reports the height in centimetres (cm) of vegetation in the inter row by treatment through time. Retention of a central mohawk on your farm allowed for greater height of vegetation, and hence less disturbance in the inter row for the life of the trial. By contrast, the complete close mow block was more regularly and heavily disturbed.

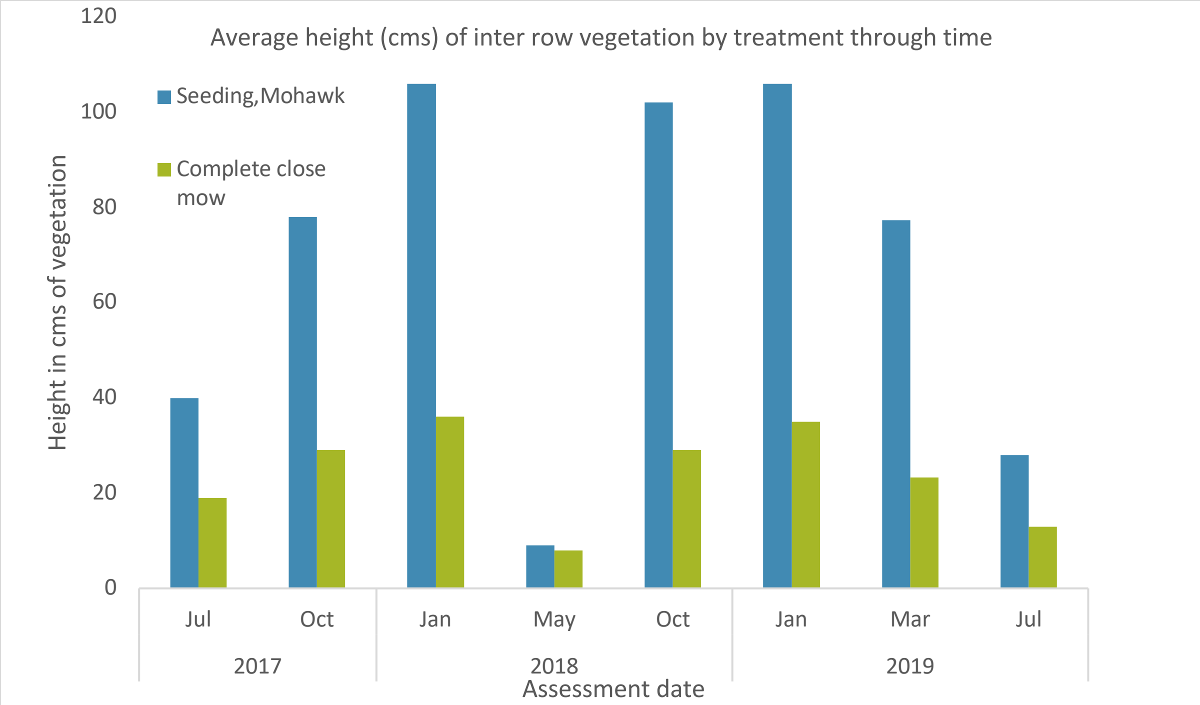


Chart 4: Average height (cm) of inter row vegetation by treatment through time. This is an average of counts taken at the three assessment points on each block.

Results of arthropod evaluation

General arthropod abundance

From March 2017 to July 2019 we identified 5,977 arthropods over 8 sampling dates (approximately every 4 months) using yellow sticky traps (YSTs). YSTs best capture flying insects such as flies, true bugs (including aphids), wasps and thrips. However non-flying insects and those not attracted to yellow are seldom caught (ants and spiders for instance). In **Chart 5,** we have collated all the arthropods over the sampling period into broad order level classification and compared the inter row and macadamia tree habitats. Most arthropod orders are similar in both treatments except for wasps (most of which are parasitoids), which are almost twice the number in the inter row of the mohawk with seeding treatment block. Booklice where higher in the trees of the mohawk with seeding. Thrips are modestly higher in the inter row (502 vs 455 specimens) but are found less in the tree where there is a mohawk with seeding (75 vs 110 specimens). Proportionally, over the years, thrip abundance in the macadamia trees was relatively high in 2017 and 2019, but similar in 2018. This could have been influenced by the block mowing alterations in 2018.

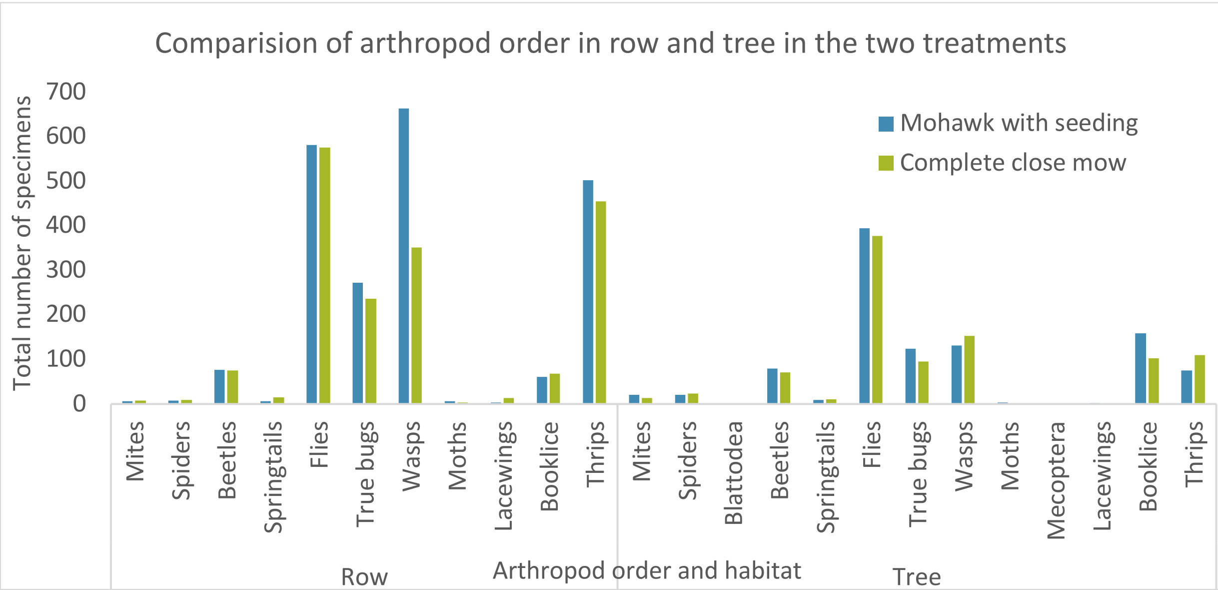


Chart 5: Abundance of arthropods divided into order level classification, comparing the mohawk with seeding and complete close mow treatments over the total sampling period.

Arthropod abundance was higher in the mohawk with seeding block (3206 specimens) compared with the close mow treatment block (2771 specimens) over the three years of the survey. **Chart 6** compares total arthropod abundance in the two habitats over the sampling period, demonstrating that the abundance was higher in the inter row of the mohawk with seeding over time. In the macadamia tree there was slightly higher arthropod abundance in 2017 in the close mow block. This changed in 2018 when higher overall abundance was observed in the mohawk block. In 2019 both treatments had similar arthropod abundance in the macadamia trees.

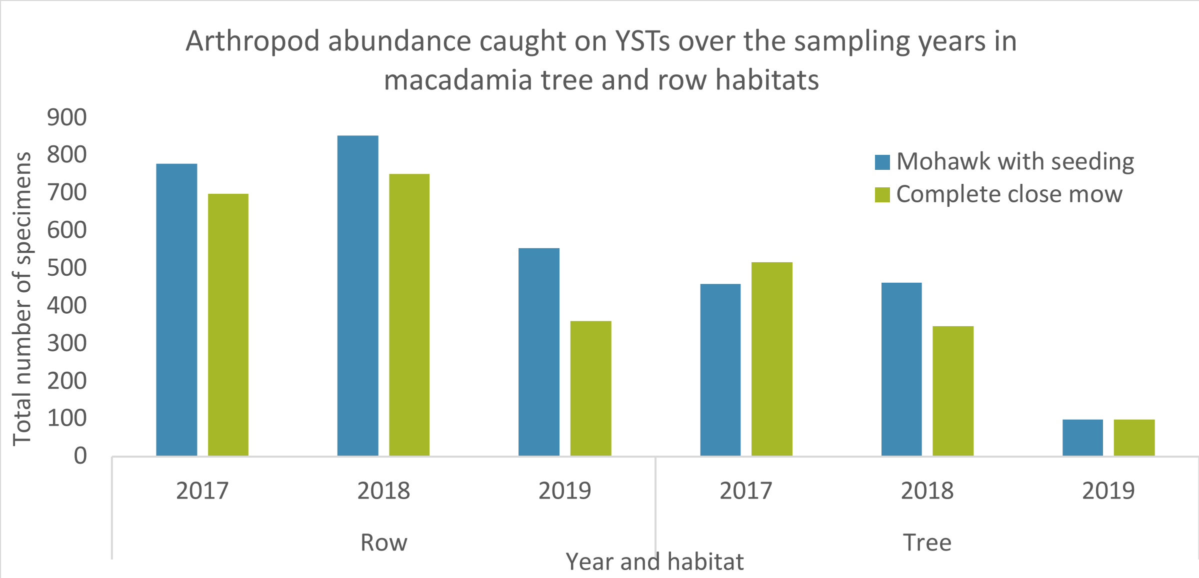


Chart 6: Total arthropod abundance of specimens collected by YSTs over the sampling period combining both the inter row and macadamia tree habitats.

Another broad level of comparing treatments is to examine the diversity of insects between treatments. In **Chart 7** we have listed the most diverse groups that we identified to family level classification. On your farm, flies are diverse, consisting of 38 families (out of 111 found in all Australian environments). In the four main insect groups, the mohawk with seeding block had more diversity of families. Prey diversity is important for the year-round nutrition of predators and parasitoids.

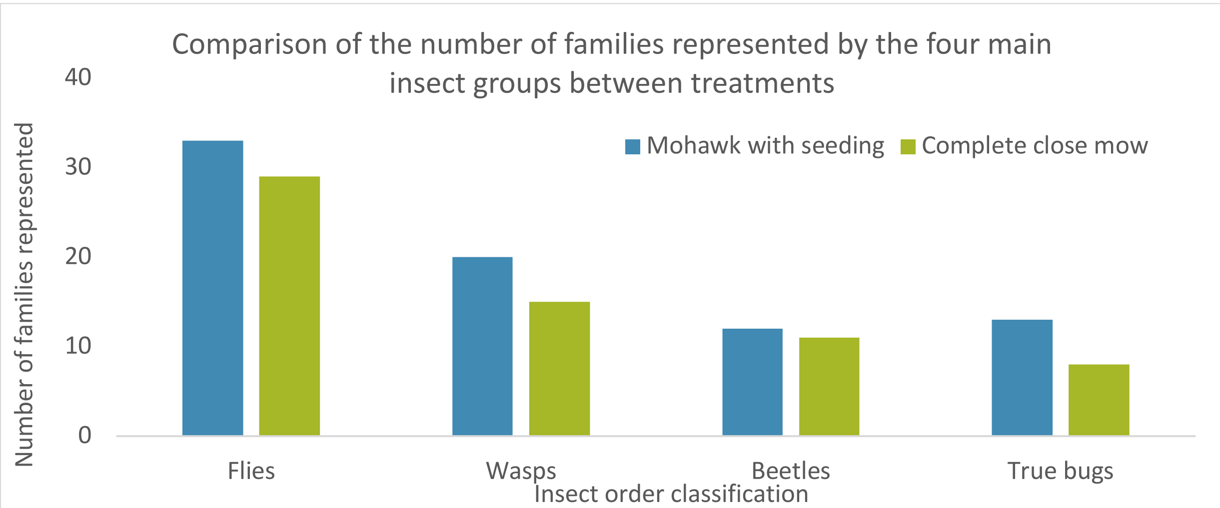


Chart 7: Comparison of the number of families represented by the four main insect groups between treatments.

Feeding Guilds

To better understand the nature of food webs on macadamia farms we have identified most insect species to family level classification, allowing us to determine the feeding guild structure of insect assemblages. The guild concept has been widely utilised by ecologists; a guild is any group of species that exploit the same resources. For instance, most insect herbivores are selective feeders, they may be specialised as leaf chewers, sap suckers, stem borers, root borers, gall formers, leaf miners etc. Beneficial insects feed as predators and parasitoids. Other important arthropod feeding groups are pollinators via nectar feeding (nectarivores). This is a good way of examining species richness and how it relates overall to farm food webs. **Chart 8** summarises the total number of arthropods grouped by feeding guild. The mohawk with seeding treatment block had higher nectarivores, parasitoids and predators than the complete close mow block.

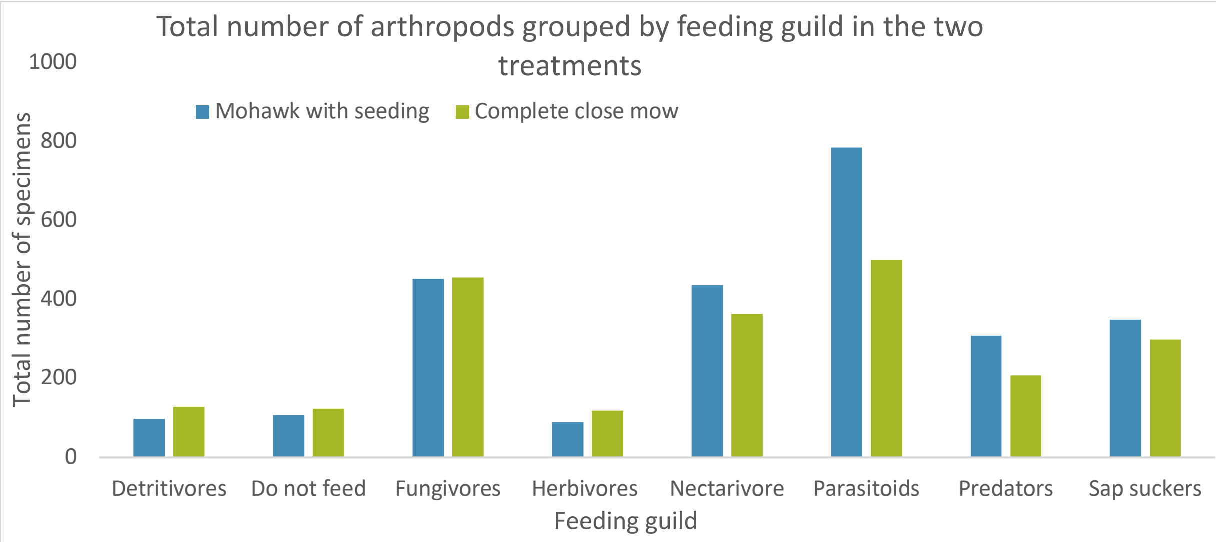


Chart 8: Total number of insects and their respective feeding guilds caught on YSTs from March 2017 to July 2019 in the two treatment blocks.

To simplify our results, by classifying all insects as prey and then separating nectivores (potential pollinators), predators and parasitoids, as four broad categories, we can compare treatments comparatively in proportions. By combining tree and inter row abundance counts between mohawk with seeding and complete mow treatments (**Chart 9**), there is a slightly greater proportion of prey in the mohawk (54%). The proportion of predators and parasitoids in the mohawk block is greater (60 and 61% respectively) than in the complete close mow block. Nectivores are modestly greater in the mohawk (55%) compared to the complete close mow block (45%).

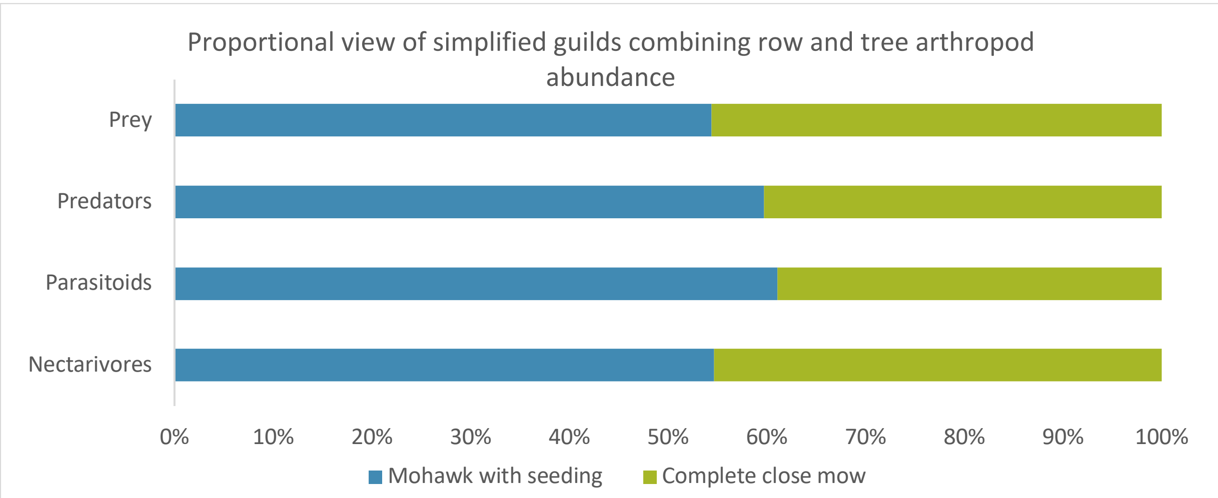


Chart 9: Representation of simplified feeding guilds in macadamia tree and inter row habitats combining all abundance data.

When we examine this ratio comparing the row habitat in mohawk and complete close mow (**Chart 11**), nectarivores have similar proportions (51% and 49% respectively). There is however proportionally greater abundance of prey in the mohawk (55%). This may account for the greater proportions of predators (61%) and parasitoids (65%) in the mohawk with seeding compared to the complete close mow block.

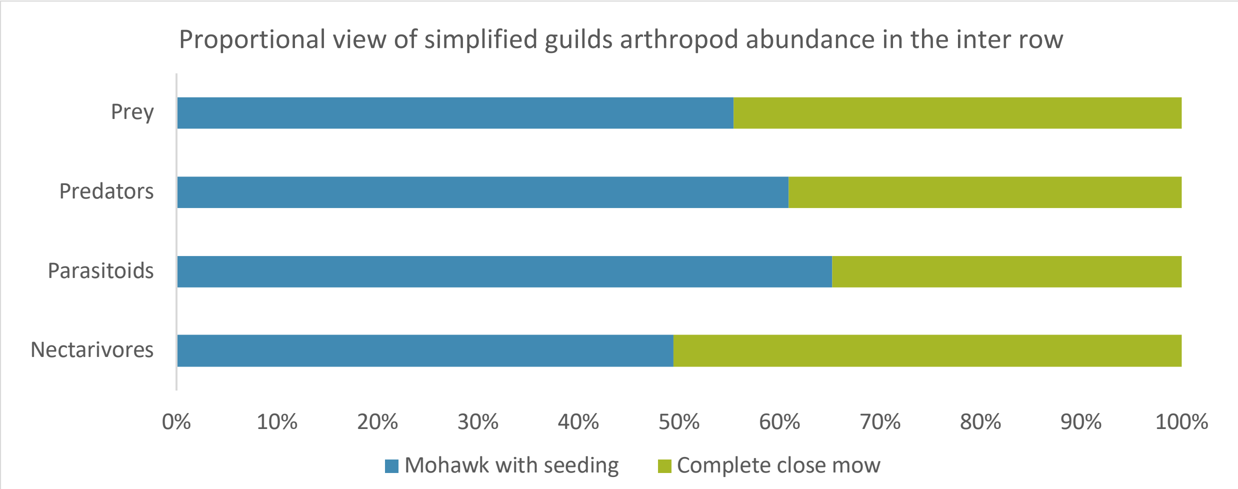


Chart 10: Representation of simplified feeding guilds in the inter row comparing the mohawk and complete close mow treatments.

In the macadamia tree (**Chart 11**) we found a slightly higher prey ratio in the mohawk with seeding (53%, 1890 specimens) to that of the complete close mow (47%, 1702 specimens), and conversely slightly less parasitoids in the mohawk with seeding (46%, 131 specimens) to that of the complete close mow (54%, 153 specimens). Given the low numbers of parasitoids this difference is small. Predators (including species from flies, beetles and true bugs) where higher in the mohawk with seeding (57%) to that of the complete close mow (43%). Nectivores (potential pollinators) were much higher in the mohawk with seeding (61%) to that of the complete close mow (39%).

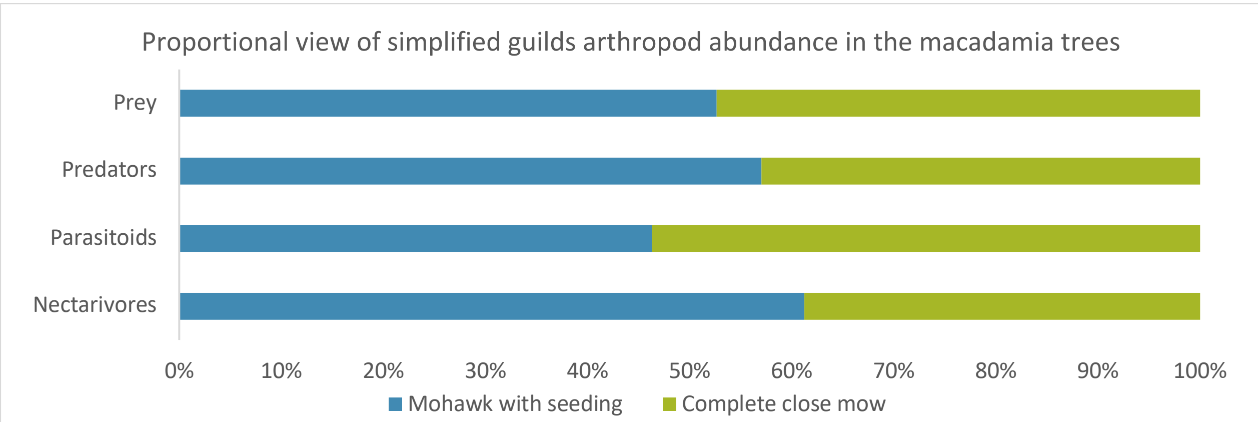


Chart 11: Representation of simplified feeding guilds in macadamia trees comparing mohawk and complete close mow treatments.

Flies as pollinators

In many ecosystems, including agricultural ones, flies are very important pollinators. Of the 150 families of flies worldwide, almost half, 71, have been shown to feed from flowers (mainly nectar) and thus in principle transmit pollen from one plant to another. This is currently an expanding area of behavioural research as we discover more about their pollinating abilities. A famous example is that we would be a world without chocolate without pollination by the chocolate midge (family Certopogonidae).

Nectivores are the most abundant flies in the orchard and there are more in the mohawk with seeding block in the macadamia tree (**Chart 12**) and these are represented mainly by phorid and sciarid flies. Conversely there were more nectarivores counted in the complete close mow block in the inter row. Sciarid species are known to be pollinators however they are generally poorly studied in Australia, as they are particularly difficult to observe in the field, and thus their roles as pollinators are probably not fully appreciated. Phorids are a very diverse family and many are important pollinators particularly in forest habitats. The most numerous Phorid genus on your farm was *Megaselia* which has over 1500 species worldwide. Some Phorids species are also known to be aphid predators. Phorid species have also been identified in northern NSW that parasitise macadamia seed weevil and fruit spotting bug.

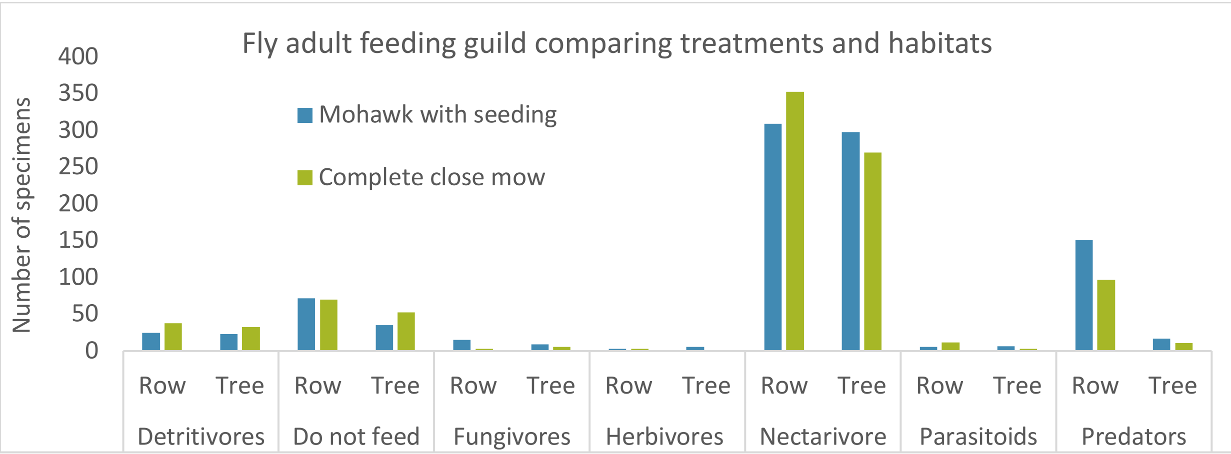


Chart 12: Fly feeding guilds structure in mow treatments in the row and trees over the sampling period.

There were large differences in the inter row where there was double the abundance of phorids in the mohawk with seeding (132 specimens) than the complete close mow (67 specimens). There were somewhat higher levels of phorids in the macadamia trees in the mohawk with seeding (129 specimens) than the complete close mow (115 specimens). Phorids where not collectively placed in the predatory guild as they are very diverse and occupy various feeding guilds as adults and larvae including scavengers, predators, herbivores, fungivores, parasitoids, and true parasites. Other nectivores included lauxaniid and conopid flies. Detritivores and fungivores were higher in the complete close mow in both tree and row habitats. Parasitoid flies were few but were more numerous in the row of the complete close mow (12 vs 6 specimens) however more numerous in the mohawk with seeding tree habitat (7 vs 3 specimens).

We identified 1,929 flies from 38 fly families on your farm. In **Chart 13** we show the total abundance of each fly family caught on YSTs over the 8 sample dates from March 2017 to July 2019. The mohawk with seeding block has a higher diversity of flies, with nine extra families (**Chart 13**). Of these families four are predators (Anthomyiidae, Asilidae, Empididae, Micropezidae) and another four are nectarivores (Micropezidae, Sciomyzidae, Stratiomyidae, Therevidae); the final family does not feed (Bibionidae). In the complete close mow, there are two parasitoid fly families that are not in the mohawk with seeding block (Conopidae, Pyrgotidae), one fungivore family (Keroplatidae), one nectivore family (Tabanidae) and one detritivore family (Heleomysidae). These families only appeared in 2018 and may be a reflection on experimental protocol modifications in that year/season. The mohawk with seeding had a greater number of predatory flies both in the inter row and macadamia tree, mostly Dolichopodidae (long legged flies) and other families included Hybotidae (dance flies) and Rhagionidae (snipe flies) (**Chart 13 and 12**).

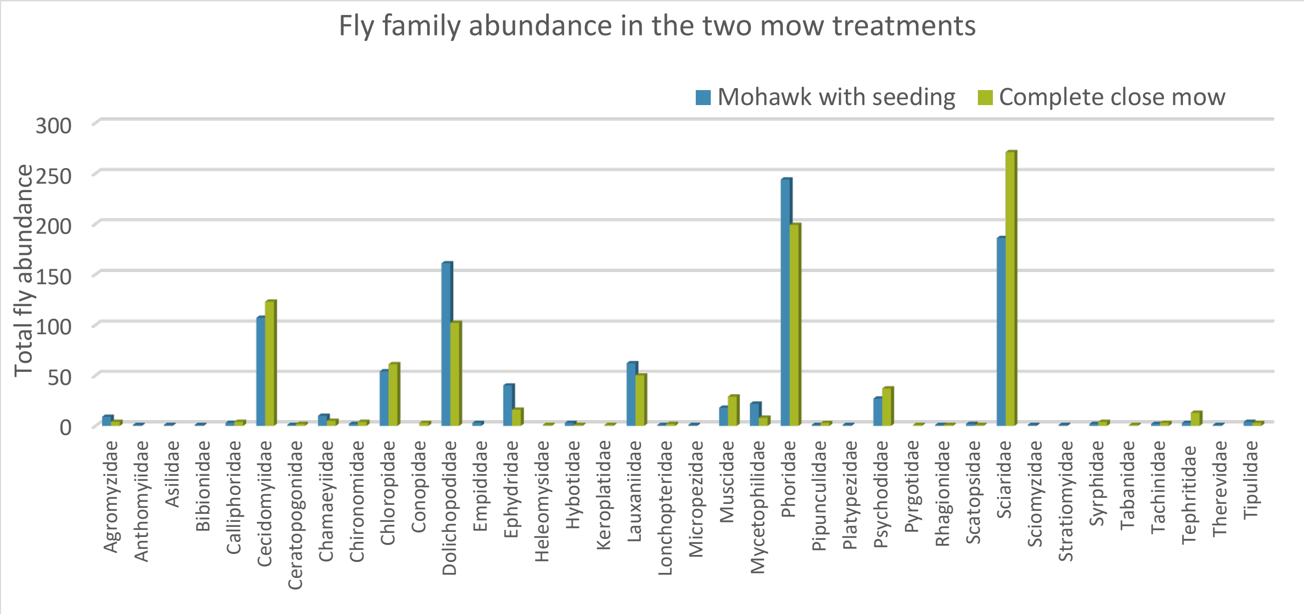


Chart 13: Total fly abundance in each fly family caught on YSTs over the 8 sample dates from March 2017 to July 2019

Wasps as parasitoids

We identified 470 specimens of wasps (Hymenoptera) on your farm, comprising of 20 families out of 77 families found in Australia, almost all of which were parasitoids. Most (90%) of the wasps caught on YST on your farm were chalcids (Superfamily Chalcidoidea). Chalcids are very important in biological control of herbivorous crop pests because they are predominantly parasitoids of lepidoptera, aphids and beetles. There were more chalcids in the mohawk with seeding (492 specimens) than the complete close mow block (336). For the first six survey dates the chalcids were not identified to family, but for the last two sampling dates they were to explore this superfamily more. In **Chart 14** we have compared the wasp families other than chalcids from 2017-2018 to better compare less numerous families. The Chalcid families from 2019 are (Encyrtidae, Eulophidae, Eupelmidae, Eurytomidae and Mymaridae). Encyrtidae is the most numerous in the mohawk with seeding block (74 specimens) compared to the complete close mow (19 specimens). Trichogrammatidae are also chalcids and include mostly MacTrix egg parasitoids, we separated them as they were released on the farm. There were twice as many Trichogrammatidae in the mohawk with seeding (105 specimens) compared to the complete close mow block (51 specimens). These numbers might be influenced by the position of any MacTrix releases. The next most numerous family is the Diapriidae; they typically attack larvae and pupae of a wide range of insects, especially flies. They were generally more numerous in the mohawk with seeding (34 specimens) than the complete close mow (28 specimens). There were several parasitoid wasp families absent from the complete close mow block (Figitidae, Mymaridae, Pergidae, Tenthredinidae and Torymidae) that are present in the mohawk with seeding block. No unique families were found only in the complete close mow block.

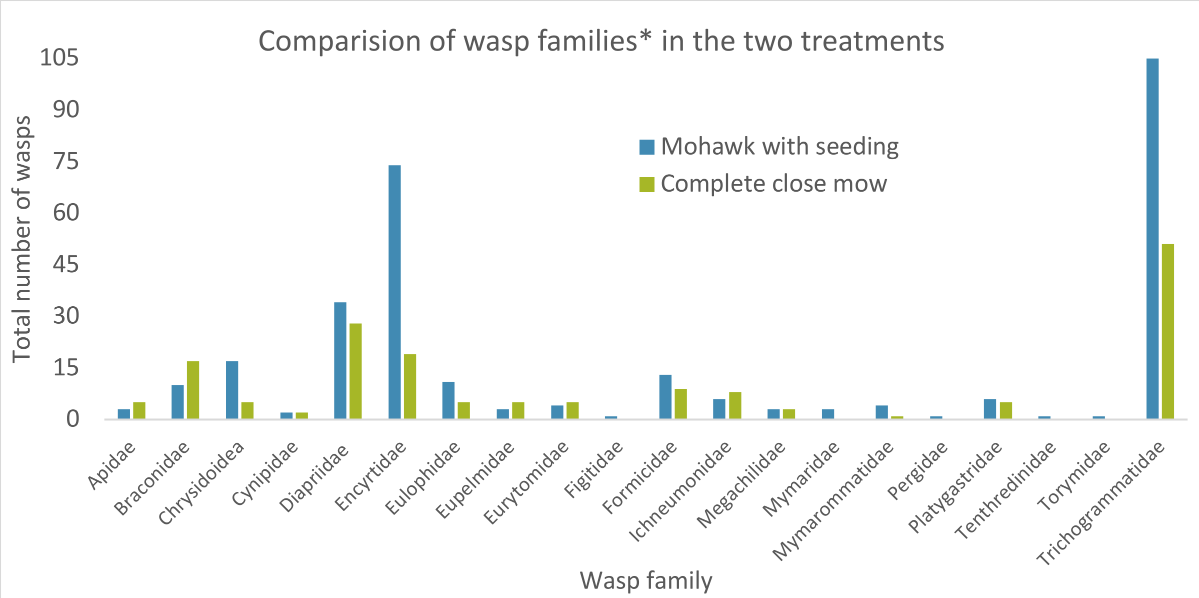


Chart 14: Comparison of the number of parasitoids caught on YSTs from March 2017 to July 2019 in row and tree * excluding the superfamily Chalcidoidea from 2017-18 dates to better compare less numerous families.

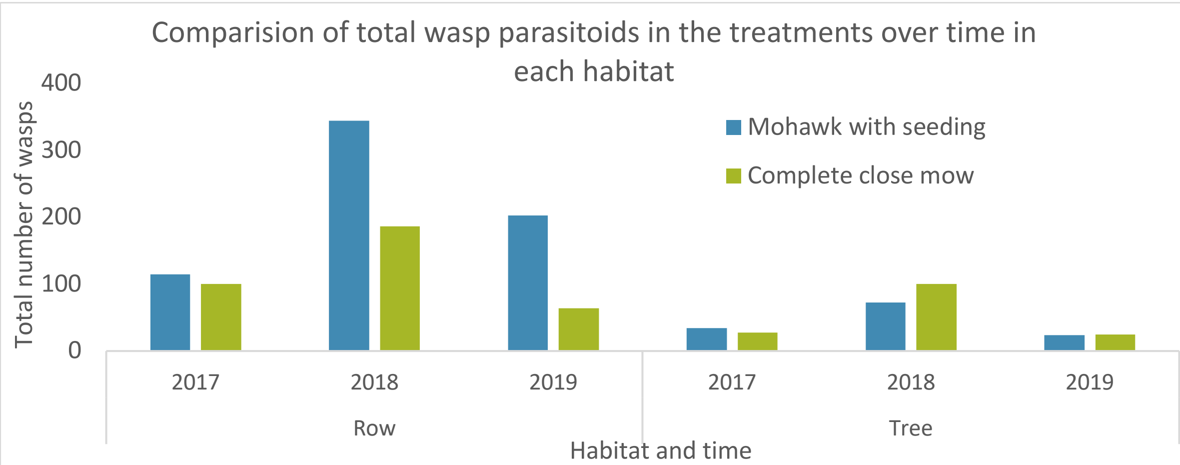


Chart 15: Comparison of abundance of wasp parasitoids in the two treatments over time in each habitat.

There is not much difference in parasitoid abundance in the macadamia tree in the two treatments (**Chart 15**). In the 2017 sample dates there was also little difference in the treatments in the inter row. However, in 2018 parasitoid numbers were double (345 vs 187 wasps); they were triple (203 vs 64) in 2019 survey dates in the mohawk with seeding treatment block.

If we examine the families in the macadamia tree (**Chart 16**), there were several families only present in the mohawk with seeding treatment including; Torymidae, Platygastridae, Mymaridae, Megachilidae and Apidae.

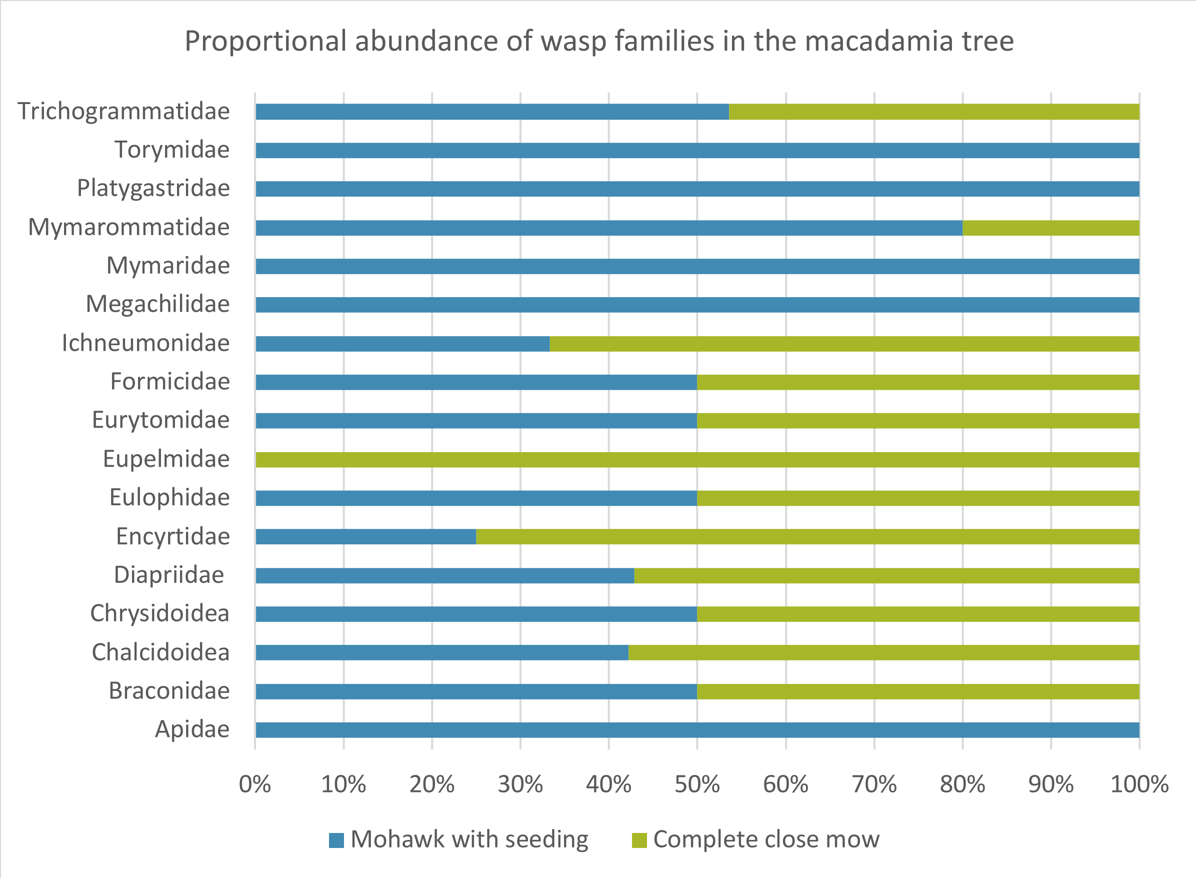


Chart 16: Proportional abundance of wasp families in the macadamia tree in the two treatments over the sampling period.

Similarly, in the inter row, there are several families that are only present in the mohawk with seeding treatment block (**Chart 17**) (Tenthredinidae, Mymaridae, Pergidae and Figitidae). Apart from Mymaridae these parasitoids were not present in the macadamia tree.

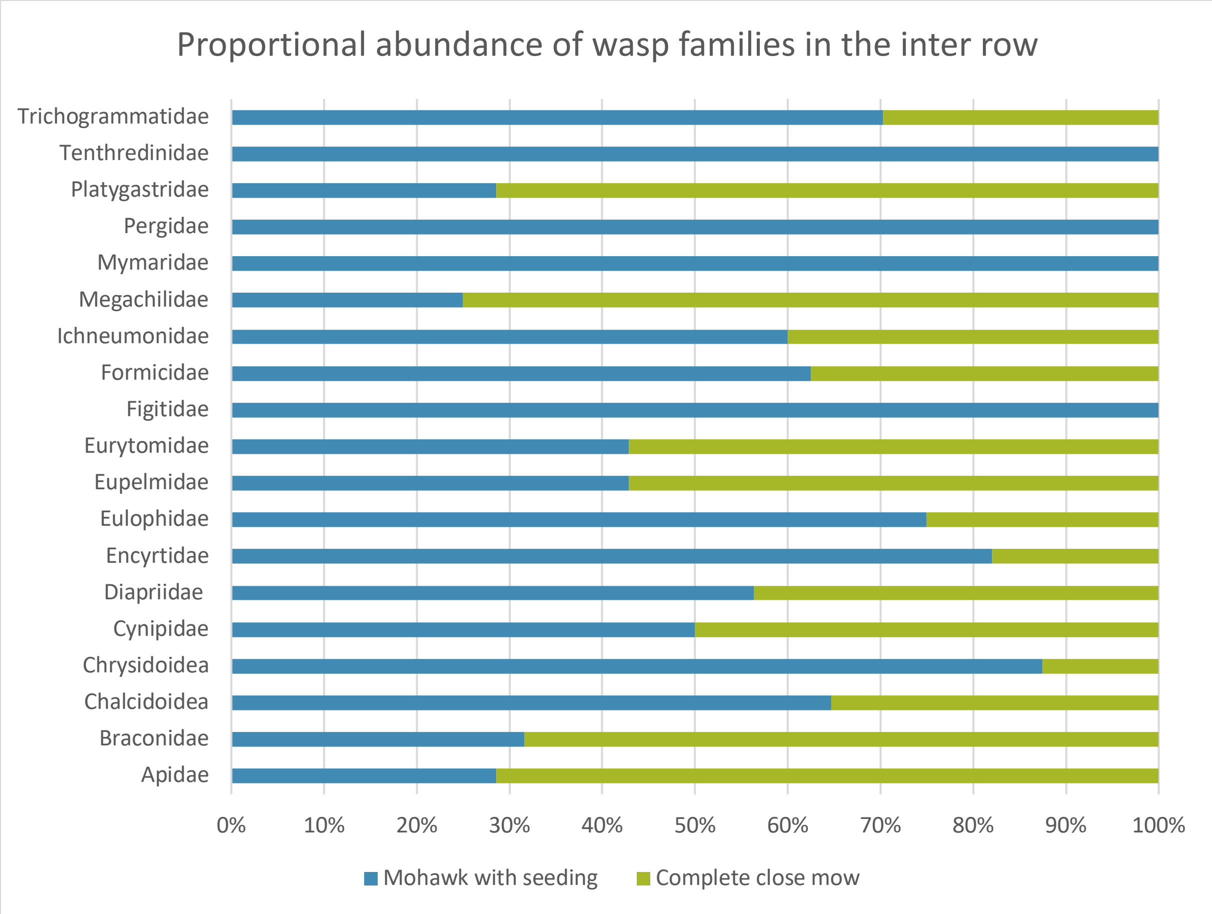


Chart 17: Proportional abundance of wasp families in the macadamia tree in the two treatments over the sampling period.

Thrips

Thrips had a higher abundance in the macadamia tree in the close mow treatment (110 specimens) than the tree of the mohawk with seeding treatment (75 specimens) (**Chart 18**), and proportionally this was greater in 2017 and 2019 sampling dates.

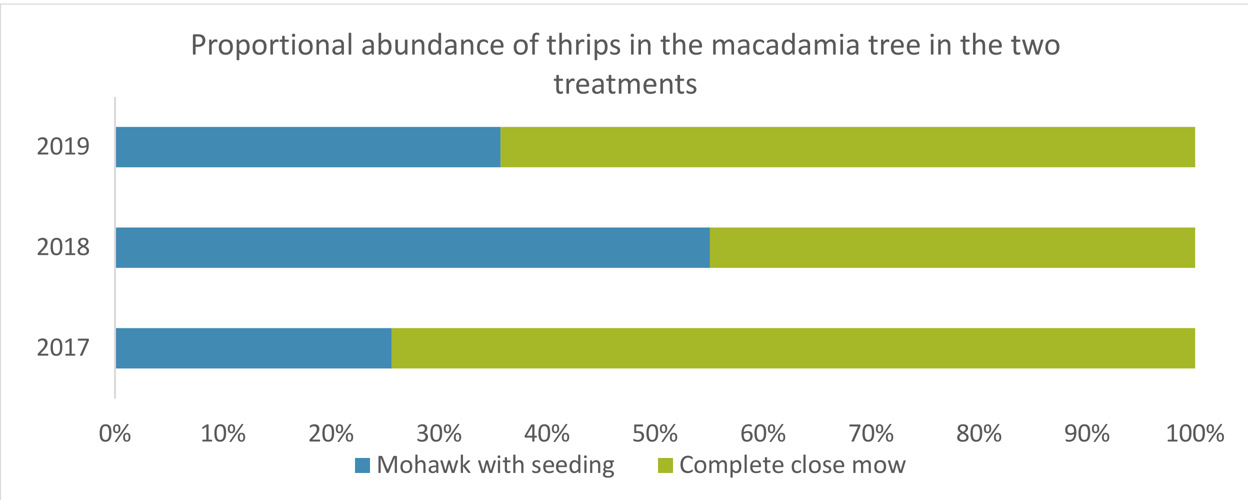


Chart 18: proportion of thrips in the macadamia tree comparing the two treatments over time.

When comparing thrip abundance in the two treatments (**Chart 19**), there are three times as many thrips in the tree of the close mow (61 specimens) as in the mohawk block in 2017. This is interesting as in the same period in the inter row thrips are twice as abundant. In 2018 thrip numbers are only slightly higher in the mohawk trees (49 specimens) and the complete mow (40 specimens). By contrast, they are twice as abundant in 2019 in the complete mow (albeit at low numbers). In 2019 thrip abundance was significantly higher in the inter row of the complete close mow compared to the mohawk with seeding block.

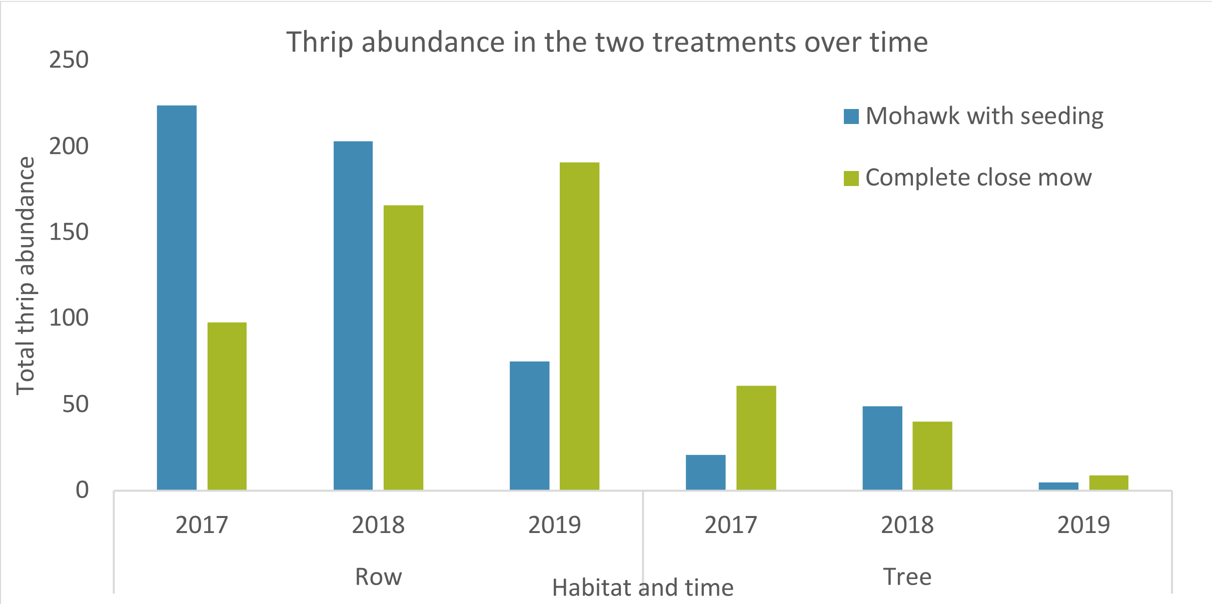


Chart 19: Total thrip abundance caught on YSTs in the two treatments over the sampling period March 2017 to July 2019.

True bugs

True bugs (Hemiptera) is an order of insects that has over 6000 species in Australia and includes species such as cicadas, aphids, scale insects and planthoppers. YSTs are not an ideal trapping method for population estimates and overall, this group is poorly represented by this technique. However, for the Hemipteran insects that we caught, they can be divided mostly into two feeding guilds (**Chart 20**). Predators are higher in the row (15 vs 7 specimens) and tree (32 vs 26 specimens) of the mohawk with seeding treatment block. Predators are from the Anthocoridae and Reduviidae families. Sap suckers (mostly aphids and leafhoppers) are somewhat more abundant in the row and tree in the mohawk with seeding block, however on any given year there are fluctuations where the complete close mow treatment block has more (2017 and 2018 inter row) and in the tree in 2019.

Diversity is greater in the mohawk with seeding treatment block (**Chart 21**) with seven families present there that are not present in the complete close mow block. However, two pest species Lygaeidae (seed bugs) and Miridae (mirids or plant bugs) were not recorded in either the tree or inter row in the mohawk with seeding treatment block, while they were recorded in the complete close mow block.

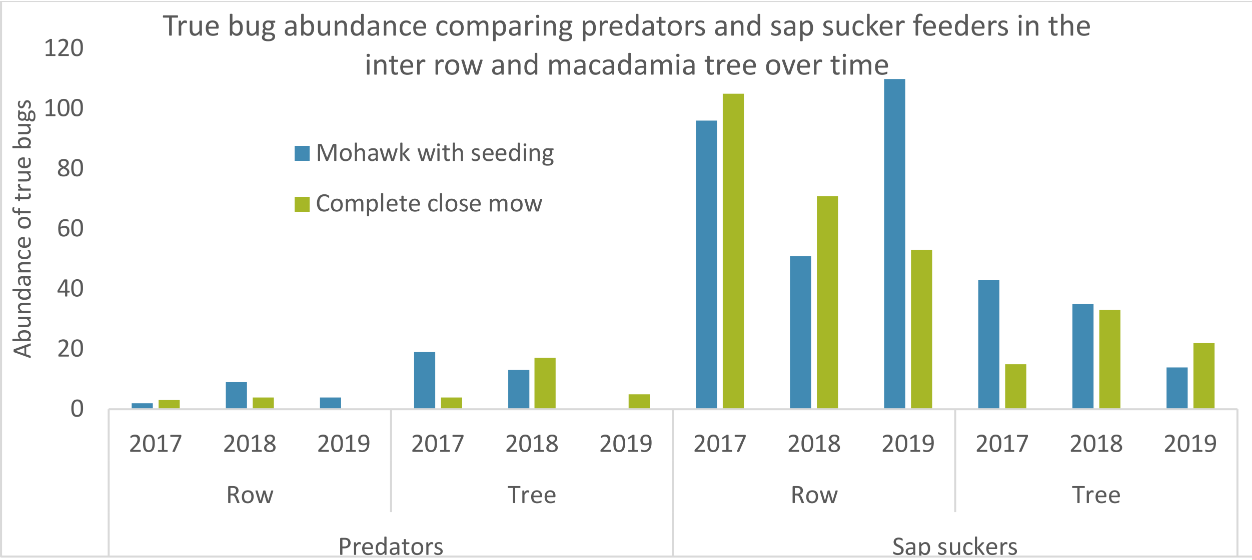


Chart 20: Comparison of true bug (Hemiptera) abundance in the two treatments in each habitat separated by the main feeding guilds over the sampling period caught on YSTs.

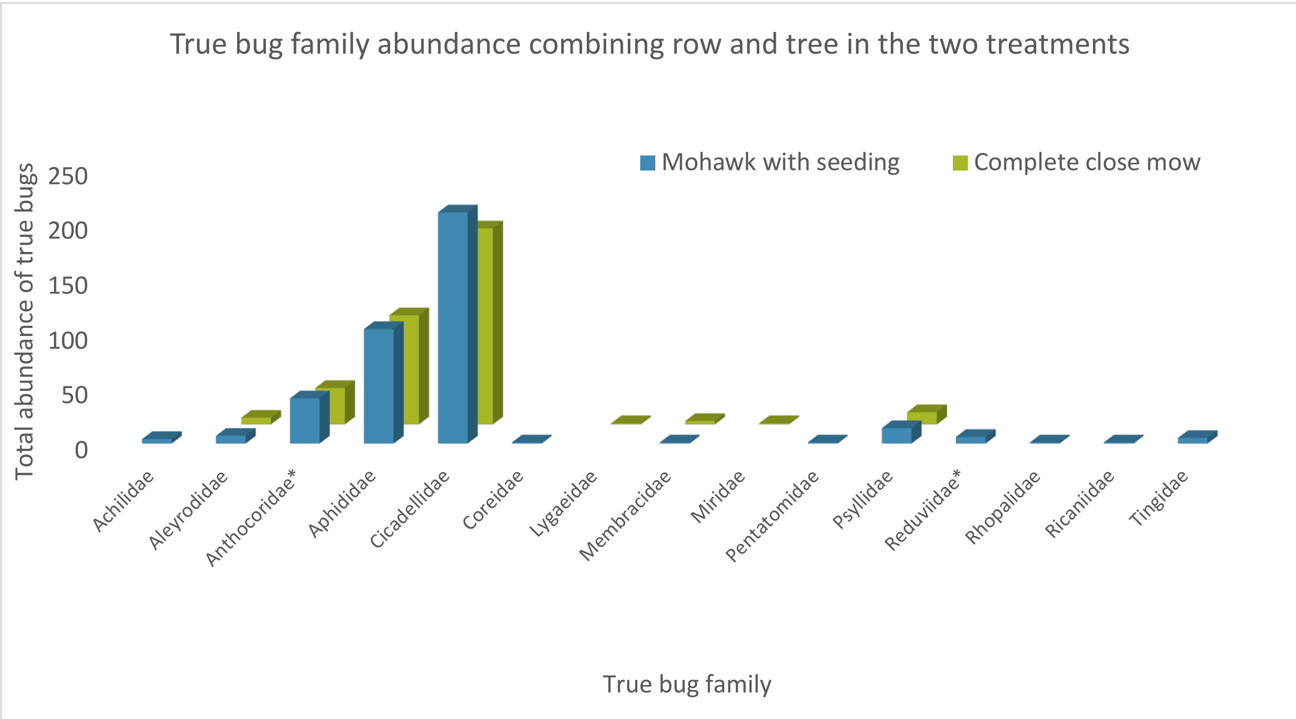


Chart 21: True bug abundance in the two treatment blocks for each family. Asterix identifies the families that are predatory.

Findings and recommendations

Your trial of mohawk with seeding has provided the inter row project with a number of useful insights into the practicalities of incorporating insectaries into the inter row. It has provided a valuable opportunity to better understand seed mix options; and suitable periods between mows to ensure appropriate rat, weed and vegetation growth-rate management. There are advantages to sustaining a mohawk during harvest if it is feasible: it keeps an insectary viable year-round especially during winter when growth slows down, and particularly in dry years. Other trial farms that removed the mohawk during harvest took many months to re-establish insectary vegetation. Optimal benefits from insectaries are possible when they are in place ahead of macadamia flowering and the annual intensification of crop pest pressure. On balance, and by the end of your trial you had found however that an increase in mowing leading into and during harvest was necessary.

It is worth noting that findings from other trial farms and other industries indicate that alternate row mow may be a reduced mow management strategy for you to consider. This involves mowing every second row on a rotating schedule, allowing all rows to "grow out" somewhat across the year but providing opportunities for mowing and management as required. This reduces the overall disturbance of beneficial arthropods, ensuring a refuge remains in place at all times for them. Beneficial arthropods will always have undisturbed areas around your farm for habitat. But it also provides opportunity to schedule removal of vegetation for rat monitoring and management. Likewise, there is opportunity to monitor and manage any "weediness" or dominance of vegetation and encourage regrowth and flowering. For your farm, this would allow you to incorporate insectaries in the orchard but give you more control over seteria dominance, potential rat problem areas, and nut drop into the reduced mow areas as the canopy continues to close over.

There were some promising increases in arthropod abundance and diversity in the mohawk with seeding trial block. In some groups such as wasp parasitoids there seems to be potential to increase their abundance and diversity further, as overall we expected more families to be represented and the overall population to be higher (excluding Mactrix) compared to more northern orchards. This maybe related to temperature differences, however further wasp parasitoid monitoring might show increases over time in conjunction with the appropriate vegetation management. Conversely fly abundance and diversity was very good (better than northern orchards) and many fly families that are predators and parasitoids were represented and had much higher populations in the mohawk with seeding block. This along with true bugs and beetle diversity increases indicated that there is potential to increase the wasp (parasitoid) abundance and diversity which is important for biological control. It is worth noting that our trial was conducted over 2.5 years, if these practices continue its likely arthropod diversity will increase further.

When the findings from all of the farms that participated in this project are taken into consideration, it is clear that insectaries have meaningful influence on orchard ecology when growers can commit to inclusion of the insectary in the orchard in terms of space allocation and long-term management. The mohawk in the inter row worked very well on your farm given row width. There are other areas on-farm worth considering, including headlands, field margins and so on where changes to management can allow for habitat suitable for beneficial arthropods. Decisions to improve plant diversity with seeding, well-timed seeding and mowing to limit dominance of one species while encouraging new growth and flowering and so on are also very influential.

Finally, the BioResources team encourages you to read the final report for the *Macadamia IPDM Program – Inter-row Project (MC16008)*, which is available via *Hort Innovation*. Here you will find out more on the benefits of insectaries for macadamia orchards and also the experiences of other trial farms in implementing and managing insectaries. There is also an exploration of the multiple ecosystem services known to flow from reduced mow inter row management practices along with improved arthropod biodiversity, including benefits for soil organic matter, nutrient cycling, water management, erosion control, weed suppression, soil carbon storage, soil microbiology and more.

Acknowledgements and thanks

The project team wishes to thank Baldwin & Ranking family for their participation, and particularly Sue for her contributions and support in providing field reports.

Final Report

"Piccadilly Park" – Macadamia Inter Row Project Results

Hort Innovation program title: The IPDM program for the macadamia industry – BioResources

Hort Innovation project code: MC16008

Date: April 2020

This report was prepared by Dr Abigail Makim and Dr Christopher M. Carr

This report was produced as part of the MC16008 extension program for participating macadamia growers and other industry professionals. It is not intended for peer review or publication. Further work is underway, processing data for statistics and additional analysis.

Summary

This project investigates the potential for the development of insectaries for conservation biocontrol through vegetation changes in the macadamia inter row. At Piccadilly Park the adoption of cover cropping is underway and is expected to increase the abundance and diversity of beneficial arthropods by creating more complex food-webs that are vital to pollination and pest suppression. The aim is to optimise the macadamia orchard for the self-regulation of pests by supporting beneficial arthropods with shelter, breeding areas, nectar, alternative hosts/prey and pollen.

Piccadilly Park and the BioResources team collaborated to investigate these ideas from mid 2018 to mid 2019.

The Piccadilly Park inter row project has provided many useful insights into the practicalities of cover cropping in macadamia orchards. Industry has been particularly concerned that change to conventional management recommendations for the inter row may lead to significant problems such as increased rat activity, invasive weeds and/or increased insect pests. The Piccadilly Park project gives other growers reassurance that innovative and sophisticated strategies for cover cropping are achievable and can be incorporated into existing orchard inter row management; and with basic monitoring and management will not lead to other problems.

Overall abundance of arthropods in the Piccadilly Park cover crop block was double that of the complete close mow block. We have found that there is numerical increase in beneficial insects without corresponding increases in herbivores or macadamia pests. Most notably parasitoids were three times more abundant in the cover crop inter row and more than double in number in the cover crop macadamia trees compared to the close mow treatment. Similarly, predators were almost three times as abundant in the cover crop block, and nearly double in number in the cover crop macadamia trees. Most insect orders were higher in the cover crop block in both the inter row and macadamia tree habitats. Thrips are the one exception, which were four times more abundant in the close mow block. When comparing the cover crop with the complete close mow proportionally, predators and parasitoids were more abundant in a ratio of 80:20 in the inter row and nectivores (potential pollinators) had a ratio of 60:40 in the inter row and trees. Overall, there were more insect families represented in the cover crop block in both the inter row and the macadamia trees.

The results for the Piccadilly Park project are likely to be enhanced and further refined into the future where the current commitment to insectaries throughout Piccadilly Park entire orchard is maintained. The Harris family have developed their own innovative strategies for cover cropping, which are compatible with standard orchard operations while allowing retention of insectary vegetation year-round. There is also scope for ongoing refinement with further targeting of seed mixes and additional strategies for limiting vegetation disturbance in the orchard inter row.

The complete final report for the *Macadamia IPDM Program - Inter Row Project (MC16008)*, is available via *Hort Innovation*. The benefits of insectaries for macadamia orchards and also the experiences of other farms engaged in implementing and managing insectaries are provided here. There is also an exploration of the multiple ecosystem services known to flow from cover cropping practices in the inter row along with improved arthropod biodiversity, including benefits for soil organic matter, nutrient cycling, water management, erosion control, weed suppression, soil carbon storage, soil microbiology and more.

Introduction

The *Hort Innovation Macadamia IPDM Program Inter Row Project* undertaken by BioResources Pty Ltd proposes that changes to the industry standard management practices of the macadamia inter row can provide valuable opportunities for conservation biocontrol. This is because the macadamia orchard inter row can support insectaries with increased vegetative diversity, increased floral resources and reduced habitat disturbance and increased habitat complexity in the orchard. This may in turn increase the presence of beneficial arthropods in the orchard. More broadly, the proposed changes in plant ecology may increase arthropod populations in general, leading to more complex food webs and better orchard self-regulation of economic pests. Furthermore, this enhanced nutritional food-web will benefit birds and micro-bats, which also have a role in pollination and pest suppression. It is estimated that beneficial insects provide 5-10 times the pest control in agricultural ecosystems as compared to chemical applications[1], because these processes are occurring all the time. By encouraging more diverse ecosystems within the orchard the likelihood and/or intensity of pest outbreaks decreases.

Piccadilly Park is one of 11 farms that have collaborated with the BioResources team to investigate these ideas. According to Rex Harris, "in August 2017 the Harris Family at Piccadilly Park Bangalow commenced a 7-year program to convert their monoculture orchard into a multi-species orchard incorporating seasonal multi species cover crops/insectaries and permanent insectaries (**Photo 1**). Each year, 1,000 trees (every second row) are being removed from their connected canopy orchard of 7 x 5 spacings to an open 14 x 5 spacings orchard, incorporating 6m wide centre strip inter-row cover crop/insectaries. The main reasons for the tree removal was the total loss of ground cover (thus loss of top-soil), the loss of macadamia nut production (dead centres) due to lack of sunlight and the opportunity to change from conventional practises of using chemical fertilisers, insecticides, fungicides and herbicides to regenerative agriculture practices."

Photo 1: Piccadilly Park dedicated permanent insectary, foreground, and native revegetation, background, adjacent to the orchard.

The Harris family worked with the BioResources team in this investigation from late 2018 to late 2019. We compared two (approximately) 1 Ha blocks. A control block was managed as industry standard with regular complete close mowing (**Photo 2**, below). A treatment block was managed with cover cropping for the project period (**Photo 3**, below). This unique comparison under one farm management system was possible because of the ongoing row removal program underway at Piccadilly Park.

[1] Pimentel, D., Stachow, U., Takacs, D.A., Brubaker, H.W., Dumas, A.R., Meaney, J.J., Onsi, D.E., Corzilius, D.B., 1992. Conserving biological diversity in agricultural/forestry systems. BioScience 42, 354-362.


Photo 2: Piccadilly Park complete close mow 20 June 2019 ***Photo 3: Piccadilly Park cover crop 20 June 2019***

With each site visit the BioResources team sampled each block for arthropods in three separate rows using yellow stick traps (YSTs), placing one YST in the inter row and one YST in a tree. We assessed the vegetation in the inter row at those three points (a quadrant of approximately 14m x 20m). The three data collection points were at least 30m apart and 50m from any block edge. We also spent time with the Piccadilly Park team discussing the project and any observations that they may have made in relation to rats, weeds, insect pests in the inter row vegetation and/or any challenges with cover cropping.

The objective of the project has been to provide other growers and industry with insights into the practical experiences of implementing insectaries for conservation biocontrol. At Piccadilly park this has specifically involved cover cropping in the inter row with monitoring to quantify results. BioResources has worked with Piccadilly Park to record that farm's inter row covering cropping system for the interest of other growers. BioResources has then sought to record observations on any relationship between cover cropping and the potential for increased rat, invasive weed and/or arthropod pest presence. Finally, BioResources has sought to monitor association between cover cropping in the inter row and changes in orchard beneficial/pest arthropod ecology.

Cover cropping in the inter row at Piccadilly Park

Potential problems

	Throughout the project, BioResources regularly monitored for and consulted with Piccadilly Park, and specifically Rex Harris and Dan Harris, on the following issues:
Rats	The project team did not observe evidence of rat activity in the project blocks during site visits. Piccadilly Park did not report any problems with rats. Piccadilly Park reported that Piccadilly Park assessed and reviewed harvested nut for rat damage and had not noticed any changes in the cover-cropping blocks. Furthermore, Piccadilly Park reported that during mulching and reseeding, they were not finding evidence of rats storing nuts in vegetated areas.
Problem weeds	The project team did not observe problem weeds during site visits. Piccadilly Park reported that the cover cropping program especially targeted any potentially invasive weeds. Piccadilly Park regularly revised seed mixes for inclusion of features such as dense root structures capable of suppressing invasive weeds; Piccadilly Park also removed some species from seed mixes where they were strongly reseeding in blocks. Piccadilly Park regularly monitored for any "weediness" from either "naturalised weeds" or seeded plant species and scheduled management as required for management.
Major insect pests of macadamias	The team monitored vegetation in the inter row for the presence of major macadamia pests including Macadamia Seed Weevil, Macadamia Nut Borer, lacebug, Green Veggie Bug (GVB), and Fruit Spotting Bug. Plant species typically found in the inter row project blocks at Piccadilly Park were not observed to host these pests. No issues or concerns were reported by Piccadilly Park.
Management of the inter row	No issues were observed by the project team during site visits. No issues were reported by Piccadilly Park. Piccadilly Park indicated that Piccadilly Park have planned extensively and invested prudently in staff education, machinery, seed, composting and fermenting systems for this task. Piccadilly Park continue to improve and develop Piccadilly Park farm-specific approach to inter row management. A number of specialised machinery options were available for seeding, roller-crimping, mowing, slashing and harvesting. Piccadilly park had strategies for easy management and maintenance under the drip-line, including selected species, targeted reseeding schedules and regular mowing. At the same time, Piccadilly Park had strategies for straightforward inclusion and maintenance of a vigorous cover crop year-round. Piccadilly Park also had designated insectary areas outside of the orchard blocks and orchard inter rows that were left undisturbed to serve as insectaries during periods of intensive reseeding.

Outcomes

This project at Piccadilly Park has provided many useful insights into opportunities for conservation biocontrol and the practicalities of cover cropping in macadamia orchards. Industry has been especially concerned that any relaxation of regular complete close mowing of the inter row may lead to significant problems with increased rat activity, invasive weeds and/or insect pests. The Piccadilly Park project gives other growers reassurance that options for cover cropping in the inter row can be incorporated into existing orchard management and with monitoring and management will not lead to other problems. Furthermore, this project gives other growers a unique insight into the management task required and the opportunities that can flow from related changes to current industry standard inter row management. There is growing interest in options and practices for seeding and cover cropping in the inter row, but there are currently limited practical examples.

Management of the Piccadilly Park project blocks for the life of the project was very strong and consistent. Furthermore, management practices can be defined as "best practice" in both the complete close mow block (which is the current industry standard) and also the cover-cropping block, insectaries, and native vegetation areas. For this reason, the results from the Piccadilly Park project are especially robust.

Given Piccadilly Park's best practice management, from the outset the project team expected to see a greater abundance and diversity of arthropods in the cover crop inter row given the impressive array of plants that were flowering, providing shelter, breeding areas, nectar, alternative hosts/prey and pollen. What was unexpected was the subsequent large increase of predators and parasitoids that visited the *macadamia trees* in the cover crop block. This is an unusual and impressive result when compared to most other farms, where we typically see relatively lower numbers of beneficial arthropods in the trees. Proportionally the comparative ratio between the complete close mow and the cover crop blocks of predators and parasitoids was 80:20 in the cover crop inter row compared to the complete close mow block. This increased food web not only provides self-regulating pest control, but also benefits in nutrient recycling, pollination and other ecosystem services. The increase in arthropod abundance did not increase macadamia pests major or minor. Further investigation to identify the impact of these beneficial arthropods could have on macadamia pests is warranted.

For an overview of *Hort Innovation Macadamia IPDM Program Inter Row Project*, the BioResources team urges Piccadilly Park to read the project's full final report, *Macadamia IPDM Program - Inter Row Project (MC16008),* which will be available via *Hort Innovation*.

Results of cover cropping in the inter row

Vegetative diversity

Four cover crops were seeded while the project was in the field for the period December 2018 to September 2019, (summer and winter crops). According to Rex Harris, "… crops were terminated approximately every 120 days and the total biomass was rolled down with a roller crimper and immediately replanted with a no-till seed drill. When cover crops were terminated and replanted, the practice was to replace every alternate row thus leaving a living thriving insectary on one side of each tree row at all times as habitat for beneficial insects. The remaining alternate rows were replaced approximately 30 day later to allow sufficient time for the new inter-row cover crop/insectary to grow and provide sufficient habitat and food …" (**Photo 4 & 5**). Species in seasonally-specific seed mixes included and were not limited to: sunflower, millet, cow pea, sorghum, mung bean, lab lab, flax, chicory, plantain, tall fescue, buckwheat, vetch, crimson clover, rye corn, oats, winter rye, forage brassica, barley, Lucerne, smart radish, tillage radish, and more. A progression of the above activities, various plants used etc can be found on Twitter @drexharris (for example, roller crimping).

Photo 4: Cover crop alternately reseeded August 2019

Photo 5: Cover crop alternate row September 2019

Further information and recommendations on this system are beyond the scope of this report. This will be available in a new project being rolled out by the BioResources team in collaboration with Piccadilly Park and the Harris family in 2020-21.

Vegetative diversity refers to the number of plant species present. Changes to inter row management decisions such as cover cropping can change plant species diversity. This can in turn be associated with diversity of arthropod species. **Chart 1** presents an average count of plant species observed in the inter row by treatment through time.

In this project we anticipated that changes to industry standard mowing practices would provide opportunities to increase the number of plant species present in the orchard. As we can see in Chart 1, this is consistently the case for the life of Piccadilly Park project, where Piccadilly Park seed selections and seeding decisions result in an inter row that can be characterised as one with "managed vegetative diversity".

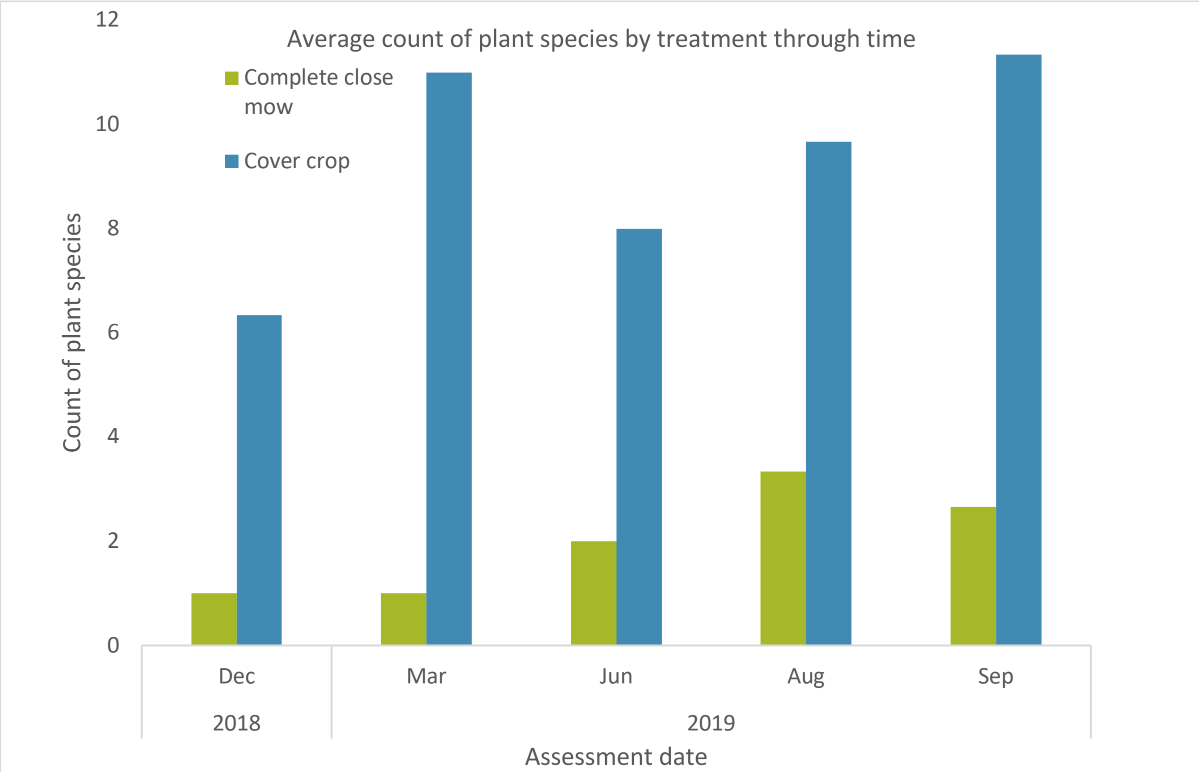


Chart 1: Average count of plant species by treatment through time. This is an average of counts taken at the three assessment points on each block.

Floral resources

Floral resources provide a food source for many beneficial arthropods and will encourage them to remain active in the orchard. **Chart 2** provides an average count of the plant species flowering at the time of the site visit. There were always flowering plant species in the cover-cropping block. In conjunction with this, we also see that these flowering species always produced a large volume of flowers as a percent of biomass in the cover-cropping block (**Photo 6**) as compared to the complete close mow block (**Chart 3**). This percentage was often very high as a consequence of the cover-crop species selected and decisions on timing and areas to mow or leave undisturbed. By contrast, the complete close mow block did not sustain any floral resources what-so-ever (**Charts 2** and **3**).

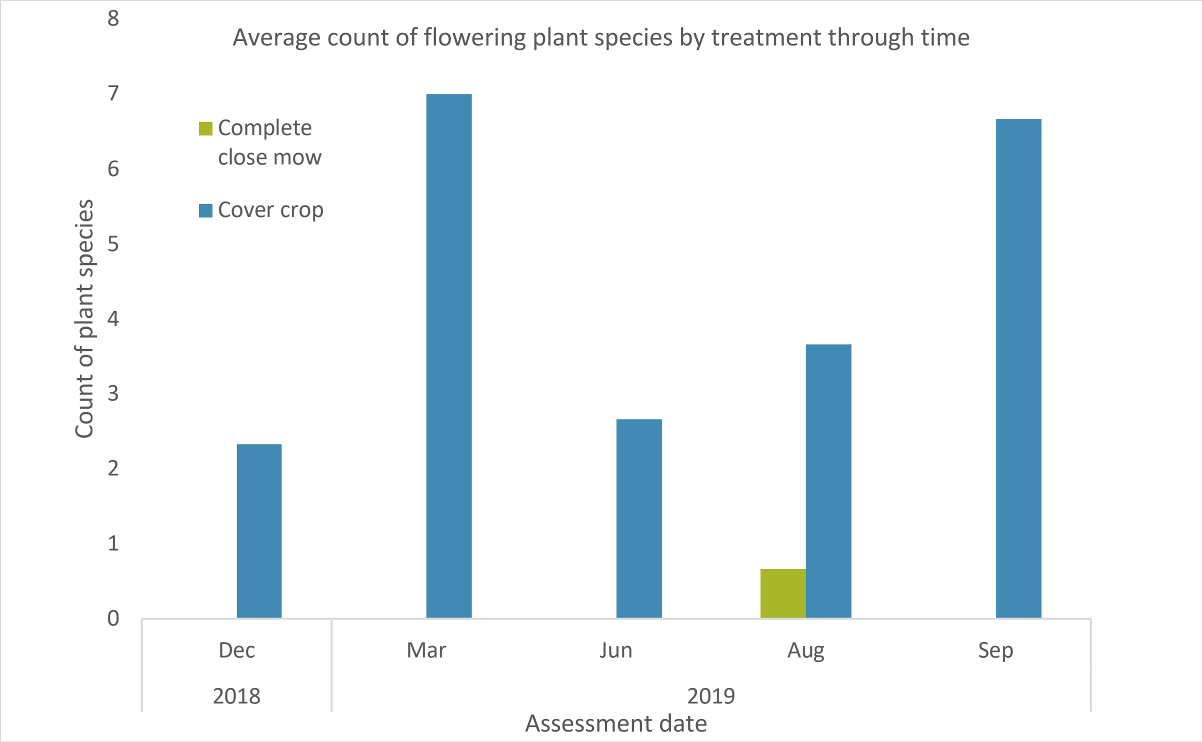


Chart 2: Average count of plant species with floral resources by treatment through time. This is an average of counts taken at the three assessment points on each block.

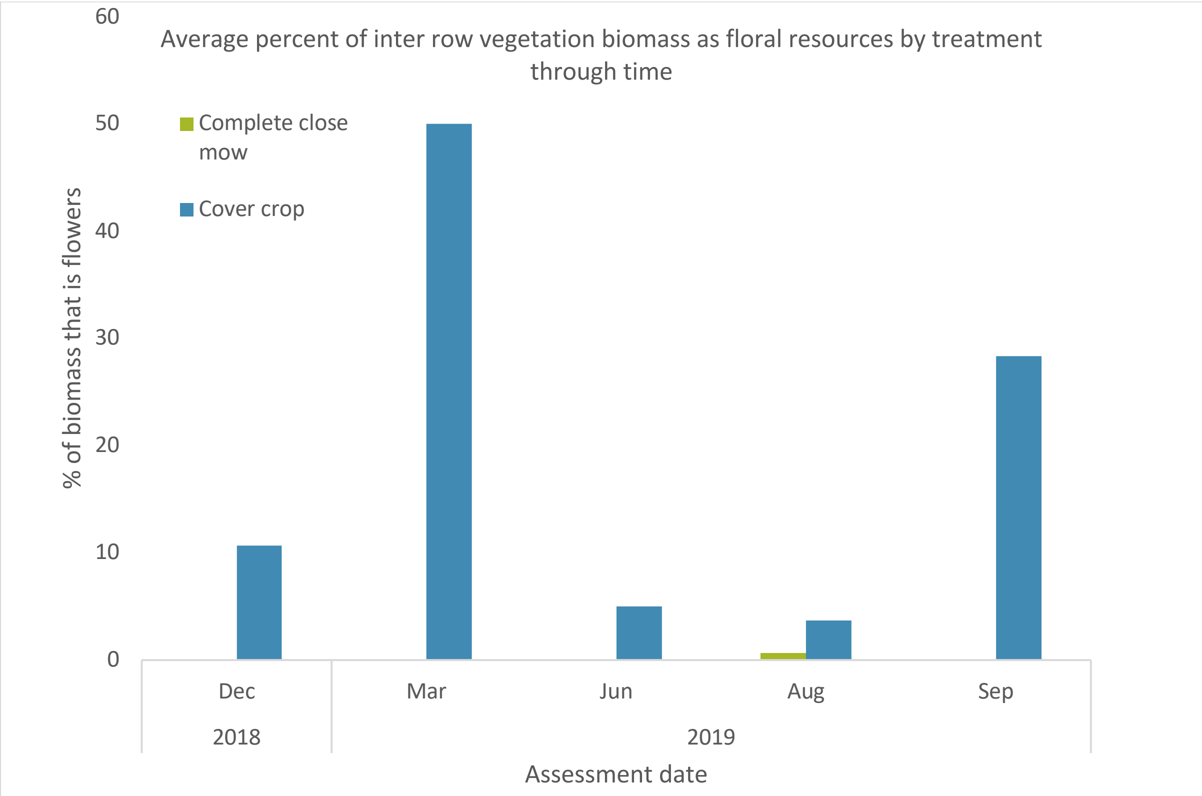


Chart 3: Average percentage of inter row vegetation biomass as floral resources by treatment through time. This is an average of counts taken at the three assessment points on each block.

Photo 6: Cover crop floral resources October 2018, including smart radish, phacelia, white clover, and vetch.

Habitat disturbance

Areas of reduced mechanical and chemical disturbance can serve as favourable habitat for beneficial insects. Undisturbed areas may also provide a refuge for beneficial arthropods for faster recovery after spraying. The measurement of height provides a good indication of rates of mechanical disturbance and habitat complexity. **Chart 4** reports the height in centimetres (cm) of vegetation in the inter row by treatment through time. Retention of a cover crop at Piccadilly Park allowed for greater height of vegetation, and hence less disturbance and more habitat complexity in the inter row for the life of the project. By contrast, the complete close mow block was regularly and heavily disturbed with very limited opportunities for vertical physical complexity.

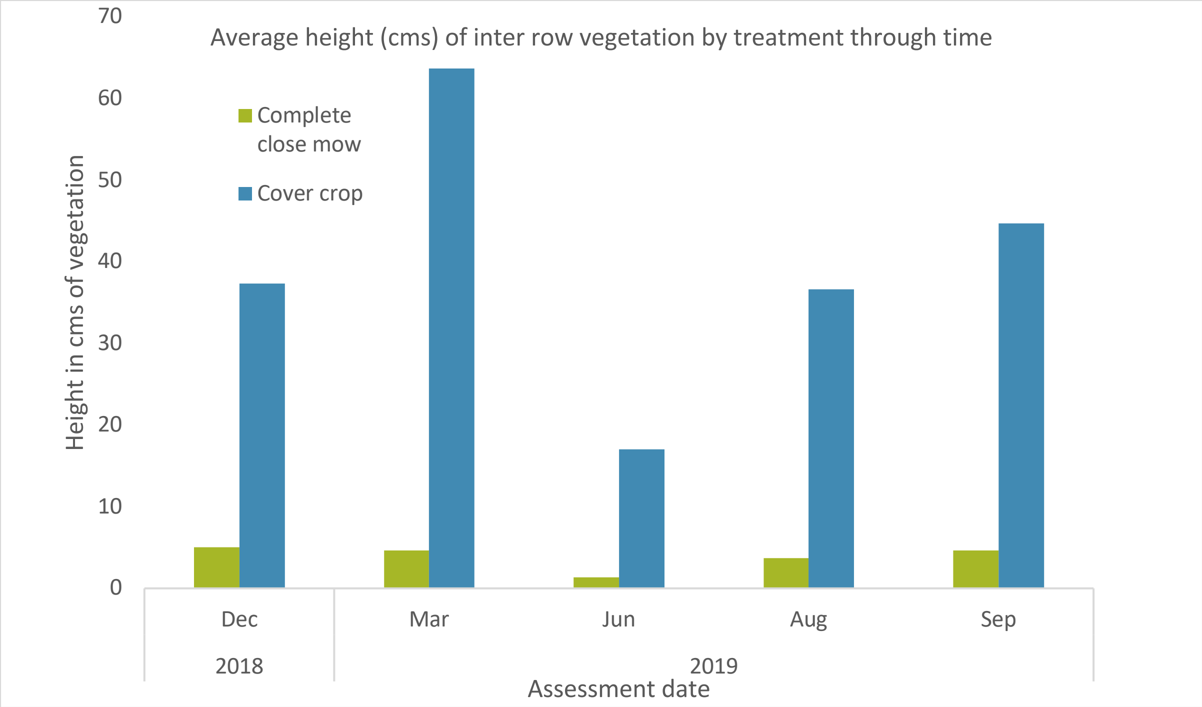


Chart 4: Average height (cm) of inter row vegetation by treatment through time. This is an average of counts taken at the three assessment points on each block.

Results of arthropod evaluation

General arthropod abundance

From December 2018 to September 2019 we conducted 4 arthropod assessments, one in each crop season. In total, we collected and identified 7,137 arthropods using yellow sticky traps (YSTs). YSTs best capture flying insects such as flies, true bugs (including aphids), wasps and thrips. However non-flying insects and those not attracted to yellow are seldom caught (e.g. ants and spiders for instance). In **Chart 5,** we compared the total number of arthropods collected on the YSTs over the four seasons in the two treatment blocks in the inter row (row) and tree habitats. There are clear differences in the total abundance of arthropods in the inter row treatments, the cover crop had 2956 specimens compared to the complete close mow treatment block with 1574 arthropod specimens. Total abundance of arthropods in the macadamia trees were not much different in the seasons except in March where the macadamia trees with the cover crop had three times as many arthropods. Certain insect groups where high in the complete close mow trees which increased overall abundance in this habitat, this included thrips in September and chironomids (non-biting midges) in June. Overall, there was greater insect *diversity* in the cover crop macadamia trees.

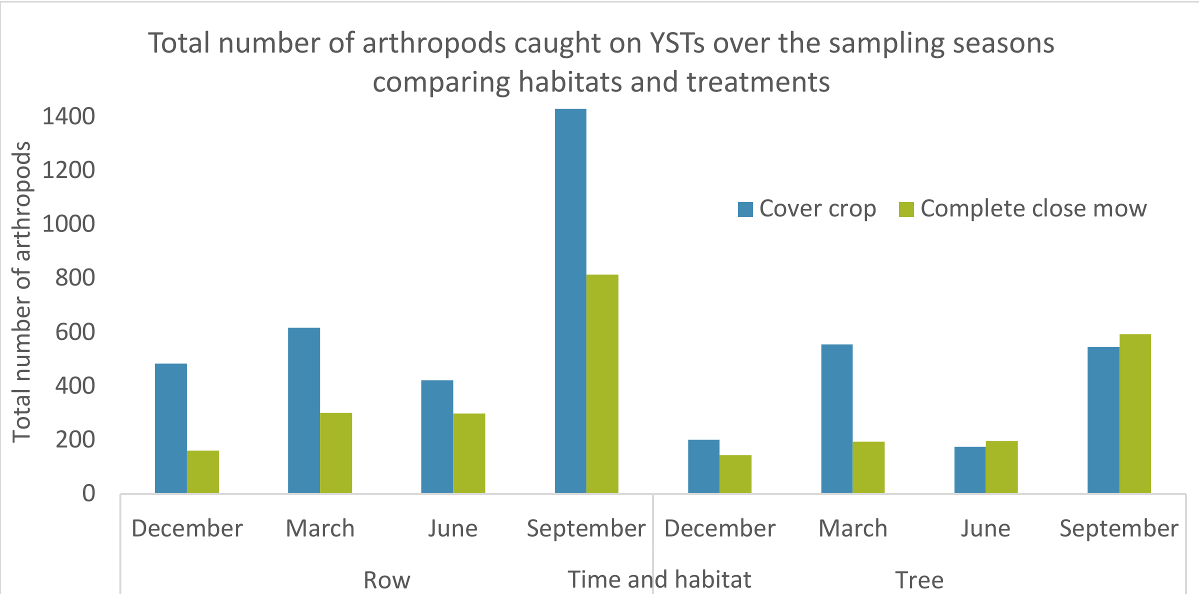


Chart 5: Total arthropod abundance caught on YSTs over the four sampling seasons compared in the inter row and tree habitats in the cover crop and complete close mow treatment blocks.

Arthropods consisted of 15 different classification orders, however many were weakly represented. The top 5 insect orders are shown in **Chart 6,** which were flies, true bugs (including aphids), wasps, lacewings and thrips. Most insect orders where higher in the cover crop block in both the inter row and macadamia tree habitats, except for thrips, which were four times more abundant in the close mow block (397 specimens) compared to thrips in the cover crop (116 specimens). Close mowing seems to have increased thrips in the trees and row compared to the cover crop block at Piccadilly Park. In theory, given the increase in predators and parasitoids in the cover crop block, we can hypothesize that this may help decrease thrip populations in macadamia trees at Piccadilly Park. Beetles (not shown in **Graph 6**) were twice as abundant in the cover crop row, however, they were equally abundant in the macadamia tree in both treatment blocks. The largest difference was in Hymenoptera, which includes ants, bees and wasps. However very few bees or ants were collected by the YST. Most of the wasps found are parasitoids.

Wasps were three times more abundant in the inter row of the cover crop (905 specimens) compared to the complete close mow (254 specimens). Similarly, in the macadamia trees there were more than double the numbers of wasps in the cover crop macadamia trees (520 specimens) compared to the complete close mow (212 specimens). The true bugs (Hemiptera, mostly plant suckers) were four times as abundant in the cover crop (551 specimens) than the complete close mow (140) inter row and comprised mostly of aphids (225 specimens) and leafhoppers (245 specimens) in the cover crop inter row. There was a moderate increase in true bugs which were predominantly leafhoppers in the cover crop macadamia tree (88 specimens) compared to the complete close mow macadamia tree (23 specimens). Flies were also a lot higher in the cover crop treatment block and we will explore this later in this report.

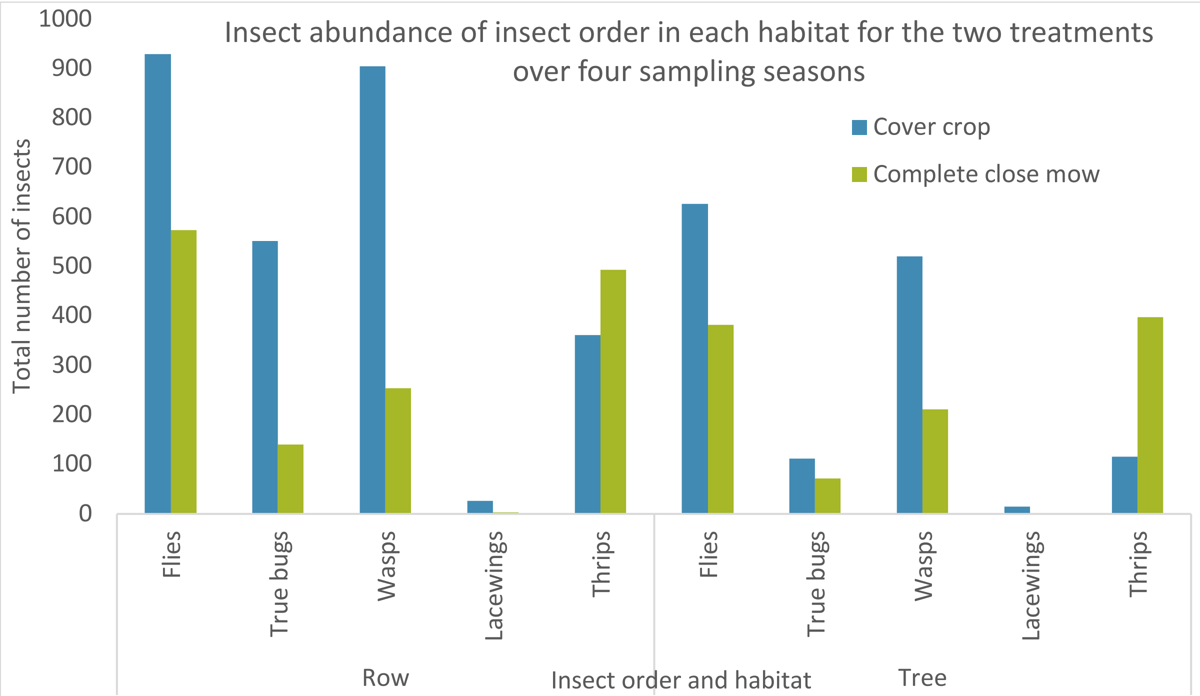


Chart 6: Comparison of the total abundance of main insect orders caught on YST in the two treatment blocks over the four sampling seasons in the inter row (row) and macadamia (tree) habitats.

Feeding Guilds

To better understand the nature of food webs on macadamia farms we have identified most insect species to family level classification, allowing us to determine the feeding guild structure of insect assemblages. The guild concept has been widely utilised by ecologists; a guild is any group of species that exploit the same resources. For instance, most insect herbivores are selective feeders, they may be specialised as leaf chewers, sap suckers, stem borers, root borers, gall formers, leaf miners etc. Beneficial insects feed as predators and parasitoids. Other important arthropod feeding groups are pollinators via nectar feeding (nectarivores). This is a good way of examining species richness and how it relates overall to farm food webs.

In **Chart 7** we have highlighted the main arthropod feeding guild groupings in the macadamia trees in the two inter row treatments. There are several other feeding guilds including borers, blood suckers, gall formers, omnivores and pollen only feeders, that were omitted as they were too few in number and did not show any treatment differences. Seed feeders (Lygaeids) and non-specialist herbivores (grasshoppers) were also similar in both treatments and had low abundance overall. Sap sucker total abundance were somewhat higher in the cover crop macadamia tree, however one trap had a very high number of leafhoppers (57 specimens) when the average number of leafhoppers in the cover crop tree was 5.1 specimens compared with an average of 2.9 specimens in the complete close mow over the four seasons. Nectivores (nectar feeders and potential pollinators), parasitoids and predators had double the abundance in the macadamia tree over the four seasons in relatively high overall abundance.

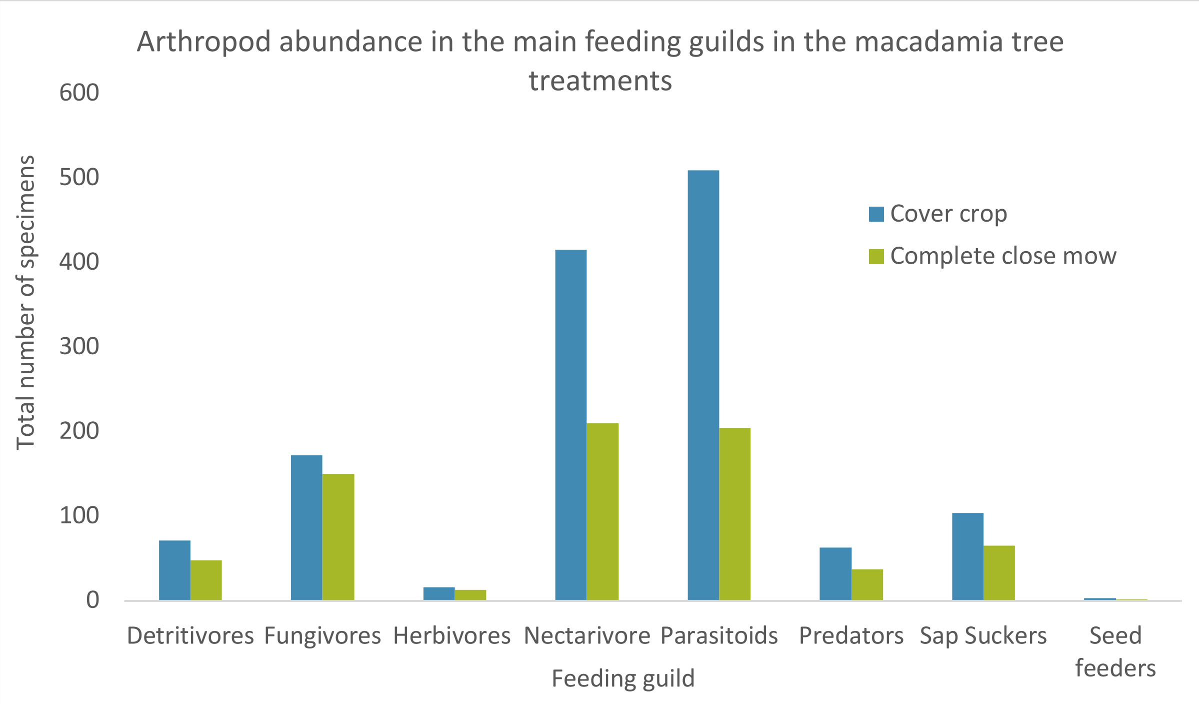


Chart 7: Comparison of the main feeding guilds of arthropods over the four seasons caught on YSTs in the macadamia tree in the two block treatments.

To simplify our results, we classified all arthropods as prey and then separated nectivores (potential pollinators), predators and parasitoids, as four broad categories. Then we can compare treatments comparatively in proportions. By combining tree and inter row abundance counts between cover crop and complete close mow treatments (**Chart 8)** we see that there are high proportions of parasitoids (76%) and predators (74%) in the cover crop block. Potential prey and nectivores are also proportionally much higher in the cover crop treatment block (62% and 61% respectively).

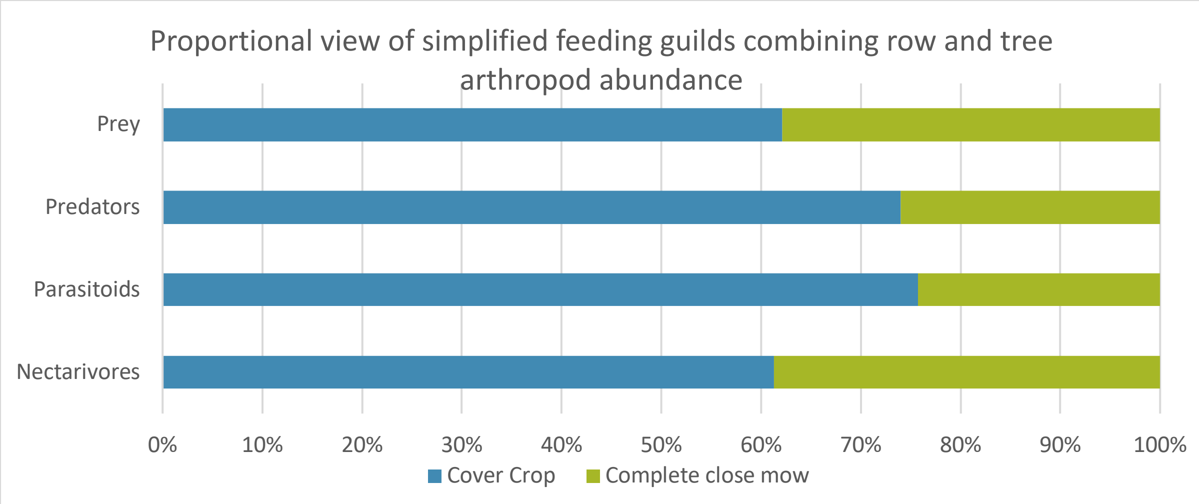


Chart 8: Representation of simplified feeding guilds in macadamia tree and inter row habitats combining all abundance data from the sampling period.

These proportions are much higher when we examine arthropod abundance in the inter row in the two treatment blocks (**Chart 9**). There are very high proportions of parasitoids (79%) and predators (80%) in the cover crop block when comparing treatments. Potential prey and nectivores are also proportionally much higher in the cover crop treatment block (65% and 61% respectively).

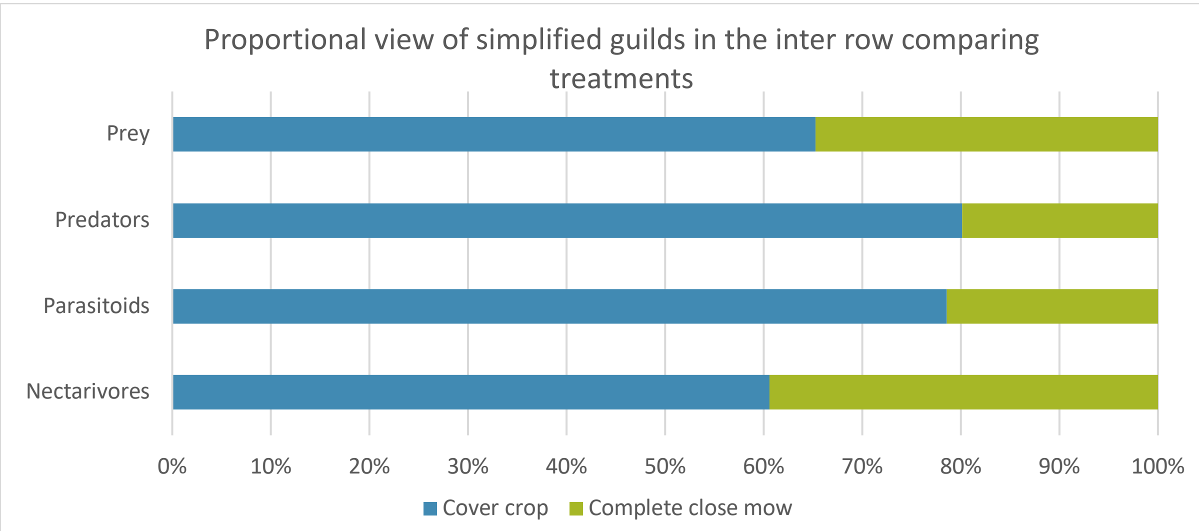


Chart 9: Representation of simplified feeding guilds in the inter row comparing the cover crop and complete close mow treatments over the whole sampling period.

We would expect that with a cover crop environment is especially attractive to beneficial arthropods because it provides shelter, breeding areas, nectar, alternative hosts/prey and pollen. But does this transfer to beneficial arthropods visiting the macadamia trees? In **Chart 10** we found that proportionally there are high numbers of predators and parastioids in the cover crop macadamia trees (71% and 63% respectively). Overall prey and nectivores are also much higher in the cover crop macadamia trees (57% and 62% respectively). This is an important result.

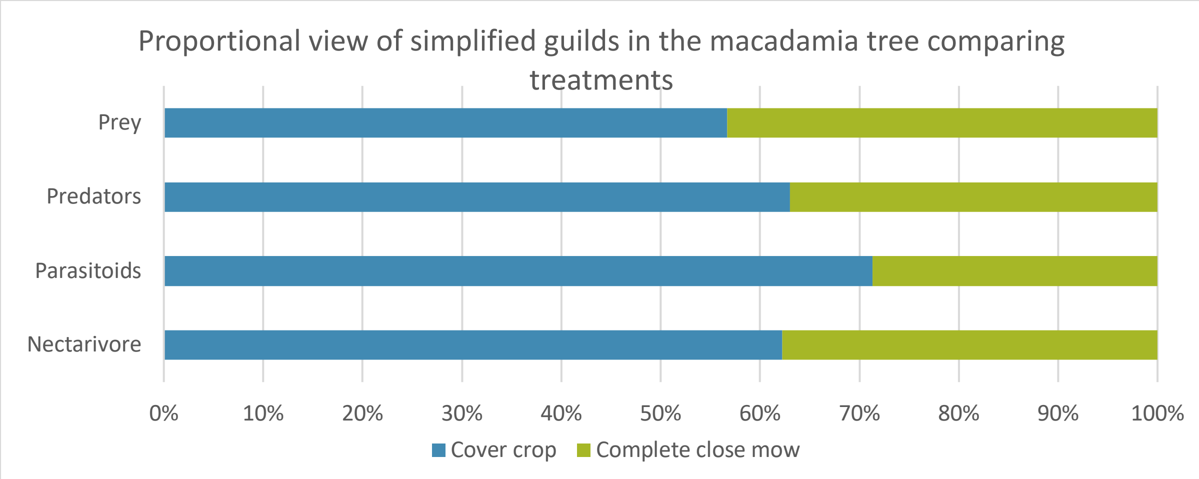


Chart 10: Representation of simplified feeding guilds in macadamia trees comparing cover crop and complete close mow treatments over the whole sampling period.

Flies as pollinators

In many ecosystems, including agricultural ones, flies are very important pollinators. Of the 150 families flies worldwide, almost half, 71, have been shown to feed from flowers (mainly nectar) and thus in principle transmit pollen from one plant to another. This is currently an expanding area of behavioural research as we discover more about their pollinating abilities. A famous example is that we would be a world without chocolate without pollination by the chocolate midge (family Certopogonidae).

We identified 2,510 flies from over 30 fly families at Piccadilly Park. In **Chart 11** we show the total abundance of each fly family over the four seasons of sampling. Most notably there are 13 families that are present in the cover crop but absent in the complete close mow block, the latter therefore being less species rich. Of the families present only in the cover crop block, several are parasitoids (Conopidae, Cryptochetidae, Tachinidae and Chamaeyiidae) and some are predators in the larval stage (Syrphidae). Syrphids (hover flies) are second only to solitary bees in their value as commercial pollinators worldwide. The Chamaeyiidae are an important family for macadamia as the larvae are predators of coccids and psyllids. Tachnids all parasitise other insects, usually the larvae of moths and butterflies, but also the larvae or adult beetles, including the macadamia seed weevil. Predatory flies such as Dolichopodidae were more abundant in the cover crop (29 specimens) than the close mow (3 specimens). Phorids were more abundant in the cover crop (478 specimens) compared to the complete close mow block (262 specimens). Phorids are a very diverse family and many are important pollinators particularly in forest habitats. The most numerous Phorid genus at Piccadilly Park was Megaselia which has over 1500 species worldwide. Some Phorids species are also known to be aphid predators.

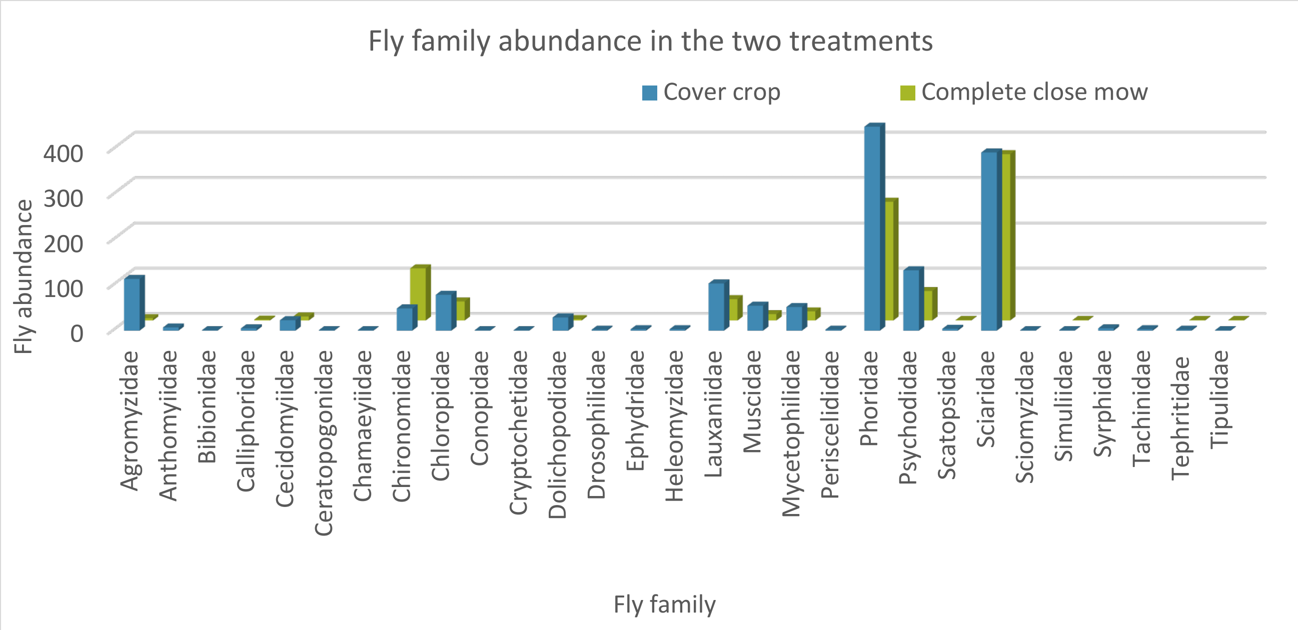


Chart 11: Total abundance of flies grouped to family level in the two treatment blocks caught in YSTs over the four seasons of sampling.

One way to visualise the difference between fly abundance is to compare the proportions of the main families in the two mow treatments (**Chart 12**). The fly family Agromyzidae has 150 species in Australia and the larvae are leaf miners, stem miners or gall makers. It is unknown if any of the specimens we caught are leaf miners of macadamia, however this would be interesting to follow up. Their feeding however provides nutrients back into the soil. The Cecidomyiidae are ubiquitous and as adults do not feed, so are unlikely to be pollinators. As larvae they are scavengers, detritivores and gall formers; some species are known to be predators of aphids. Several studies have highlighted the pollinating abilities of Lauxaniidae adults and they have been found to be particularly important pollinators of some orchids. The larvae are generally fungivores. Muscids have been found to be very important pollinators in some environments such as the tundra. They are detritivores as are Psychodidae, both familes are important for the recycling of nutrients back into the soil, as they feed on dead leaves, twigs and subsequent decaying mould.

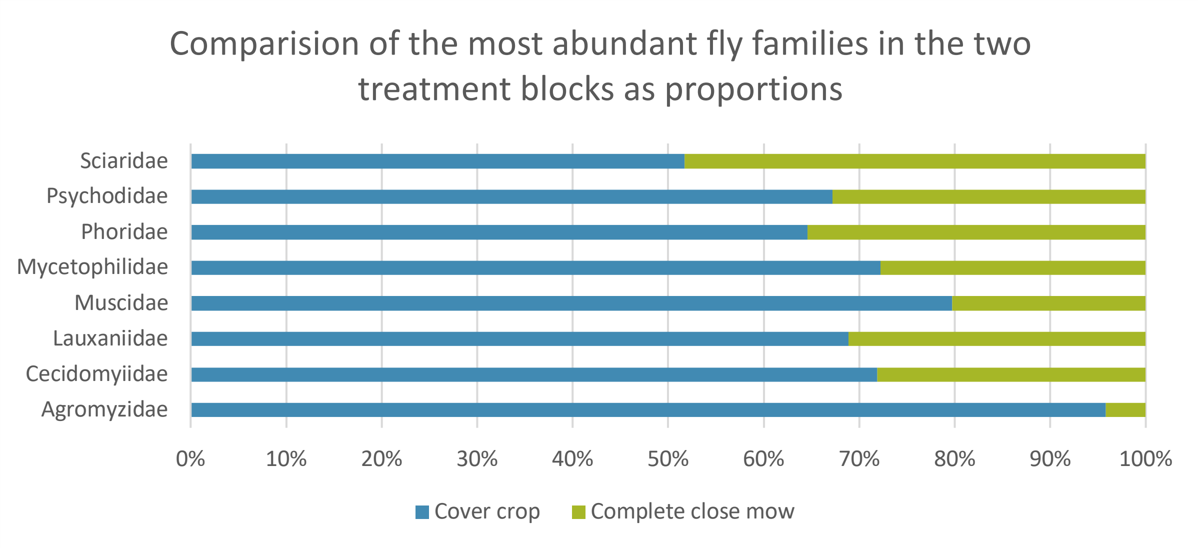


Chart 12: Proportions of the most abundant fly families in the two mow treatments across the four seasons of sampling by YSTs.

There are several fly families absent in the macadamia trees of the close mow treatment (**Chart 13**) that are nectivores/potential pollinators (Bibionidae, Anthomyiidae, Ephydridae, Drosophilidae, Ceratopogonidae and Syrphidae), detritivores that recycle nutrients (Heleomyzidae) and parastoids (Cryptochetidae and Tachinidae) which are all present in the cover crop trees. Overall, there is proportionally greater abundance and diversity of most fly families in the macadamia trees in the cover crop block.

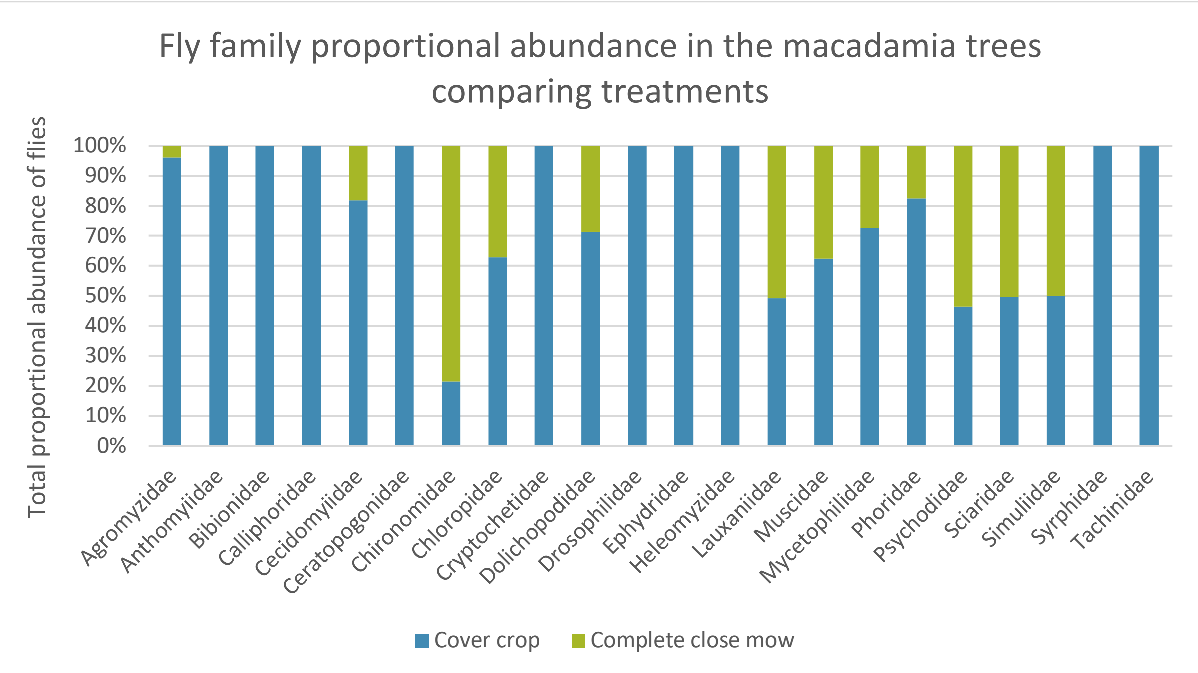


Chart 13: The proportion of fly abundance across different families in the macadamia trees of the cover crop and complete close mow treatments over the four seasons of sampling by YSTs.

Wasp parasitoids

We identified 1889 specimens of wasps at Piccadilly Park, comprising of 26 families out of 77 families found in Australia, almost all of which were parasitoids. One of the main treatment differences at Piccadilly Park was a substantial increase in parasitoids in the cover crop block (1423 specimens) compared to the complete close mow block (466 specimens). The innate host-finding attributes of parasitoids are well developed, and many parasitoids may be considered habitat specialists rather than host specialists.

In **Chart 14** we compared parasitoid families in the two treatment blocks. The most abundant wasp family was the Encyrtidae which is a diverse family of small parasitic wasps and was highly more numerous in the cover crop block (667 specimens) compared to the complete close mow treatment (39 specimens). A lot of the species in this family are parasitoids of true bugs (including aphids, coccids, psyllids, whiteflies, leaf hopper etc). They were most numerous in the cover crop (546 specimens) however were five times more abundant in the cover crop macadamia trees (121 specimens) than in the close mow block (23 specimens). Several other wasp families also had this trend including braconid wasps (27 specimens in the cover crop tree, compared to 4 specimens in close mow trees) and other families that had 10 times more wasps in the cover crop trees (Bethylidae, Diapriidae and Platygastridae). The Eurytomidae family was the only family that had the opposite trend, with 39 specimens sampled in the complete close mow block trees as compared to 4 specimens in cover crop trees. Some parasitoid families were not found in the close mow block trees but were in the cover crop trees including Agaonidae, Eucharitidae, Figitidae and Pteromalidae families. The Trichogrammatidae were more abundant in the cover crop treatment (233 specimens) compared to the complete close mow row and trees (145 specimens). The Trichogrammatidae are egg parasitoids and include the MacTrix species; there was more than double their abundance in the macadamia trees where there was a cover crop. However, because MacTrix is released at Piccadilly Park it is possible that the positioning of the releases may have influenced trap catches.

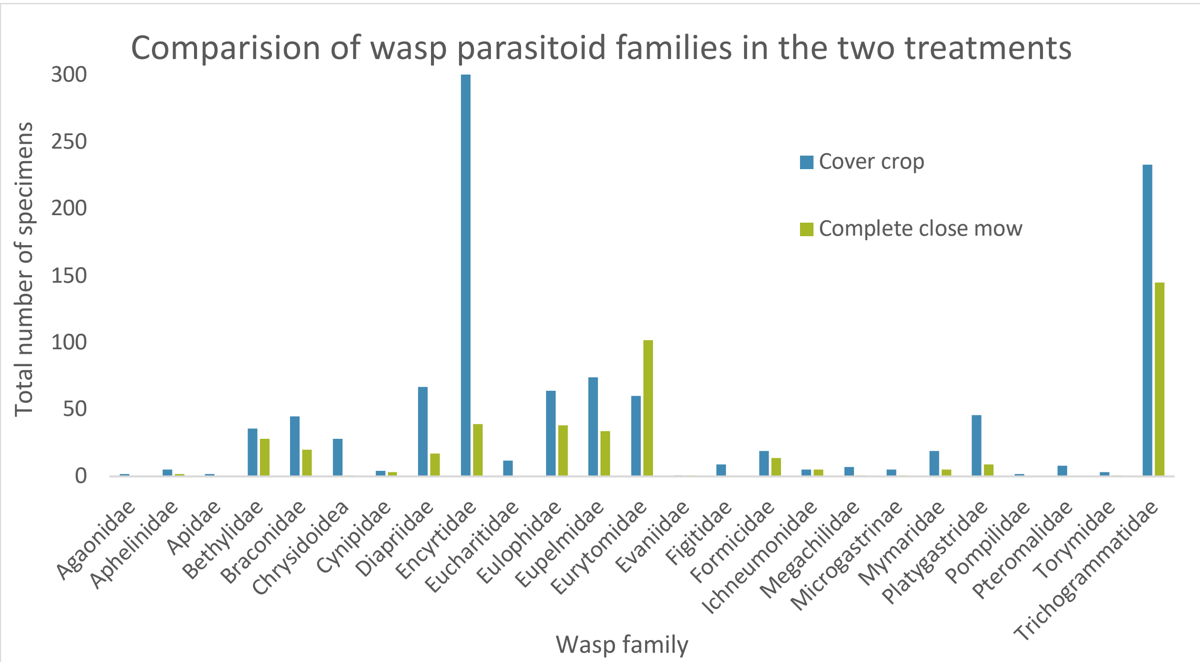


Chart 14: Comparison of wasp families in the two treatment blocks over the four seasons of YST sampling. Note that due to the high number of Encyrtidae (667 specimens) the graph only illustrates a maximum of 300 specimens.

Chart 15 compares the total abundance of parasitoids in both the inter row and trees in the two treatment blocks. The cover crop inter row has more three times as many parasitoids (886 vs 243 specimens) and almost that ratio in the cover crop trees (505 specimens) compared to the close mow trees (205 specimens).

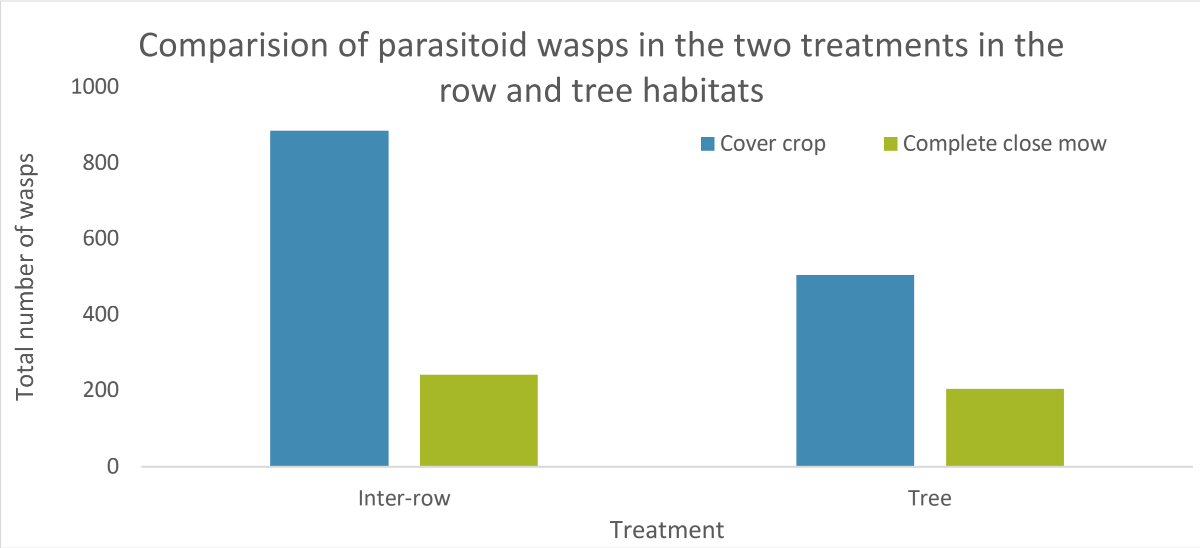


Chart 15: Comparison of the total abundance of parasitoids in both the inter row and macadamia trees in the two treatment blocks.

Findings and recommendations

The Piccadilly Park project has yielded unique and powerful insights within the context of Bioresources’ investigation into the considerable potential for conservation biocontrol and insectaries in the macadamia inter row. The Harris family have devised and implemented cover cropping for insectaries and other ecosystem services in the inter row and elsewhere at Piccadilly Park. This includes selective seed mixes, selective and scheduled reseeding, targeted mowing for different functional zones (drip-line and cover crop), retention of alternate inter rows for insectary during periods of intensive mowing and reseeding, and commitment to insectaries in areas adjacent to the orchard blocks. Areas of native vegetation also add value for beneficial arthropod habitat.

The Piccadilly Park project demonstrates that with appropriate decision support (crop consultants), decision-making, investment, planning, scheduling and delivery, the true potential of the macadamia inter row is realised. The BioResources project team further acknowledges that the results we present here on arthropods build on an existing farm-management philosophy, which has been in development for 10 years and includes investment in soil health (composting, fermentation and production of biological agents for improved microbiology), roll-out of integrated pest and disease management (IPDM), and macadamia tree row removal. From here there is scope to further refine and target seed mixes (for example select plant species that are especially attractive to biocontrol parasitoids with plantings timed to provide them with resources when they need them most).

Whilst some of the original intention in sowing seed mixes was to manage soil health following row removal at Piccadilly Park, cover cropping is also a strategy to enhance other ecosystem services including pest suppression by encouraging the activity of predators and parasitoids. Certainly, the BioResources team found this to be true as parasitoids were three times more abundant in the cover crop inter row and more than double in number in the cover crop macadamia trees compared to the close mow treatment. Similarly, predators were almost three times as abundant in the cover crop block and had nearly double the population in the cover crop macadamia trees. We also found strong numbers for soil beneficial arthropods. However, it should be noted that even in the complete close mow block a thriving population of beneficial insects is present, when compared to many other farms participating in this project where native vegetation and cover cropping (as present at Piccadilly Park) are not incorporated into the farm system. Across the whole orchard at Piccadilly Park, the Harris family have developed over the years several areas to increase vegetational diversity, which have also increased the overall farm biodiversity which maintains ecosystem functions. Even prey diversity, for example, can have a powerful effect on the nutrition, reproduction and survival of natural enemies.

This study involved initial monitoring the presence of arthropods in response to cover cropping in the orchard. There are however some limitations to this approach, namely untangling the complex food webs of the orchard ecology, and what impact this has on pest control, soil health, yield and other benefits. Further investigation of this will strengthen pest suppression. The Harris family’s conscious minimization of insecticides, particularly during the project period has undoubtedly further helped maintain beneficial arthropod populations as chemical controls are a major impediment to biological control.

When the findings from all of the farms that participated in this project are taken into consideration, it is clear that insectaries have meaningful influence on orchard ecology when growers can commit to inclusion of the insectary in the orchard in terms of space allocation and long-term management. This is very strongly evidenced at Piccadilly Park, where there is a commitment to “managed vegetative diversity" in the inter row, headlands, field margins and other areas for habitat suitable for beneficial insects. As the Harris family have demonstrated, decisions to improve plant diversity with seeding, well-timed seeding, native revegetation, and so on are very influential. Detailed recommendations for cover cropping in macadamia orchards will be available in a forthcoming project, being rolled out by the BioResources team in collaboration with Piccadilly Park in 2020-21 (**Photo 7**).

Photo 7: Piccadilly Park inter row cover crop February 2020. As Piccadilly Park continues with row removal and cover cropping in 2020-21, BioResources will work with them to gather and present results and recommendations. Check www.bioresources.com.au for updates.

Acknowledgements and thanks

The project team wishes to thank the Harris family for their participation, and particularly Rex and Dan for contributions and support in the field.

Final Report

"Alloway" – Macadamia Inter Row Trial Results

Hort Innovation program title: The IPM program for the macadamia industry – BioResources

Hort Innovation project code: MC16008

Date: February 2020

Summary

This project proposes that reduced mowing in the macadamia inter row may improve vegetation there for the purposes of an insectary. Where managed reduced mowing is possible, it is further proposed that beneficial arthropods crucial to pollination, pest suppression and the “food-web” will be present and active in higher numbers. This can decrease the likelihood and/or intensity of pest outbreaks because populations of beneficial invertebrates are always present within the orchard.

“Alloway” worked with the BioResources team to investigate these ideas from early 2017 to mid 2019.

The reduced mowing trial hosted by “Alloway” has provided several useful insights into the practicalities of reduced mow options in macadamia orchards, and especially the mohawk. Industry has been particularly concerned that reduced mowing of the inter row may lead to significant problems such as increased rat activity, invasive weeds and/or increased insect pests. The trial at “Alloway” gives other growers reassurance that a mohawk can be incorporated into existing orchard inter row management and with basic monitoring and management will not lead to other problems.

Findings in terms of the benefits of a mohawk for beneficial arthropods in the orchard at “Alloway” are observable but modest. This is not an unusual outcome with field experiments where there are so many unpredictable and uncontrollable factors in play.

When the numbers of beneficial arthropods were combined and compared between treatments, there were more beneficial arthropods within the inter rows of the mohawk block compared to the complete close mow block for each year. The pattern of beneficial abundance in the tree was less clear compared to the inter row.

Parasitoids were more often sampled from the inter row with the mohawk when compared against the complete close mow block. They were also often sampled at considerably higher numbers in the mohawk. These are significant results and suggest that inter row management strongly influences the presence of parasitoids, including biocontrols. An inter row insectary, including a mohawk, may give parasitoids more opportunity for the suppression of pests in the orchard.

These results for “Alloway” are likely to be enhanced into the future with sustained commitment to insectaries throughout the orchard that are compatible with standard orchard operations, the inclusion of seeding options, and further refined strategies for reduced mowing including alternate row mowing.

The BioResources team encourages you to read the final report for the *Macadamia IPDM Program - Inter Row Project (MC16008)*, which is available via *Hort Innovation*. Here you will find out more on the benefits of insectaries for macadamia orchards and also the experiences of other trial farms in implementing and managing insectaries. There is also an exploration of the multiple ecosystem services known to flow from reduced mow inter row management practices along with improved arthropod biodiversity, including benefits for soil organic matter, nutrient cycling, water management, erosion control, weed suppression, soil carbon storage, soil microbiology and more.

Introduction

This project proposes that reduced mowing in the macadamia inter row may increase vegetative diversity, increase floral resources, and reduce habitat disturbance. This may in turn increase the presence of beneficial arthropods in the orchard. More broadly, the proposed changes in plant ecology may increase arthropod populations in general, the over-whelming majority of which are non-economic and will be food for beneficial arthropods. Furthermore, this enhanced nutritional food-web will benefit birds and micro-bats, which have a role in pollination and pest suppression. Having a “food-web” within the orchard decreases the likelihood and/or intensity of pest outbreaks because populations of beneficial invertebrates are always present within the orchard.

These propositions warrant investigation because an increased presence of beneficial arthropods in the orchard may result in improved pest suppression and also improved pollination, via reduced crop damage, reduced inputs like chemical applications, and subsequently improved yields.

“Alloway” worked with the BioResources team in this investigation from early 2017 to mid 2019. We compared two 1 Ha blocks. A control block was managed as industry standard with regular mowing (**Photo 1**, below). A treatment block was managed with reduced mowing, sustaining a centre mohawk for most of the trial period (**Photo 2**, below).

Photo 1: “Alloway” complete close mow 14 December 2017

Photo 2: “Alloway” mohawk 14 December 2017

As you will recall, with each site visit the BioResources team sampled each block for arthropods in three separate rows using yellow stick traps (YSTs), placing one YST in the inter row and one YST in a tree. We assessed the vegetation in the inter row at those three points (a quadrant of approximately 10m x 20m). The three data collection points were at least 30m apart, and 50m from any block edge. We also spent time with you discussing the trial and any observations that you may have made in relation to rats, weeds, insect pests in the inter row vegetation and/or any challenges with reduced mowing.

The objective of the trial has been to provide growers with on-farm practical experience in reduced mowing complimented by vegetative and invertebrate monitoring to quantify results.

BioResources first worked with growers to consider practical options for reduced mowing that are compatible with the seasonal demands of orchard management. It has then sought to provide information on any relationship between reduced mowing and the potential for increased rat, invasive weed, and/or arthropod pest presence. Finally, the trial has sought to monitor association between changes in inter row vegetation management and changes in orchard beneficial/pest arthropod ecology.

Reduced mowing in the inter row at "Alloway"

Reduced mowing trial and potential problems

	Throughout the trial, BioResources regularly monitored for and consulted with Ray Norris, Ngarie Meyer and/or Johan Oostheisen, on the following issues:
Rats	No issues were observed by the project team during site visits. No issues were reported by the "Alloway" team. It was noted that the orchard soil is very compact and sandy and rats are not generally a problem in the orchard.
Problem weeds	No issues were observed by the project team during site visits. No issues were reported by the "Alloway" team.
Major insect pests of macadamias	No issues were observed by the project team during site visits. The team monitored vegetation in the inter row for the presence of major macadamia pests including Macadamia Nut Borer, Fruit Spotting Bug and Green Veggie Bug. Plant species typically found in the inter row trial blocks at "Alloway" were not observed to host these pests. No issues were reported by the "Alloway" team.
Management of the inter row	No issues were observed by the project team during site visits. No issues were reported by the "Alloway" team. A number of different machinery options were available for slashing and harvesting, which suited straightforward inclusion of a mohawk in the trial block year-round.

Outcomes

The reduced mowing trial hosted by "Alloway" has provided several useful insights into the practicalities of reduced mow options in macadamia orchards, and especially the mohawk. Industry has been particularly concerned that reduced mowing of the inter row may lead to significant problems such as increased rat activity, invasive weeds and/or increased insect pests. The trial at "Alloway" gives other growers reassurance that a mohawk can be incorporated into existing orchard inter row management and with basic monitoring and management will not lead to other problems.

The trial, which compared a complete close mow block with a mohawk block at "Alloway" was adversely impacted by the dry and hot seasons of 2018 and 2019. These conditions limited growth in the mohawk and as a result a strong experimental distinction between the control block (**Photo 3,** below) and the treatment mohawk block (**Photo 4**, below) was not consistently possible for the life of the project.

Thus, findings in terms of the benefits of a mohawk for beneficial arthropods in the orchard at "Alloway" are observable but modest. This is not an unusual outcome with field experiments where there are so many unpredictable and uncontrollable factors in play.

In so much as the potential for inter row insectaries in macadamia orchards is concerned, the BioResources team urges you to read the project's final report, *Macadamia IPDM Program - Inter Row*

Project (MC16008), which will be available via *Hort Innovation*. A number of the project's other trial farms enjoyed more benign circumstances in their trial blocks, and the results there are very encouraging.

Photo 3: "Alloway" complete close mow 22 August 2018

Photo 4: "Alloway" mohawk 22 August 2018

Results of reduced mowing in the inter row at "Alloway"

Vegetative diversity

Vegetative diversity refers to the number of plant species present. Changes to regular mowing can change plant species diversity. This can in turn be associated with diversity of arthropod species. **Chart 1** presents an average count of plant species observed in the inter row by treatment through time.

In this trial we anticipated that reduced mowing would increase the number of plant species present in the orchard. However, we found on some participating farms, including "Alloway", that through time, less mowing *reduced* plant species diversity. This is because some species such as Rhodes grass tend to heavily dominate other plant species, if not mown occasionally **(Chart 2)**.

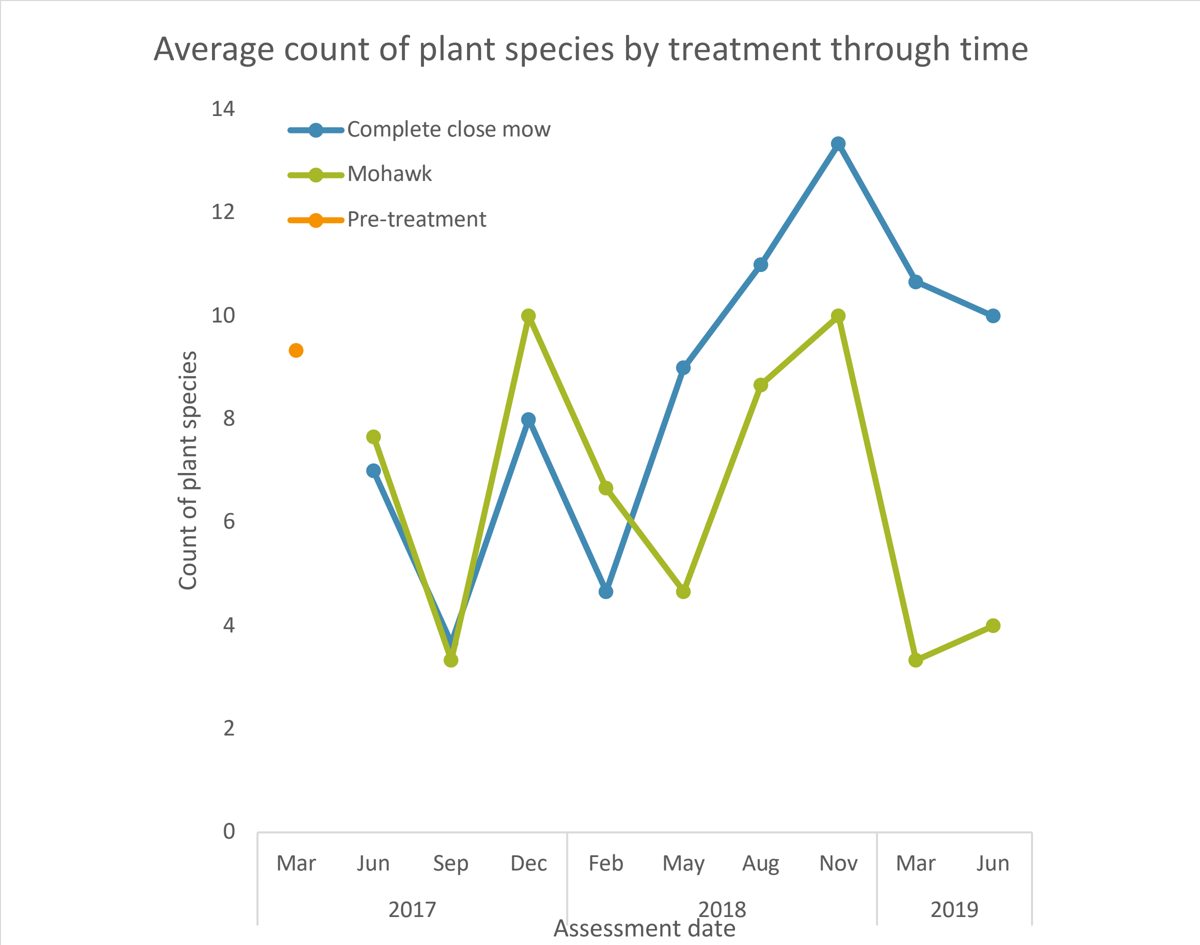


Chart 1: Average count of plant species by treatment through time. This is an average of counts taken at the three assessment points on each block.

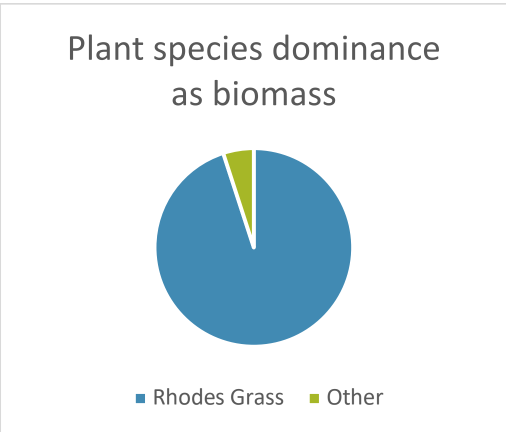


Chart 2: Plant species dominance as biomass

Values recorded for plant species can be somewhat misleading. The experimental method required recording of every plant species observed. Often however, many of these species were present at a very low relative percentage and as very small specimens with 2 or 3 leaves at most.

Rhodes grass (**Chart 2**) was a dominant species as total volume of biomass.

Rhodes grass in the mohawk provided a comparatively less disturbed physical habitat for beneficial insects.

Floral resources

Floral resources provide a food source for many beneficial arthropods and will encourage them to remain active in the orchard. **Chart 3** provides an average count of the plant species flowering at the time of the site visit.

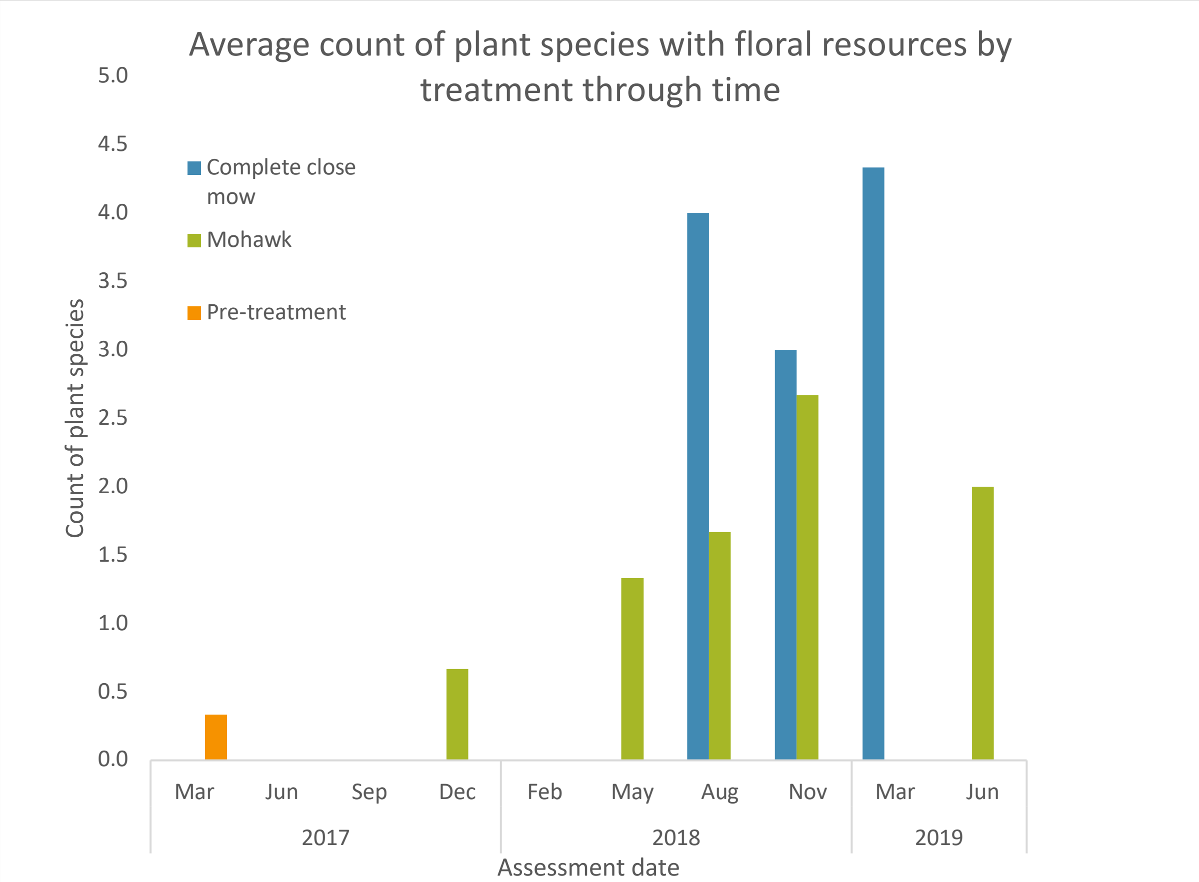


Chart 3: Average count of plant species with floral resources by treatment through time. This is an average of counts taken at the three assessment points on each block.

Overall, the presence of floral resources in the trial at "Alloway" was very limited. The experiment did not achieve either a good distinction between the control and the treatment blocks or anticipated improved floral resources from reduced mowing. This was a result of the hot, dry conditions and also the dominance of Rhodes grass in the mohawk. We also found that mowing sometimes encouraged more flowering in the complete close mow block because of the plant species mix.

Habitat disturbance

Areas of reduced mechanical and chemical disturbance can serve as favourable habitat for beneficial insects. Undisturbed areas may also provide a refuge for beneficial arthropods for faster recovery after spraying. The measurement of plant height provides a good indication of rates of mechanical disturbance. **Chart 4** reports the average height in centimetres (cm) of vegetation in the inter row by treatment through time.

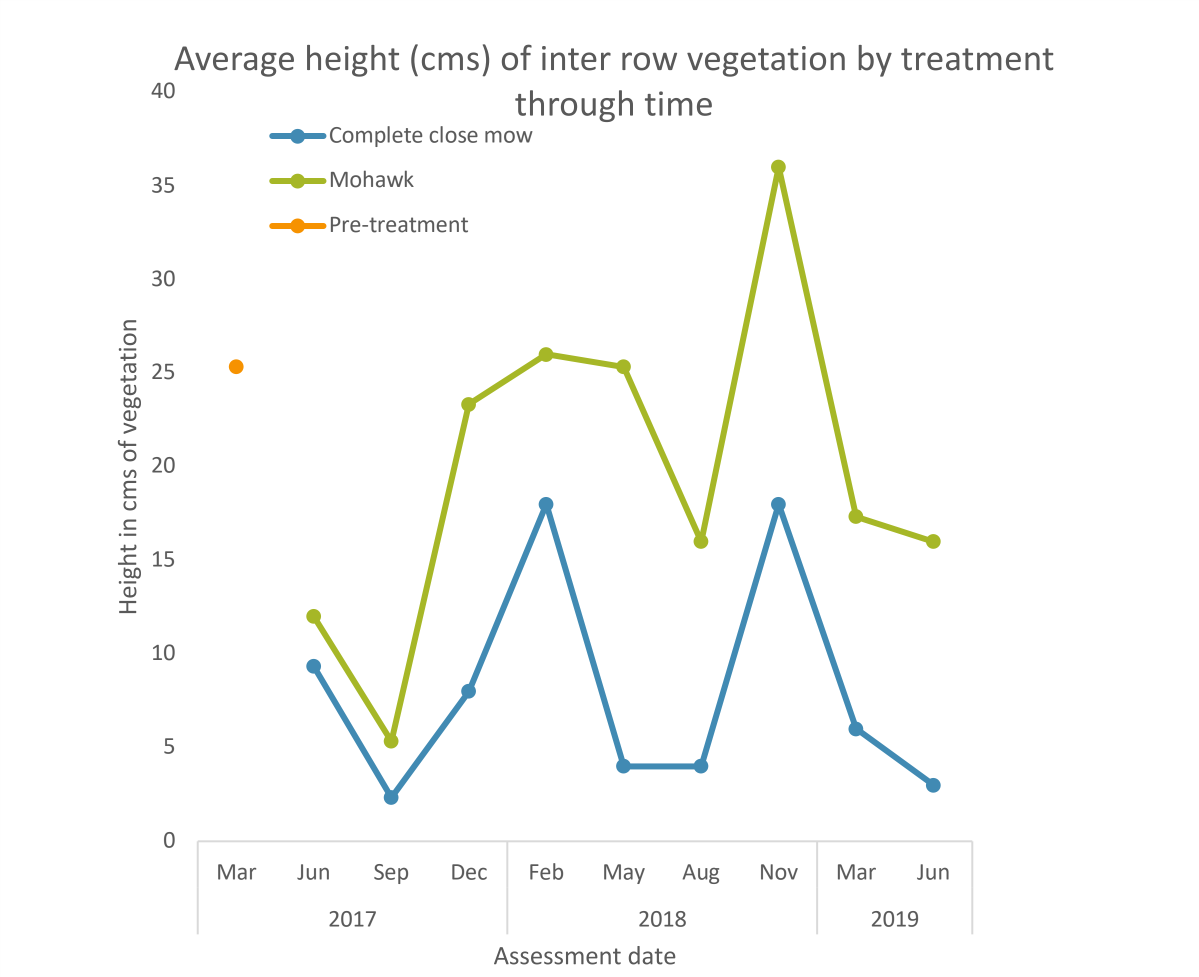


Chart 4: Average height (cm) of inter row vegetation by treatment through time. This is an average of counts taken at the three assessment points on each block.

Retention of a central mohawk at "Alloway" allowed for greater height of vegetation and hence less disturbance in the inter row for the life of the trial.

Examination of other undisturbed areas at "Alloway" such as field margins revealed lady beetles on un-mown grasses. See **Photo 5**, lady beetle pupae.

Reduced disturbance allowed the lady beetle to complete its lifecycle.

Lady beetle larvae are voracious predators of macadamia pests including mites and aphids.

Photo 5: Lady beetle pupae within "Alloway" field margin 23 February 2018

Results of arthropod evaluation

General arthropod abundance

Charts 5 and 6 present the total average numbers of individuals collected for several arthropod groups sampled during the project, comparing the mohawk with the complete close mow. We used YSTs to sample arthropods within both the inter row and trees. Like all sampling methods, YSTs have biases, which need to be taken into consideration. YSTs sample winged arthropods during flight (though non-winged arthropods do get caught occasionally). Their colour, yellow, is particularly attractive to parasitoids, flies and thrips, which were very well sampled during this project. The abundance data presented below shows only the winged arthropod groups, robber flies, lacewings, aphids, whiteflies, beetles, hemiptera (sap suckers excluding aphids), pollinators (flies), parasitoids and thrips. Other important arthropod groups, such as spiders and ants were not well sampled using YSTs and are thus omitted from **Charts 5 and 6**.

Parasitoids, flies (pollinators), thrips and other hemiptera (excluding aphids, which are generally not well sampled by YSTs) were the most abundant arthropod groups sampled during this trial. All of these arthropod groups were more abundant within the inter row than the trees (see x-axis when comparing charts 5 and 6), though thrips were in similar numbers within the complete close mow block. In total, parasitoid numbers were roughly equal between treatments in the trees, though there were more in inter rows of the mohawk block. Pollinator and thrip numbers were higher within trees of the complete close mow block, though within the inter row the opposite trends were seen. Hemiptera were in very low numbers in the trees, though slightly higher in the mohawk block, and in the inter rows they were higher within the complete close mow block.

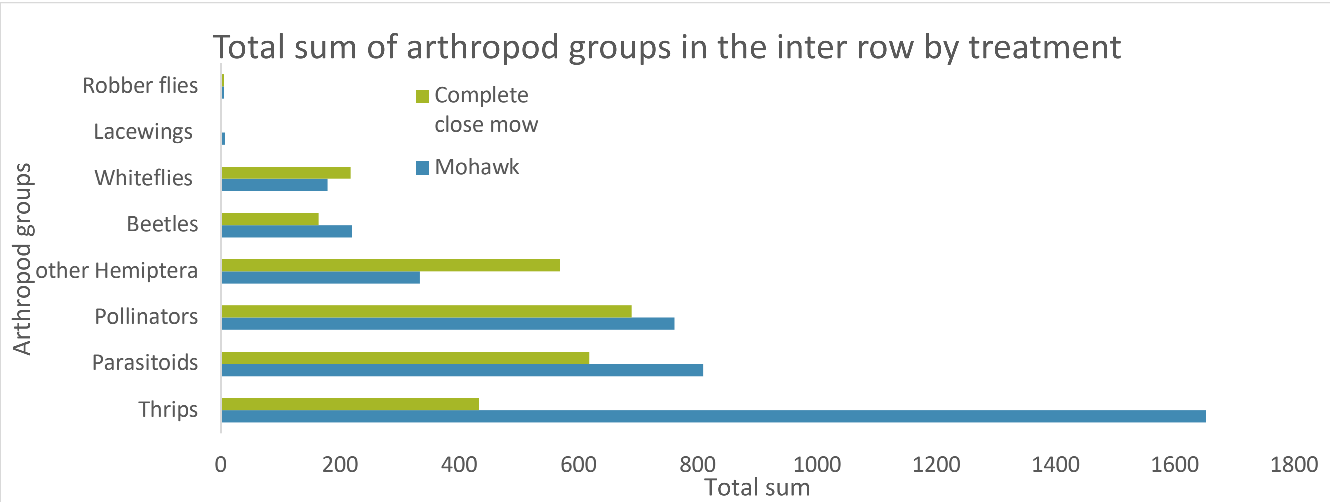


Chart 5: Total sum of each arthropod group within the inter row, compared between the two treatments, over the sampling period.

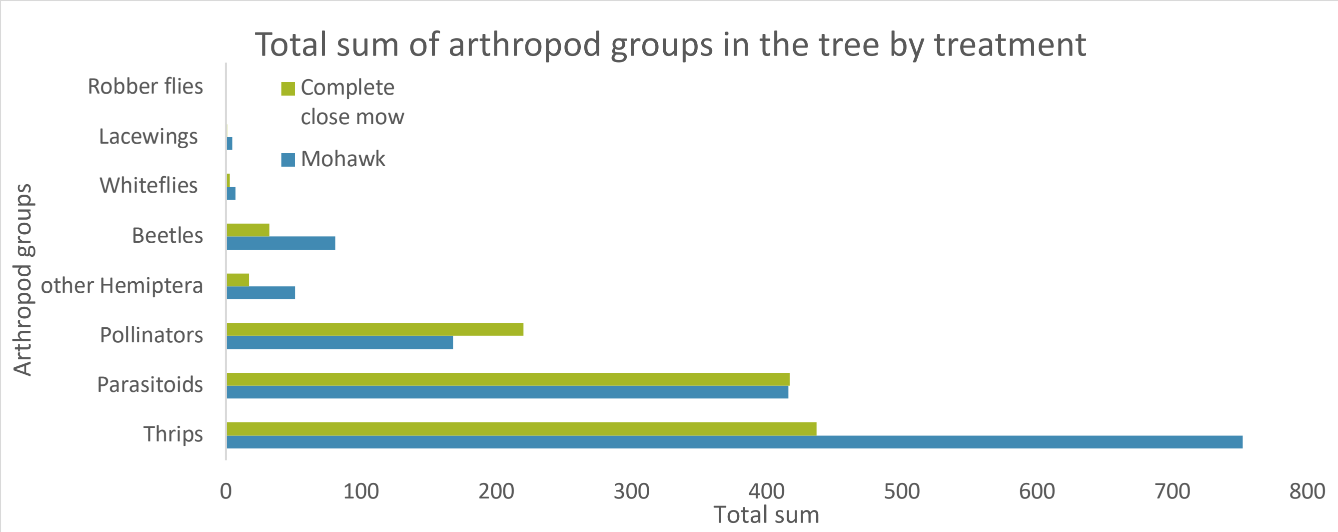


Chart 6: Total sum of each arthropod group within the tree, compared between the two treatments, over the sampling period.

A focussed look at thrips

In **Charts 5 and 6** thrips stands out as a group with the greatest total number of individuals collected. Thrips numbers spiked very strongly in September 2017 in the mohawk block in both the inter row and tree (see **Charts 7 and 8**). This was a one-off event and it may be associated with several different things. For example, it is worth noting that the week the YSTs were out for this assessment period, mill-mud was being distributed (**Photo 6**) and heavy pruning, hedging and mulching were under way in the trial blocks (**Photo 7**). This is noted not as a specific causal factor, but rather as several significant disturbances that may have influenced populations at that time.

Photo 6: complete close mow 20 September 2017

Photo 7: mohawk 20 September 2017

Thrips are broadly categorised as 'herbivores' because the majority feed on the outer layer of plant cells, but most thrips also feed on pollen, and help in plant pollination. Other groups of thrips feed on fungal spores and some are predatory and important in biological control.

In a broader context, thrips play an important part within the food web because they are abundant, soft-bodied and are small and palatable, so many predatory insects eat them. Within **Chart 7** you will see that thrips are abundant at low levels (with the exception of September 2017) throughout the entire sampling period in the inter row and with no preference for mohawk or complete close mow treatment. Within the tree (**Chart 8**), thrips fluctuate at low levels but are not always present. The inter row therefore plays an important part in ensuring there is always food for beneficial invertebrates, so that pest outbreaks are less likely to happen within the tree, and if an outbreak does occur that it is controlled quickly by the nearby predatory (beneficial) arthropods.

Standard on-farm monitoring of macadamia pests including thrips was discussed during site visits. Concerns for problematic numbers of thrips in the trial blocks were not raised at any point, beyond concerns with thrips at a farm-wide level.

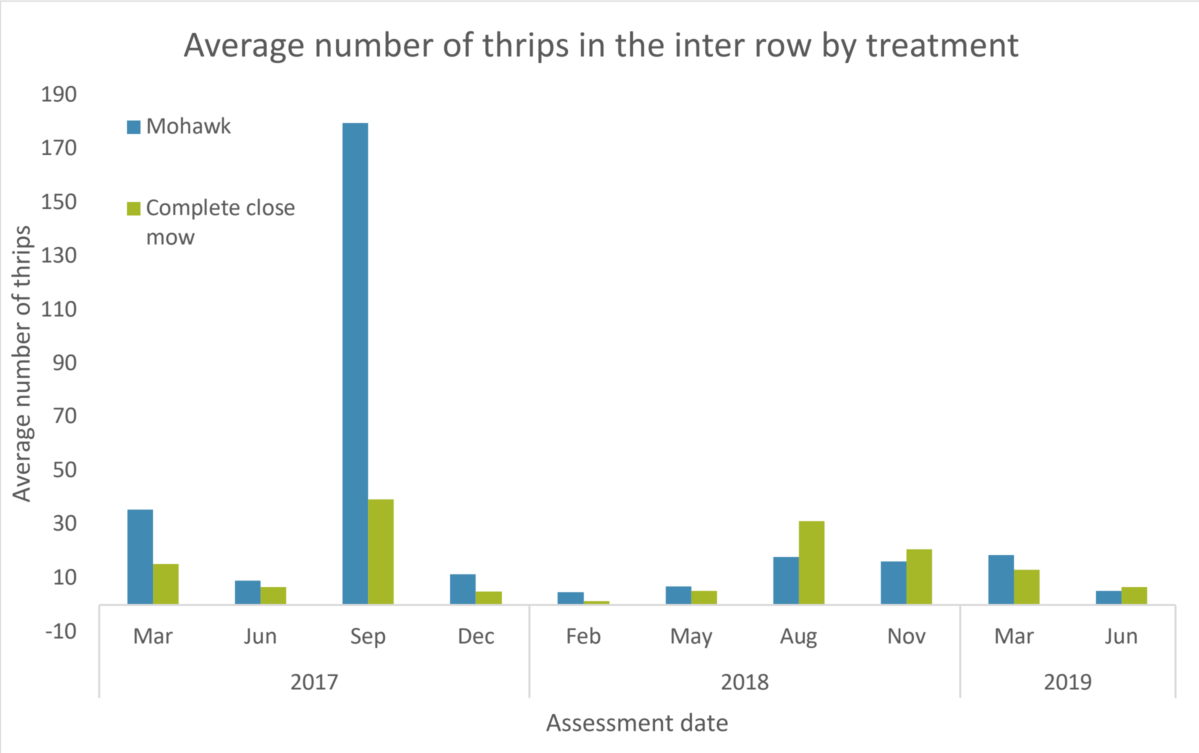


Chart 7: Average number of thrips by treatment through time – sampled in the inter row. This is an average number taken from the three assessment points on each block.

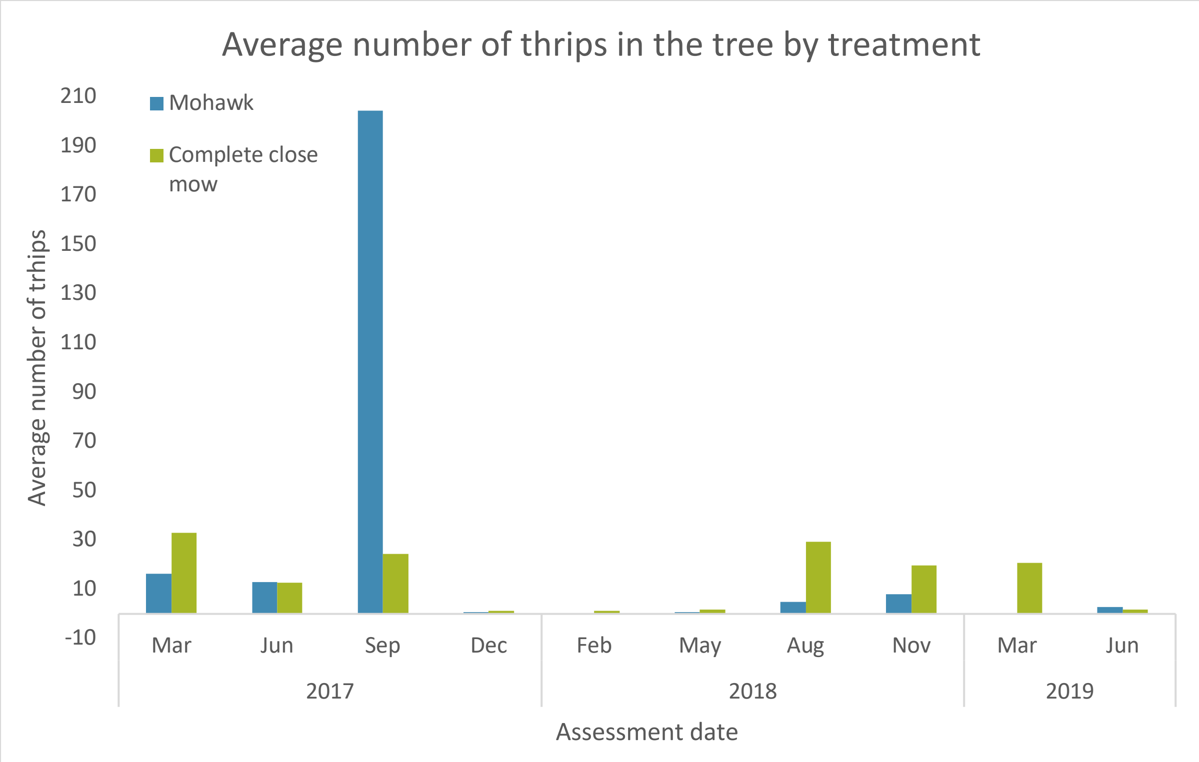


Chart 8: Average number of thrips by treatment through time – sampled in the tree. This is an average number taken from the three assessment points on each block.

Beneficial arthropod abundance

Beneficial insects sampled in the project included predators (ants, spiders, lacewings, robber flies, rove beetles), parasitoids (Hymenoptera), and pollinators (Diptera, syrphids). When the numbers of these beneficial invertebrates were combined and compared between treatments, there were more beneficial invertebrates within the inter rows of the mohawk block compared to the complete close mow block for each year (**Chart 9**).

Within the tree there were fewer beneficial arthropods than in the inter row (see y-axis when comparing charts 9 and 10). The pattern of beneficial abundance in the tree was less clear compared to the inter row and beneficial numbers were higher in the complete close mow block in two of the three sampling years (**Chart 10**). Whilst this might seem to be worrying, the two groups that were sampled in highest numbers were parasitoids and flies, which move around a lot. These would move into the tree when opportunities in the tree benefit them i.e. when there is nectar for food or hosts to parasitise.

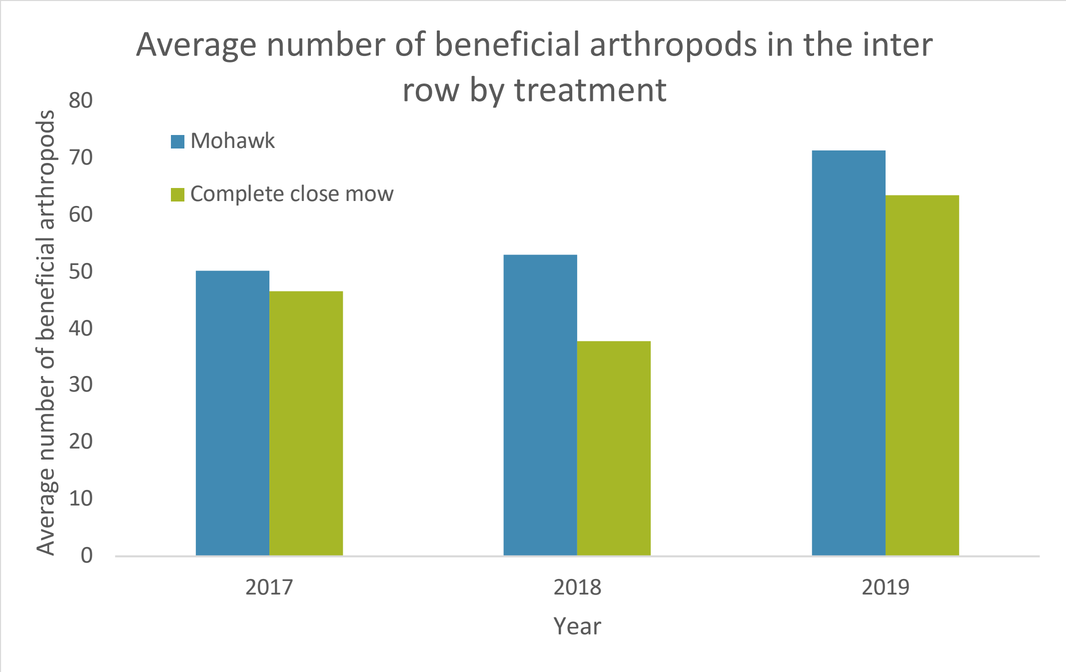


Chart 9: Average number of beneficial arthropods (predators, parasitoids and pollinators) sampled in the inter row. This is an average number taken from the three assessment points on each block.

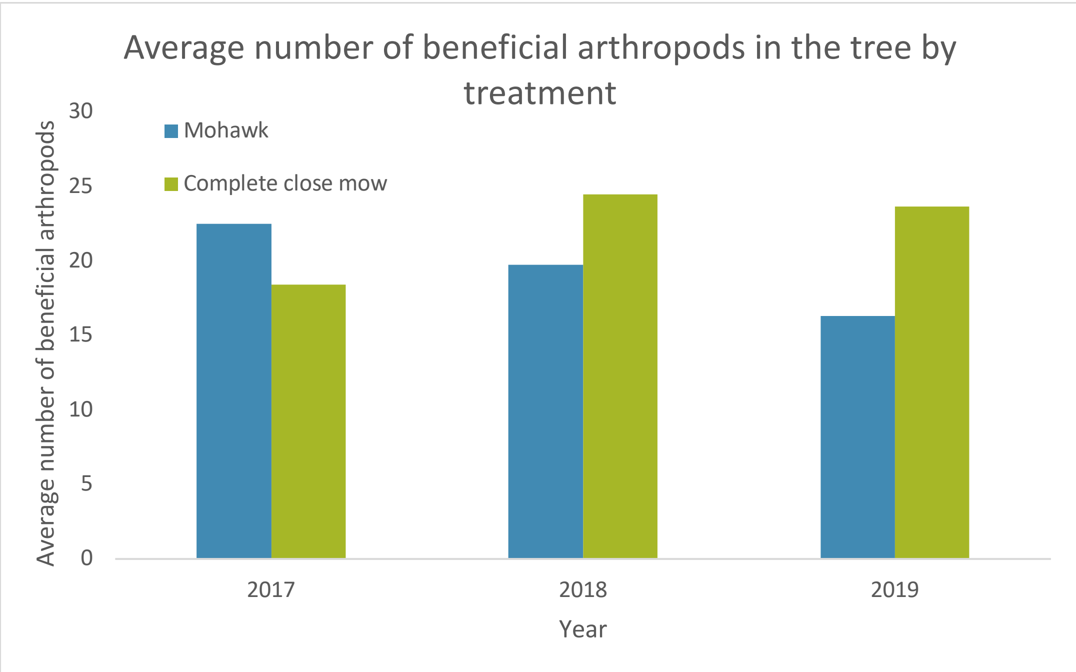


Chart 10: Average number of beneficial arthropods (predators, parasitoids and pollinators) sampled in the tree. This is an average number taken from the three assessment points on each block.

A focussed look at parasitoids

Parasitoids were representatively sampled by the YST catches, thus providing a meaningful indication of how the inter row treatments affect this important group of beneficial invertebrates. This sample includes MacTrix and Anastatus releases along with other hymenoptera already present in the orchard environment.

Parasitoids were more often sampled from the inter row with the mohawk when compared against the complete close mow block (7 out of 10 times). They were also often sampled at considerably higher numbers in the mohawk (**Chart 11**). These are significant results and suggest that inter row management strongly influences the presence of parasitoids, including biocontrols. An inter row insectary, including a mohawk, may give parasitoids more opportunity for the suppression of pests in the orchard.

There was less distinction between the treatments in the tree. Sometimes parasitoids samples from trees within the complete close mow block were higher than the mohawk block and vice versa (**Chart 12**). This does not necessarily mean that the parasitoids do not move from the mohawk into the tree, but that they only move in high numbers into the tree when there are hosts or nectar sources there.

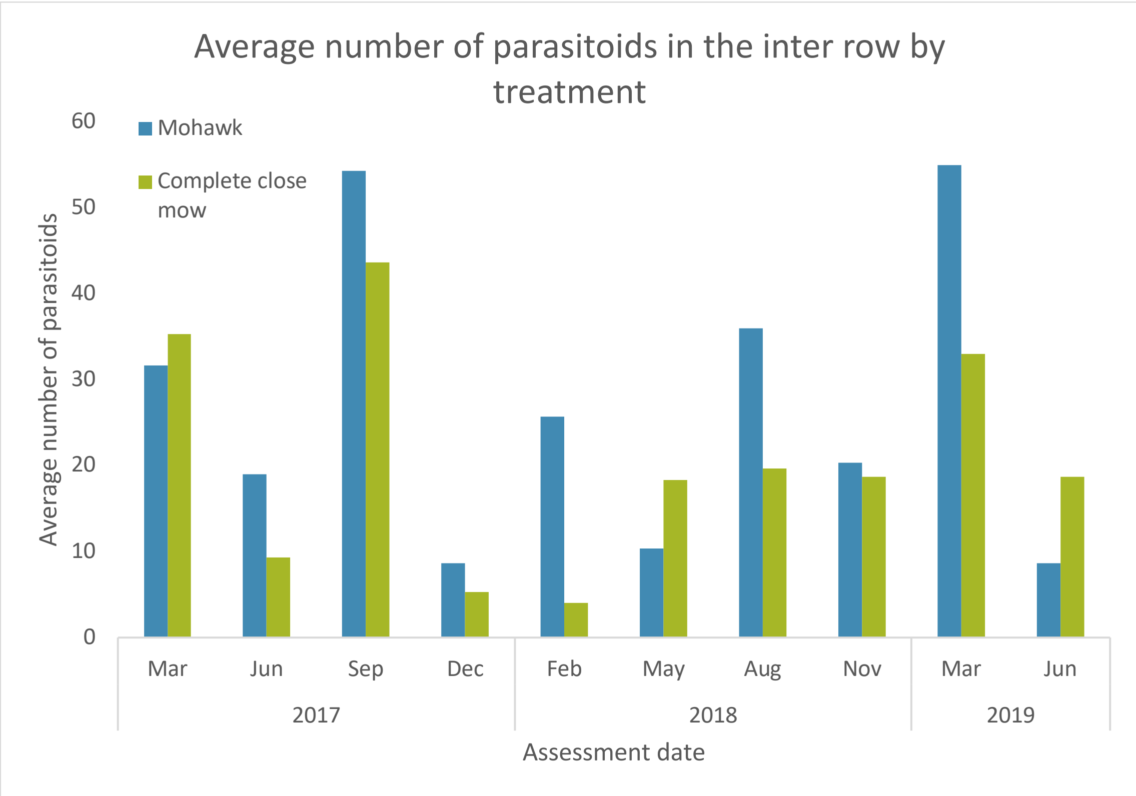


Chart 11: Average number of parasitoids by treatment through time – sampled in the inter row. This is an average number taken from the three assessment points on each block.

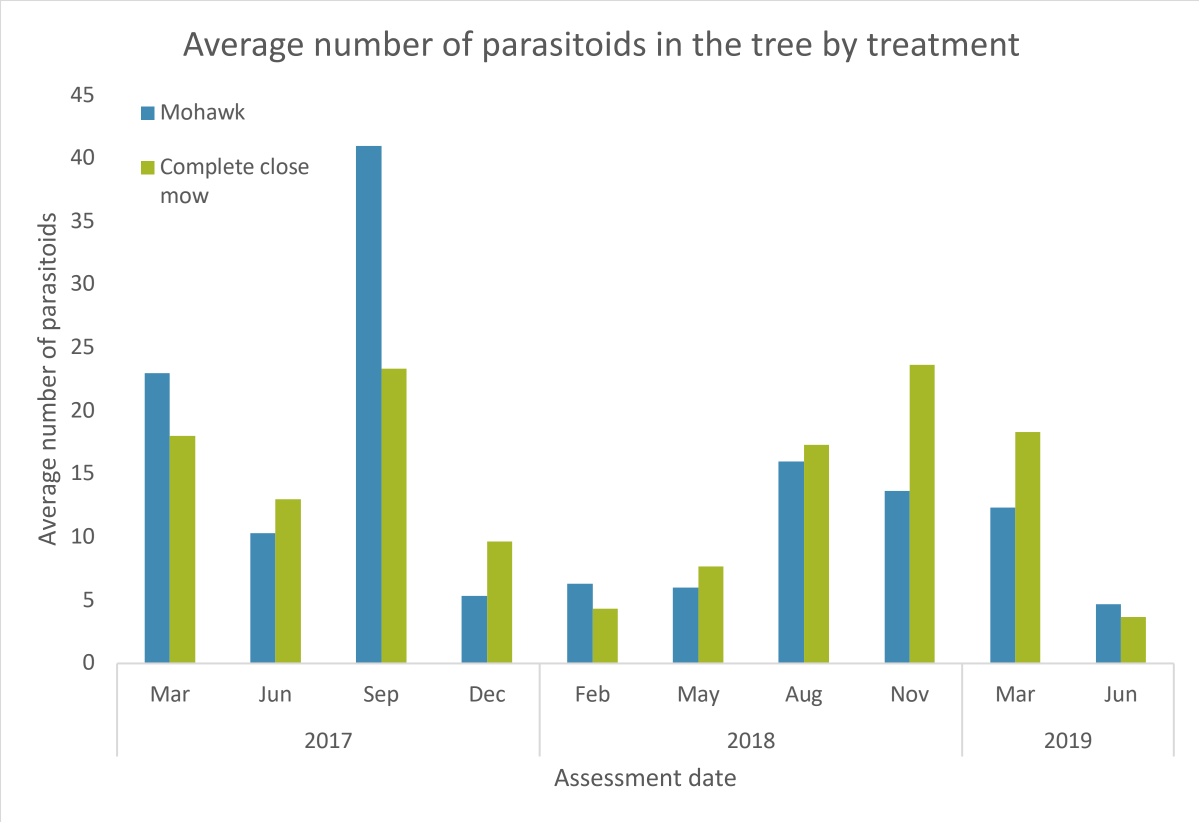


Chart 12: Average number of parasitoids by treatment through time – sampled in the tree. This is an average number taken from the three assessment points on each block.

Findings and recommendations

Mohawk worked very well at "Alloway", given the 10m rows and availability of machinery of a suitable configuration. Retaining a mohawk year-round, including during harvest, proved to be relatively straight-forward at "Alloway". The principal advantage of the mohawk reduced mow approach is that it can be sustained during harvest. This can be especially advantageous during winter, and particularly in dry years, because it keeps an insectary viable during slow growth periods. Farms that removed the mohawk during harvest took many months to re-establish insectary vegetation when compared to "Alloway". Optimal benefits from insectaries are possible when they are in place ahead of macadamia flowering and the annual intensification of crop pest pressure.

Rhodes grass is a good choice for the mohawk at "Alloway", given its hardiness for the difficult soil conditions and its desirable functional characteristics in an insectary. Some growers do not like clumping grasses in the inter row, but "Alloway" consistently reported that Rhodes was a good fit for standard farm operations. However, intermittent mowing to prevent dominance of Rhodes and encourage flowering of other species is recommended in this situation.

Options for increasing the plant species diversity in the inter row were discussed: green panic for the mohawk, and; smother grass, couch, lotononis, and white clover for carpeting were noted. In this connection, improved floral resources through seeding of the inter row is an important consideration. There is strong interest in the broader industry for seeding of the inter row and cover cropping and an extensive range of seed options is emerging.

It is worth noting that findings from other trial farms and other industries indicate that alternate row mow may be a better management option than the mohawk for many growers outside of harvest. This involves mowing every second row on a rotating schedule, allowing all rows to “grow out” somewhat across the year but providing opportunities for mow management as required. This reduces the overall disturbance of beneficial arthropods, ensuring a refuge remains in place at all times for them.

Findings from other farms where seasonal conditions were not as impactful for the life of the trial as they were at “Alloway” indicate that insectaries have meaningful influence on orchard ecology when growers can commit to inclusion of the insectary in the orchard in terms of space allocation and long-term management. At “Alloway” the inter row worked very well given row width. There are other areas on-farm worth considering, including headlands, field margins and so on where changes to management can allow for habitat suitable for beneficial insects. Decisions to improve plant diversity with seeding, well-timed seeding and mowing to limit dominance of one species while encouraging new growth and flowering and so on are very influential.

Finally, the BioResources team encourages you to read the final report for the *Macadamia IPDM Program - Inter Row Project (MC16008)*, which is available via *Hort Innovation*. Here you will find out more on the benefits of insectaries for macadamia orchards and also the experiences of other trial farms in implementing and managing insectaries. There is also an exploration of the multiple ecosystem services known to flow from changed inter row management practices along with improved arthropod biodiversity, including benefits for soil organic matter, nutrient cycling, water management, erosion control, weed suppression, soil carbon storage, soil microbiology and more.

Acknowledgements and thanks

The project team wishes to thank the "Alloway" ownership and management team for their participation, and particularly Ray Norris, Ngarie Meyer and Johan Oostheisen for their contributions and support.

Final Report

"Bundaberg Sugar" – Macadamia Inter Row Trial Results

Hort Innovation program title: The IPM program for the macadamia industry – BioResources

Hort Innovation project code: MC16008

Date: February 2020

Summary

This project proposes that reduced mowing in the macadamia inter row may improve vegetation there for the purposes of an insectary. Where managed reduced mowing is possible, it is further proposed that beneficial arthropods crucial to pollination, pest suppression and the “food-web” will be present and active in higher numbers. This can decrease the likelihood and/or intensity of pest outbreaks because populations of beneficial invertebrates are always present within the orchard.

“Bundaberg Sugar” worked with the BioResources team to investigate these ideas from early 2017 to mid 2019.

The reduced mowing trial hosted by “Bundaberg Sugar” has provided several useful insights into the practicalities of reduced mow options in macadamia orchards. Industry has been particularly concerned that reduced mowing of the inter row may lead to significant problems such as increased rat activity, invasive weeds and/or increased insect pests. The trial at “Bundaberg Sugar” gives other growers reassurance that reduced mowing can be incorporated into existing orchard inter row management and with basic monitoring and management will not lead to other problems. Furthermore, the challenges experienced at “Bundaberg Sugar” in terms of managing a mohawk have been invaluable in assisting the project team develop recommendations of alternate row mow as a good option for many macadamia orchards.

Findings in terms of the benefits of a mohawk for beneficial arthropods in the orchard at “Bundaberg Sugar” are unfortunately not observable. This is not an unusual outcome with field experiments where there are so many unpredictable and uncontrollable factors in play.

These results for “Bundaberg Sugar” are likely to be enhanced into the future with sustained commitment to insectaries throughout the orchard that are compatible with standard orchard operations, the inclusion of seeding options, and further refined strategies for reduced mowing including alternate row mowing.

The BioResources team encourages you to read the final report for the *Macadamia IPDM Program - Inter Row Project (MC16008)*, which is available via *Hort Innovation*. Here you will find out more on the benefits of insectaries for macadamia orchards and also the experiences of other trial farms in implementing and managing insectaries. There is also an exploration of the multiple ecosystem services known to flow from reduced mow inter row management practices along with improved arthropod biodiversity, including benefits for soil organic matter, nutrient cycling, water management, erosion control, weed suppression, soil carbon storage, soil microbiology and more.

Introduction

This project proposes that reduced mowing in the macadamia inter-row may increase vegetative diversity, increase floral resources, and reduce habitat disturbance. This may in turn increase the presence of beneficial arthropods in the orchard. More broadly, the proposed changes in plant ecology may increase arthropod populations in general, the over-whelming majority of which are non-economic and will be food for beneficial arthropods. Furthermore, this enhanced nutritional food-web will benefit birds and micro-bats, which have a role in pollination and pest suppression. Having a "food-web" within the orchard decreases the likelihood and/or intensity of pest outbreaks because populations of beneficial invertebrates are always present within the orchard.

These propositions warrant investigation because an increased presence of beneficial arthropods in the orchard may result in improved pest suppression and also improved pollination, via reduced crop damage, reduced inputs like chemical applications, and subsequently improved yields.

"Bundaberg Sugar" worked with the BioResources team in this investigation from early 2017 to mid 2019. We compared two 1 Ha blocks. A control block was managed as industry standard with regular mowing (**Photo 1**, below). A treatment block was managed with reduced mowing, with a centre mohawk where conditions permitted (**Photo 2**, below).

Photo 1: "Bundaberg Sugar" complete close mow 15 Dec 2017 ***Photo 2: "Bundaberg Sugar" mohawk 15 Dec 2017***

As you will recall, with each site visit the BioResources team sampled each block for arthropods in three separate rows using yellow stick traps (YSTs), placing one YST in the inter row and one YST in a tree. We assessed the vegetation in the inter row at those three points (a quadrant of approximately 10m x 20m). The three data collection points were at least 30m apart, and 50m from any block edge. We also spent time with you discussing the trial and any observations that you may have made in relation to rats, weeds, insect pests in the inter row vegetation and/or any challenges with reduced mowing.

The objective of the trial has been to provide growers with practical experience in reduced mowing on-farm with monitoring to quantify results.

BioResources first worked with growers to consider practical options for reduced mowing that are compatible with the seasonal demands of orchard management. It has then sought to provide information on any relationship between reduced mowing and the potential for increased rat, invasive weed, and/or arthropod pest presence. Finally, the trial has sought to monitor association between changes in inter-row vegetation management and changes in orchard beneficial/pest arthropod ecology.

Reduced mowing in the inter row at “Wiley”

Reduced mowing and potential problems

	Throughout the trial, BioResources regularly monitored for and consulted with Sue Wiley, on the following issues:
Rats	No issues were observed by the project team during site visits. No issues were reported by the “Bundaberg Sugar” team. It was noted that the existing rat management program would be sufficient to the task.
Problem weeds	No issues were observed by the project team during site visits. No issues were reported by the “Bundaberg Sugar” team. Rhodes grass presented some challenges within the context of the reduced mowing trial, but was this easily resolved with intermittent targeted seasonal slashing and high slashing.
Major insect pests of macadamias	No issues were observed by the project team during site visits. The team monitored vegetation in the inter row for the presence of major macadamia pests including Macadamia Nut Borer, Fruit Spotting Bug and Green Veggie Bug. Plant species typically found in the inter row trial blocks at “Bundaberg Sugar” were not observed to host these pests. No issues were reported by the “Bundaberg Sugar” team.
Management of the inter row	A number of management issues emerged throughout the life of the trial. Row width and machinery configuration were not compatible with a mohawk, especially during harvest. Rhodes grass in the mohawk caused problems for the harvester in particular.

Outcomes

The “Bundaberg Sugar” trial has provided a number of useful insights into the practicalities of reduced mow options in macadamia orchards, and especially the mohawk. Industry has been especially concerned that reduced mowing of the inter row may lead to significant problems with increased rat activity, invasive weeds and/or insect pests. Results on these issues for the “Bundaberg Sugar” trial give other growers reassurance that reduced mowing can be incorporated into existing orchard inter row management and with basic monitoring and management will not lead to other problems.

Some trial farms, including “Bundaberg Sugar”, found through time that maintaining a mohawk in the orchard in parallel with standard orchard operations was difficult. This was a result of a combination of row width, available machinery, and dominant plant species (especially Rhodes grass) and most especially a problem during harvest. This is an important finding, and as will be discussed below, the project team and some participating growers formed the opinion that alternate row mow outside of harvest may be a more suitable reduced mow strategy in such circumstances.

A number of issues in the trial blocks including difficulties with consistent scheduling of the mowing protocols and hot and dry conditions meant that an experimental distinction between the control block and the treatment mohawk block was not possible for the life of the project. More often than not, the vegetation on the two blocks was very similar. As a result, findings for your trial in terms of the benefits of a mohawk for beneficial insects in the orchard as compared to the complete close mow are unfortunately not observable. This is not an unusual outcome with field experiments where there are so many unpredictable and uncontrollable factors in play.

Photo 3: "Bundaberg Sugar" complete close mow 21 Feb 2018 ***Photo 4: "Bundaberg Sugar" mohawk 21 Feb 2018***

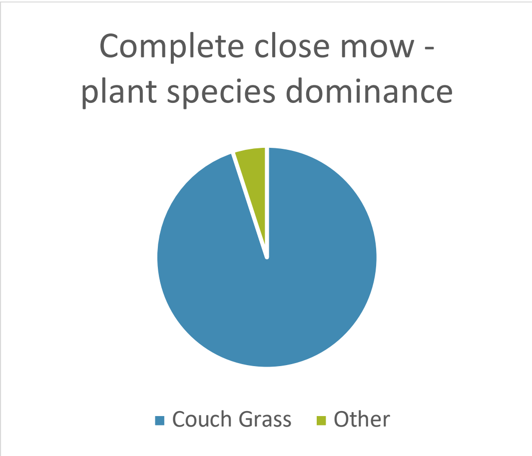
In so much as the potential for inter row insectaries in macadamia orchards is concerned, the BioResources team urges you to read the project's final report, *Macadamia IPDM Program - Inter Row Project (MC16008),* which will be available via *Hort Innovation*. A number of the project's other trial farms enjoyed more benign circumstances in their trial blocks, and the results there are very encouraging.

Results of reduced mowing in the inter row at Bundaberg Sugar

Vegetative diversity

Vegetative diversity refers to the number of plant species present. Changes to regular mowing can change plant species diversity. This can in turn be associated with diversity of arthropod species. **Charts 1 and 2** present data reflecting plant species observed in the inter row by treatment through time.

As you will know in relation to standard inter row management, mowing encourages dominance of couch grass. Baring this in mind, this project has purposefully trialled reduced mowing to investigate changes in plant species diversity. Couch grass (**Chart 1**) was, as expected, consistently the dominant species as total volume of biomass in the complete close mow block where there was more regular mowing.



The experimental method required recording of every plant species observed. Often however, many of these species were present at a low relative percentage and as small individual specimens.

We can say on balance, reduced mowing did increase plant species diversity somewhat in terms of the distribution of each plant species present as a proportion of biomass.

Chart 1: Plant species dominance as biomass

In **Chart 2** you can see that through time we were however unable to develop a strong experimental distinction between the two blocks in terms of number of plant species present in the inter row. There is no clear pattern of the number of plant species by treatment.

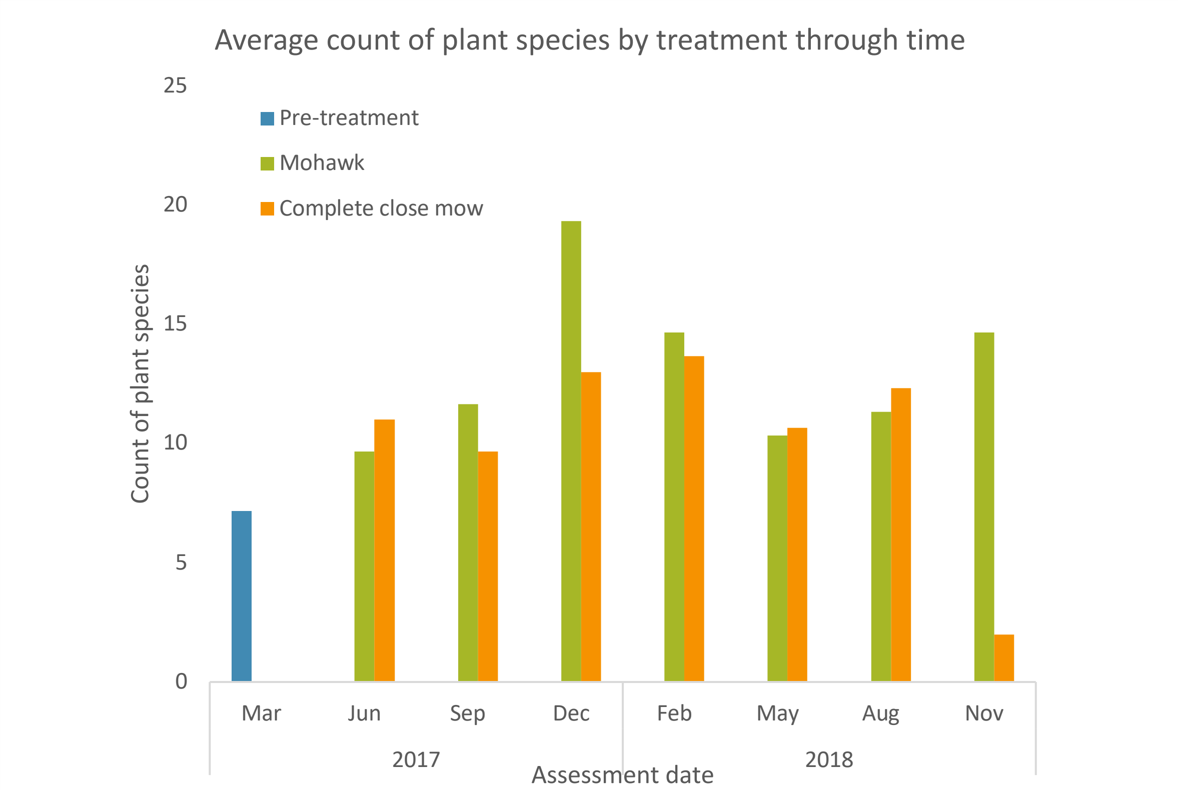


Chart 2: Average count of plant species by treatment through time. This is an average of counts taken at the three assessment points on each block.

Floral resources

Floral resources provide a food source for many beneficial arthropods and will encourage them to remain active in the orchard. In this trial we anticipated that reduced mowing would improve the availability of floral resources for beneficial arthropods.

Chart 3 provides an average count of the plant species flowering at the time of site visits. We can see that reduced mowing did encourage more flowering for most assessment dates. In **Chart 4**, we can see that the mohawk block also sustained a larger percentage of floral resources as a total percent of biomass for all counts. This result gives the strongest indication for this trial site of potential improvements to inter row vegetation possible with reduced mowing. This percentage was however typically at very low levels when compared to what was recorded for other trial sites where the reduced mowing was more consistently sustained.

As already noted, a number of unforeseen events interfered with the experimental protocols and we were unable to promote a mohawk and furthermore unable to achieve a clear and sustained distinction between the mohawk and complete close mow blocks. This accounts for the somewhat inconclusive results described here.

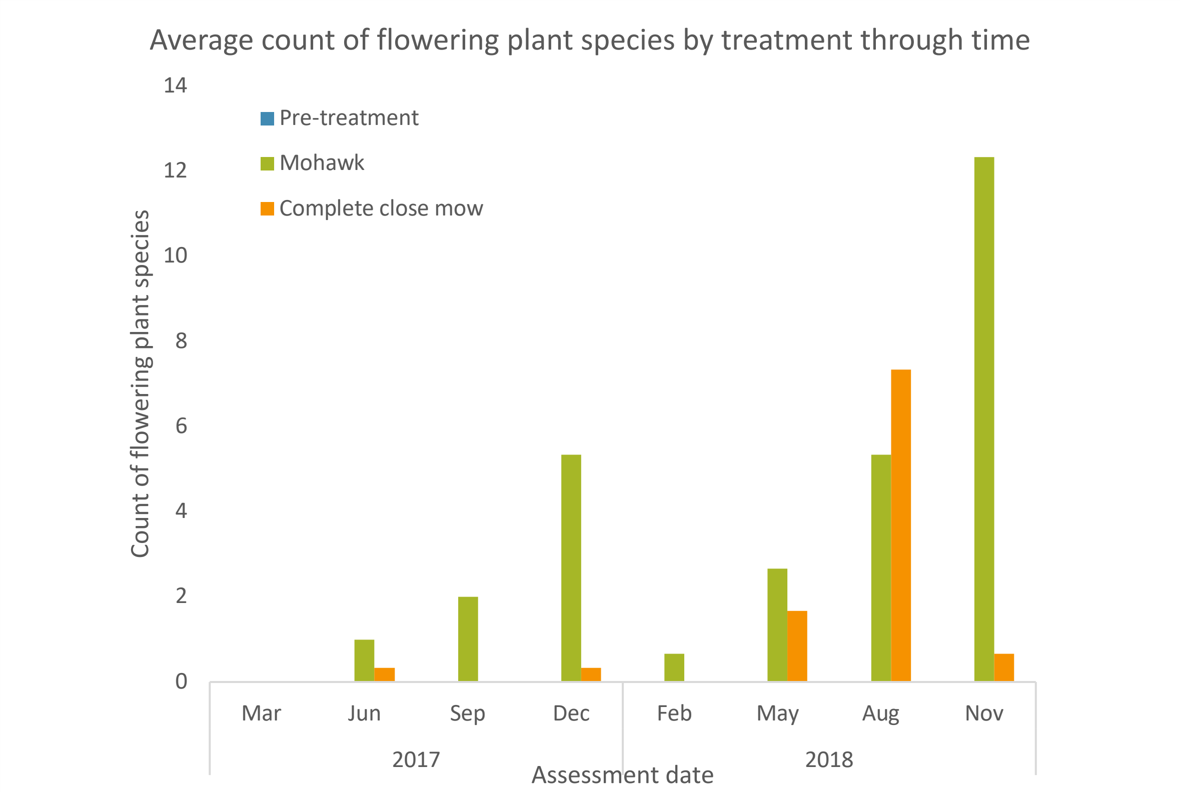


Chart 3: Average count of plant species with floral resources by treatment through time. This is an average of counts taken at the three assessment points on each block.

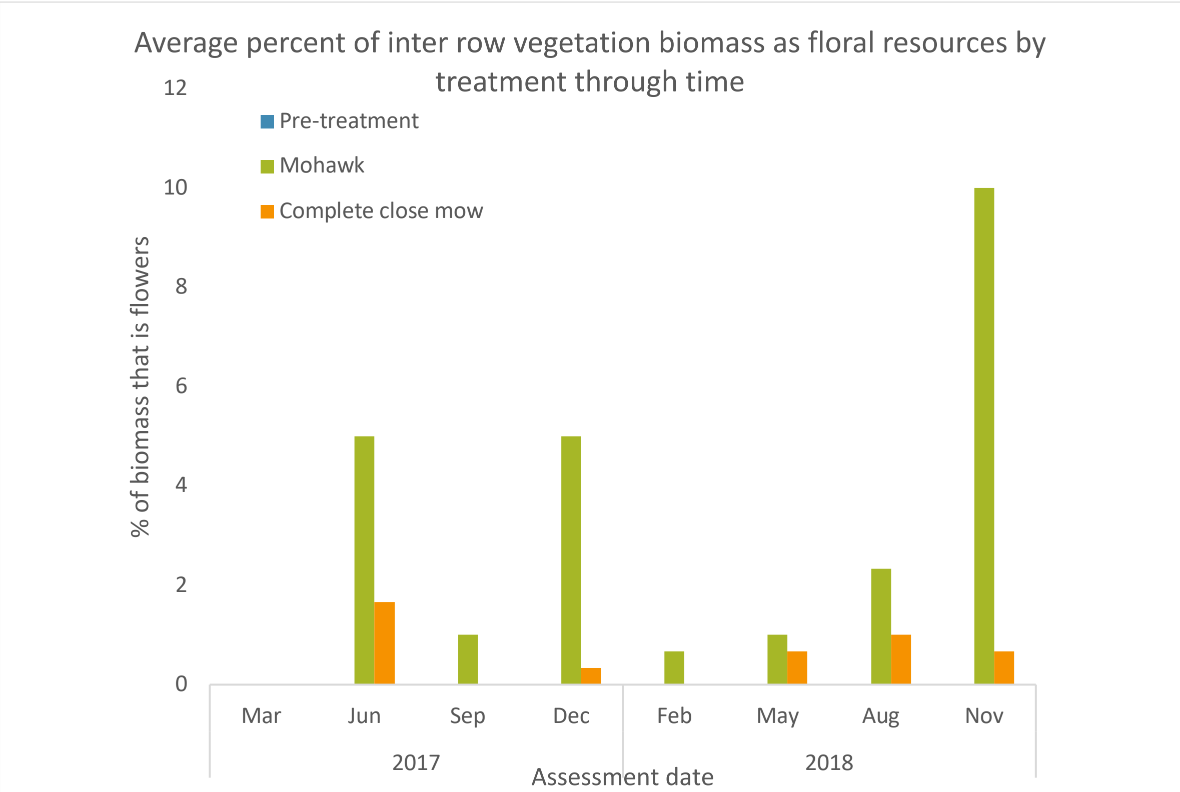


Chart 4: Average percentage of inter row vegetation biomass as floral resources by treatment through time. This is an average of counts taken at the three assessment points on each block.

Habitat disturbance

Areas of reduced mechanical and chemical disturbance can serve as favourable habitat for beneficial insects. Undisturbed areas may also provide a refuge for beneficial arthropods for faster recovery after spraying. The measurement of height provides a good indication of rates of mechanical disturbance. **Chart 5** reports the height in cm of vegetation in the inter row by treatment through time. Retention of a central mohawk on your farm allowed for greater height of vegetation, and hence less disturbance, in the inter row for the life of the trial. Again, while we can see greater height in the mohawk indicating reduced disturbance, this is at a much lower overall rate as compared to other trial sites.

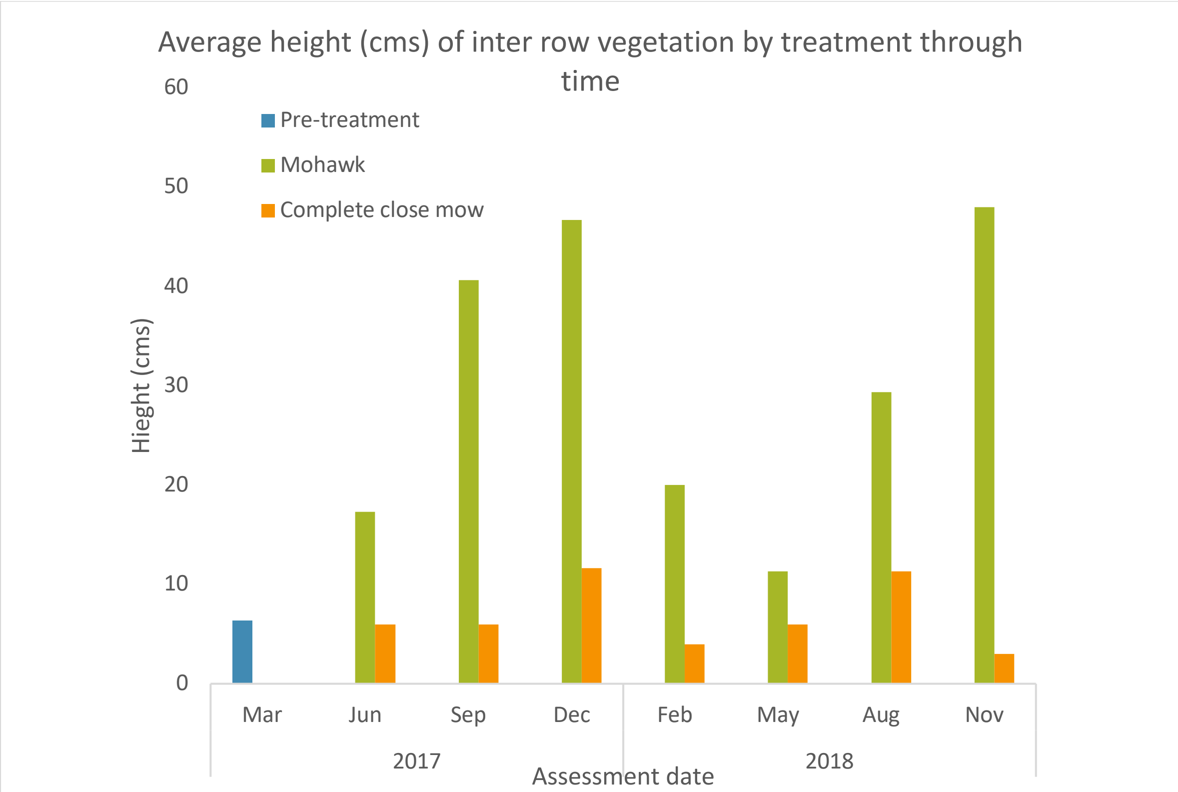


Chart 5: Average height (cm) of inter row vegetation by treatment through time. This is an average of counts taken at the three assessment points on each block.

Results of arthropod evaluation

General arthropod abundance

Charts 6 and 7 present the total numbers of individuals collected for several arthropod groups sampled during the project, comparing the mohawk with the complete close mow. We used yellow sticky traps (YSTs) to sample arthropods within both the inter row and trees. Like all sampling methods, YSTs have biases, which need to be taken into consideration. YSTs sample winged arthropods during flight (though non-winged arthropods do get caught occasionally). Their colour, yellow, is particularly attractive to parasitoids, flies and thrips, which were very well sampled during this project. The abundance data presented below shows only the winged arthropod groups, robber flies, lacewings, aphids, whiteflies, beetles, hemiptera (sap suckers excluding aphids and scale), pollinators (flies), parasitoids and thrips. Other important arthropod groups, such as spiders and ants were not well sampled using YSTs and are omitted from **Charts 6 and 7**.

Thrips, parasitoids, pollinators (flies) and hemiptera (sap suckers excluding aphids and scale) were the most abundant arthropod groups sampled during this trial. Within both the inter row and trees, thrips were sampled in greatest abundance (**Charts 6 and 7**). The only distinct treatment difference is seen for thrips, where as a sum total, more were sampled in the mohawk block for both inter row and trees (**Charts 6 and 7**).

After looking at **Charts 6 and 7** it is important to then look at any treatment differences in more depth by analysing patterns over the entire sampling period. The following sections will take a focussed look at thrips, parasitoids, and pollinators.

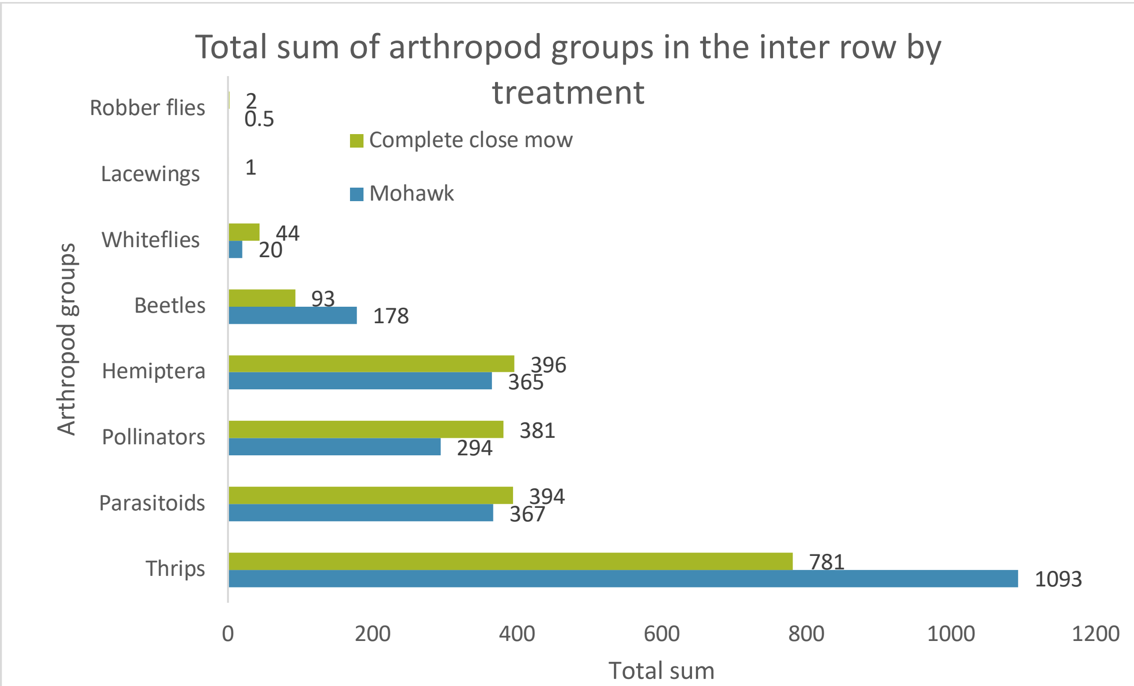


Chart 6: Arthropod abundance: average count by group by treatment through time – sampled in the inter row. This is an average of counts taken at the three assessment points on each block.

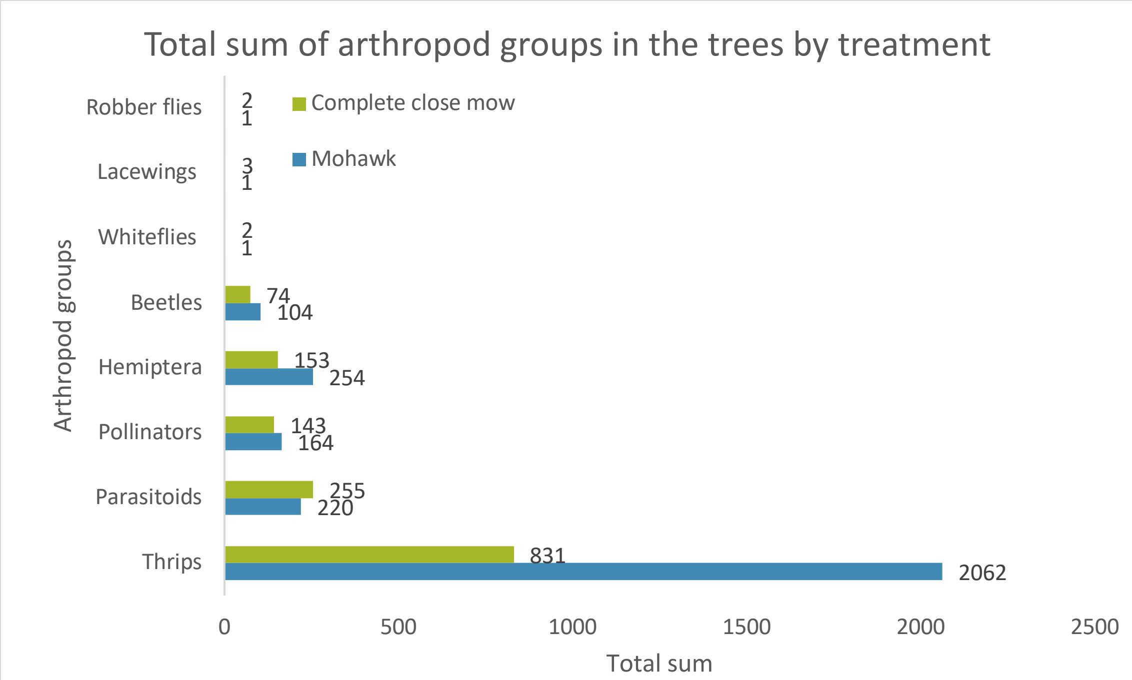


Chart 7: Arthropod abundance: average count by group by treatment through time – sampled in the tree. This is an average of counts taken at the three assessment points on each block.

A focussed look at thrips

Thrips are broadly categorised as 'herbivores' because the majority feed on the outer layer of plant cells, but most thrips also feed on pollen, and help in plant pollination. Other groups of thrips feed on fungal spores and some are predatory and important in biological control.

In a broader context, thrips play an important part within the food web because they are abundant, soft-bodied and are small and palatable, so many predatory insects eat them. Thrips only reach pest status within macadamias when populations are high and the crop itself is at a vulnerable stage i.e. flowering or leaf flush.

Within **Charts 8 and 9** you will see that thrips have been sampled in high numbers from the inter row and tree during two particular sampling months, September 2017 and November 2018. Within the inter row, the two dates with high thrip numbers show opposite trends in terms of treatment differences (**Chart 8**), which indicates that there was not a consistent and clear distinction between the mohawk inter rows and the complete close mow inter rows. Within the trees, the mohawk block has significantly higher numbers of thrips on those two dates (**Chart 9**) and this could represent differences between the tree foliage on these two dates, or that thrips are moving from the inter row into the tree, particularly in November 2018 where the treatment difference is large.

Whilst these high thrip numbers seen within the inter row may look like cause for concern, the inter row can potentially play an important part in ensuring there is always food for beneficial invertebrates, so that pest outbreaks are less likely to happen within the tree. As discussed in the **Introduction**, a healthy ecosystem within the inter row depends on the correct mix of plant species and the right balance between minimal disturbance and necessary management.

Standard on-farm monitoring of macadamia pests including thrips was discussed during site visits. Concerns for problematic numbers of thrips in the trial blocks were not raised at any point.

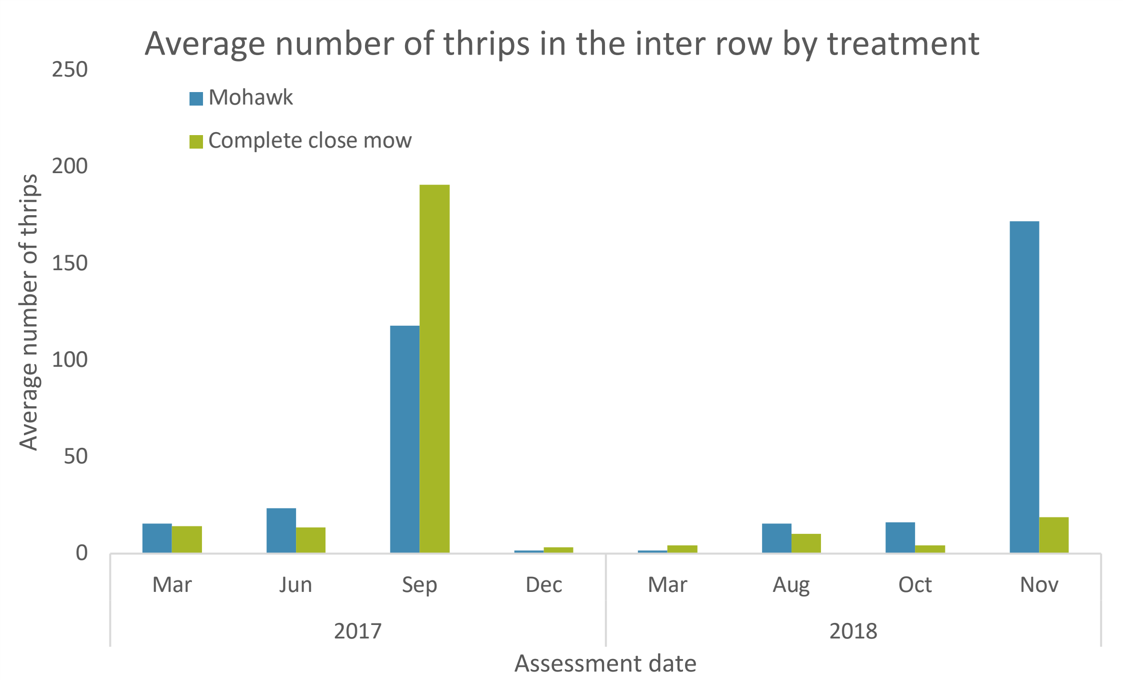


Chart 8: Average number of thrips by treatment through time – sampled in the inter row. This is an average number taken from the three assessment points on each block.

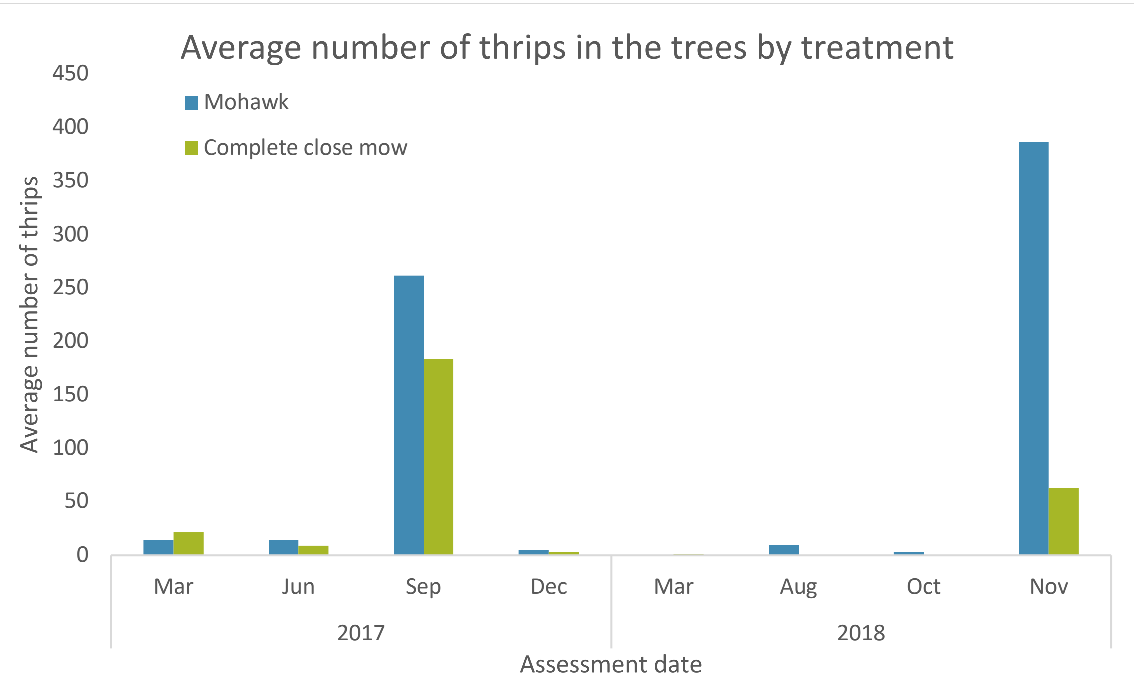


Chart 9: Average number of thrips by treatment through time – sampled in the tree. This is an average number taken from the three assessment points on each block.

A focussed look at parasitoids

Parasitoids were representatively sampled by the YST catches, thus providing a meaningful indication of how the inter row treatments affect this important group of beneficial invertebrates. This sample includes MacTrix and Anastatus releases along with other hymenoptera already present in the orchard environment.

Within the inter row, there was no clear and consistent difference between treatments in terms of parasitoid abundance (**Chart 10**). There are a few dates where there are modest treatment differences (but no consistent trend showing preference for one treatment over another). This is difficult to explain and likely reflects biocontrol releases and also any slight difference in the inter row vegetation between treatments. Any reduction in mowing/disturbance in the inter row and hence better provision of nectar sources and hosts (other invertebrates to parasitise) will favour parasitoid populations.

Within the trees, parasitoids were sampled in similar (slightly lower) numbers to the inter row (check y-axis when comparing **Charts 10 and 11**). During 2018, there were less parasitoids sampled from trees compared to 2017 (**Chart 11**), which may reflect hotter/drier weather conditions experienced in 2018.

Overall these inconsistent results are multifactorial: biocontrol releases, bigger environmental extremes and the mixed fortunes of the mowing protocols were more influential than our experiment in reduced mowing. We would like to highlight that other farms able to sustain a mohawk had substantially more parasitoids sampled from the mohawk block and in the mohawk inter row as compared to the trees.

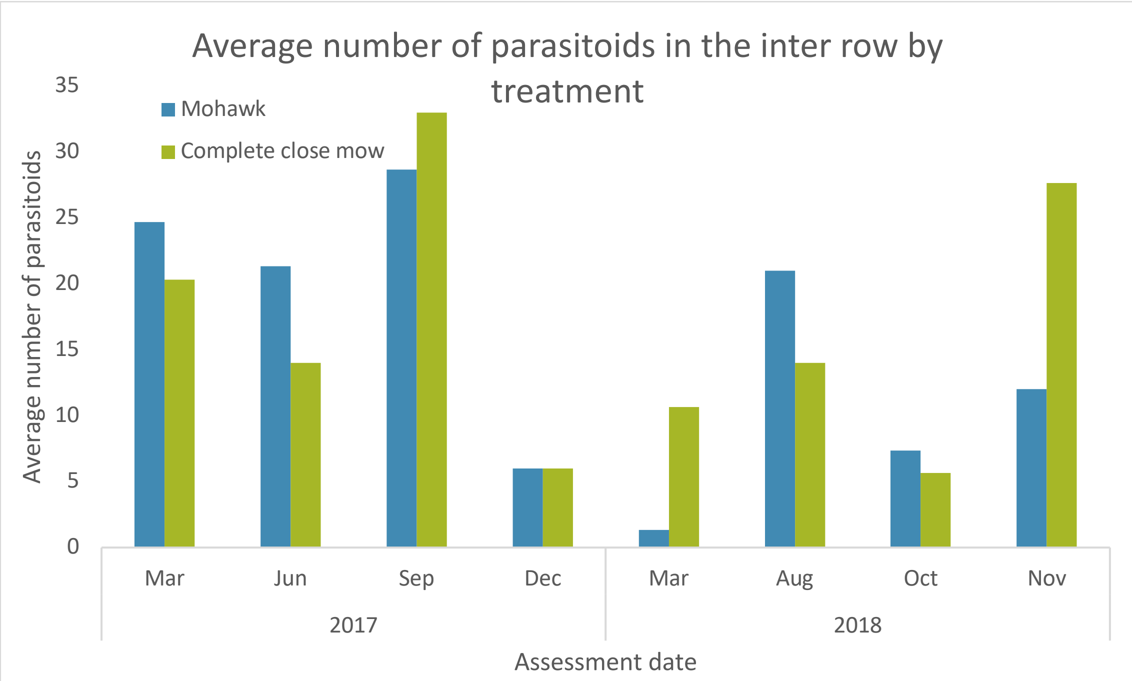


Chart 10: Average number of parasitoids by treatment through time – sampled in the inter row. This is an average number taken from the three assessment points on each block.

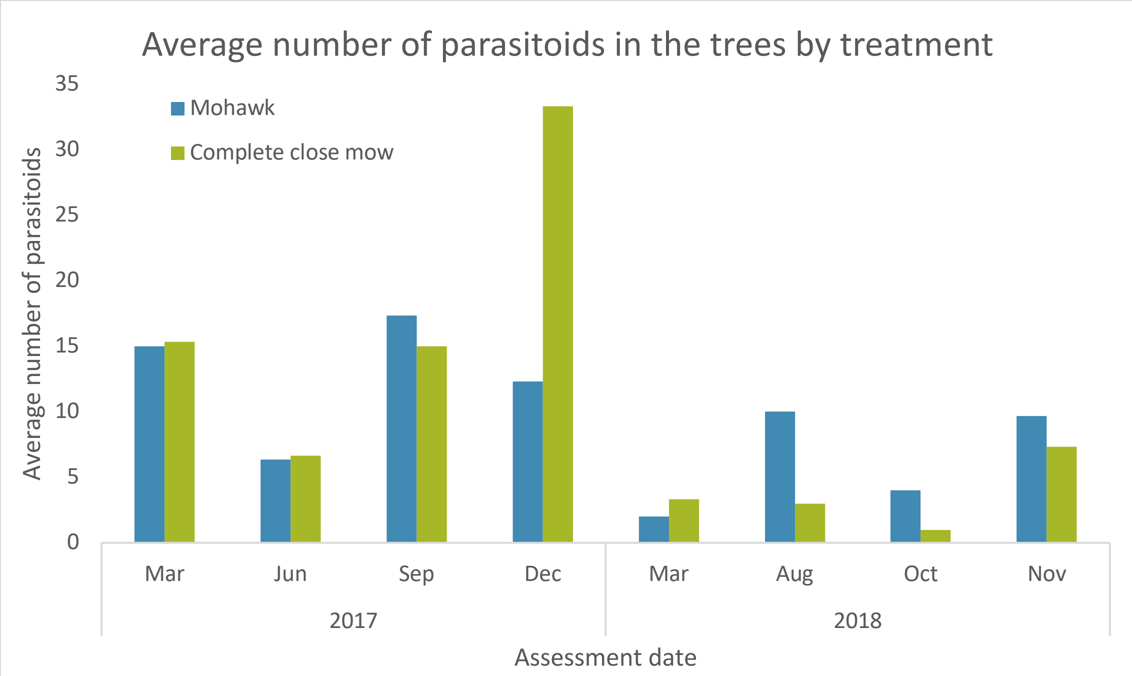


Chart 11: Average number of parasitoids by treatment through time – sampled in the tree. This is an average number taken from the three assessment points on each block.

A focussed look at pollinators

As seen in **Charts 6 and 7,** pollinators were one of the most abundant arthropod groups sampled by YSTs in both inter rows and trees in this trial, with roughly similar numbers to parasitoids. Pollinators are arthropods which carry pollen from one plant to another, and these are predominantly bees, moths and butterflies, and a substantial proportion of beetles and flies. YSTs do not sample bees, beetles, moths or butterflies particularly well, but flies are well sampled by YSTs so our term 'pollinators' encapsulates only flies. Flies are also an important food source for predatory insects such as spiders.

Within both inter row and trees, there was no clear and consistent difference between treatments in terms of pollinator abundance (**Charts 12 and 13**). Relatively low fly (pollinator) numbers indicate that floral resources were scarce and/or often disturbed within the inter row.

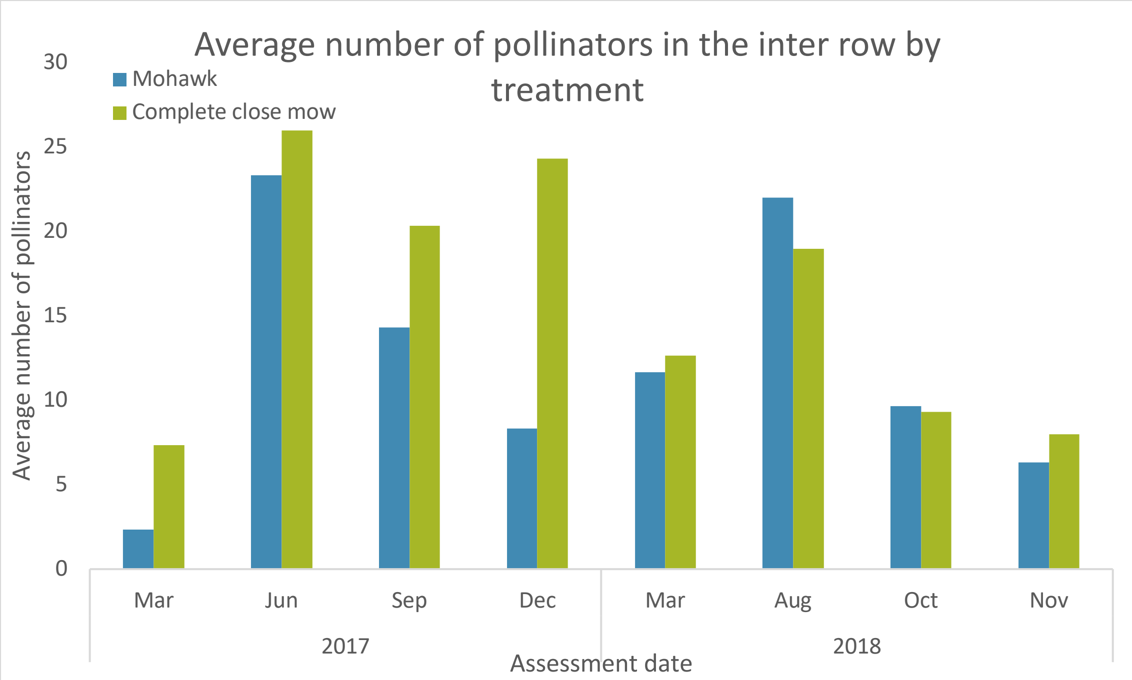


Chart 12: Average number of pollinators by treatment through time – sampled in the inter row. This is an average number taken from the three assessment points on each block.

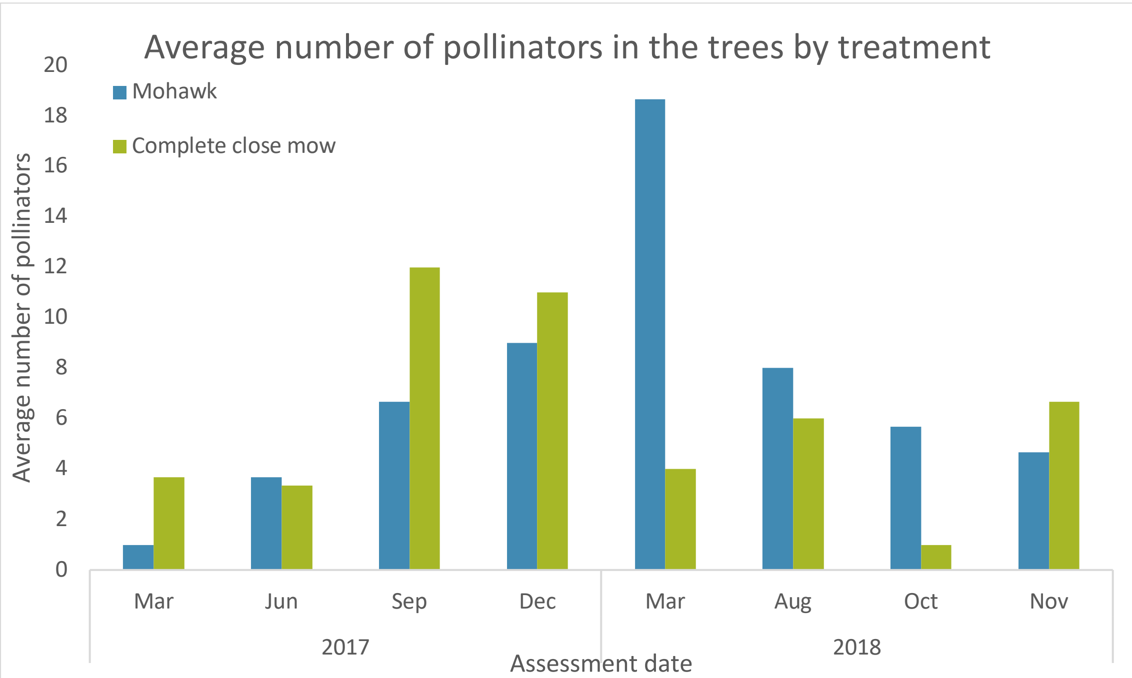


Chart 13: Average number of pollinators by treatment through time – sampled in the tree. This is an average number taken from the three assessment points on each block.

Findings and recommendations

Mohawk-style reduced mowing did not work as well at "Bundaberg Sugar" as it did on some other farms. This was a common problem where row width was less than 10m. Retaining a mohawk year-round at "Bundaberg Sugar" proved to be difficult at times, and impossible during harvest. This difficulty was compounded by Rhodes grass becoming ropey when left un-mown and then tangling in the finger-wheel tracks of the harvester. By documenting these challenges, we can nonetheless provide industry with useful recommendations on orchards most suited (or otherwise) to mohawk reduced mowing.

It is worth noting that findings from other trial farms and other industries indicate that alternate row mow may be a better management option than the mohawk for many growers outside of harvest. This involves mowing every second row on a rotating schedule, allowing all rows to "grow out" somewhat across the year but providing opportunities for mow management as required. This reduces the overall disturbance of beneficial arthropods, ensuring a refuge remains in place at all times for them.

Options for increasing the plant species diversity for insectaries at "Bundaberg Sugar" were discussed, as follows:

- Proven, very hardy and observed in your region and soils - lotononis, Wynn cassia, seradella, creeping vigna,
- With a bit of winter rain these should establish and perform very well - sunflower, sunn hemp, millet,
- Worth experimenting with as they have very good field insectary characteristics - buckwheat, vetch, tillage radish, chicory.

There is strong interest in the broader industry for seeding of the inter row and cover cropping and an extensive range of seed options is emerging.

Findings from other farms where unexpected events were not as impactful on the experiment for the life of the trial as they were at "Bundaberg Sugar" indicate that insectaries have meaningful influence on orchard ecology when growers can commit to inclusion of the insectary in the orchard in terms of space allocation and long-term management. At "Bundaberg Sugar" the inter row mohawk did not work very well given row width. Alternate row mow as a better option is discussed above. And there are other areas on-farm worth considering, including headlands, field margins and so on where changes to management can allow for habitat suitable for beneficial insects. Decisions to improve plant diversity with selective seeding, well-timed seeding and mowing to limit dominance of one species while encouraging new growth and flowering and so on are very influential.

Finally, the BioResources team encourages you to read the final report for the *Macadamia IPDM Program - Inter Row Project (MC16008)*, which is available via *Hort Innovation*. Here you will find out more on the benefits of insectaries for macadamia orchards and also the experiences of other trial farms in implementing and managing insectaries. There is also an exploration of the multiple ecosystem services known to flow from changed inter row management practices along with improved arthropod biodiversity, including benefits for soil organic matter, nutrient cycling, water management, erosion control, weed suppression, soil carbon storage, soil microbiology and more.

Acknowledgements and thanks

The project team wishes to thank the “Bundaberg Sugar” ownership and management team for their participation, and particularly Sean Cox and Wayne Donald for their contributions and support.

Final Report

“Elanora” – Macadamia Inter Row Trial Results

Hort Innovation program title: The IPM program for the macadamia industry – BioResources

Hort Innovation project code: MC16008

Date: February 2020

Summary

This project proposes that reduced mowing in the macadamia inter row may improve vegetation there for the purposes of an insectary. Where managed reduced mowing is possible, it is further proposed that beneficial arthropods crucial to pollination, pest suppression and the “food-web” will be present and active in higher numbers. This can decrease the likelihood and/or intensity of pest outbreaks because populations of beneficial invertebrates are always present within the orchard.

“Elanora” worked with the BioResources team to investigate these ideas from early 2017 to mid 2019.

The reduced mowing trial hosted by “Elanora” has provided several useful insights into the practicalities of reduced mow options in macadamia orchards, and especially the mohawk. Industry has been particularly concerned that reduced mowing of the inter row may lead to significant problems such as increased rat activity, invasive weeds and/or increased insect pests. The trial at “Elanora” gives other growers reassurance that a mohawk can be incorporated into existing orchard inter row management and with basic monitoring and management will not lead to other problems.

Findings in terms of the benefits of a mohawk for beneficial arthropods in the orchard at “Elanora” are observable but modest. This is not an unusual outcome with field experiments where there are so many unpredictable and uncontrollable factors in play.

These results for “Elanora” are likely to be enhanced into the future with sustained commitment to insectaries throughout the orchard that are compatible with standard orchard operations, the inclusion of seeding options, and further refined strategies for reduced mowing including alternate row mowing.

The BioResources team encourages you to read the final report for the *Macadamia IPDM Program - Inter Row Project (MC16008)*, which is available via *Hort Innovation*. Here you will find out more on the benefits of insectaries for macadamia orchards and also the experiences of other trial farms in implementing and managing insectaries. There is also an exploration of the multiple ecosystem services known to flow from reduced mow inter row management practices along with improved arthropod biodiversity, including benefits for soil organic matter, nutrient cycling, water management, erosion control, weed suppression, soil carbon storage, soil microbiology and more.

Introduction

This project proposes that reduced mowing in the macadamia inter row may increase vegetative diversity, increase floral resources, and reduce habitat disturbance. This may in turn increase the presence of beneficial arthropods in the orchard. More broadly, the proposed changes in plant ecology may increase arthropod populations in general, the over-whelming majority of which are non-economic and will be food for beneficial arthropods. Furthermore, this enhanced nutritional food-web will benefit birds and micro-bats, which have a role in pollination and pest suppression. Having a "food-web" within the orchard decreases the likelihood and/or intensity of pest outbreaks because populations of beneficial invertebrates are always present within the orchard.

These propositions warrant investigation because an increased presence of beneficial arthropods in the orchard may result in improved pest suppression and also improved pollination, via reduced crop damage, reduced inputs like chemical applications, and subsequently improved yields.

"Elanora" worked with the BioResources team in this investigation from early 2017 to mid 2019. We compared two 1 Ha blocks. A control block was managed as industry standard with regular mowing (**Photo 1**, below). A treatment block was managed with reduced mowing, sustaining a centre mohawk for most of the trial period (**Photo 2**, below).

Photo 1: "Elanora" complete close mow 7 July 2017

Photo 2: "Elanora" mohawk 7 July 2017

As you will recall, with each site visit the BioResources team sampled each block for arthropods in three separate rows using yellow stick traps (YSTs), placing one YST in the inter row and one YST in a tree. We assessed the vegetation in the inter row at those three points (a quadrant of approximately 10m x 20m). The three data collection points were at least 30m apart, and 50m from any block edge. We also spent time with you discussing the trial and any observations that you may have made in relation to rats, weeds, insect pests in the inter row vegetation and/or any challenges with reduced mowing.

The objective of the trial has been to provide growers with on-farm practical experience in reduced mowing complimented by vegetative and invertebrate monitoring to quantify results.

BioResources first worked with growers to consider practical options for reduced mowing that are compatible with the seasonal demands of orchard management. It has then sought to provide information on any relationship between reduced mowing and the potential for increased rat, invasive weed, and/or arthropod pest presence. Finally, the trial has sought to monitor association between changes in inter row vegetation management and changes in orchard beneficial/pest arthropod ecology.

Reduced mowing in the inter row at "Elanora"

Reduced mowing trial and potential problems

	Throughout the trial, BioResources regularly monitored for and consulted with Tod, on the following issues:
Rats	No issues were observed by the project team during site visits. Rats were a pre-existing concern for the "Elanora" team and an especially significant issue in the two trial blocks prior to commencement of the trial. The "Elanora" team reported that rats in this area had been "severe" for the past 13 years and an ongoing management program was in place. The "Elanora" team undertook to carefully monitor potential movement of rats from existing and known areas under trees and out into the mohawk area. The "Elanora" team reported that mohawks had been kept in these blocks in previous years, but these were removed as part of the rat management program. At the conclusion of the trial the "Elanora" team reported that rats were not the problem that had been anticipated. It was suggested that drier conditions and intermittent management of the mohawk may have kept their numbers low. At no point in the life of the trial did you report movement of rats from known problem areas into the mohawk.
Problem weeds	Minor issues were observed by the project team during site visits in terms of increasing dominance by Setaria grass, which became heavy and clumping in the absence of mowing. Minor issues were reported by the "Elanora" team in terms of dominance by Setaria grass. This was managed with intermittent slashing and spot herbicide spraying, as required.
Major insect pests of macadamias	No issues were observed by the project team during site visits. The team monitored vegetation in the inter row for the presence of major macadamia pests including Macadamia Nut Borer, Fruit Spotting Bug and Green Veggie Bug. Plant species typically found in the inter row trial blocks at "Elanora" were not observed to host these pests. No issues were reported by the "Elanora" team.
Management of the inter row	No major issues were observed by the project team during site visits. It was observed that in instances of "high mowing" a good result was achieved in encouraging flowering of plants species. Minor modifications were implemented by the "Elanora" team in terms of tailoring the mohawk to suit farm operations. The width of the mohawk was reduced during harvest; it was intermittently slashed to remove Setaria. The machinery options available for slashing and harvesting suited straightforward inclusion of a mohawk in the trial block year-round.

Outcomes

The reduced mowing trial hosted by “Elanora” has provided several useful insights into the practicalities of reduced mow options in macadamia orchards, and especially the mohawk. Industry has been particularly concerned that reduced mowing of the inter row may lead to significant problems such as increased rat activity, invasive weeds and/or increased insect pests. The trial at “Elanora” gives other growers reassurance that a mohawk can be incorporated into existing orchard inter row management and with basic monitoring and management will not lead to other problems.

The trial, which compared a complete close mow block with a mohawk block at “Elanora” was adversely impacted by the dry seasons of 2018 and 2019 and there were some issues with Setaria grass dominating the mohawk, which required mowing. These conditions limited the mohawk and as a result a strong experimental distinction between the control block (**Photo 3,** below) and the treatment mohawk block (**Photo 4**, below) was not consistently possible for the life of the project.

Thus, findings in terms of the benefits of a mohawk for beneficial arthropods in the orchard at “Elanora” are observable but modest. This is not an unusual outcome with field experiments where there are so many unpredictable and uncontrollable factors in play.

In so much as the potential for inter row insectaries in macadamia orchards is concerned, the BioResources team urges you to read the project’s final report, *Macadamia IPDM Program - Inter Row Project (MC16008),* which will be available via *Hort Innovation*. A number of the project’s other trial farms enjoyed more experimentally robust circumstances in their trial blocks, and the results there are very encouraging.

Photo 3: “Elanora” complete close mow 3 October 2018

Photo 4: “Elanora” mohawk 3 October 2018

Results of reduced mowing in the inter row at "Elanora"

Vegetative diversity

Vegetative diversity refers to the number of plant species present. Changes to regular mowing can change plant species diversity. This can in turn be associated with diversity of arthropod species. **Chart 1** presents an average count of plant species observed in the inter row by treatment through time. We can see that the mohawk consistently supported a higher number of plant species through time. It should be noted however that the complete close mow block nonetheless also supported a high number of species in experimental terms, where ideally, we were looking for a very low number of plant species in a range of one to three species.

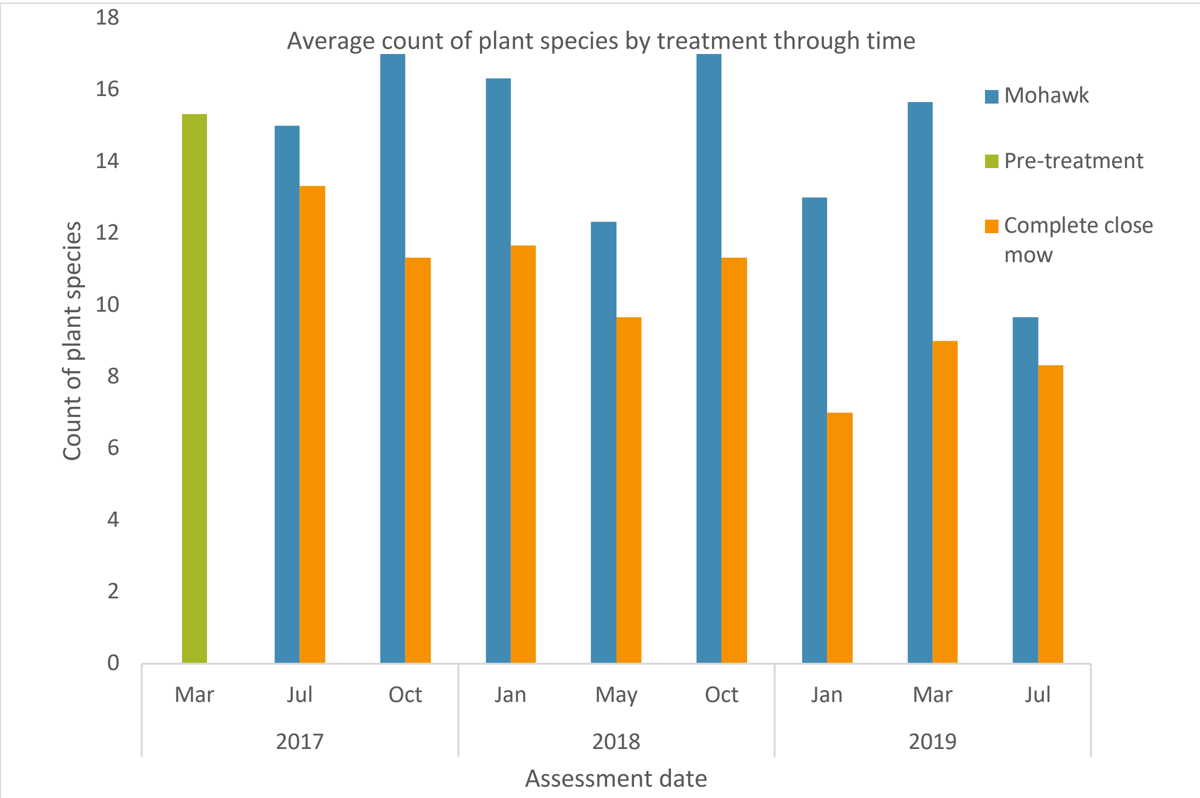


Chart 1: Average count of plant species by treatment through time. This is an average of counts taken at the three assessment points on each block.

Floral resources

Floral resources provide a food source for many beneficial arthropods and will encourage them to remain active in the orchard. **Chart 2** provides an average count of the plant species flowering at the time of the site visit. The presence of floral resources in the trial at "Elanora" was somewhat limited. This was a result of the dry conditions and also the overall plant species mix, which was often dominated by Setaria grass. But we can see that when flowers were present in the orchard, they were more likely to be in the mohawk.

In **Chart 3**, we can see that the mohawk block sustained a larger percentage of floral resources for all assessment dates.

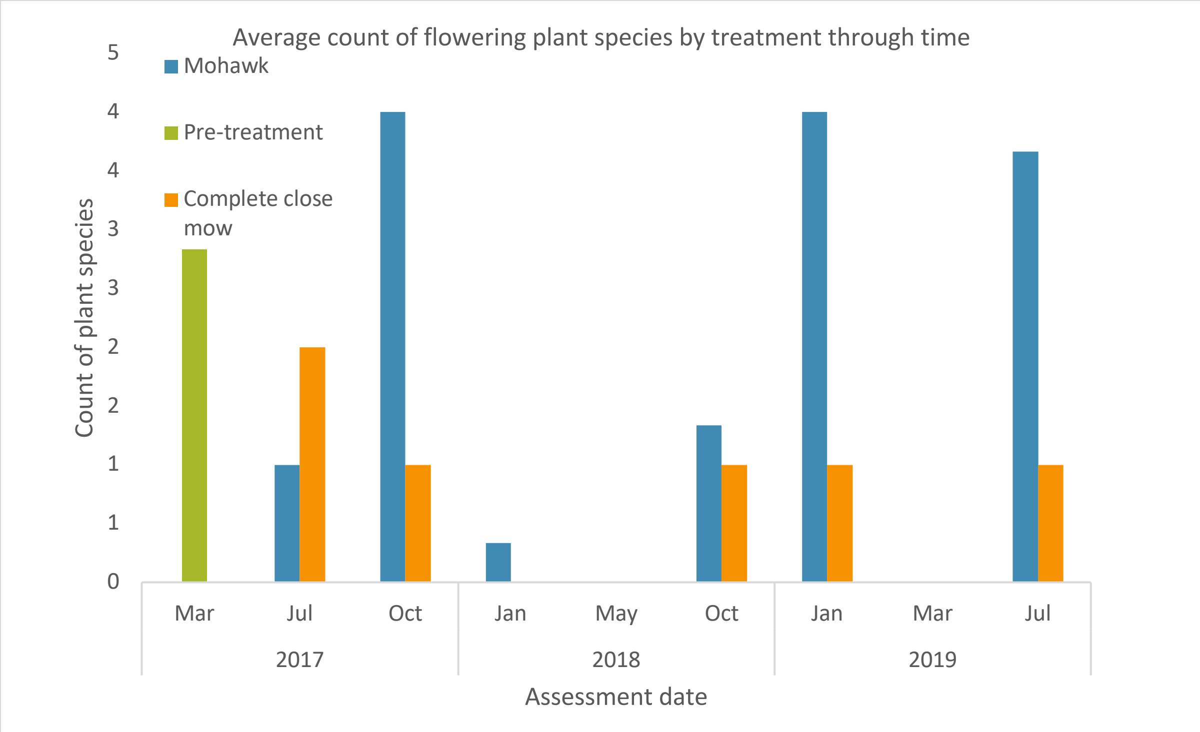


Chart 2: Average count of plant species with floral resources by treatment through time. This is an average of counts taken at the three assessment points on each block.

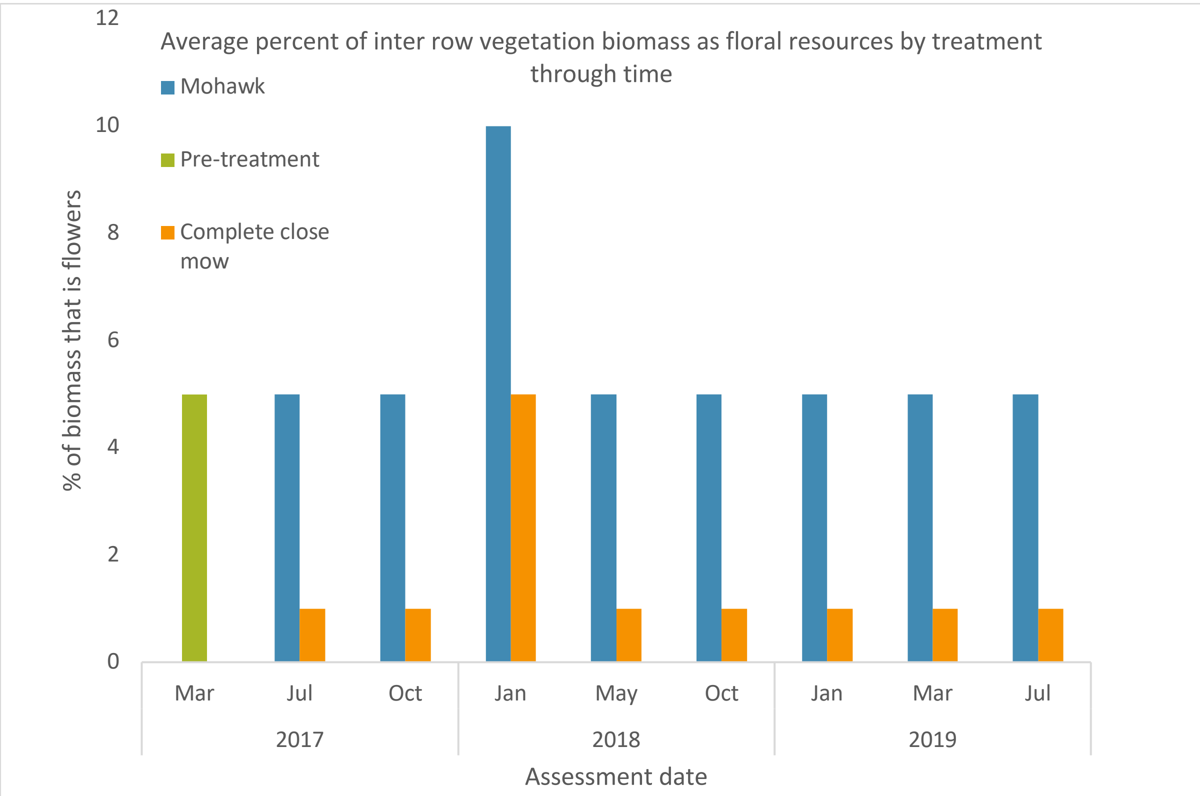


Chart 3: Average percentage of inter row vegetation biomass as floral resources by treatment through time. This is an average of counts taken at the three assessment points on each block.

Habitat disturbance

Areas of reduced mechanical and chemical disturbance can serve as favourable habitat for beneficial insects. Undisturbed areas may also provide a refuge for beneficial arthropods for faster recovery after spraying. The measurement of plant height provides a good indication of rates of mechanical disturbance. **Chart 4** reports the average height in centimetres (cm) of vegetation in the inter row by treatment through time. Retention of a central mohawk at "Elanora" allowed for greater height of vegetation and hence less disturbance in the inter row for the life of the trial.

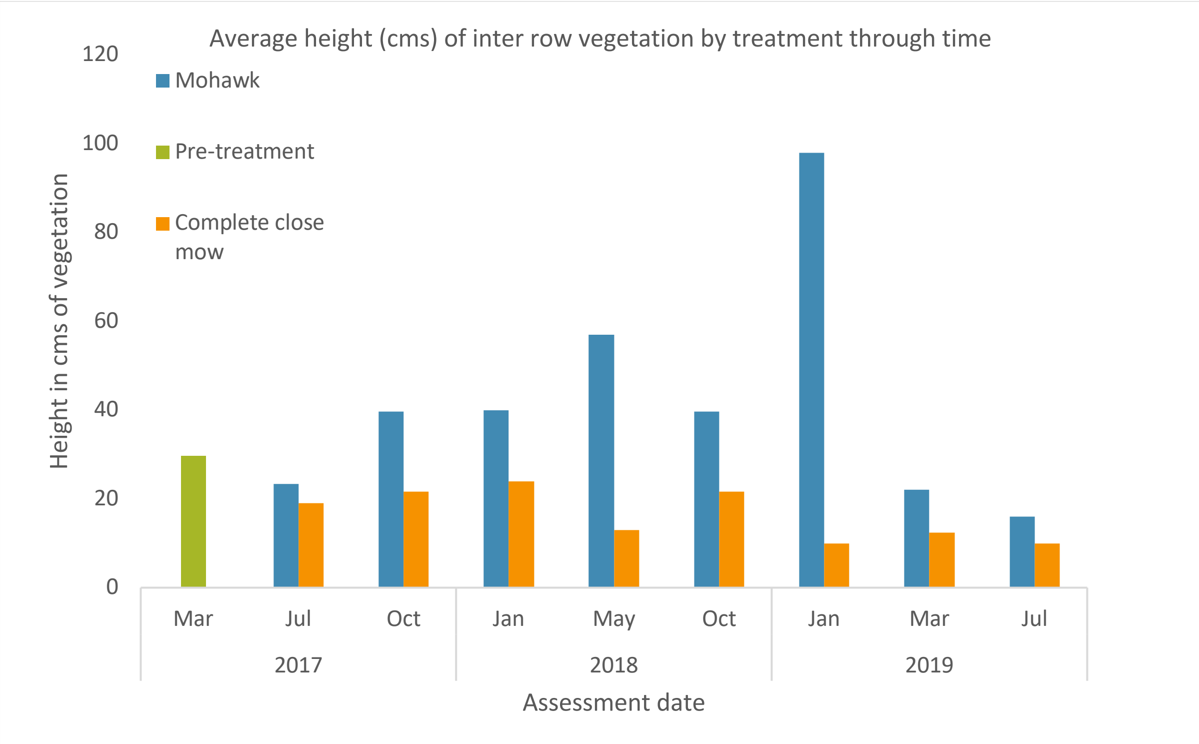


Chart 4: Average height (cm) of inter row vegetation by treatment through time. This is an average of counts taken at the three assessment points on each block.

Photo 5: Lady beetle on Setaria flower "Elanora" 10 May 2018

While Setaria grass became unfavourably dominant at times, intermittent mowing did allow it to flower in the mohawk at "Elanora", providing food and habitat for many beneficial arthropods including lady beetles (**Photo 5**).

Reduced disturbance allowed the lady beetle to complete its lifecycle.

Lady beetle larvae are voracious predators of macadamia pests including mites and aphids.

Results of arthropod evaluation

General arthropod abundance

Charts 5 and 6 present the total numbers of individuals collected for several arthropod groups sampled during the project, comparing the mohawk with the complete close mow. We used yellow sticky traps (YSTs) to sample arthropods within both the inter row and trees. Like all sampling methods, YSTs have biases, which need to be taken into consideration. YSTs sample winged arthropods during flight (though non-winged arthropods do get caught occasionally). Their colour, yellow, is particularly attractive to parasitoids, flies and thrips, which were very well sampled during this project. The abundance data presented below shows only the winged arthropod groups, robber flies, lacewings, aphids, whiteflies, beetles, hemiptera (sap suckers excluding aphids), pollinators (flies), parasitoids and thrips. Other important arthropod groups, such as spiders and ants were not well sampled using YSTs and are omitted from **Charts 5 and 6**.

Parasitoids, flies (pollinators) and thrips were the most abundant arthropod groups sampled during this trial on your farm. Within the inter row, thrips and pollinators were in greatest abundance (**Chart 5**), whilst in the trees there were far more parasitoids and pollinators than there were thrips (**Chart 6**). Treatment differences were seen in both the inter row and tree between the most abundant arthropod groups. There were significantly more thrips sampled from inter rows within the complete close mow block compared to the mohawk block (**Chart 5**). From the tree, significantly more parasitoids and pollinators were sampled from the mohawk block compared to the complete close mow block (**Chart 6**).

From this we can see that the most striking results indicate that pollinators and parasitoids are much more active in the trees of the mohawk block.

After looking at **Charts 5** and **6** it is important to then look at any treatment differences in more depth by analysing patterns over the entire sampling period. The following sections will take a focussed look at thrips, parasitoids and pollinators.

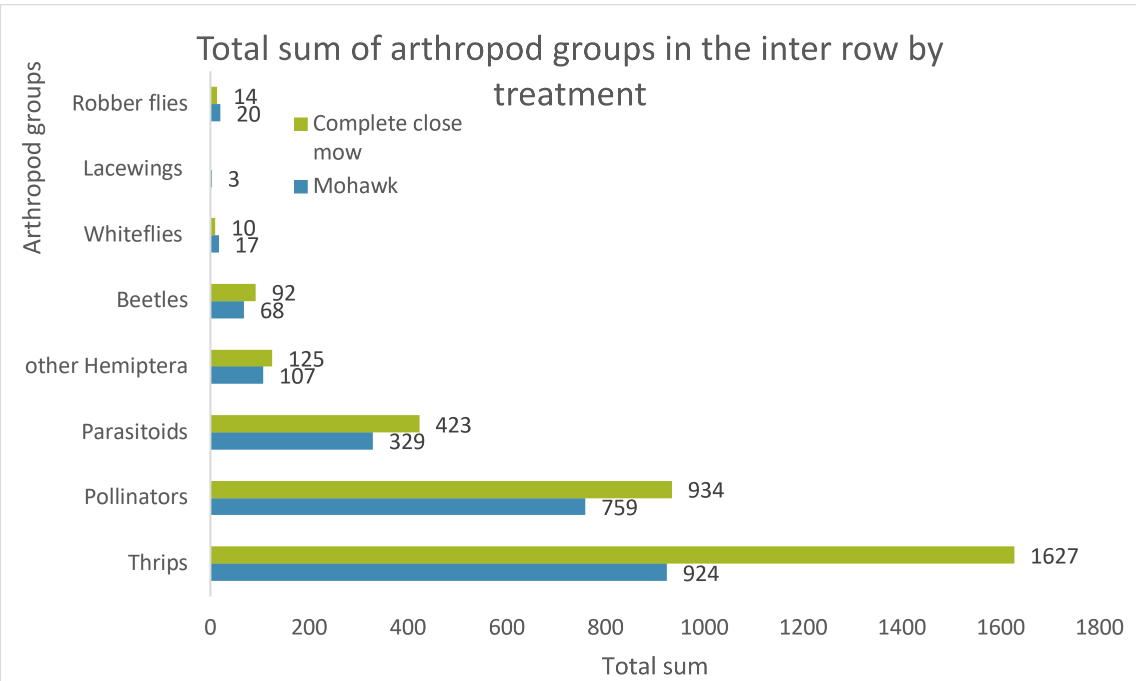


Chart 5: Total sum of each arthropod group within the inter row, compared between the two treatments, over the sampling period.

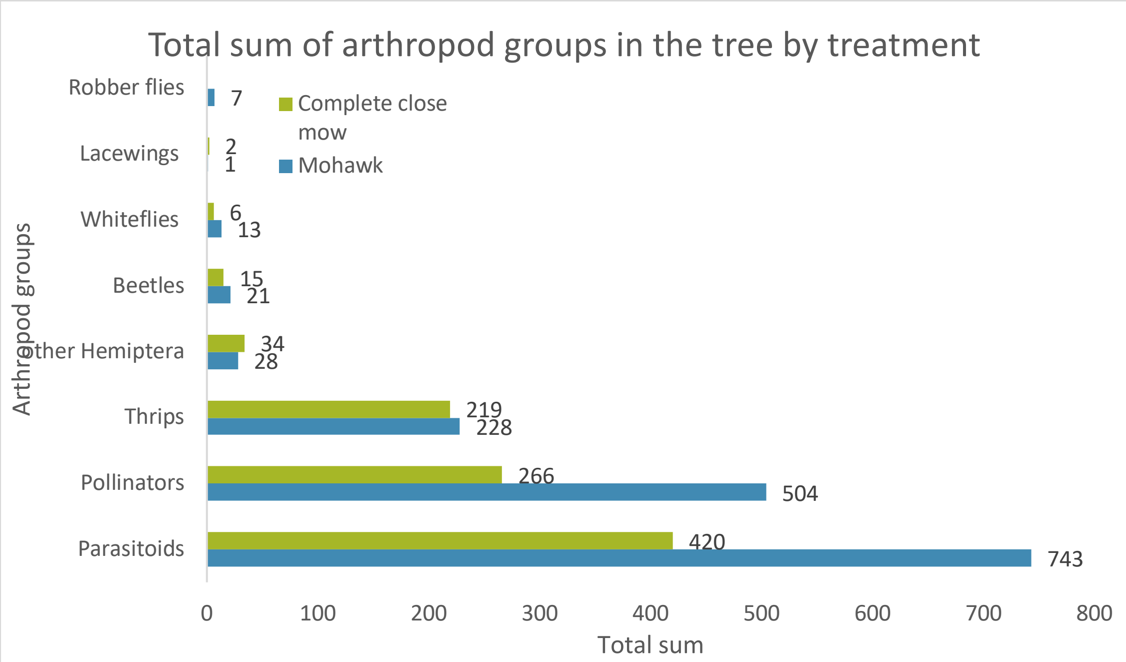


Chart 6: Total sum of each arthropod group within the tree, compared between the two treatments, over the sampling period.

A focussed look at thrips

Thrips are broadly categorised as ‘herbivores’ because the majority feed on the outer layer of plant cells, but most thrips also feed on pollen, and help in plant pollination. Other groups of thrips feed on fungal spores and some are predatory and important in biological control.

In a broader context, thrips play an important part within the food web because they are abundant, soft-bodied and are small and palatable, so many predatory insects eat them. Thrips only reach pest status within macadamias when populations are high and the crop itself is at a vulnerable stage i.e. flowering or leaf flush.

Within **Chart 7** you will see that thrips have been sampled in relatively high numbers from the inter row during three sampling periods, October 2017, January 2018 and January 2019. Overall thrips were more abundant in the inter rows of the complete close mow block, which we can infer is more vulnerable to such outbreaks due to frequent mechanical disturbance and a lower abundance/diversity of beneficial arthropods.

Within the trees, thrips were sampled in consistently low numbers (in the order of 10 to 20 individuals per sample) within both treatment blocks (**Chart 8**). Note the y axis in **Chart 7** and **Chart 8** are presented to different scale. There was no clear or consistent pattern between treatments in terms of thrips in trees throughout the sampling period.

Whilst these high numbers seen within the inter row may look like cause for concern, the inter row can potentially play an important part in ensuring there is always food for beneficial invertebrates, so that pest outbreaks are less likely to happen within the tree. As discussed in the **Introduction**, a healthy ecosystem within the inter row depends on the correct mix of plant species and the right balance between minimal disturbance and necessary management.

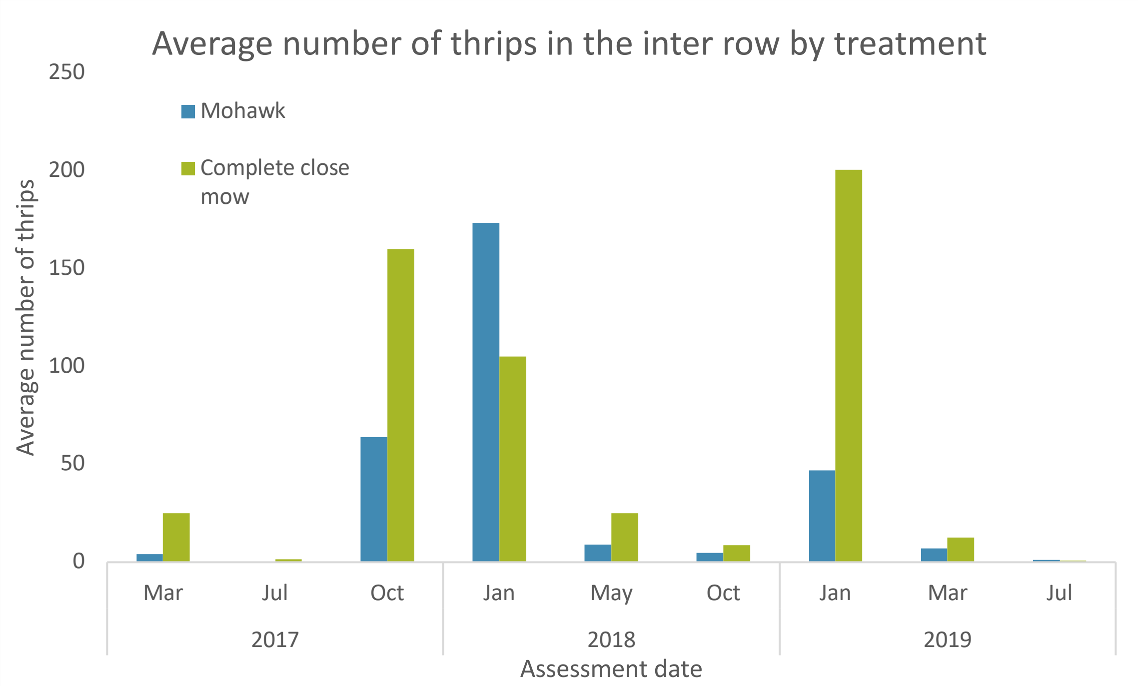


Chart 7: Average number of thrips by treatment through time – sampled in the inter row. This is an average number taken from the three assessment points on each block.

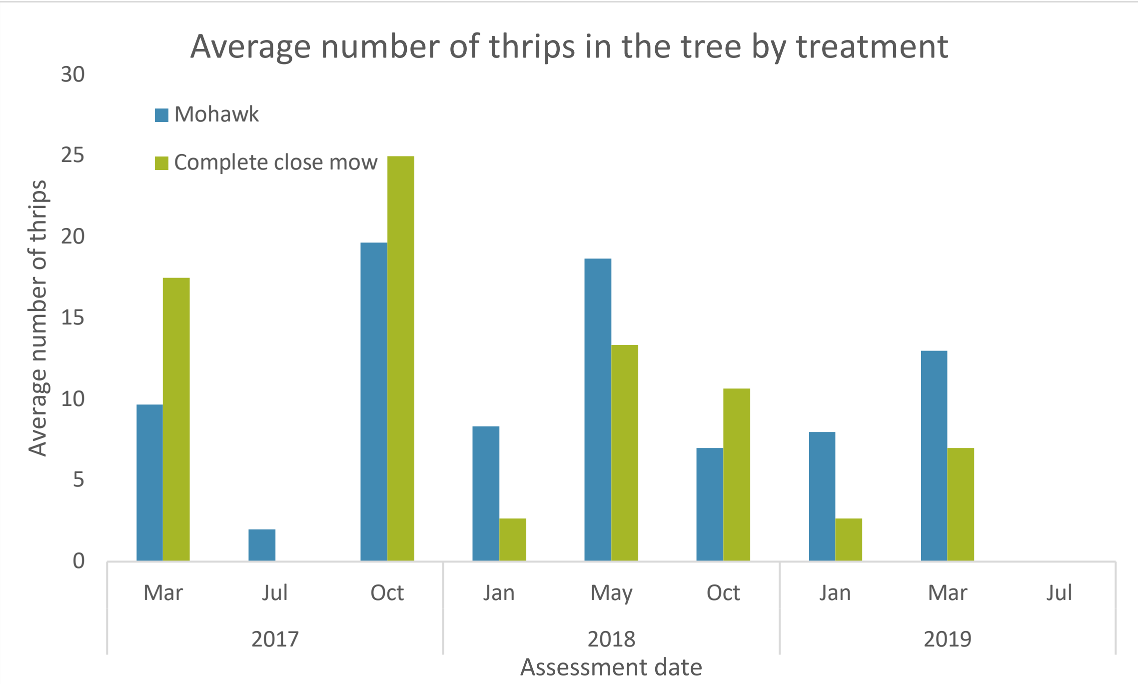


Chart 8: Average number of thrips by treatment through time – sampled in the tree. This is an average number taken from the three assessment points on each block.

A focussed look at parasitoids

Parasitoids were representatively sampled by the YST catches, thus providing a meaningful indication of how the inter row treatments affect this important group of beneficial invertebrates. This sample includes biocontrol releases along with other hymenoptera already present in the orchard environment.

Within the inter row, parasitoids were sampled consistently at approximately 10-30 per sample in both treatment blocks throughout the sampling period, with the exception of the month of July where samples of parasitoids were less than 5 per sample (**Chart 9**). Whilst parasitoids were more often sampled in slightly higher numbers within inter rows of the complete close mow block compared to the mohawk block, the overall difference in parasitoid abundance between inter row treatments is not significant (**Chart 9**).

Within the trees, parasitoids were in relatively high numbers throughout the sampling period (check y-axis when comparing **Charts 9 and 10** because they are presented to different scale), with a large spike in numbers in Jan 2018 (**Chart 10**). Releases of biocontrols (MacTrix) within the month of January 2018 may have accounted for a proportion of the high parasitoid numbers, the majority of which were in the mohawk block. Overall, there were higher numbers of parasitoids in trees with the mohawk block for most sampling dates when compared to the complete close mow block (**Chart 10**).

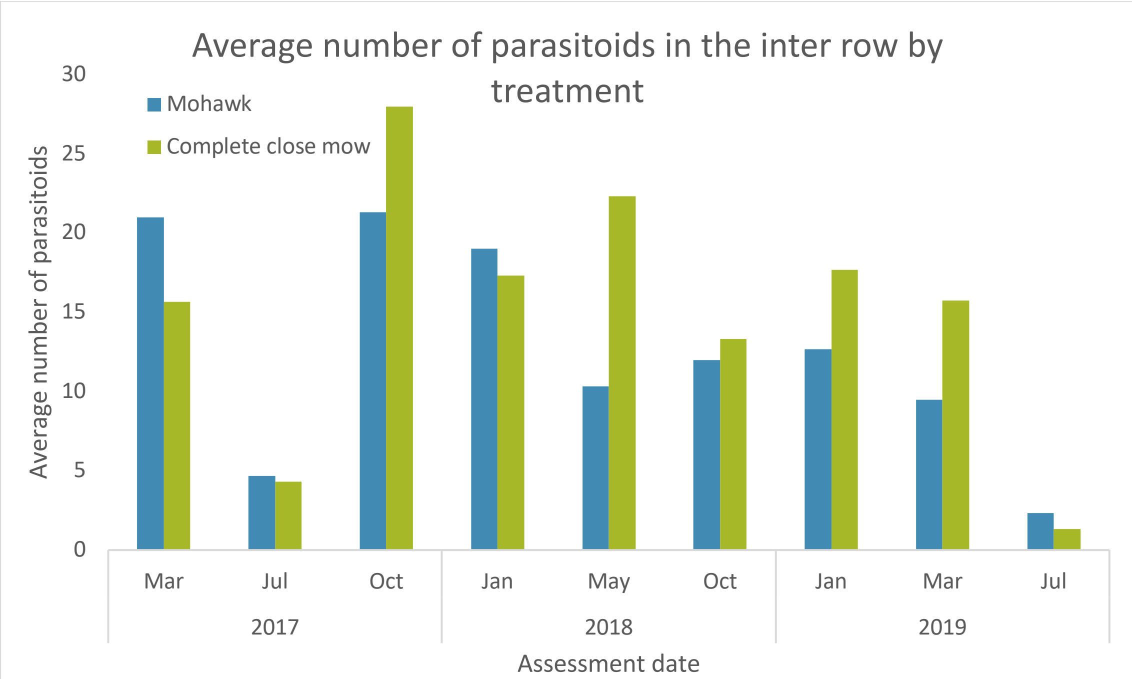


Chart 9: Average number of parasitoids by treatment through time – sampled in the inter row. This is an average number taken from the three assessment points on each block.

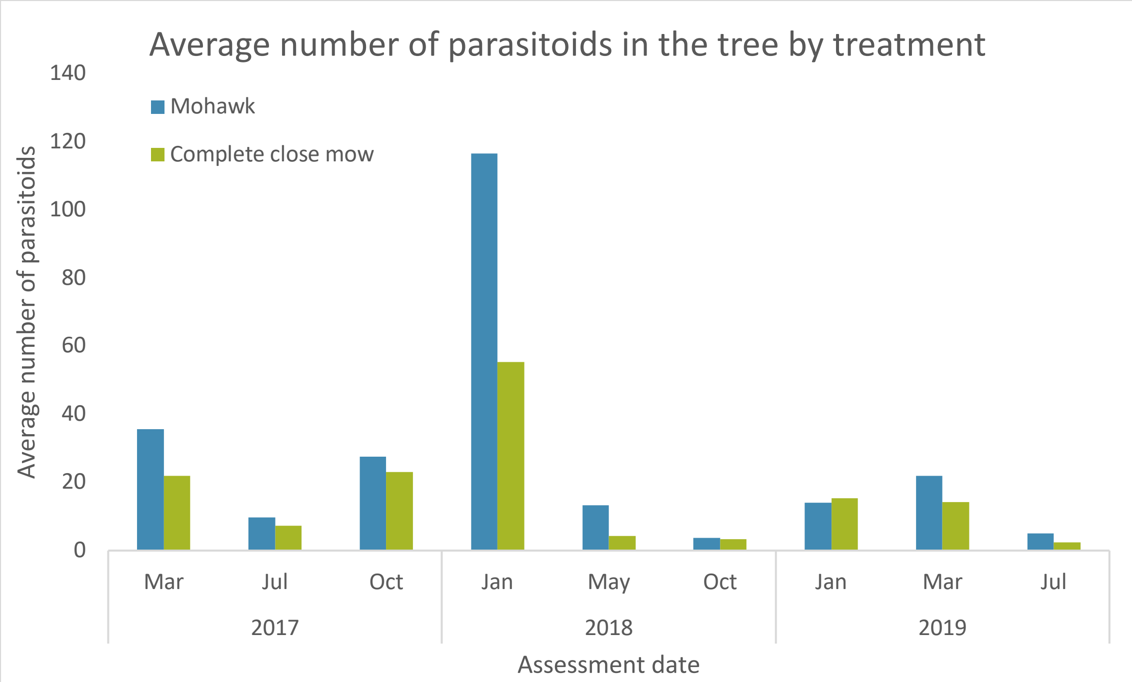


Chart 10: Average number of parasitoids by treatment through time – sampled in the tree. This is an average number taken from the three assessment points on each block.

A focussed look at pollinators

As seen in **Charts 5 and 6,** pollinators were one of the most abundant arthropod groups sampled by YSTs in both inter rows and trees in this trial. Pollinators are arthropods which carry pollen from one plant to another, and these are predominantly bees, moths and butterflies, beetles and flies. YSTs do not sample bees, beetles, moths or butterflies particularly well, but flies are well sampled by YSTs so our term 'pollinators' encapsulates only flies. Flies are also an important food source for predatory insects such as spiders.

Within the inter row, pollinators were sampled consistently between approximately 10-40 per sample in both treatment blocks throughout the sampling period, with the exception July 2017 where pollinator numbers spiked to between 80 and 100 (**Chart 11**). There was no clear or consistent pattern for pollinator abundance when comparing treatments in the inter row (**Chart 11**).

Within the trees, pollinator numbers were clearly higher with the mohawk block compared to the complete close mow block for the majority of the sampling period (**Chart 12**). Pollinator numbers in trees were again sampled consistently between approximately 10-40 per sample throughout the sampling period (see y-axis when comparing **charts 11** and **12**), through throughout 2017 and 2018 pollinators were significantly more abundant within the mohawk block (**Chart 12**). This treatment difference may have been due to the closer proximity of the sampling points within the mohawk block to non-crop vegetation, and/or a greater abundance of floral resources within the mohawk block to support a greater pollinator population.

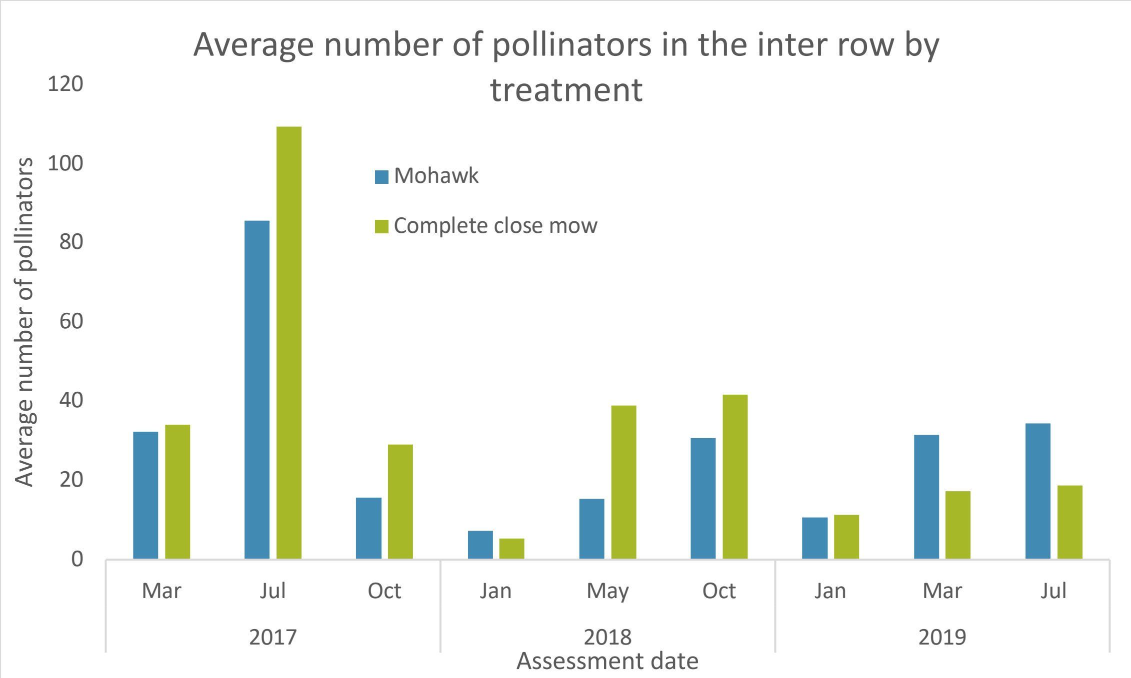


Chart 11: Average number of pollinators by treatment through time – sampled in the inter row. This is an average number taken from the three assessment points on each block.

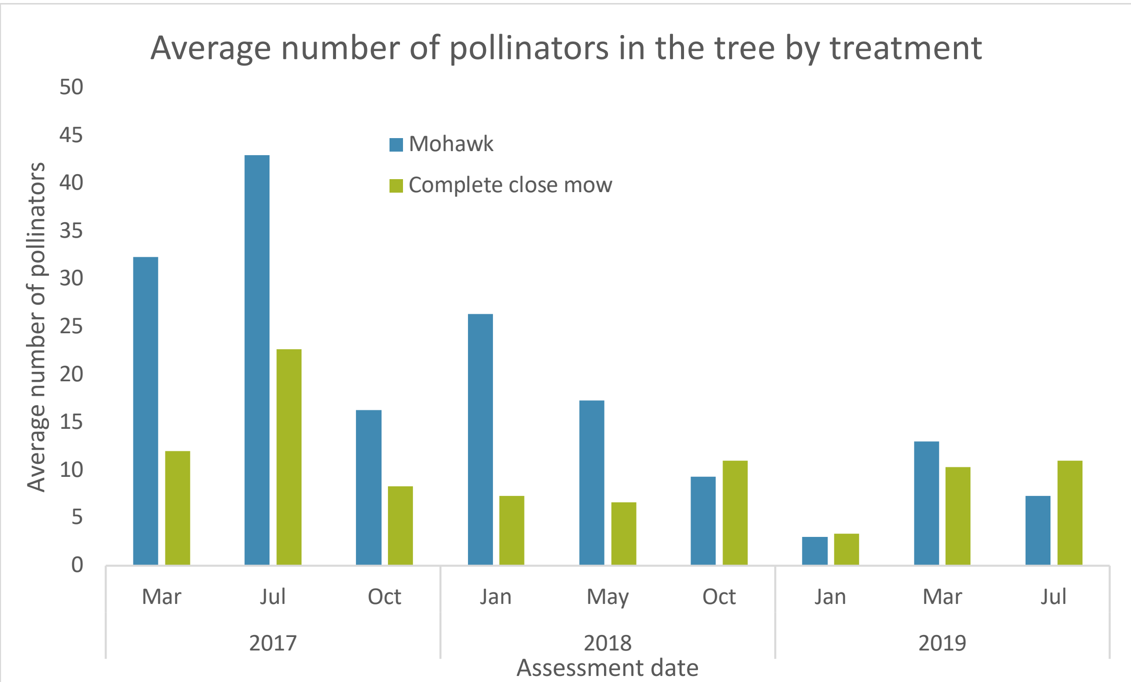


Chart 12: Average number of pollinators by treatment through time – sampled in the tree. This is an average number taken from the three assessment points on each block.

Findings and recommendations

Mohawk worked very well at “Elanora”, given the 10m rows and availability of machinery of a suitable configuration. Retaining a mohawk year-round, including during harvest, proved to be relatively straight-forward at “Elanora”. The principal advantage of the mohawk reduced mow approach is that it can be sustained during harvest. This can be especially advantageous during winter, and particularly in dry years, because it keeps an insectary viable during slow growth periods. Farms that removed the mohawk during harvest took many months to re-establish insectary vegetation when compared to “Elanora”. Optimal benefits from insectaries are possible when they are in place ahead of macadamia flowering and the annual intensification of crop pest pressure.

Setaria grass had mixed results for the mohawk at “Elanora”. Its hardiness and vigorous flowering provide desirable functional characteristics in an insectary. But it can quickly become dominant, limiting vegetative diversity while also presenting more demands for slashing and mowing to avoid clumping and caught nut. We discussed options for seeding to limit Setaria and improve plant diversity. Improved floral resources through seeding of the inter row is an important consideration. There is strong interest in the broader industry for seeding of the inter row and cover cropping and an extensive range of seed options is emerging.

It is worth noting that findings from other trial farms and other industries indicate that alternate row mow may be a better management option than the mohawk for many growers outside of harvest. This involves mowing every second row on a rotating schedule, allowing all rows to “grow out” somewhat across the year but providing opportunities for mow management as required. This reduces the overall disturbance of beneficial arthropods, ensuring a refuge remains in place at all times for them.

Findings from other farms where seasonal conditions were not as impactful for the life of the trial as they were at “Elanora” indicate that insectaries have meaningful influence on orchard ecology when growers can commit to inclusion of the insectary in the orchard in terms of space allocation and long-term management. At “Elanora” the inter row worked very well given row width. There are other areas on-farm worth considering, including headlands, field margins and so on where changes to management can allow for habitat suitable for beneficial insects. Decisions to improve plant diversity with seeding, well-timed seeding and mowing to limit dominance of one species while encouraging new growth and flowering and so on are very influential.

Finally, the BioResources team encourages you to read the final report for the *Macadamia IPDM Program - Inter Row Project (MC16008)*, which is available via *Hort Innovation*. Here you will find out more on the benefits of insectaries for macadamia orchards and also the experiences of other trial farms in implementing and managing insectaries. There is also an exploration of the multiple ecosystem services known to flow from changed inter row management practices along with improved arthropod biodiversity, including benefits for soil organic matter, nutrient cycling, water management, erosion control, weed suppression, soil carbon storage, soil microbiology and more.

Acknowledgements and thanks

The project team wishes to thank the "Elanora" ownership and management team for their participation, and particularly Tod for his contributions and support in the field.

Final Report

"Hotson" – Macadamia Inter Row Trial Results

Hort Innovation program title: The IPM program for the macadamia industry – BioResources

Hort Innovation project code: MC16008

Date: February 2020

Summary

This project proposes that reduced mowing in the macadamia inter row may improve vegetation there for the purposes of an insectary. Where managed reduced mowing is possible, it is further proposed that beneficial arthropods crucial to pollination, pest suppression and the "food-web" will be present and active in higher numbers. This can decrease the likelihood and/or intensity of pest outbreaks because populations of beneficial invertebrates are always present within the orchard.

You worked with the BioResources team to investigate these ideas from early 2017 to mid 2019.

Your reduced mowing trial has provided several useful insights into the practicalities of reduced mow options in macadamia orchards, and especially the mohawk. Industry has been particularly concerned that reduced mowing of the inter row may lead to significant problems such as increased rat activity, invasive weeds and/or increased insect pests. Your trial gives other growers reassurance that a mohawk can be incorporated into existing orchard inter row management and with basic monitoring and management will not lead to other problems.

Findings in terms of the benefits of a mohawk for beneficial arthropods in your trial are unfortunately not clear. There were a number of challenges sustaining the reduced mow experimental protocols for the life of the trial, which in turn impacted the arthropod populations sampled. Other confounding factors arising out of the experimental design also impacted local arthropod communities. This is not an unusual outcome with field experiments where there are so many unpredictable and uncontrollable factors in play.

Other trial sites participating in this project enjoyed relatively more experimentally benign conditions and these demonstrate that the benefits of insectaries are likely to be realised with sustained commitment to insectaries throughout the orchard that are compatible with standard orchard operations, the inclusion of seeding options, and further refined strategies for reduced mowing including alternate row mowing.

The BioResources team encourages you to read the final report for the *Macadamia IPDM Program - Inter Row Project (MC16008)*, which is available via *Hort Innovation*. Here you will find out more on the benefits of insectaries for macadamia orchards and also the experiences of other trial farms in implementing and managing insectaries. There is also an exploration of the multiple ecosystem services known to flow from reduced mow inter row management practices along with improved arthropod biodiversity, including benefits for soil organic matter, nutrient cycling, water management, erosion control, weed suppression, soil carbon storage, soil microbiology and more.

Introduction

This project proposes that reduced mowing in the macadamia inter row may increase vegetative diversity, increase floral resources, and reduce habitat disturbance. This may in turn increase the presence of beneficial arthropods in the orchard. More broadly, the proposed changes in plant ecology may increase arthropod populations in general, the over-whelming majority of which are non-economic and will be food for beneficial arthropods. Furthermore, this enhanced nutritional food-web will benefit birds and micro-bats, which have a role in pollination and pest suppression. Having a "food-web" within the orchard decreases the likelihood and/or intensity of pest outbreaks because populations of beneficial invertebrates are always present within the orchard.

These propositions warrant investigation because an increased presence of beneficial arthropods in the orchard may result in improved pest suppression and also improved pollination, via reduced crop damage, reduced inputs like chemical applications, and subsequently improved yields.

You worked with the BioResources team in this investigation from early 2017 to mid 2019. We compared two 1 Ha blocks. A control block was managed as industry standard with regular mowing (**Photo 1**, below). A treatment block was managed with reduced mowing, sustaining a centre mohawk for most of the trial period (**Photo 2**, below).

Photo 1: "Hotson" complete close mow 3 May 2017

Photo 2: "Hotson" mohawk 3 May 2017

As you will recall, with each site visit the BioResources team sampled each block for arthropods in three separate rows using yellow stick traps (YSTs), placing one YST in the inter row and one YST in a tree. We assessed the vegetation in the inter row at those three points (a quadrant of approximately 10m x 20m). The three data collection points were at least 30m apart, and 50m from any block edge. We also spent time with you discussing the trial and any observations that you may have made in relation to rats, weeds, insect pests in the inter row vegetation and/or any challenges with reduced mowing.

The objective of the trial has been to provide growers with on-farm practical experience in reduced mowing complimented by vegetative and invertebrate monitoring to quantify results.

BioResources first worked with growers to consider practical options for reduced mowing that are compatible with the seasonal demands of orchard management. It has then sought to provide information on any relationship between reduced mowing and the potential for increased rat, invasive weed, and/or arthropod pest presence. Finally, the trial has sought to monitor association between changes in inter row vegetation management and changes in orchard beneficial/pest arthropod ecology.

Reduced mowing in the inter row at "Hotson"

Reduced mowing trial and potential problems

	Throughout the trial, BioResources regularly monitored for and consulted with Anthony and Ian Hotson, on the following issues:
Rats	For the majority of the trial's life, the project team did not observe rat activity. Some burrows/nests were observed in the mohawk by the project team during one site visit towards the end of the trial period (below). Anthony Hotson reported increased rat activity in January 2019 in the mohawk block. You estimated a potential loss of $25-30 per day as a result in this block. Your preference was for immediate close mowing, to be continued for a couple of months, and then a return to mohawk mowing at a later date. This action was taken and no further problems with rats were reported to the project team.
Problem weeds	No issues were observed by the project team during site visits. In the final analysis Kikuyu grass became very "weedy" within the context of the trial, making management of a high value inter row insectary difficult. No issues were reported by the "Hotson" team.
Major insect pests of macadamias	No issues were observed by the project team during site visits. The team monitored vegetation in the inter row for the presence of major macadamia pests including Macadamia Nut Borer, Fruit Spotting Bug and Green Veggie Bug. Plant species typically found in the inter row trial blocks at "Hotson" were not observed to host these pests. No issues were reported by the "Hotson" team.
Management of the inter row	No issues were observed by the project team during site visits. No issues were reported by the "Hotson" team. A number of different machinery options were available for slashing and harvesting, which suited straightforward inclusion of a mohawk in the trial block year-round.

Outcomes

Your reduced mowing trial has provided several useful insights into the practicalities of reduced mow options in macadamia orchards, and especially the mohawk. Industry has been particularly concerned that reduced mowing of the inter row may lead to significant problems such as increased rat activity, invasive weeds and/or increased insect pests. Your trial gives other growers reassurance that a mohawk can be incorporated into existing orchard inter row management and with basic monitoring and management will not lead to other problems.

The trial, which compared a complete close mow block with a mohawk block was however adversely impacted by issues with Kikuyu grass heavily dominating the mohawk, which we were unable to adequately resolve in the life of the trial. As a result, a strong experimental distinction between the control block (**Photo 3,** below) and the treatment mohawk block (**Photo 4**, below) was not consistently possible for the life of the project.

Photo 3: “Hotson” complete close mow 12 September 2018

Photo 4: “Hotson” mohawk 12 September 2018

Furthermore, the proximity of the control block to the forested fence line area and neighbouring crops and also the two trial blocks to each other may have had a more significant influence on encouraging local arthropod populations into the trial area than the project’s experimental design could factor in (**Photo 5**). These conditions limited our ability to maintain a strong experimental distinction between the control block and the treatment mohawk block for the life of the project.

Thus, findings in terms of the benefits of a mohawk for beneficial arthropods in your orchard are unfortunately not clear. This is not an unusual outcome with field experiments where there are so many unpredictable and uncontrollable factors in play.

In so much as the potential for inter row insectaries in macadamia orchards is concerned, the BioResources team urges you to read the project’s final report, *Macadamia IPDM Program - Inter Row Project (MC16008)*, which will be available via Hort Innovation. A number of the project’s other trial farms enjoyed more experimentally robust circumstances in their trial blocks, and the results there are very encouraging.

Photo 5: “Hotson” map of experimental site and experimental design. The non-crop adjacent vegetation including the forested fence line on the far right-hand side of the photo was likely very influential over arthropod ecology in the blocks, as was the proximity of the two blocks to each other.

Results of reduced mowing in the inter row at “Hotson’s”

Vegetative diversity

Vegetative diversity refers to the number of plant species present. Changes to regular mowing can change plant species diversity. This can in turn be associated with diversity of arthropod species. **Chart 1** presents an average count of plant species observed in the inter row by treatment through time.

In this trial we anticipated that reduced mowing would increase the number of plant species present in the orchard. However, we found on some participating farms, including yours, that through time, less mowing unfavourably impacted plant species diversity. This is because some species such as Kikuyu grass tend to heavily dominate other plant species, if not mown occasionally **(Chart 2)**. This is in fact a valuable insight and helps the project to provide growers with guidelines on “managed vegetative diversity” for insectaries.

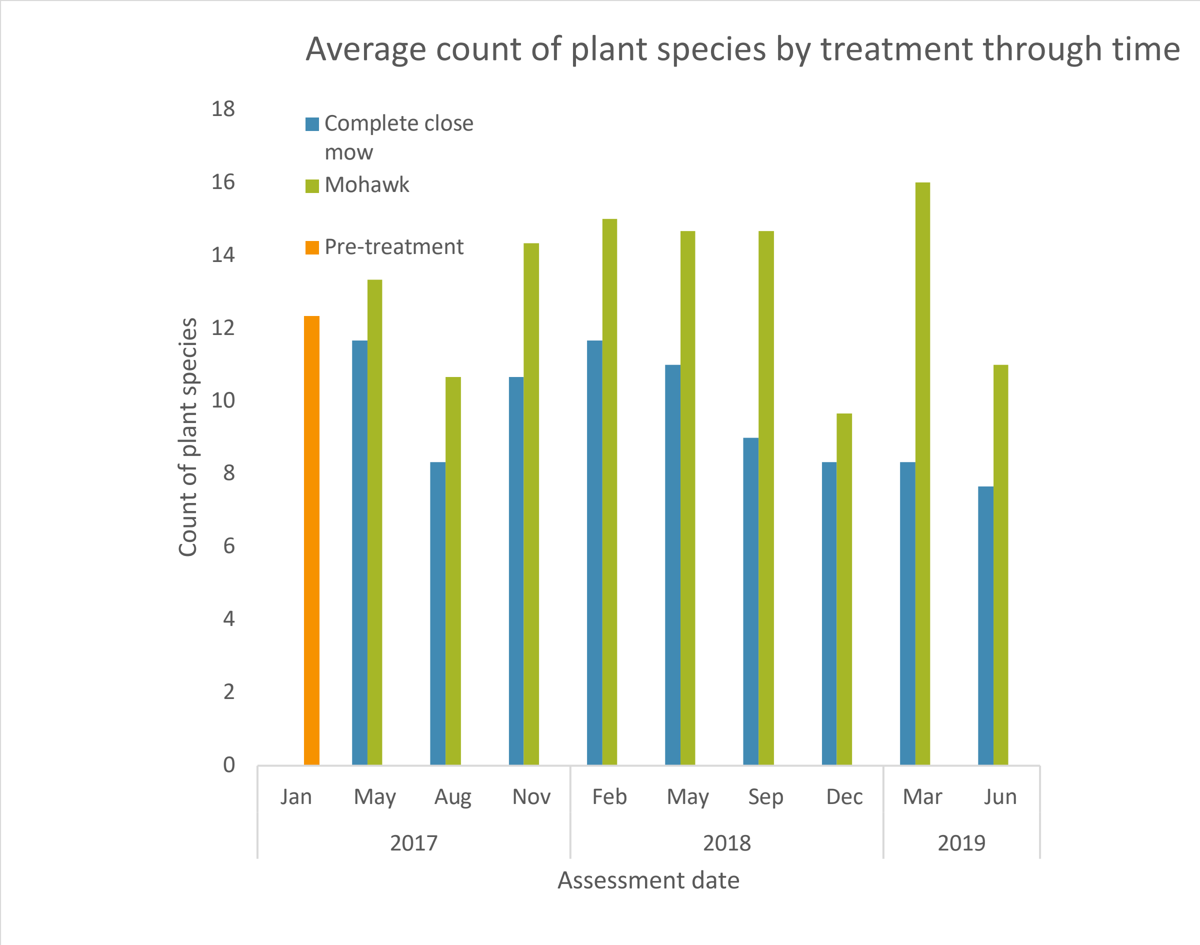
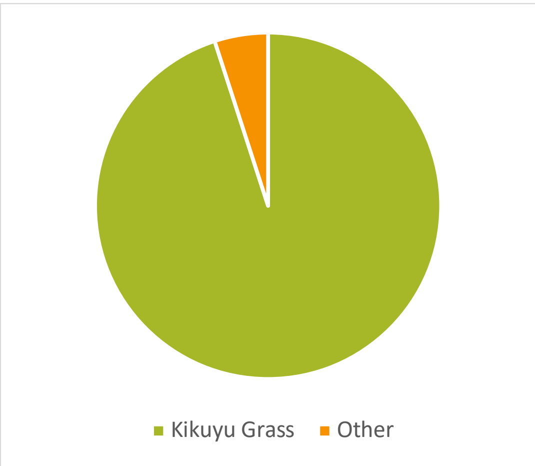


Chart 1: Average count of plant species by treatment through time. This is an average of counts taken at the three assessment points on each block.



Values recorded for plant species in **Chart 1** can be somewhat misleading. The experimental method required recording of every plant species observed. Often however, many of these species were present at a very low relative percentage and as very small specimens with 2 or 3 leaves at most.

Kikuyu grass (**Chart 2**) was a consistently dominant species as total volume of biomass in the mohawk. Unfortunately, it has low value in an insectary given its limited capacity for flowering and also its allelopathic suppression of other flowering plants species.

Chart 2: Plant species dominance as % of biomass in the mohawk block. Kikuyu grass dominated the mohawk block for the life of the trial.

Floral resources

Floral resources provide a food source for many beneficial arthropods and will encourage them to remain active in the orchard. **Chart 3** provides an average count of the plant species flowering at the time of the site visit. We can see that the mohawk sustained a greater number of plant species with floral resources for the life of the project. In **Chart 4**, we can see that the mohawk block was also more likely to sustain a larger volume of floral resources as a percentage of biomass through time. Furthermore, we can see that there are floral resources in the mohawk at greater percentages as compared to the complete close mow block.

However, these values in the mohawk are at relatively low percentages, with low value for beneficial arthropods. While a number of flowering "naturalised weeds" were present, the dominance of Kikuyu grass in the mohawk muted their capacity for floral resources.

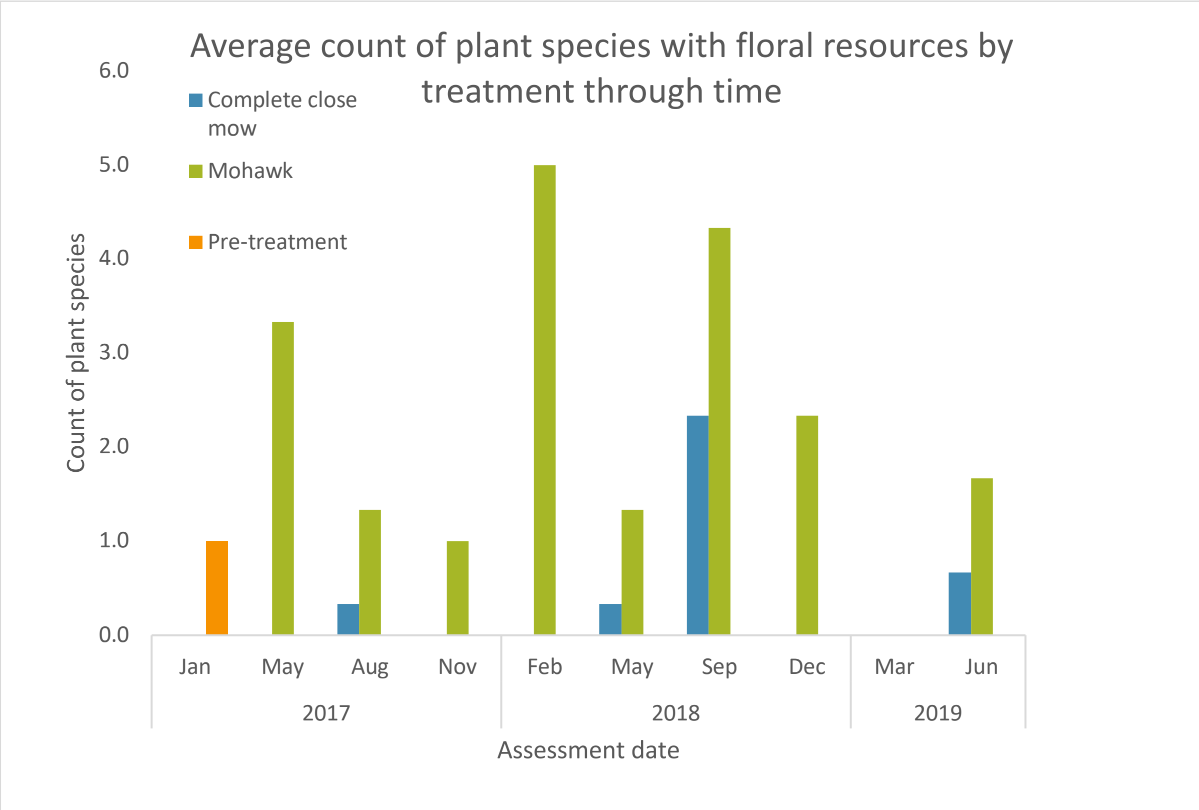


Chart 3: Average count of plant species with floral resources by treatment through time. This is an average of counts taken at the three assessment points on each block.

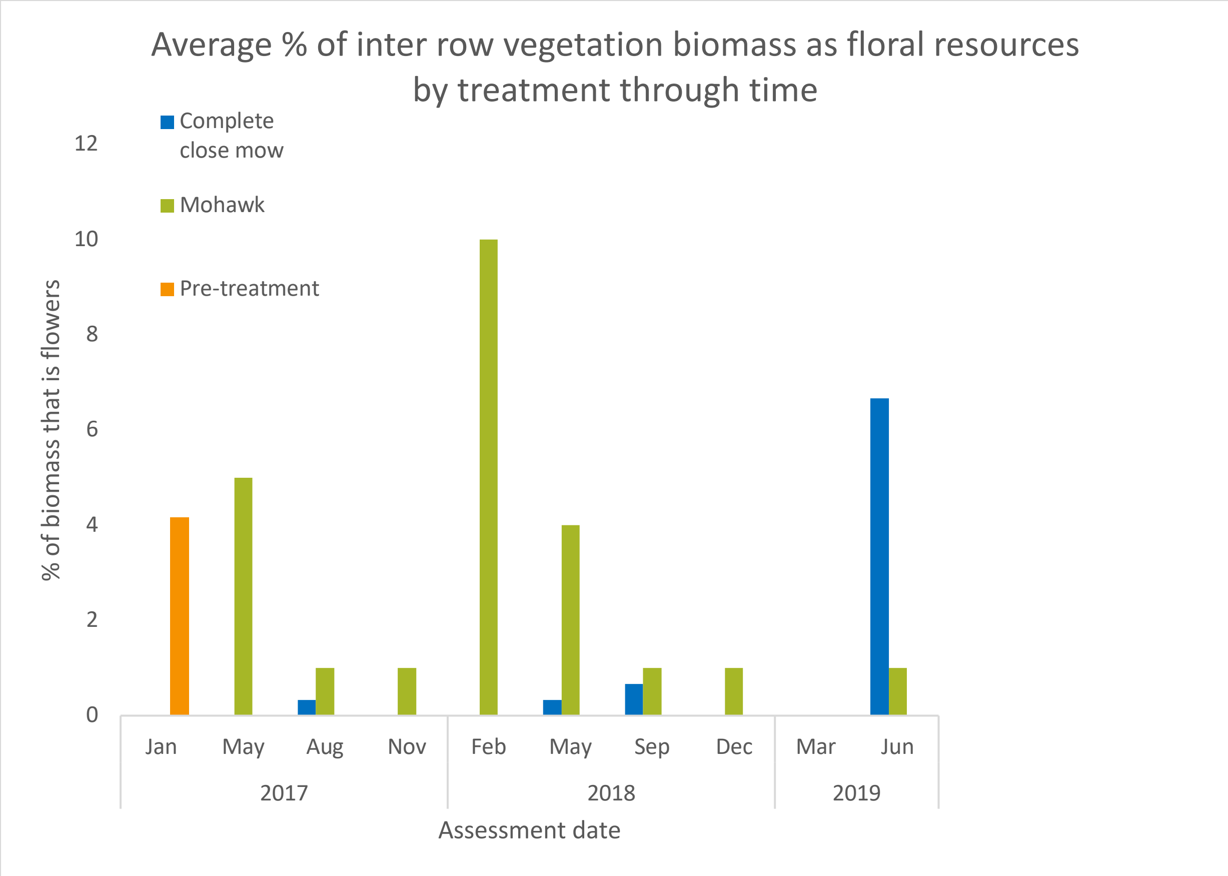


Chart 4: Average percentage of inter row vegetation biomass as floral resources by treatment through time. This is an average of counts taken at the three assessment points on each block.

Habitat disturbance

Areas of reduced mechanical and chemical disturbance can serve as favourable habitat for beneficial insects. Undisturbed areas may also provide a refuge for beneficial arthropods for faster recovery after spraying. The measurement of plant height provides a good indication of rates of mechanical disturbance. **Chart 5** reports the average height in centimetres (cm) of vegetation in the inter row by treatment through time. Retention of a central mohawk allowed for greater height of vegetation and hence less disturbance in the inter row for the life of the trial.

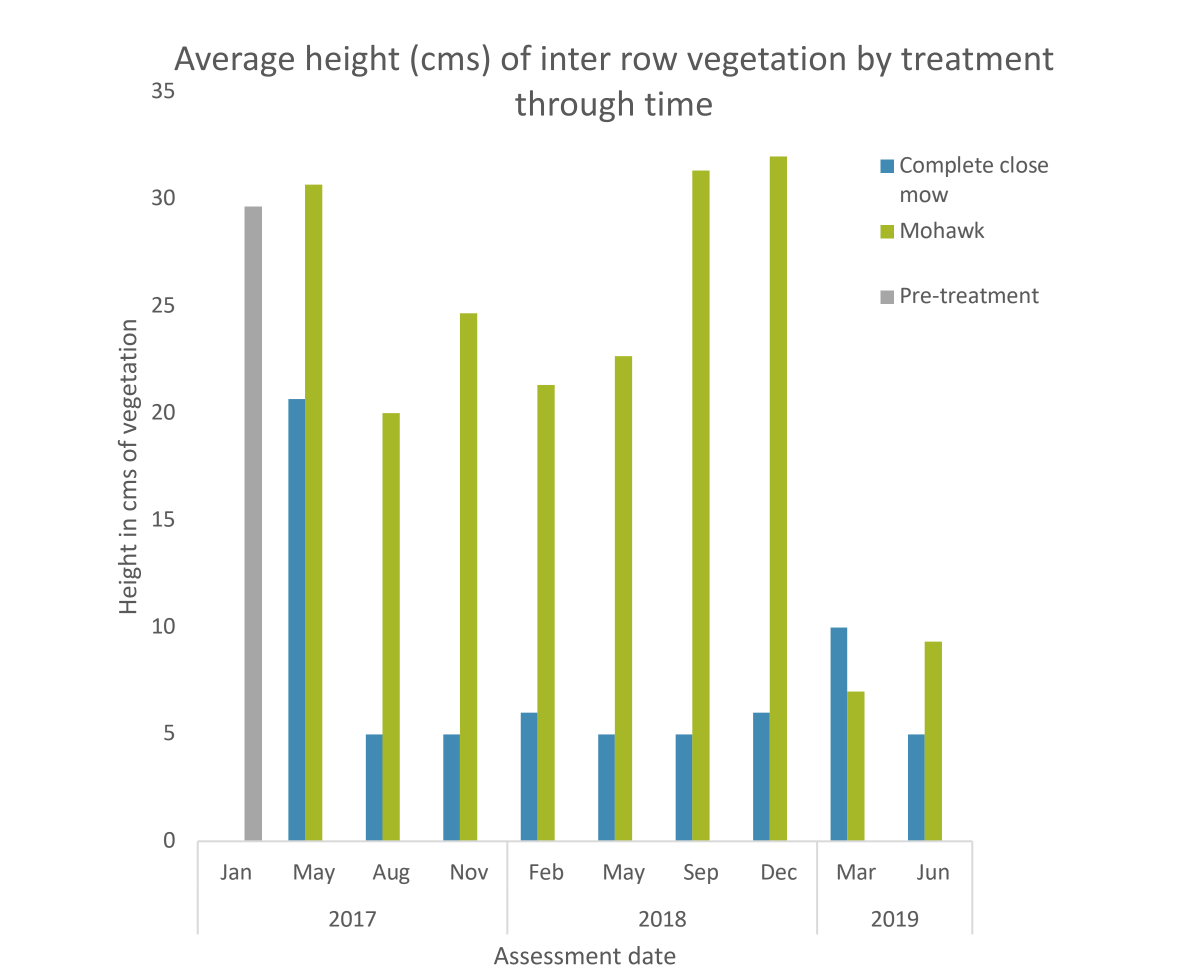


Chart 5: Average height (cm) of inter row vegetation by treatment through time. This is an average of counts taken at the three assessment points on each block.

Examination of other undisturbed areas on your farm such as field margins revealed spiders. See **Photo 5**, golden orb spider.

Reduced disturbance allowed the spider to maintain its web and complete its lifecycle.

Spiders are important generalist predators and will eat major macadamia pests including fruit spotting bug, macadamia nut borer, green veggie bug, macadamia seed weevil and lacebug.

Photo 5: Golden orb spider at "Hotson" field margin 15 May 2018

Results of arthropod evaluation

General arthropod abundance

Charts 5 and 6 present the total numbers of individuals collected for several arthropod groups sampled during the project, comparing the mohawk with the complete close mow, and therein inter row with trees. We used yellow sticky traps (YSTs) to sample arthropods within both the inter row and trees. Like all sampling methods, YSTs have biases, which need to be taken into consideration. YSTs sample winged arthropods during flight (though non-winged arthropods do get caught occasionally). Their colour, yellow, is particularly attractive to parasitoids, flies and thrips, which were very well sampled during this project. The abundance data presented below shows only the winged arthropod groups, robber flies, lacewings, aphids, whiteflies, beetles, hemiptera (sap suckers excluding aphids), pollinators (flies), parasitoids and thrips. Other important arthropod groups, such as spiders and ants were not well sampled using YSTs and are thus omitted from **Charts 5 and 6**.

Parasitoids, flies (pollinators) and thrips were the most abundant arthropod groups sampled during this trial. Typically, we expect to see higher numbers for these arthropods within the inter row as compared to the trees for both the complete close mow and mohawk blocks. However, on your farm there were pollinators, parasitoids and thrips in *similar* numbers within the inter row and the tree (check data labels on bars when comparing **Charts 5 and 6**). This relatively unusual result is difficult to explain but we attribute it to a number of confounding factors relating to the experimental design and difficulties with mowing protocols, as explained in **Outcomes** and **Results of Reduced Mowing**, above. It is likely that plant resources attractive to beneficial arthropods were represented at equally low rates in both the inter row and the tree for both the complete close mow and mohawk blocks.

In total, parasitoid numbers were roughly double in both trees (**Chart 6**) and inter rows (**Chart 5**) of the complete close mow block compared to the mohawk block. Pollinator numbers were higher in inter rows (**Chart 5**) of the complete close mow block, but similar in numbers between treatment blocks within trees (**Chart 6**). Thrips were a little higher in inter rows of the mohawk block compared to the complete close mow block (**Chart 5**), but within the trees thrip numbers were approximately triple within the complete close mow block compared to the mohawk block (**Chart 6**).

A number of factors could explain the higher numbers of pollinators, parasitoids and thrips within the complete close mow block. These include the close proximity of the complete close mow block to adjacent fence line and neighbouring crop vegetation. Winged invertebrates, such as flies and thrips that breed within adjacent vegetation, can fly coincidentally into the crop for additional food/host resources within the inter row and trees at the time that YSTs were out. In the case of parasitoids, we further speculate that this block was in especially close proximity to release areas for biocontrols.

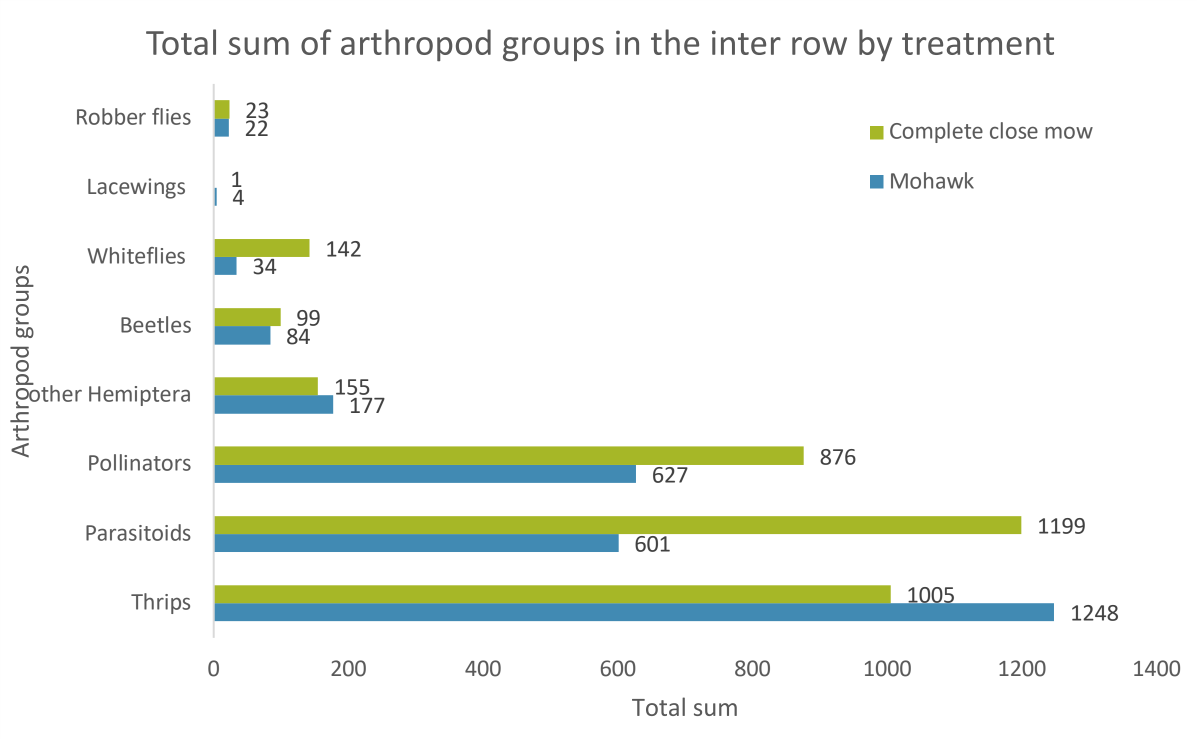


Chart 5: Total sum of each arthropod group within the inter row, compared between the two treatments, over the sampling period.

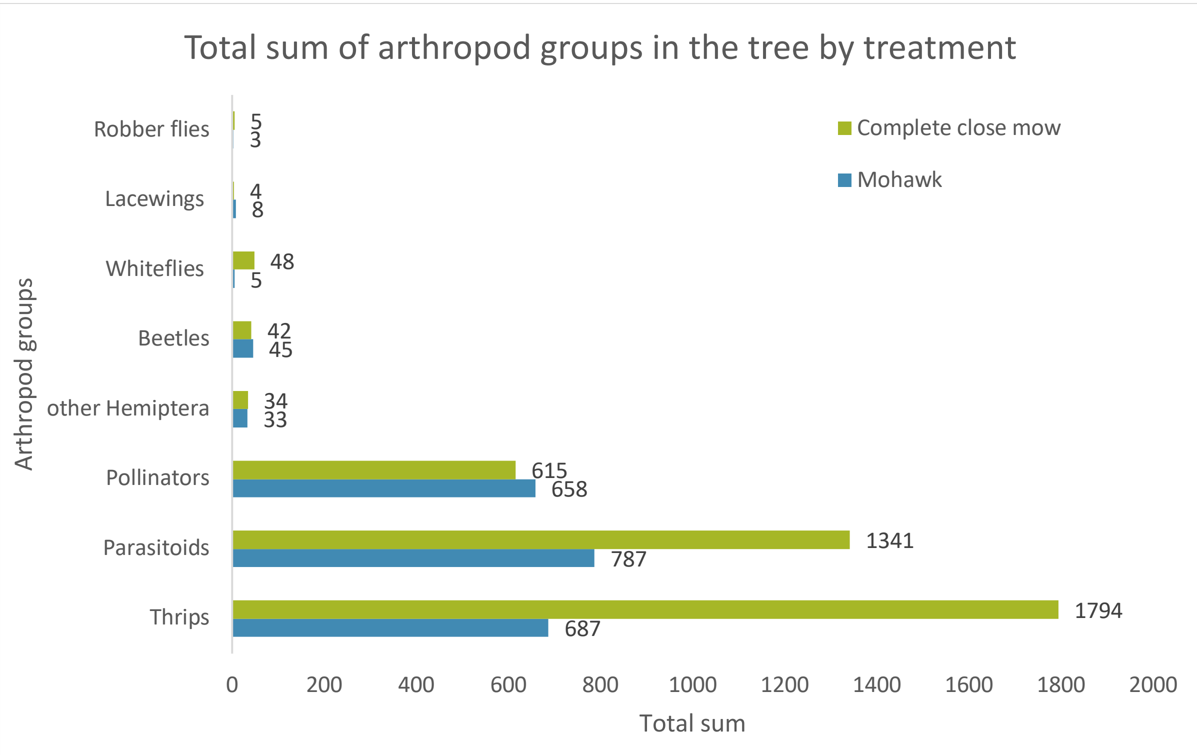


Chart 6: Total sum of each arthropod group within the tree, compared between the two treatments, over the sampling period.

A focussed look at thrips

In **Charts 5 and 6** thrips stands out as a group with the greatest total number of individuals collected. Thrips numbers spiked in both inter row and tree of both treatment blocks (though in higher numbers within complete close mow block) in December 2018, and less so in January 2017 and February 2018 (see **Charts 7 and 8**).

Thrips are broadly categorised as 'herbivores' because the majority feed on the outer layer of plant cells, but most thrips also feed on pollen, and help in plant pollination. Other groups of thrips feed on fungal spores and some are predatory and important in biological control.

In a broader context, thrips play an important part within the food web because they are abundant, soft-bodied and are small and palatable, so many predatory insects eat them. Within **Chart 7** you will see that thrips are abundant at low levels in the inter row throughout the entire sampling period (with the exception of December 2018 and less so in January 2017 and February 2018). Within the tree (**Chart 8**), thrips fluctuate at low levels but are often present in very low numbers. The inter row can potentially play an important part in ensuring there is always food for beneficial invertebrates, so that pest outbreaks are less likely to happen within the tree, and if an outbreak does occur that it is controlled quickly by the nearby predatory (beneficial) arthropods. As discussed in the **Introduction**, a healthy ecosystem within the inter row depends on the correct mix of plant species and the right balance between minimal disturbance and necessary management.

Standard on-farm monitoring of macadamia pests including thrips was discussed during site visits. Concerns for problematic numbers of thrips in the trial blocks were not raised at any point, beyond concerns with thrips at a farm-wide level.

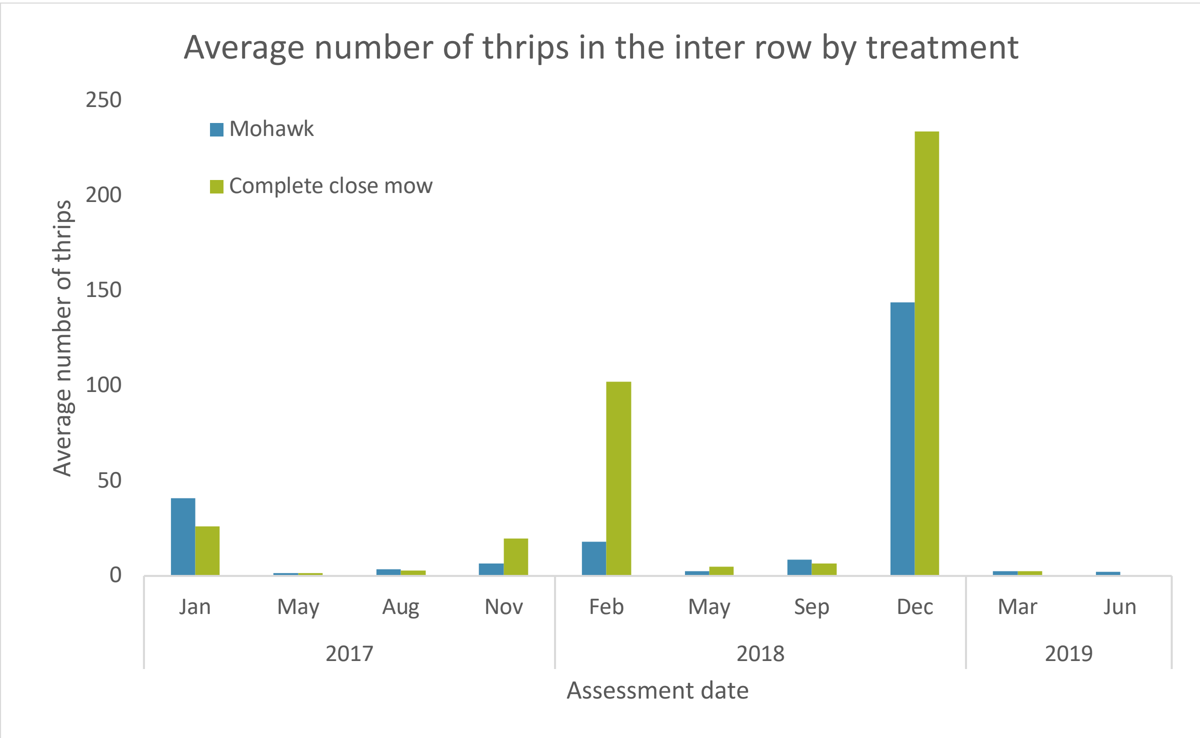


Chart 7: Average number of thrips by treatment through time – sampled in the inter row. This is an average number taken from the three assessment points on each block.

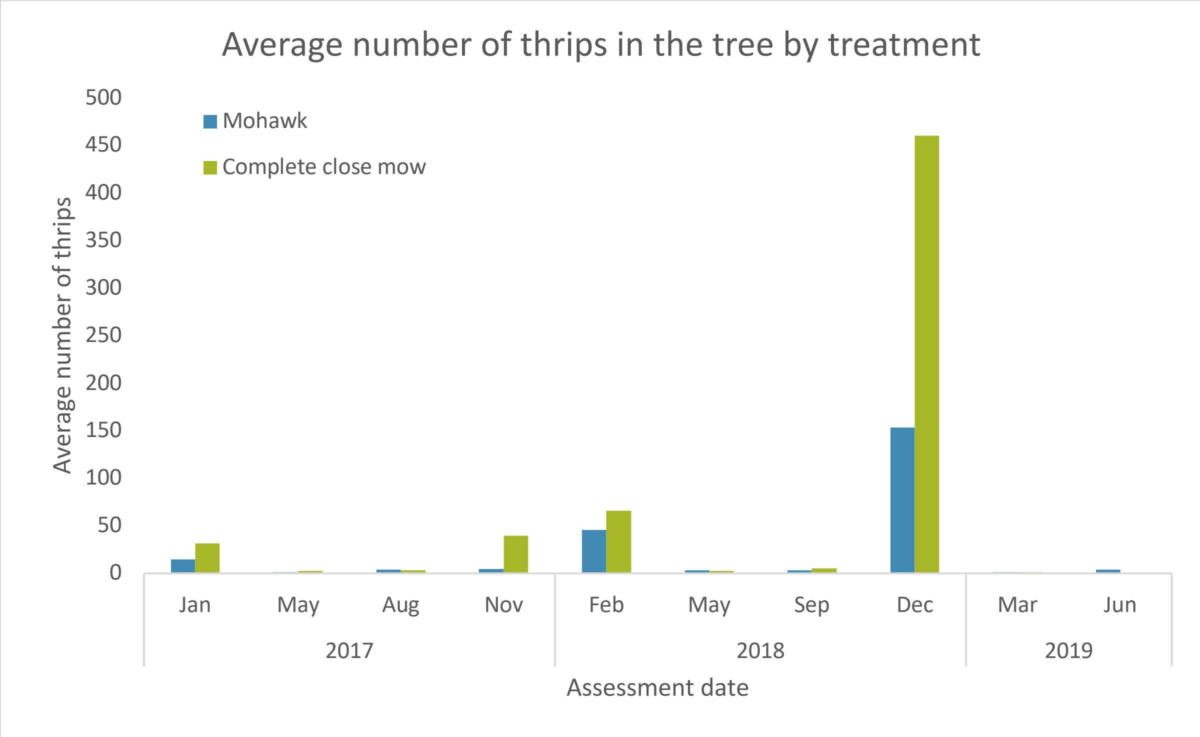


Chart 8: Average number of thrips by treatment through time – sampled in the tree. This is an average number taken from the three assessment points on each block.

A focussed look at parasitoids

Parasitoids were representatively sampled by the YST catches, providing a meaningful indication of how the inter row treatments affect this important group of beneficial invertebrates. This samples included MacTrix and Anastatus from previous releases and other hymenoptera already present in the orchard environment.

Parasitoids were more often sampled in greater abundance from inter rows within the complete close mow block compared to the mohawk block (**Chart 9**). These differences occurred more often in the warmer months for each sampling year. Explanatory factors that could have influenced this difference in parasitoid abundance between the treatments are: 1. Closer proximity of the complete close mow block to forested fence-line non-crop vegetation (see **Photo 5** within the **Introduction**) and/or; 2. Biocontrol releases along the fence-line.

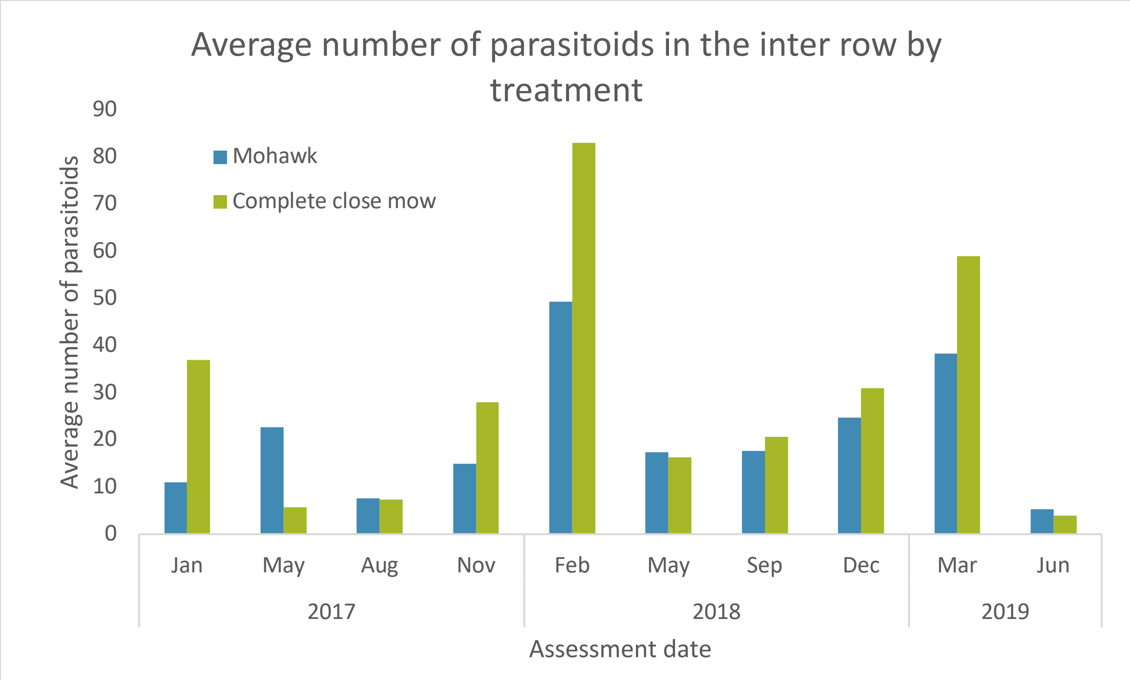


Chart 11: Average number of parasitoids by treatment through time – sampled in the inter row. This is an average number taken from the three assessment points on each block.

Within the trees, parasitoid numbers were relatively high throughout the entire sampling period, though three dates with outstandingly high numbers of parasitoids obscure the rest of the dates (**Chart 12**). Parasitoid numbers are often higher within the trees than within the inter rows, which is highly unusual. Again, parasitoids were more often sampled in greater abundance from trees within the complete close mow block compared to the mohawk block (**Chart 12**), and the same explanatory factors as listed for the inter row results apply.

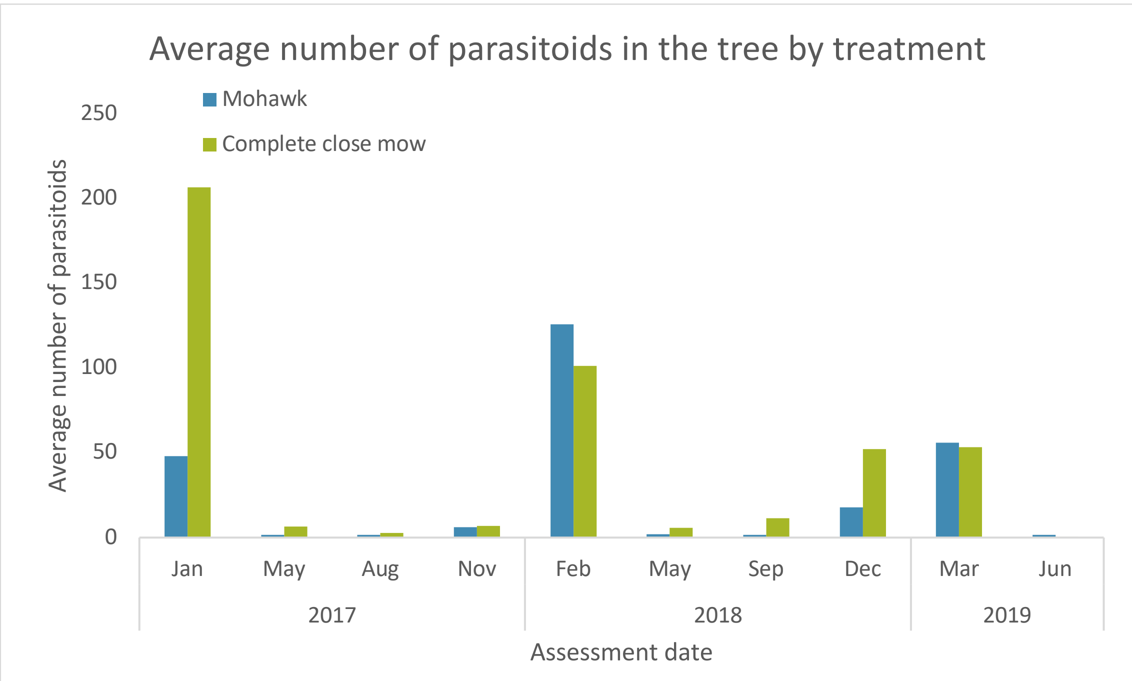


Chart 12: Average number of parasitoids by treatment through time – sampled in the tree. This is an average number taken from the three assessment points on each block.

Findings and recommendations

The mohawk did not work very well for your trial, largely as a result of the habit for heavy dominance by kikuyu with reduced mowing. We were unable to correct this within the limits of a trial setting and it serves as an important lesson for other growers that reduced mowing alone may be insufficient where the objective is improved vegetative diversity for the purposes of an insectary. While the associated results for arthropod populations were disappointing, the lessons learned in terms of "problem plant species" specifically in orchard inter row insectaries are very useful indeed.

It is worth noting that findings from other trial farms and other industries indicate that alternate row mow may be a better management option than the mohawk for many growers outside of harvest. This involves mowing every second row on a rotating schedule, allowing all rows to "grow out" somewhat across the year but providing opportunities for mow management as required. This reduces the overall disturbance of beneficial arthropods, ensuring a refuge remains in place at all times for them.

Options for increasing the plant species diversity with seeding in the inter row were discussed during some of our site visits. Species able to suppress kikuyu (which has limited value in an insectary) and with improved floral resources is an important consideration. There is strong interest in the broader industry for seeding of the inter row and cover cropping and an extensive range of seed options is emerging.

Findings from other farms where experimental conditions were sustained for the life of the trial indicate that insectaries have meaningful influence on orchard ecology when growers can commit to inclusion of the insectary in the orchard in terms of space allocation and long-term management. An inter row insectary can work very well on your farm given row width. There are also other areas on-farm worth considering, including headlands, field margins and so on where changes to management can allow for habitat suitable for beneficial insects. Decisions to improve plant diversity with seeding, well-timed seeding and mowing to limit dominance of one species while encouraging new growth and flowering and so on are very influential.

Finally, the BioResources team encourages you to read the final report for the *Macadamia IPDM Program - Inter Row Project (MC16008)*, which is available via *Hort Innovation*. Here you will find out more on the benefits of insectaries for macadamia orchards and also the experiences of other trial farms in implementing and managing insectaries. There is also an exploration of the multiple ecosystem services known to flow from changed inter row management practices along with improved arthropod biodiversity, including benefits for soil organic matter, nutrient cycling, water management, erosion control, weed suppression, soil carbon storage, soil microbiology and more.

Acknowledgements and thanks

The project team wishes to thank the Hotson family for their participation, and particularly Anthony and Ian their contributions and support out in the field.

Final Report

"Thomas" – Macadamia Inter Row Trial Results

Hort Innovation program title: The IPM program for the macadamia industry – BioResources

Hort Innovation project code: MC16008

Date: February 2020

Summary

This project investigates the potential for the development of insectaries through vegetation changes in the inter row via reduced mowing. Adoption of reduced mowing where possible is expected to increase the abundance and diversity of beneficial arthropods by creating more complex food-webs that are vital to pollination and pest suppression. Our aim is to optimise macadamia orchards for the self-regulation of pests by supporting beneficial arthropods with shelter, breeding areas, nectar, alternative hosts/prey and pollen.

You worked with the BioResources team to investigate these ideas from early 2017 to mid 2019.

Your reduced mowing trial has provided several useful insights into the practicalities of reduced mow options in macadamia orchards. Industry has been particularly concerned that reduced mowing of the inter row may lead to significant problems such as increased rat activity, invasive weeds and/or increased insect pests. Your trial gives other growers reassurance that reduced mowing can be incorporated into existing orchard inter row management and with basic monitoring and management will not lead to other problems. Furthermore, the challenges experienced with your trial in terms of managing a mohawk have been invaluable in assisting the project team develop recommendations for alternate row mow as a good option for many macadamia orchards.

Findings in terms of the difference between a reduced mow inter row and a complete close mow inter row for beneficial arthropods in your orchard are not observable. While we learned a lot about options for reduced mowing, the inconsistently applied reduced mow treatment resulted in inconsistent arthropod data. There were also issues with other confounding factors including hot and dry weather. This is not an unusual outcome with field experiments where there are so many unpredictable and uncontrollable factors in play.

Your results for this trial are likely to be enhanced into the future with sustained commitment to insectaries throughout the orchard that are compatible with standard orchard operations, the inclusion of seeding options, and further refined strategies for reduced mowing including alternate row mowing.

The BioResources team encourages you to read the final report for the *Macadamia IPDM Program - Inter Row Project (MC16008)*, which is available via *Hort Innovation*. Here you will find out more on the benefits of insectaries for macadamia orchards and also the experiences of other trial farms in implementing and managing insectaries. There is also an exploration of the multiple ecosystem services known to flow from reduced mow inter row management practices along with improved arthropod biodiversity, including benefits for soil organic matter, nutrient cycling, water management, erosion control, weed suppression, soil carbon storage, soil microbiology and more.

Introduction

This project proposes that reduced mowing in the macadamia inter row may increase vegetative diversity, increase floral resources and reduce habitat disturbance. This may in turn increase the presence of beneficial arthropods in the orchard. More broadly, the proposed changes in plant ecology may increase arthropod populations in general, leading to more complex food webs and better orchard self-regulation of economic pests. Furthermore, this enhanced nutritional food-web will benefit birds and micro-bats, which also have a role in pollination and pest suppression. Finally, it is estimated that beneficial insects provide 5-10 times the pest control in agricultural ecosystems as compared to chemical applications[1], as these processes are occurring all the time. By encouraging more diverse ecosystems within the orchard the likelihood and/or intensity of pest outbreaks decreases.

You worked with the BioResources team in this investigation from early 2017 to mid 2019. We compared two 1 Ha blocks. A control block was managed as industry standard with regular mowing (**Photo 1**, below). A treatment block was managed with reduced mowing, with a centre mohawk where conditions permitted (**Photo 2**, below).

Photo 1: "Thomas" complete close mow 23 Nov 2017

Photo 2: "Thomas" mohawk 23 Nov 2017

As you will recall, with each site visit the BioResources team sampled each block for arthropods in three separate rows using yellow stick traps (YSTs), placing one YST in the inter row and one YST in a tree. We assessed the vegetation in the inter row at those three points (a quadrant of approximately 10m x 20m). The three data collection points were at least 30m apart, and 50m from any block edge. We also spent time with you discussing the trial and any observations that you may have made in relation to rats, weeds, insect pests in the inter row vegetation and/or any challenges with reduced mowing.

The objective of the trial has been to provide growers with practical experience in reduced mowing on-farm with monitoring to quantify results.

BioResources first worked with growers to consider practical options for reduced mowing that are compatible with the seasonal demands of orchard management. It has then sought to provide information on any relationship between reduced mowing and the potential for increased rat, invasive weed, and/or arthropod pest presence. Finally, the trial has sought to monitor association between changes in inter-row vegetation management and changes in orchard beneficial/pest arthropod ecology.

[1] Pimentel, D., Stachow, U., Takacs, D.A., Brubaker, H.W., Dumas, A.R., Meaney, J.J., Onsi, D.E., Corzilius, D.B., 1992. Conserving biological diversity in agricultural/forestry systems. BioScience 42, 354-362.

Reduced mowing in the inter row at "Falkirk Farms"

Reduced mowing and potential problems

	Throughout the trial, BioResources regularly monitored for and consulted with Aimee and James Thomas and their management team, on the following issues:
Rats	Rat holes were observed in the mohawk block by the project team during some site visits but not most. You noted that the general area of the farm where the mohawk trial was located experienced some pre-existing rat pressure. Rat activity was observed in the mohawk area during the trial. Rats were making nests and taking nut when it was caught in the mohawk. Changes to mohawk width and then eventually moving to alternate row mow resolved this issue. You maintained a consistent rat management program throughout the trial.
Problem weeds	No issues were observed by the project team during site visits. No issues were reported by the "Falkirk Farms" team. Heavy and ropey older grass presented some challenges for the harvester, but this was resolved with more regular mowing and then a switch to alternate row mowing.
Major insect pests of macadamias	No issues were observed by the project team during site visits. The team monitored vegetation in the inter row for the presence of major macadamia pests including Macadamia Nut Borer, Fruit Spotting Bug and Green Veggie Bug. Plant species typically found in the inter row trial blocks at "Falkirk Farms" were not observed to host these pests. No issues were reported by the "Falkirk Farms" team.
Management of the inter row	You made a number of management innovations throughout the life of the trial. Row width and machinery configuration were not really compatible with a mohawk. Nut was getting caught in the mohawk for a period of time and going mouldy; this adversely impacted nut sample quality. The mohawk width was reduced. The mohawk continued to impede mowing and harvest operations and it was completely removed for harvest. You trialled mowing at different heights. You were interested in optimising the timing of inter row activities like profiling. Eventually it was decided that alternate row mow provided a better balance between conserving vegetation for an insectary and managing the rate and bulk of growth, rather than the mohawk.

Outcomes

Your trial has provided a number of useful insights into the practicalities of reduced mow options in macadamia orchards, and especially the mohawk and alternate row mow. Industry has been especially concerned that reduced mowing of the inter row may lead to significant problems with increased rat activity, invasive weeds and/or insect pests. Results on these issues for your trial give other growers reassurance that reduced mowing can be incorporated into existing orchard inter row management and with basic monitoring and management will not lead to other problems.

Some trial farms, including yours, found through time that maintaining a mohawk in the orchard in parallel with standard orchard operations was difficult. This was a result of a combination of row width and available machinery and was most especially a problem during harvest. This is an important finding, and the project team and participating growers including yourselves formed the opinion that alternate row mow outside of harvest may be a more suitable reduced mow strategy in such circumstances.

Over the life of your trial there were a number of challenges to the consistent incorporation of a reduced mow option into the inter row. More generally there were also cumulative impacts from some irregular mowing, hot and dry weather conditions especially in 2018, and variable timing of spraying between blocks, all of which will have introduced confounding factors into the experimental data. As a result, findings for your trial in terms of the benefits of reduced mowing for beneficial arthropods in the orchard as compared to the complete close mow are not observable. This is not an unusual outcome with field experiments where there are so many unpredictable and uncontrollable factors in play.

In so much as the potential for inter row insectaries in macadamia orchards is concerned, the BioResources team urges you to read the project’s final report, *Macadamia IPDM Program - Inter Row Project (MC16008),* which will be available via *Hort Innovation*. A number of the project’s other trial farms enjoyed more experimentally robust circumstances in their trial blocks, and the results there are very encouraging.

Results of reduced mowing in the inter row

Vegetative diversity

Vegetative diversity refers to the number of plant species present. Changes to regular mowing can change plant species diversity. This can in turn be associated with diversity of arthropod species. **Chart 1** presents data reflecting plant species observed in the inter row by treatment through time. We can see that more plant species are present in the mohawk for every assessment date.

The difference between the two blocks was in fact stronger than this data suggests. The experimental method required recording of all observed plant species. However, in the complete close mow block the majority of species recorded were present in very low numbers and as very small individual specimens. Generally, couch grass dominated there. In the mohawk block by contrast, the was a more even distribution of biomass across a number of species. In summary reduced mowing greatly improved plant species diversity.

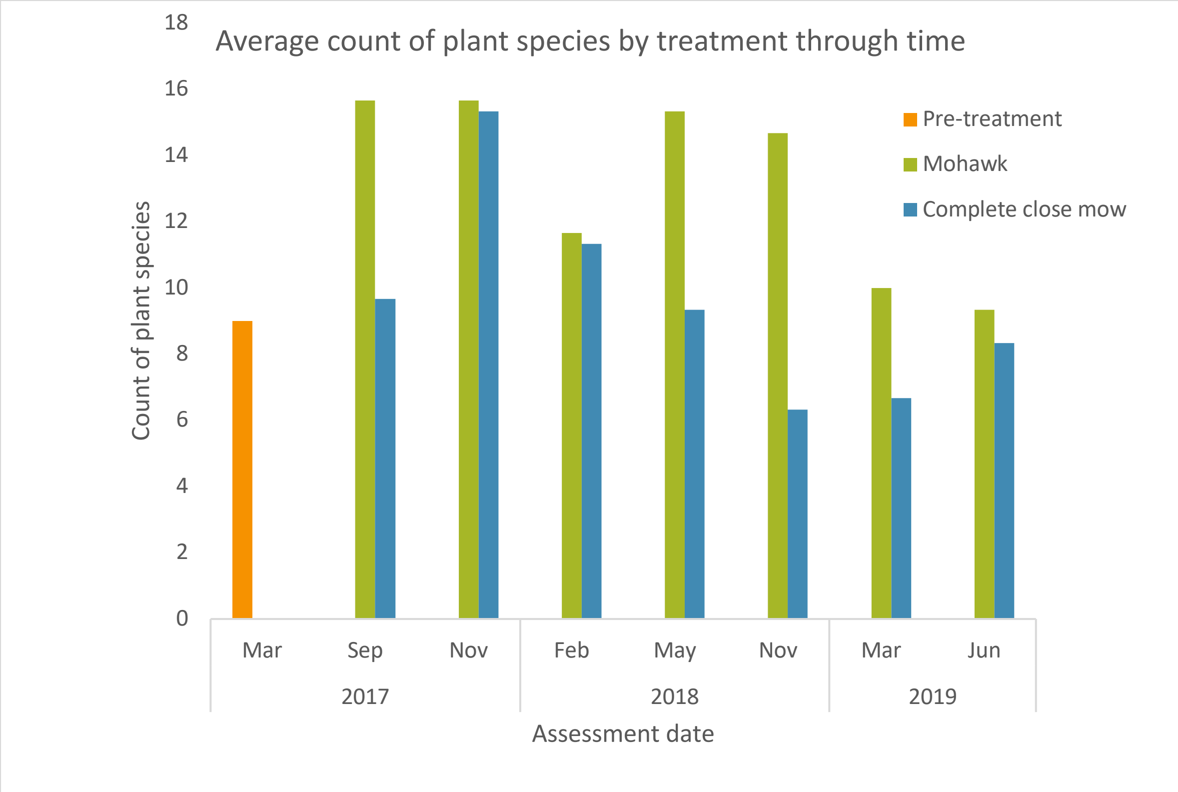


Chart 1: Average count of plant species by treatment through time. This is an average of counts taken at the three assessment points on each block.

Floral resources

Floral resources provide a food source for many beneficial arthropods and will encourage them to remain active in the orchard. In this trial we anticipated that reduced mowing would improve the availability of floral resources for beneficial arthropods. **Chart 2** provides an average count of the plant species flowering at the time of site visits. We can see that the mohawk sustained a greater number of plant species with floral resources for the life of the project. In trial terms, this result demonstrates a distinction between the two blocks for the life of the trial where mowing is reduced. When it comes to performance as an experimental insectary, the results for floral resources in the mohawk block are relatively low. Seeding is an important future consideration here.

In **Chart 3**, we can see that the mohawk block was also more likely to sustain a larger volume of floral resources as a percentage of biomass through time. Furthermore, we can see that there are floral resources in the mohawk at much greater overall percentages as compared to the complete close mow block. Again, this is a useful result for trialling reduced mowing, but a relatively low result for an experimental insectary, where one of the management objectives is high volumes of floral resources. This result arises from the existing plant species mix.

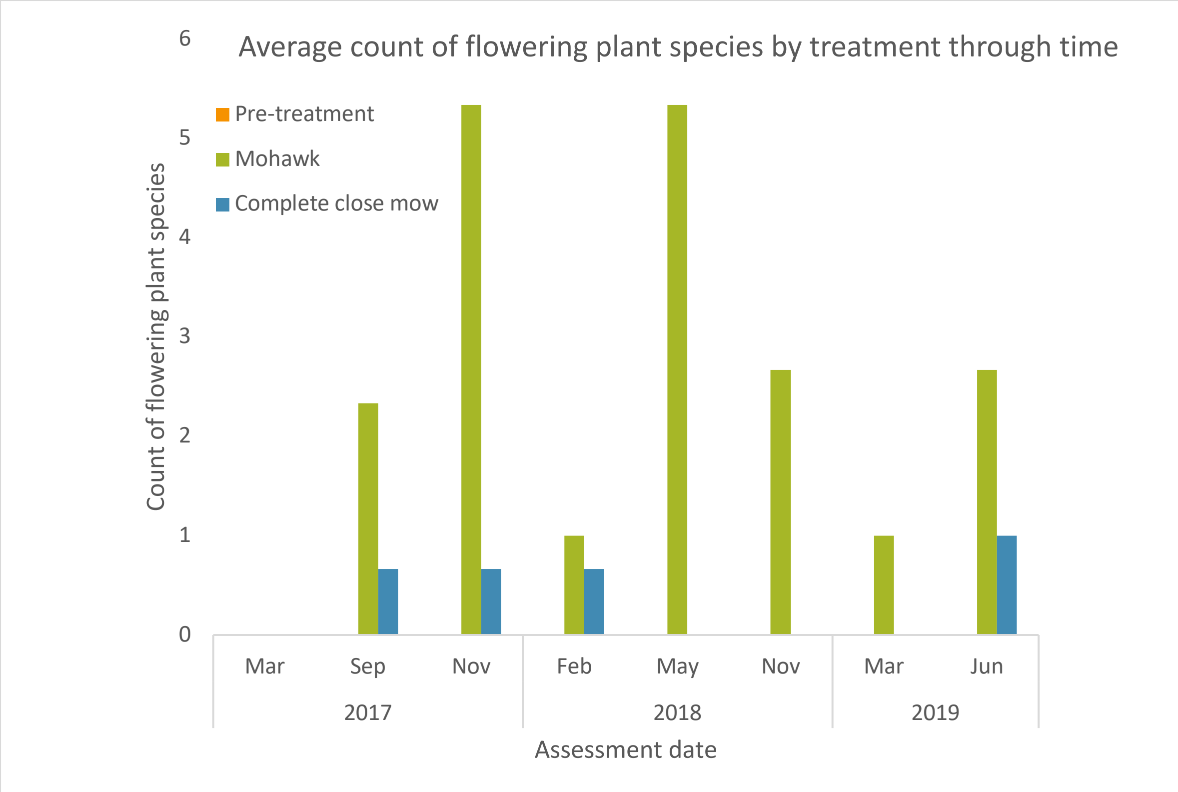


Chart 2: Average count of plant species with floral resources by treatment through time. This is an average of counts taken at the three assessment points on each block.

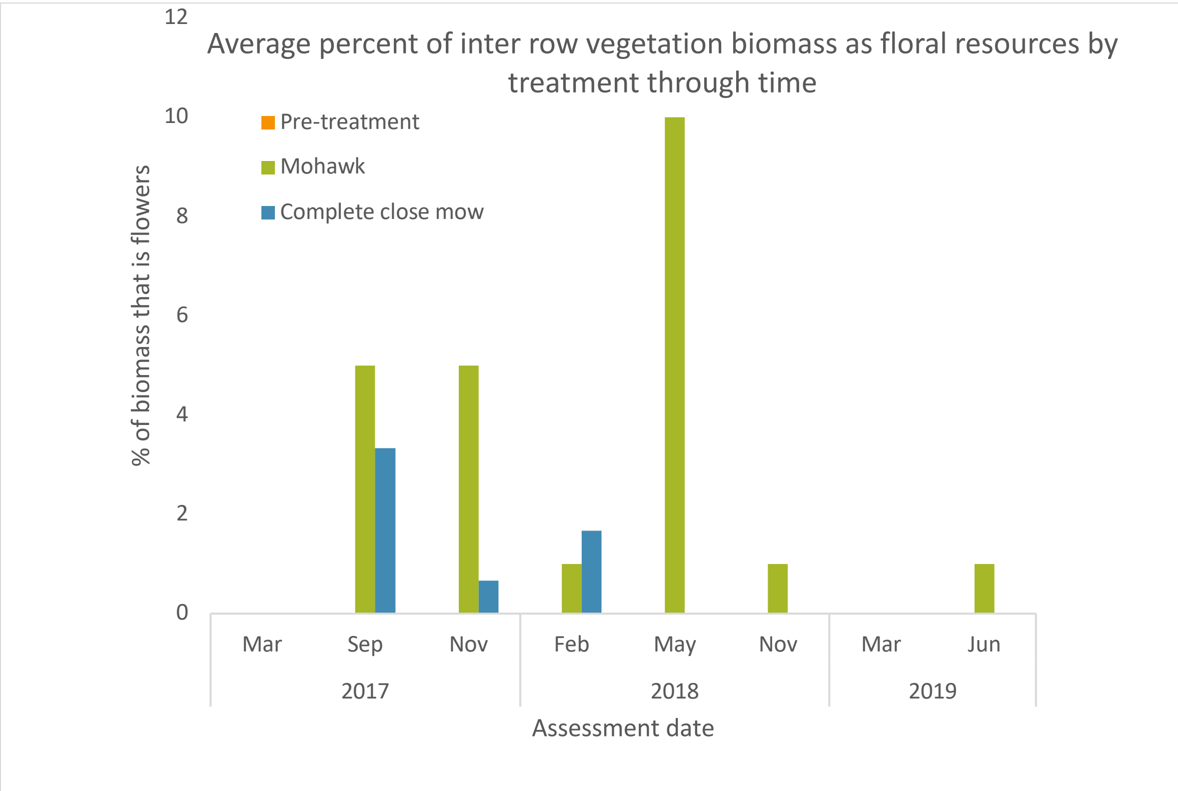


Chart 3: Average percentage of inter row vegetation biomass as floral resources by treatment through time. This is an average of counts taken at the three assessment points on each block.

Habitat disturbance

Areas of reduced mechanical and chemical disturbance can serve as favourable habitat for beneficial arthropods. Undisturbed areas may also provide a refuge for beneficial arthropods for faster recovery after spraying. The measurement of height provides a good indication of rates of mechanical disturbance. **Chart 5** reports the height in centimetres (cm) of vegetation in the inter row by treatment through time. Retention of a central mohawk on your farm allowed for greater height of vegetation, and hence less disturbance, in the inter row for the life of the trial.

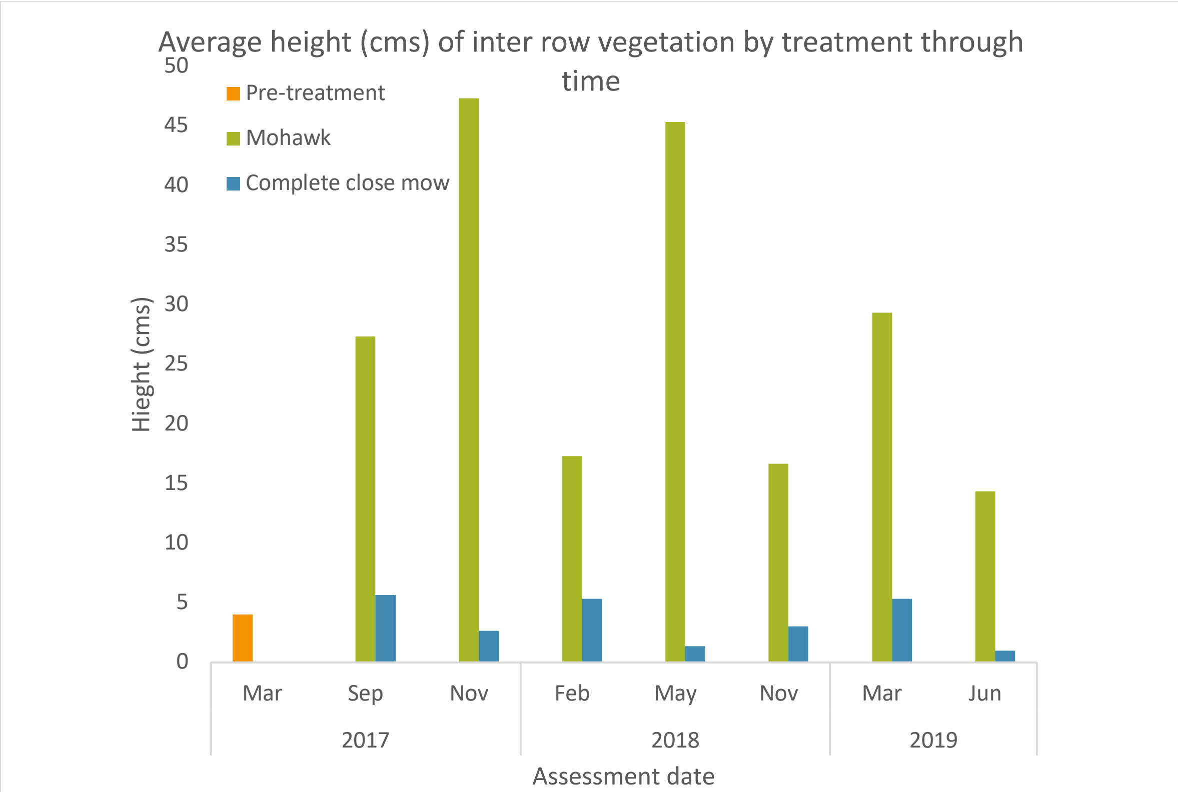


Chart 4: Average height (cm) of inter row vegetation by treatment through time. This is an average of counts taken at the three assessment points on each block.

Results of arthropod evaluation

General arthropod abundance

Charts 5 and 6 present the total numbers of individuals collected for several arthropod groups sampled during the project, comparing the mohawk with the complete close mow. We used yellow sticky traps (YSTs) to sample arthropods within both the inter row and trees. Like all sampling methods, YSTs have biases, which need to be taken into consideration. YSTs sample winged arthropods during flight (though non-winged arthropods do get caught occasionally). Their colour, yellow, is particularly attractive to parasitoids, flies and thrips, which were very well sampled during this project. The abundance data presented below shows only the winged arthropod groups, robber flies, lacewings, aphids, whiteflies, beetles, hemiptera (sap suckers excluding aphids and scale), pollinators (flies), parasitoids and thrips. Other important arthropod groups, such as spiders and ants were not well sampled using YSTs and are omitted from **Charts 5 and 6**.

Thrips, parasitoids, pollinators (flies) were the most abundant arthropod groups sampled during this trial. Within the inter row, parasitoids, pollinators, thrips and hemiptera were all highly abundant (listed in descending order of sample size) (**Chart 5**). In the trees, numbers of hemiptera were relatively low, while pollinators, thrips and parasitoids were all sampled in similarly high numbers (**Chart 6**).

As will be discussed in further detail, below, the overall differences between samples of groups by treatment is small, and there are no clear or consistent patterns discernible through time. The only arthropod group that clearly differs in abundance between the treatment blocks in both inter row and trees are parasitoids. Total parasitoid numbers were higher in both inter rows and trees of the complete close mow block compared to the mohawk block (**Charts 5 and 6**), however, as you will see in **Charts 9 and 10** within the subsection, below, **A focussed look at parasitoids**, only one or two sampling dates showed a significant difference between treatment blocks, and so this difference in parasitoid numbers may be caused by a number of confounding factors, rather than the inter row treatment.

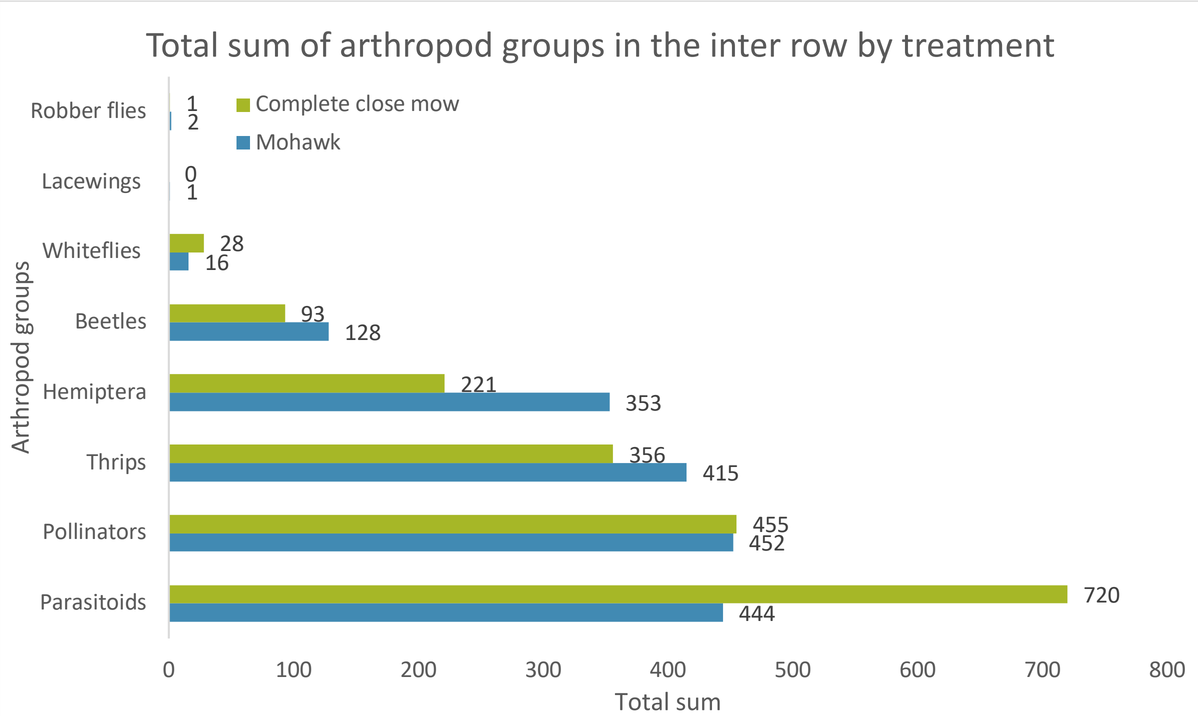


Chart 5: Arthropod abundance: average count by group by treatment through time – sampled in the inter row. This is an average of counts taken at the three assessment points on each block.

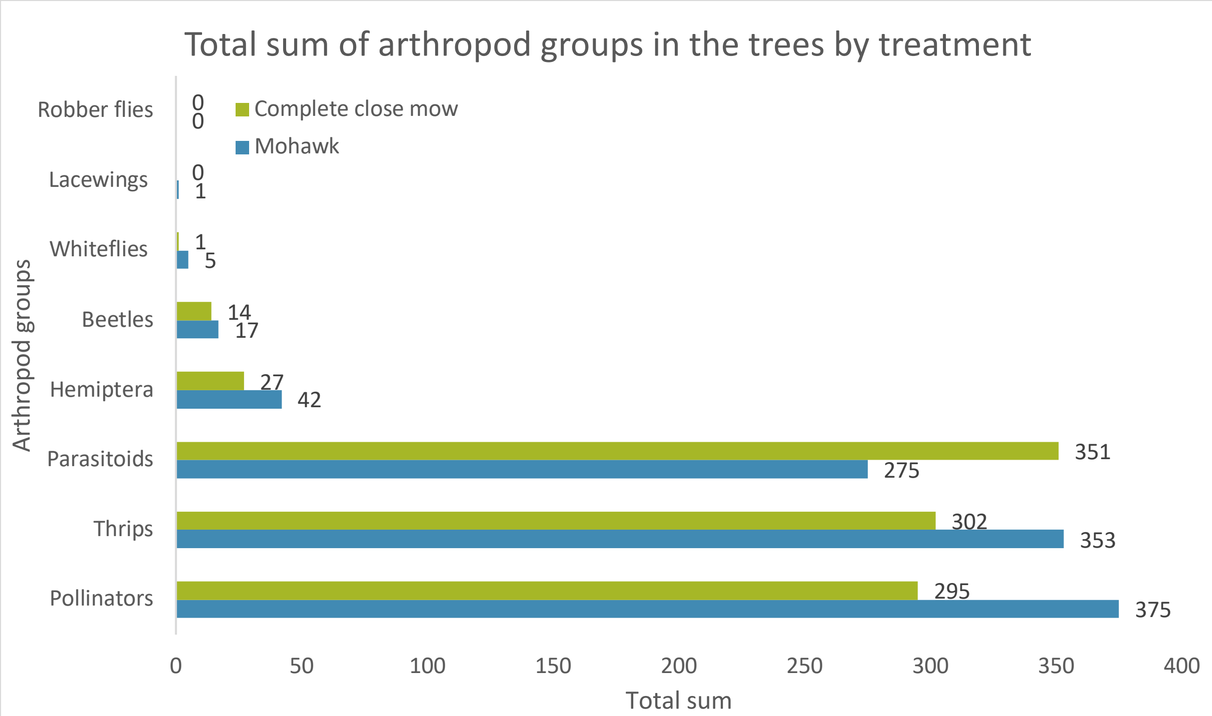


Chart 6: Arthropod abundance: average count by group by treatment through time – sampled in the tree. This is an average of counts taken at the three assessment points on each block.

A focussed look at thrips

Thrips are broadly categorised as 'herbivores' because the majority feed on the outer layer of plant cells, but most thrips also feed on pollen, and help in plant pollination. Other groups of thrips feed on fungal spores and some are predatory and important in biological control.

In a broader context, thrips play an important part within the food web because they are abundant, soft-bodied and are small and palatable, so many predatory insects eat them. Thrips only reach pest status within macadamias when populations are high and the crop itself is at a vulnerable stage i.e. flowering or leaf flush.

Within **Charts 7 and 8** you will see that thrips were sampled in reasonably low numbers (around 10-20 individuals per YST) for the majority of the sampling period in both inter row and trees in both treatment blocks. There was, however, two sampling periods within the trees where thrip numbers spiked to somewhat higher levels, and this was in March 2017 and March 2019 (**Chart 8**). We also observed during our February 2018 site visit that thrips had caused higher levels of damage to leaf flush in trees in both treatment blocks, however, this spike was not recorded by our sampling in February 2018, possibly because the thrip population had already spiked then returned to lower levels by the time we were trapping. Within the inter rows, thrips were only sampled in high numbers in March 2019 (**Chart 7**), and numbers during this sampling period were significantly higher in the mohawk block compared to the complete close mow block, both within the inter and trees (**Charts 7 and 8**).

Overall, treatment differences with regards to thrip numbers in both inter row or trees were neither clear nor consistent over the sampling period on your farm. A properly distinguished and well maintained 'mohawk' within the inter row may expect to see higher numbers of thrips compared to an inter row that is closely mowed. But within the inter row, thrips can potentially play an important part in ensuring there is always food for beneficial invertebrates, so that pest outbreaks are less likely to happen within the tree. As discussed in the **Introduction** and **Results of reduced mow in the inter row**, a healthy ecosystem within the inter row depends on the correct mix of plant species and the right balance between minimal disturbance and necessary management.

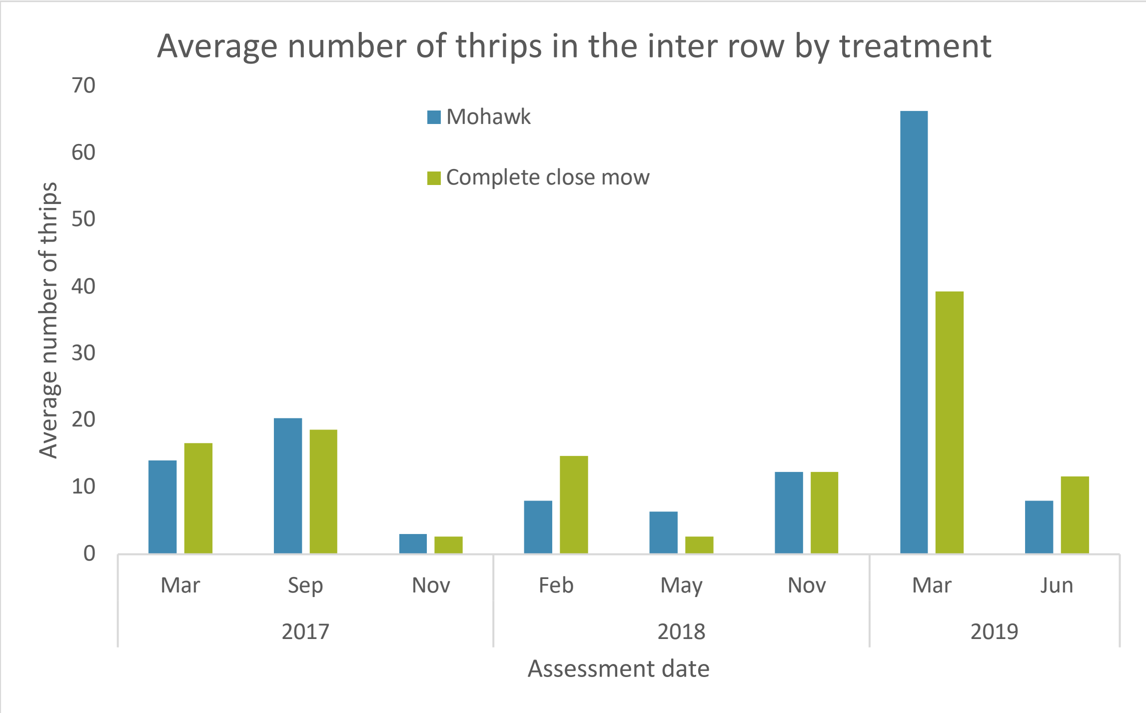


Chart 7: Average number of thrips by treatment through time – sampled in the inter row. This is an average number taken from the three assessment points on each block.

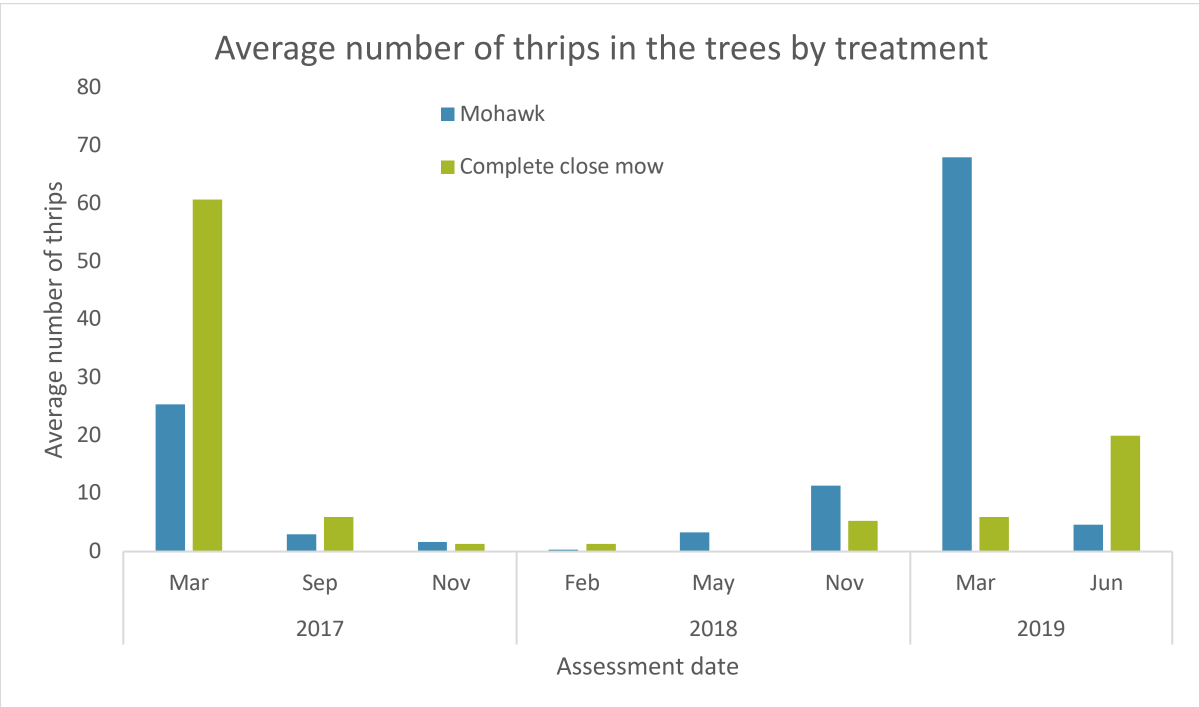


Chart 8: Average number of thrips by treatment through time – sampled in the tree. This is an average number taken from the three assessment points on each block.

A focussed look at parasitoids

Parasitoids are representatively sampled using yellow sticky traps and can provide a meaningful indication of how the inter row treatments affect this important group of beneficial invertebrates. This sample includes MacTrix and Anastatus releases along with other hymenoptera already present in the orchard environment.

Within the inter row, there was no consistent difference between treatments in terms of parasitoid abundance (**Chart 9**). Parasitoids were in relatively low and comparatively similar numbers within inter rows of both treatment blocks throughout the sampling period with one exception. In March 2019 there was a spike in parasitoid numbers within inter rows of the complete close mow block (**Chart 9**). As this spike in parasitoid numbers also occurred in the trees of both treatment blocks (**Chart** 10), it is unlikely that inter row vegetation was responsible for the increased parasitoid numbers.

Within the trees, parasitoids were sampled in slightly lower numbers than the inter row (check y-axis when comparing **Charts 9 and 10**). In other farms where a mohawk has been able to be established and maintained, there are substantially more parasitoids sampled from the mohawk inter row compared to the trees. During 2018, there were less parasitoids sampled from trees compared to 2017 (**Chart 10**), which may reflect hotter/drier weather conditions experienced in 2018. The spike in parasitoid numbers sampled within trees of both treatment blocks during March 2019 may have been due to favourable weather conditions and an increase in host arthropods during that period.

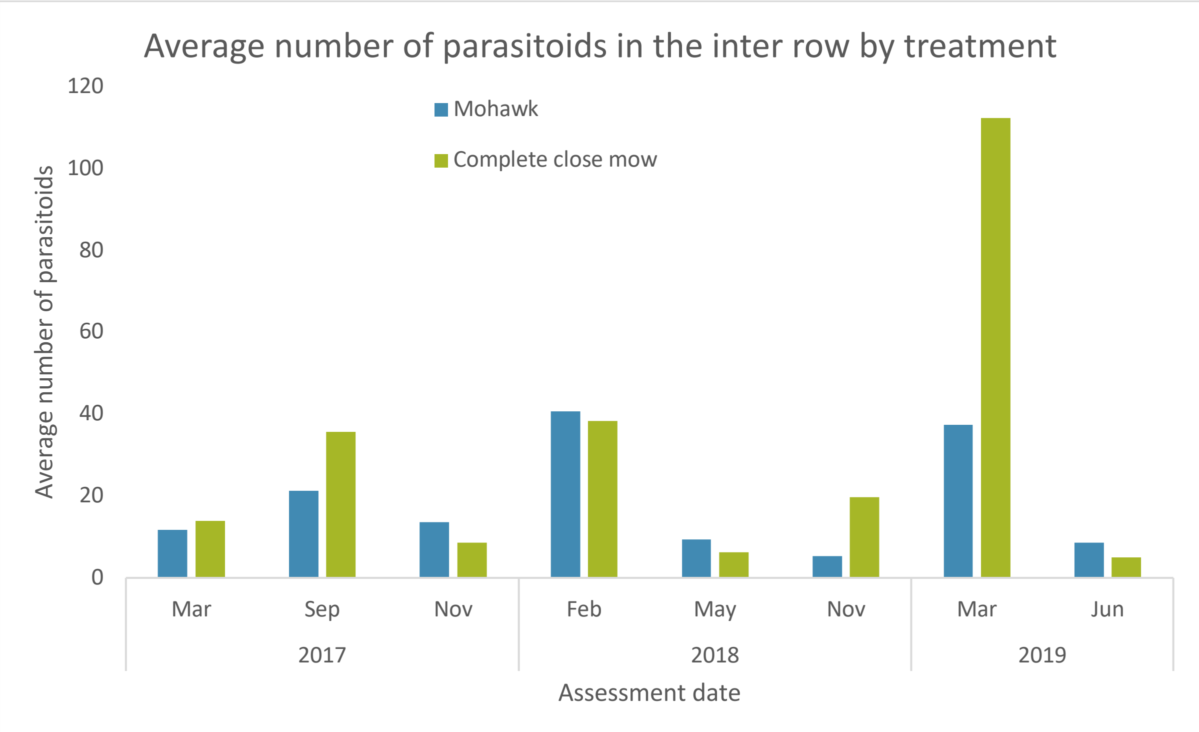


Chart 9: Average number of parasitoids by treatment through time – sampled in the inter row. This is an average number taken from the three assessment points on each block.

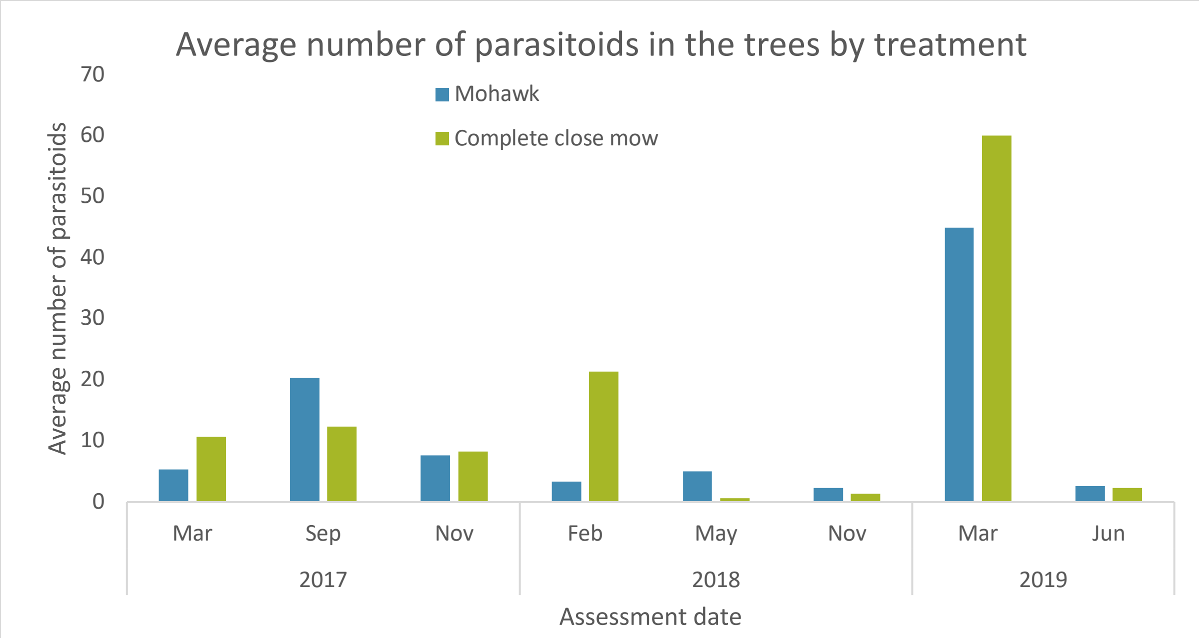


Chart 10: Average number of parasitoids by treatment through time – sampled in the tree. This is an average number taken from the three assessment points on each block.

A focussed look at pollinators

As seen in **Charts 5 and 6,** pollinators were one of the most abundant arthropod groups sampled by YSTs in both inter rows and trees in this trial, with roughly similar numbers to parasitoids. Pollinators are arthropods which carry pollen from one plant to another, and these are predominantly bees, moths and butterflies, and a substantial proportion of beetles and flies. YSTs do not sample bees, beetles, moths or butterflies particularly well, but flies are well sampled by YSTs so our term 'pollinators' encapsulates only flies. Flies are also an important food source for predatory insects such as spiders.

Within both inter row and trees, there was no clear or consistent difference between treatments in terms of pollinator abundance over the sampling period (**Charts 11 and 12**). Within the inter row, a spike in pollinator numbers within the mohawk block in September 2017 (**Chart 11**) suggests during this period the mohawk itself was functioning relatively well as an insectary compared to other months. Within the trees, a spike in pollinator numbers within both treatment blocks occurred in November 2017 which may be related to compost/manure, which was being spread in both trial blocks during the week that the YSTs were out (given that pollinators evaluated here are all flies).

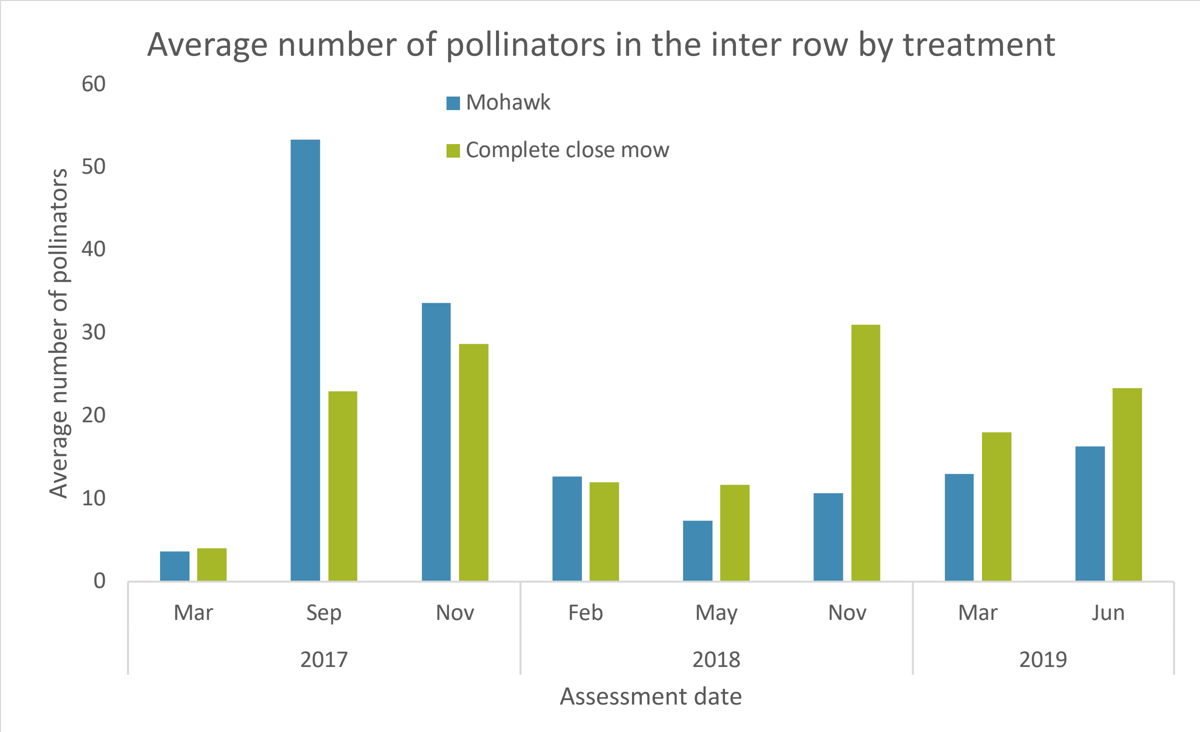


Chart 11: Average number of pollinators by treatment through time – sampled in the inter row. This is an average number taken from the three assessment points on each block.

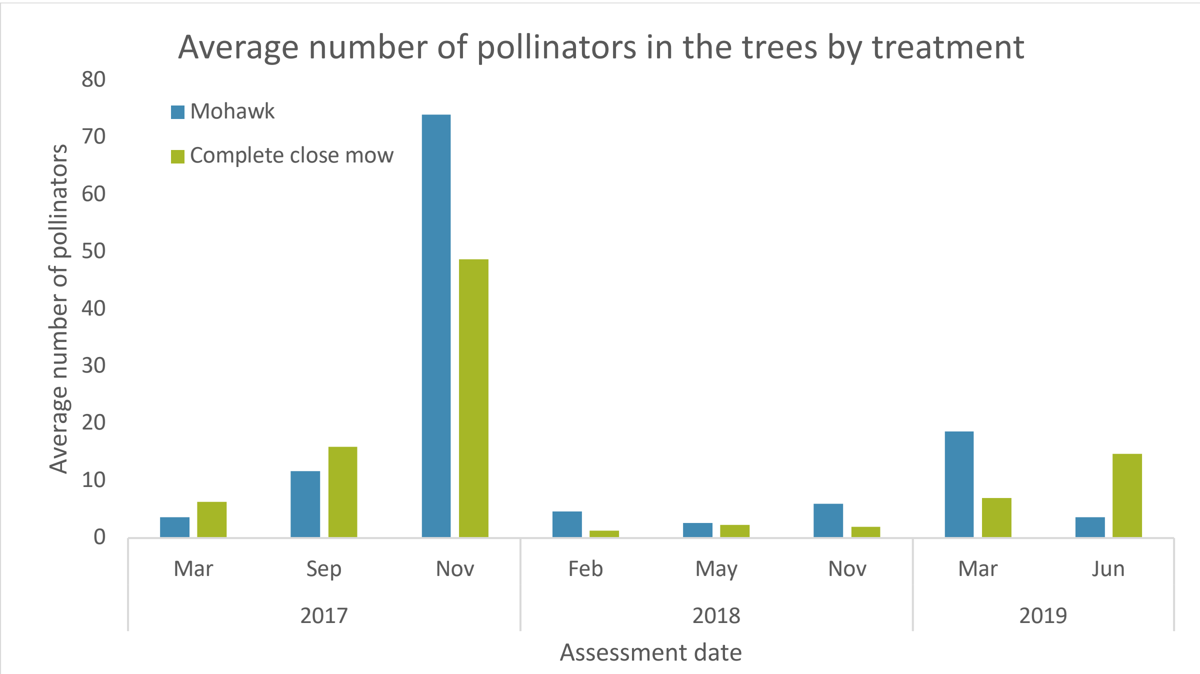


Chart 12: Average number of pollinators by treatment through time – sampled in the tree. This is an average number taken from the three assessment points on each block.

Findings and recommendations

Mohawk-style reduced mowing did not work as well with your trial as it did on some other farms. This was a common outcome for this project on a number of farms with a row width of less than 10m. Retaining a mohawk year-round, proved to be difficult at times, especially in relation to the requirements of harvest. Where you responded to these challenges with a series of innovations, we can provide industry with useful recommendations on a range of reduced mowing options, as suitable on a farm-by-farm basis.

In particular, we found in the concluding months of your trial that alternate row mow was likely a better management option than the mohawk, outside of harvest. You switched from mohawk to mowing every second row on a rotating schedule, allowing all rows to "grow out" somewhat across the year but providing opportunities for mow management as required. This reduces the overall disturbance of beneficial arthropods, ensuring a refuge remains in place at all times for them.

These useful iterations in deciding on a best-fit reduced mow approach for your orchard meant however, that we were unable to sustain a consistent treatment for the purposes of a field experiment. This is reflected in the inconsistent results for arthropod data, where we are consequently unable to discern clear or consistent trends associated with a comparison of the two trial blocks. In the final analysis, we also found that while the reduced mowing on your farm did somewhat improve the inter row for the purposes of an insectary, this was at very low rates particularly when floral resources are considered. We discussed the timing of mowing, such that existing grasses on-farm have more opportunity to flower, which will provide attractive nectar and particularly pollen for beneficial arthropods.

We also discussed the potential for seeding your inter row with suitable seed mixes and cover crops. The floral resources available in the vegetation currently present in the trial blocks' inter rows are quite limited. You can consider some seeding or even cover crops if you wish to use their features for more targeted benefits from the inter row including improved seasonally-specific resources for pollinators and parasitoids, along with other ecosystem services.

Overall, project findings indicate that insectaries have meaningful influence on orchard ecology when growers can commit to inclusion of the insectary in the orchard in terms of space allocation and long-term management. For your trial, the inter row mohawk did not work very well given row width. Alternate row mow is a better option and is discussed above. And there are other areas on-farm worth considering, including headlands, field margins and so on where changes to management can allow for habitat suitable for beneficial arthropods. Decisions to improve plant diversity with selective seeding, well-timed seeding and mowing to limit dominance of one species while encouraging new growth and flowering and so on are very influential.

Finally, the BioResources team encourages you to read the final report for the *Macadamia IPDM Program - Inter Row Project (MC16008)*, which is available via *Hort Innovation*. Here you will find out more on the benefits of insectaries for macadamia orchards and also the experiences of other trial farms in implementing and managing insectaries. There is also an exploration of the multiple ecosystem services known to flow from changed inter row management practices along with improved arthropod biodiversity, including benefits for soil organic matter, nutrient cycling, water management, erosion control, weed suppression, soil carbon storage, soil microbiology and more.

Acknowledgements and thanks

The project team wishes to thank the Aimee and James Thomas for their participation, contributions and support.

Final Report

"Wiley" – Macadamia Inter Row Trial Results

Hort Innovation program title: The IPM program for the macadamia industry – BioResources

Hort Innovation project code: MC16008

Date: February 2020

Summary

This project proposes that reduced mowing in the macadamia inter row may improve vegetation there for the purposes of an insectary. Where managed reduced mowing is possible, it is further proposed that beneficial arthropods crucial to pollination, pest suppression and the "food-web" will be present and active in higher numbers. This can decrease the likelihood and/or intensity of pest outbreaks because populations of beneficial invertebrates will be present within the orchard.

You worked with the BioResources team to investigate these ideas from early 2017 to mid 2019.

Your reduced mowing trial has provided several useful insights into the practicalities of reduced mow options in macadamia orchards and especially the mohawk. Industry has been particularly concerned that reduced mowing of the inter row may lead to significant problems such as increased rat activity, invasive weeds and/or increased insect pests. Your trial gives other growers reassurance that a mohawk can be incorporated into existing orchard inter row management and with basic monitoring and management will not lead to other problems.

Findings in terms of the benefits of a mohawk for beneficial arthropods in the orchard for your trial are observable but overall are modest biodiversity increases. This is not an unusual outcome with field experiments where there are so many unpredictable and uncontrollable factors in play.

The results for your trial are likely to be enhanced into the future where you can maintain your current commitment to insectaries throughout your entire orchard. You have developed your own innovative strategies for reduced mowing, which are compatible with standard orchard operations while allowing retention of some vegetation year-round. Your farm enjoys an unusually diverse mix of naturalised weeds and natives in the inter row with desirable characteristics for an insectary and which is also reasonably easily managed for weediness. You can consider some seeding with cover crops if you wish to use their features for more targeted benefits from the inter row including improved seasonally-specific resources for pollinators and parasitoids, along with other ecosystem services (see below).

The BioResources team encourages you to read the final report for the *Macadamia IPDM Program - Inter Row Project (MC16008)*, which is available via *Hort Innovation*. Here you will find out more on the benefits of insectaries for macadamia orchards and also the experiences of other trial farms in implementing and managing insectaries. There is also an exploration of the multiple ecosystem services known to flow from reduced mow inter row management practices along with improved arthropod biodiversity, including benefits for soil organic matter, nutrient cycling, water management, erosion control, weed suppression, soil carbon storage, soil microbiology and more.

Introduction

This project proposes that reduced mowing in the macadamia inter row may increase vegetative diversity, increase floral resources and reduce habitat disturbance. This may in turn increase the presence of beneficial arthropods in the orchard. More broadly, the proposed changes in plant ecology may increase arthropod populations in general, the over-whelming majority of which are non-economic and will be food for beneficial arthropods. Furthermore, this enhanced nutritional food-web will benefit birds and micro-bats, which have a role in pollination and pest suppression. Having a food-web within the orchard decreases the likelihood and/or intensity of pest outbreaks because populations of beneficial invertebrates are present within the orchard feeding on other arthropods.

These propositions warrant investigation because an increased presence of beneficial arthropods in the orchard may result in improved pest suppression and also improved pollination, via reduced crop damage, reduced inputs like chemical applications and subsequently improved yields.

You worked with the BioResources team in this investigation from early 2017 to mid 2019. We compared two (approximately) 1 Ha blocks. A control block was managed as industry standard with regular mowing (**Photo 1**, below). A treatment block was managed with reduced mowing, sustaining a centre mohawk for most of the trial period (**Photo 2**, below).

Photo 1: "Wiley" complete close mow 17 March 2017

Photo 2: "Wiley" mohawk 17 March 2017

As you will recall, with each site visit the BioResources team sampled each block for arthropods in three separate rows using yellow stick traps (YSTs), placing one YST in the inter row and one YST in a tree. We assessed the vegetation in the inter row at those three points (a quadrant of approximately 10m x 20m). The three data collection points were at least 30m apart and 50m from any block edge. We also spent time with you discussing the trial and any observations that you may have made in relation to rats, weeds, insect pests in the inter row vegetation and/or any challenges with reduced mowing.

The objective of the trial has been to provide growers with practical experience in reduced mowing on-farm with monitoring to quantify results.

BioResources first worked with growers to consider practical options for reduced mowing that are compatible with the seasonal demands of orchard management. It has then sought to provide information on any relationship between reduced mowing and the potential for increased rat, invasive weed and/or arthropod pest presence. Finally, the trial has sought to monitor association between changes in inter row vegetation management and changes in orchard beneficial/pest arthropod ecology.

Reduced mowing in the inter row at "Wiley"

Reduced mowing and potential problems

	Throughout the trial, BioResources regularly monitored for and consulted with Sue Wiley, on the following issues:
Rats	The project team observed evidence of rat activity in the mohawk during some but certainly not all site visits. You were aware of this but were unconcerned. You noted that you do have rats on-farm, but you were satisfied that existing management approaches were satisfactory and that the reduced mowing trial did not concern you in terms of potential changed rat behaviour or increased populations. You noted that you use the tendency of rats to nest and burrow in the mohawk for monitoring and also management, whereby you heavily slash out areas where rats are observed. You made a general observation relating to pruning that rats will nest under branches on the ground, even if they have only been there for one night.
Problem weeds	The project team observed during site visits from August 2017 onwards that Cobbler's Pegs became increasingly dominant and woody in the absence of intermittent mowing. You confirmed this observation. You modified your mohawk management to include intermittent mowing and slashing of selected areas, as suited your management requirements. Other potentially invasive woody weeds observed by the project team included Wild Tobacco and Paddy's Lucerne in low numbers. You reported that these were not a major concern and you would remove with slashing as suited you.
Major insect pests of macadamias	No issues were observed in the inter row by the project team during site visits. The team monitored vegetation in the inter row for the presence of major macadamia pests including Macadamia Seed Weevil, Macadamia Nut Borer, Fruit Spotting Bug and Green Veggie Bug. Plant species typically found in the inter row trial blocks at on your farm were not observed to host these pests. No issues were reported by you. This includes minor pests such as thrips, which were observed in the data, but you did not report problems with thrips damage in your trees.
Management of the inter row	No issues were observed by the project team during site visits. No issues were reported by you. A number of machinery options were available for mowing, slashing and harvesting, which suited straightforward inclusion of a mohawk in the trial block year-round.

Outcomes

Your trial has provided several useful insights into the practicalities of reduced mow options in macadamia orchards and especially the mohawk. Industry has been especially concerned that reduced mowing of the inter row may lead to significant problems with increased rat activity, invasive weeds and/or insect pests. Your trial gives other growers reassurance that a mohawk can be incorporated into existing orchard inter row management and with basic monitoring and management will not lead to other problems.

Results for your trial were greatly impacted by site-specific local plant species and their response to the experimental protocols (notably, Cobbler's Pegs). Furthermore, the proximity of the control block to the rainforest creek area and also the two trial blocks to each other may have had a more significant influence on encouraging local arthropod populations into the trial area than the project's experimental design could factor in (**Photo 3**). These conditions limited our ability to maintain a strong experimental distinction between the control block and the treatment mohawk block for the life of the project.

Thus, findings in terms of the benefits for beneficial arthropods in a mohawk as distinct from complete close mow in your orchard were confounded by difficulties with experimental design. This is not an unusual outcome with field experiments where there are so many unpredictable and uncontrollable factors in play.

In so much as the potential for inter row insectaries in macadamia orchards is concerned, the BioResources team urges you to read the project's final report, *Macadamia IPDM Program - Inter Row Project (MC16008),* which will be available via *Hort Innovation*.

Photo 3: "Wiley" map of experimental site and experimental design. The non-crop adjacent vegetation including the rainforest creek on the far right-hand side of the photo was likely very influential over arthropod ecology in the blocks, as was the proximity of the two blocks to each other.

Results of reduced mowing in the inter row

Vegetative diversity

Vegetative diversity refers to the number of plant species present. Changes to regular mowing can change plant species diversity. This can in turn be associated with diversity of arthropod species. **Chart 1** presents an average count of plant species observed in the inter row by treatment through time.

In this trial we anticipated that reduced mowing would increase the number of plant species present in the orchard. However, we found on some participating farms, including yours, that through time, less mowing *reduced* plant species diversity somewhat. This is because the presence of some species such as Cobbler's Pegs can become so dominant that they suppress other plant species in the absence of occasional mowing. As we discussed during site visits, un-mowed areas of Cobbler's Pegs became woody and shady through time, crowding out other plant species.

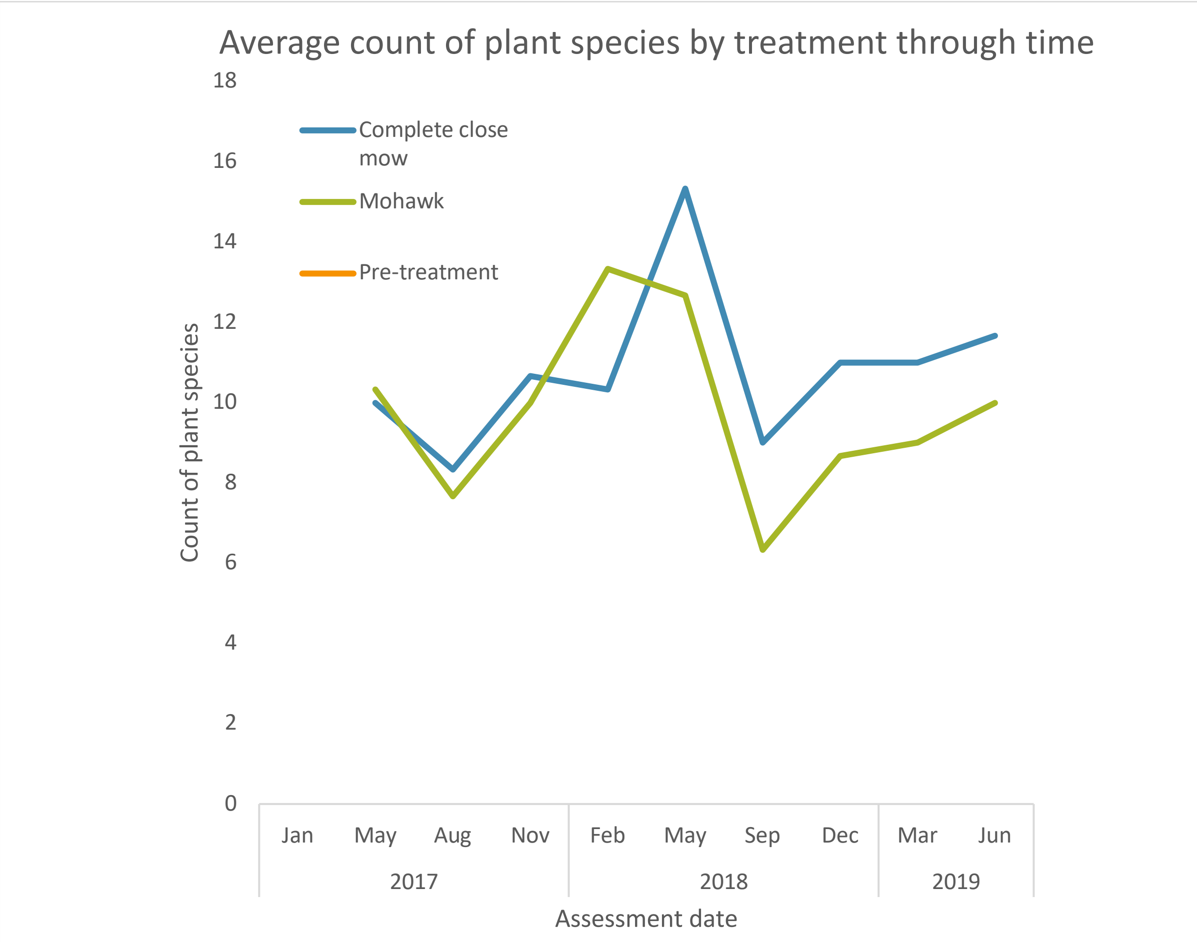


Chart 1: Average count of plant species by treatment through time. This is an average of counts taken at the three assessment points on each block.

Floral resources

Floral resources provide a food source for many beneficial arthropods and will encourage them to remain active in the orchard. **Chart 2** provides an average count of the plant species flowering at the time of the site visit. There were consistently higher numbers of flowering plant species in the mohawk block. In conjunction with this, we also see that these flowering species always produced a larger volume of flowers as a percent of biomass in the mohawk block as compared to the complete close mow block (**Chart 3**).

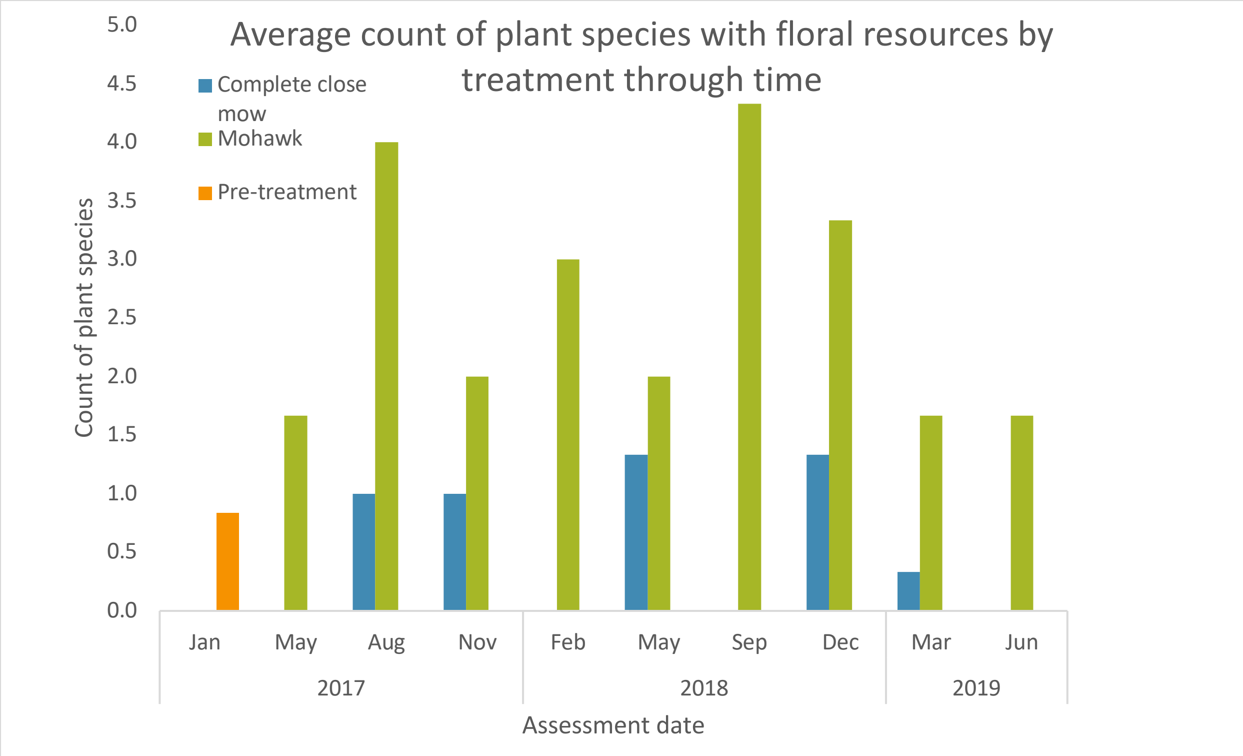


Chart 2: Average count of plant species with floral resources by treatment through time. This is an average of counts taken at the three assessment points on each block.

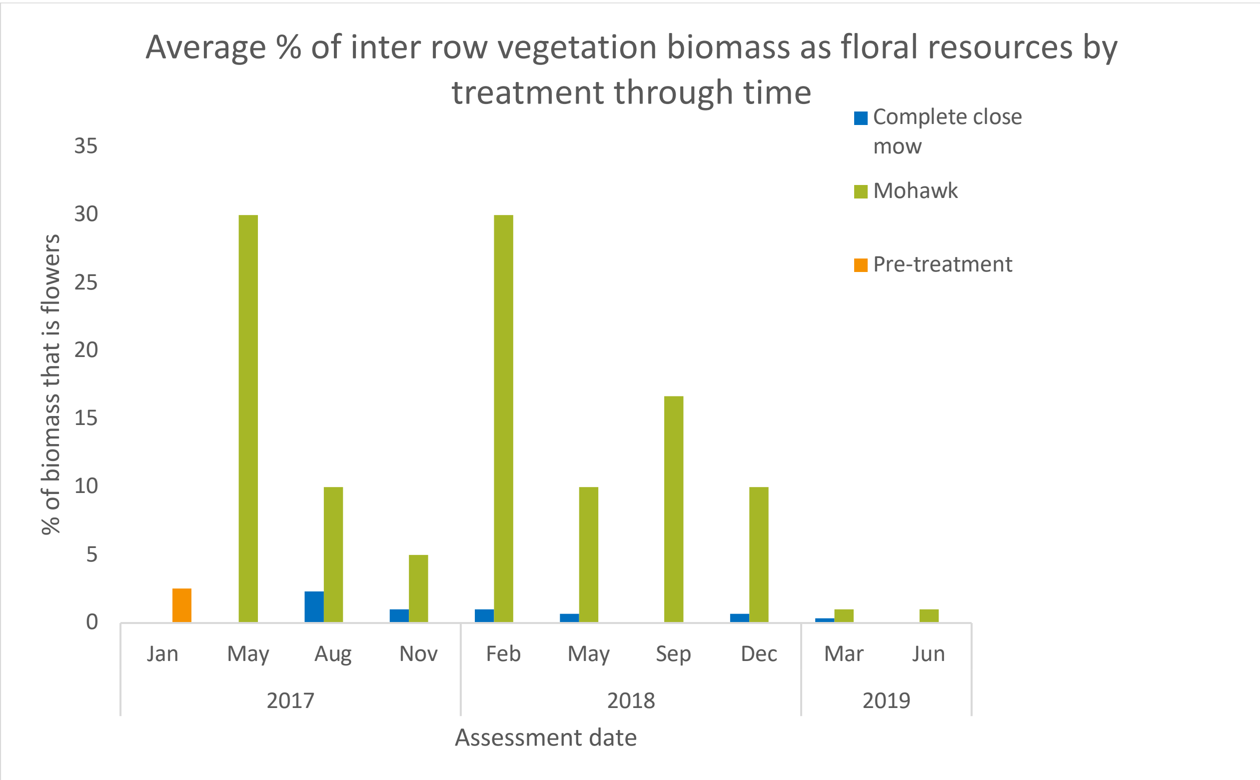


Chart 3: Average percentage of inter row vegetation biomass as floral resources by treatment through time. This is an average of counts taken at the three assessment points on each block.

Habitat disturbance

Areas of reduced mechanical and chemical disturbance can serve as favourable habitat for beneficial insects. Undisturbed areas may also provide a refuge for beneficial arthropods for faster recovery after spraying. The measurement of height provides a good indication of rates of mechanical disturbance. **Chart 4** reports the height in centimetres (cm) of vegetation in the inter row by treatment through time. Retention of a central mohawk on your farm allowed for greater height of vegetation, and hence less disturbance in the inter row for the life of the trial.

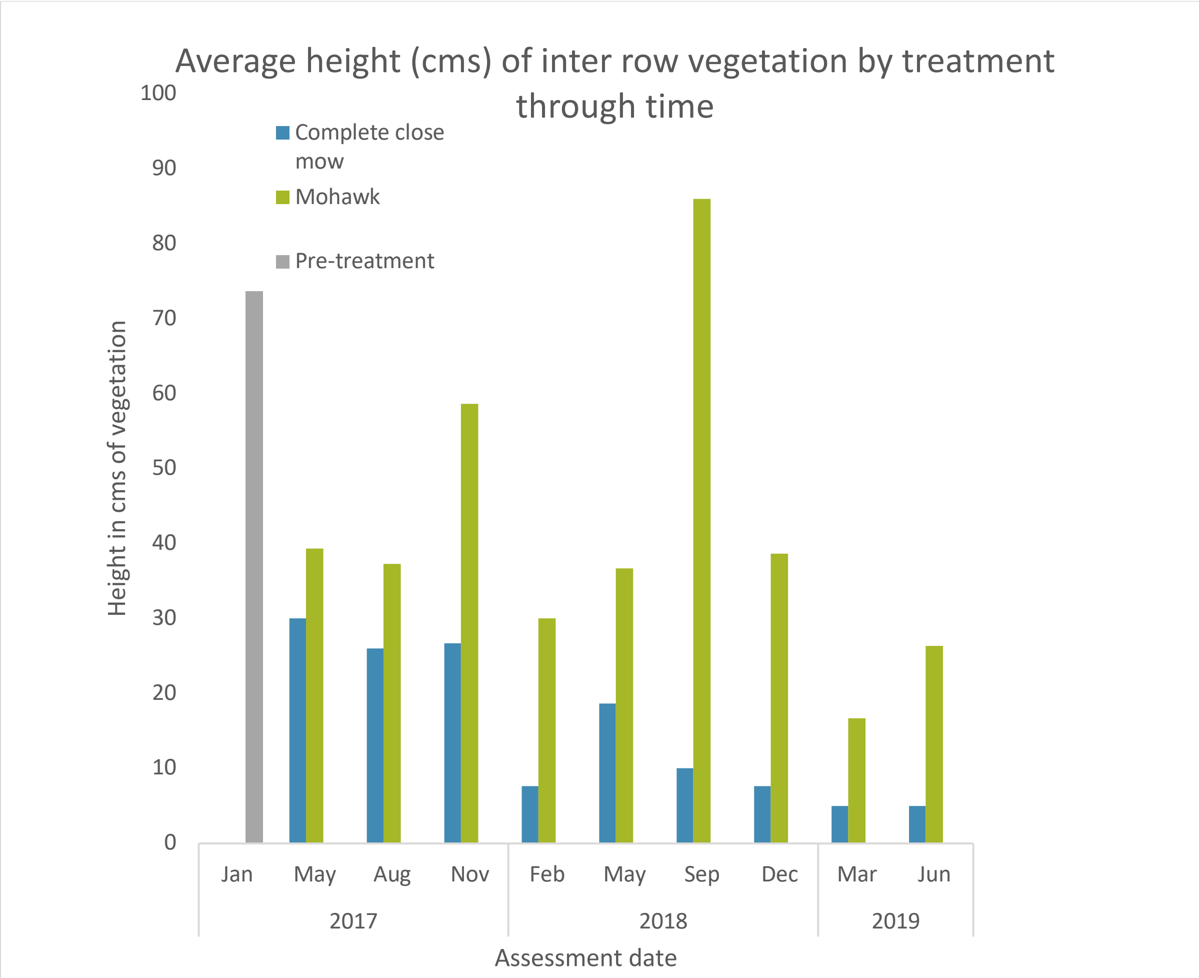


Chart 4: Average height (cm) of inter row vegetation by treatment through time. This is an average of counts taken at the three assessment points on each block.

Results of arthropod evaluation

General arthropod abundance

Charts 5 and 6 present the total numbers of individuals collected for several arthropod groups sampled during the project, comparing the mohawk with the complete close mow. We used yellow sticky traps (YSTs) to sample arthropods within both the inter row and trees. Like all sampling methods, YSTs have biases, which need to be taken into consideration. YSTs sample winged arthropods during flight (though non-winged arthropods do get caught occasionally). Their colour, yellow, is particularly attractive to parasitoids, flies and thrips, which were very well sampled during this project. The abundance data presented below shows only the winged arthropod groups; robber flies, lacewings, aphids, whiteflies, beetles, hemiptera (sap suckers excluding aphids), pollinators (flies), parasitoids and thrips. Other important arthropod groups, such as spiders and ants were not well sampled using YSTs and are thus omitted from **Charts 5 and 6**.

Parasitoids, flies (pollinators) and thrips were the most abundant arthropod groups sampled during this trial. All of these arthropod groups were more abundant within the inter row than the trees (see x-axis when comparing **Charts 5 and 6**). In total, parasitoid numbers were slightly higher in trees with the mohawk block, but there were far more in inter rows within the complete close mow block. This is likely at least partially the result of regular releases of biocontrols along the crop perimeter and in the rainforest area, which are adjacent to the complete close mow block. Pollinator numbers were roughly equal between treatments in the trees as well as inter rows, while thrip numbers were higher in both inter rows and trees of the mohawk block. Whitefly, beetle and hemipterans were also sampled in substantial numbers from both trees and inter rows of both treatment blocks.

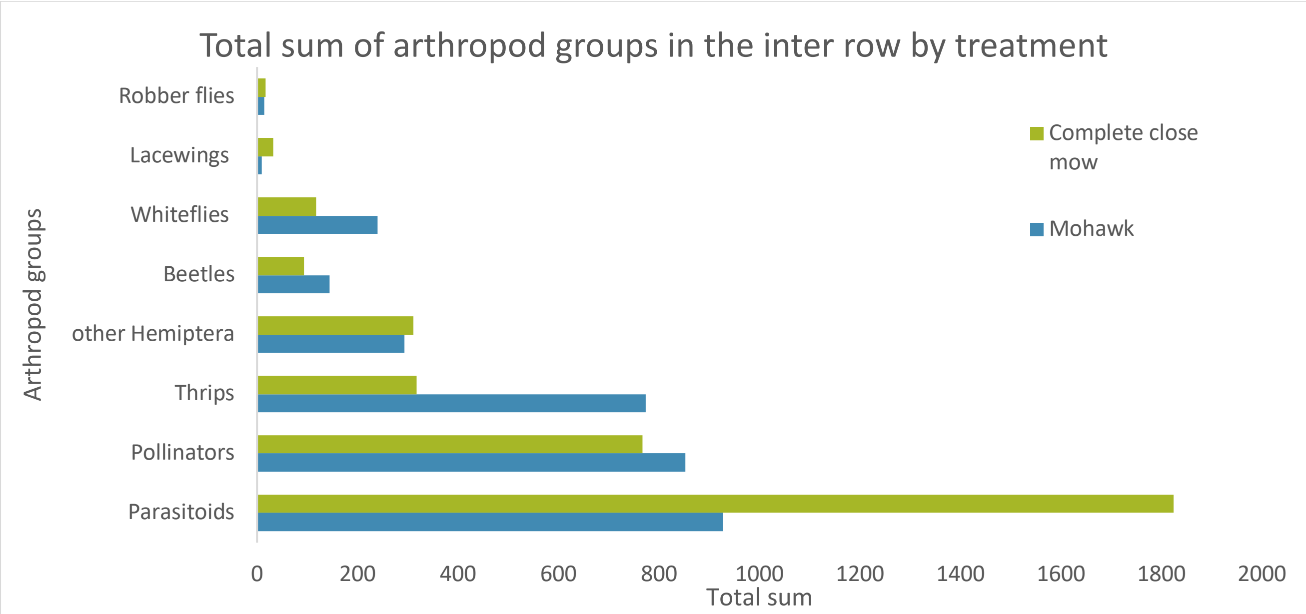


Chart 5: Total sum of each arthropod group within the inter row, compared between the two treatments, over the sampling period.

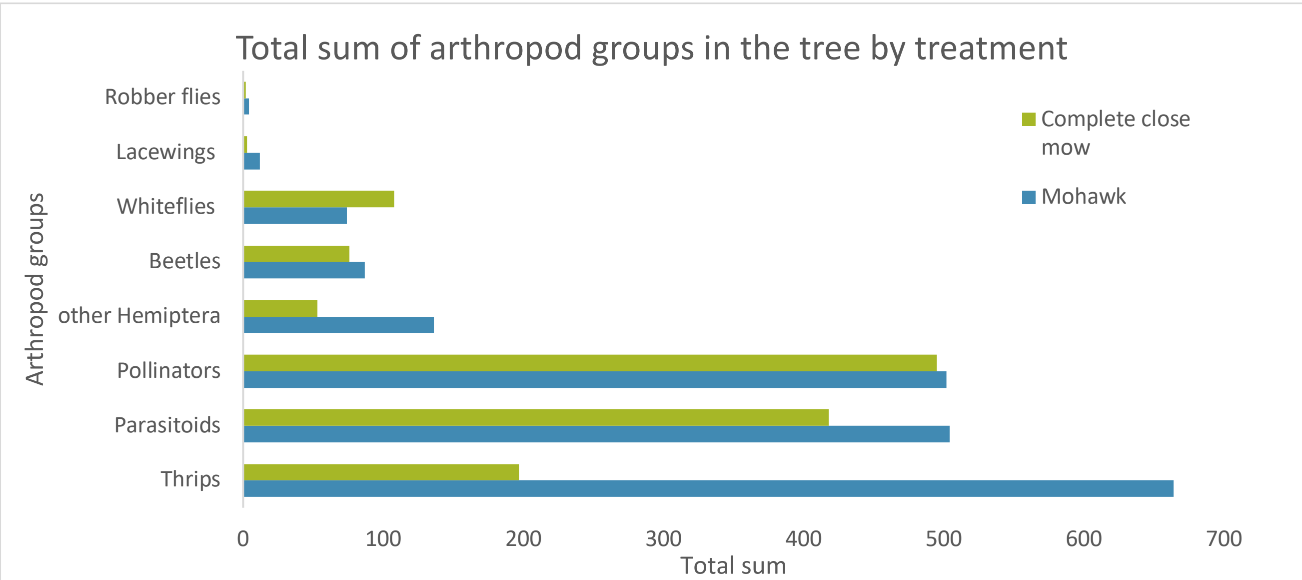


Chart 6: Total sum of each arthropod group within the tree, compared between the two treatments, over the sampling period.

A focussed look at thrips

In **Charts 5 and 6** thrips dominate as a group with high numbers of individuals collected, especially within the mohawk block. Within the mohawk block, thrip numbers spiked in the inter row in December and February of 2018 (see **Chart 7**) and within the tree in August 2017 (flowering period) as well as in December and February of 2018 (see **Chart 8**). Thrip populations breeding within adjacent vegetation fly into the crop for additional resources when their populations are high or when there are specific food resources in abundance, such as crop flowering or leaf flush.

Thrips are broadly categorised as 'herbivores' because the majority feed on the outer layer of plant cells, but most thrips also feed on pollen and help in plant pollination. Other groups of thrips feed on fungal spores and some are predatory and important biological control agents.

In a broader context, thrips play an important part within the food web because they are abundant, soft-bodied and are small and palatable, so many predatory insects eat them. Within **Charts 7 and 8** you will see that thrips are present in both inter row and tree of both treatments throughout the entire sampling period. Thrips play an important part in the food web, ensuring there is always food for predatory invertebrates (and vertebrates). The presence of a healthy food web within the orchard ecosystem allows better self-regulation of insect populations where pest outbreaks are less intense and may not require the use of chemical applications.

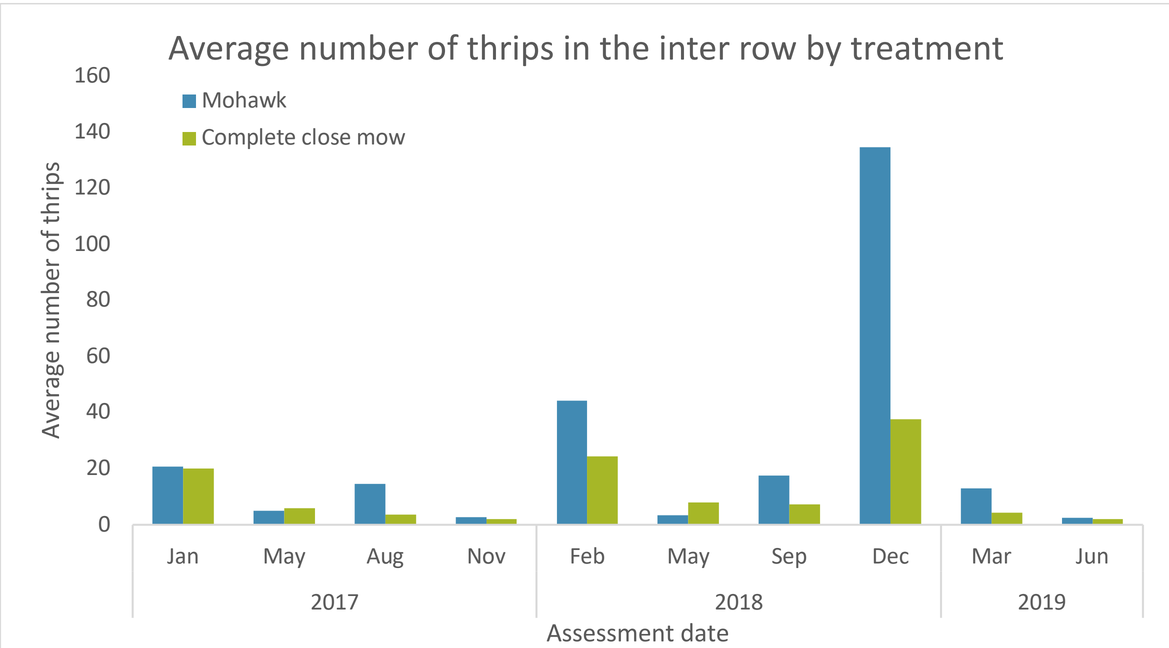


Chart 7: Average number of thrips by treatment through time – sampled in the inter row. This is an average number taken from the three assessment points on each block.

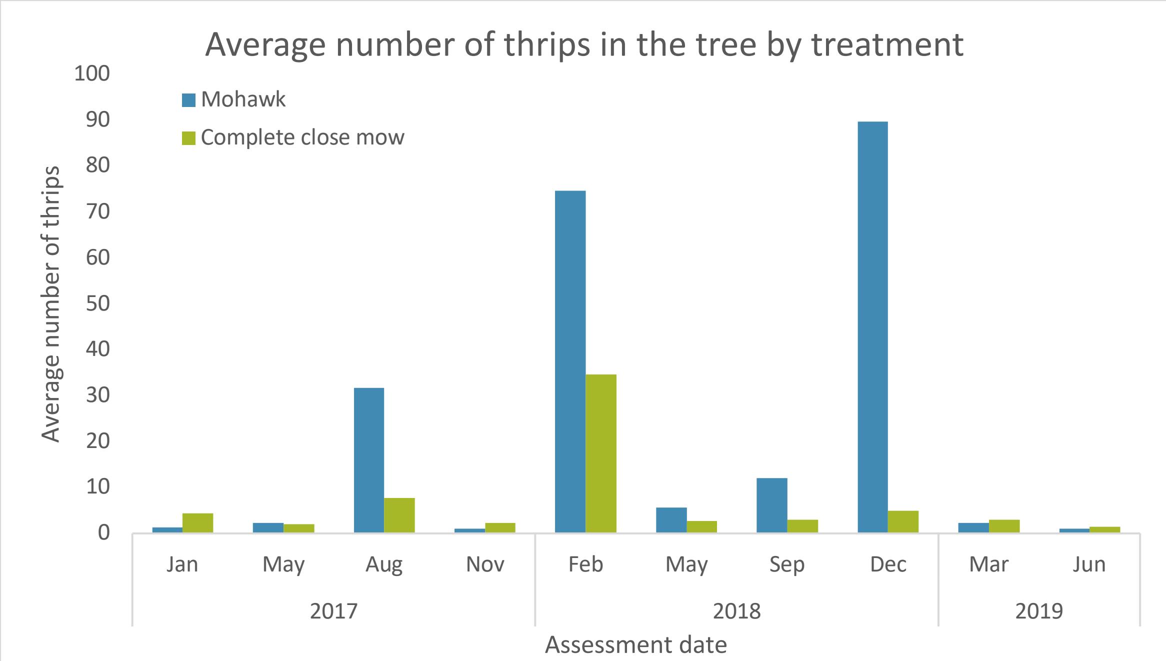


Chart 8: Average number of thrips by treatment through time – sampled in the tree. This is an average number taken from the three assessment points on each block.

Arthropod recovery after insecticide spray

On 15/8/2017 Barrier Plus was sprayed within the orchard to target an outbreak of lacebug. YSTs collected arthropods in both inter-row and tree 1 day prior to the spray, then 16 days after the spray and again 52 days after the spray. The YSTs collected arthropods over 7 days, hence each bar represents what was sampled in the 7 days leading up to either '1 day prior; 16 days post or 52 days post spray'.

We have chosen to represent what happened to three important arthropod groups, (thrips, parasitoids and herbivores (total sum of hemiptera (excluding aphids) and whiteflies)). All three groups of arthropods were chosen because they are representatively sampled using YSTs and each showed interesting responses to the insecticide application. **Charts 9, 10 , 11 and 12** show the average number of thrips, parasitoids and herbivores sampled from the inter row (**Charts 9 and 10**) and tree (**Charts 11 and 12**) in response to the insecticide application (1 day prior to spray; 16 days post spray and 52 days post spray). Treatment differences with regards to arthropod responses are compared.

The most dramatic response was by thrips, which in all the inter row and tree samples barely changed from 1 day prior to application to 16 days post application but then increased exponentially by 52 days post application (**Charts 9-12)**. Whilst we can only speculate on the reasons for such high thrip numbers at 52 days post application, one possibility is that the thrip population was not completely wiped out by the chemical application, however the beneficial arthropods were. Hence the thrip population was able to recover unhindered without natural predators. Unfortunately, we could not effectively sample many beneficial arthropod groups such as spiders and predatory beetles using YSTs so we cannot determine how they were affected by the spray application.

Treatment differences were seen in thrip recovery post spray application. Within the inter row, thrip numbers barely changed at 16 days post application, though at 52 days post application there were an average of 347 thrips per sample from the mohawk block (**Chart 9**) compared to approximately half that (162) in the complete close mow block (**Chart 10**). Within the tree there was less treatment difference; at

52 days post spray there were an average of 213 per sample from the mohawk block (**Chart 11**), compared to 275 per sample from the complete close mow block (**Chart 12**).

Herbivores and parasitoids did not respond as dramatically to the spray application as thrips. In the trees within both treatment blocks, average numbers of both herbivores and parasitoids only just recovered to levels prior to spray application by 52 days post spray (**Charts 11 and 12**). Within the inter row, both parasitoids and herbivores increased to reasonably high numbers by 52 days post spray, with average numbers of both groups approximately double within the mohawk block (**Chart 9**) compared to the complete close mow inter rows (**Chart 10**).

Interestingly, parasitoid numbers within the inter row showed clear treatment differences at 16- and 52-days post spray (**Charts 9 and 10**). Within the mohawk inter rows, parasitoid numbers were on average double that when compared to the complete close mow inter rows at both 16 and 52 days post spray. Within the trees, parasitoids within both treatment blocks did not recover well, even by 52 days post spray (**Charts 11 and 12).** This suggests that the inter row, particularly the mohawk inter rows provided a refuge for chemically sensitive parasitoids.

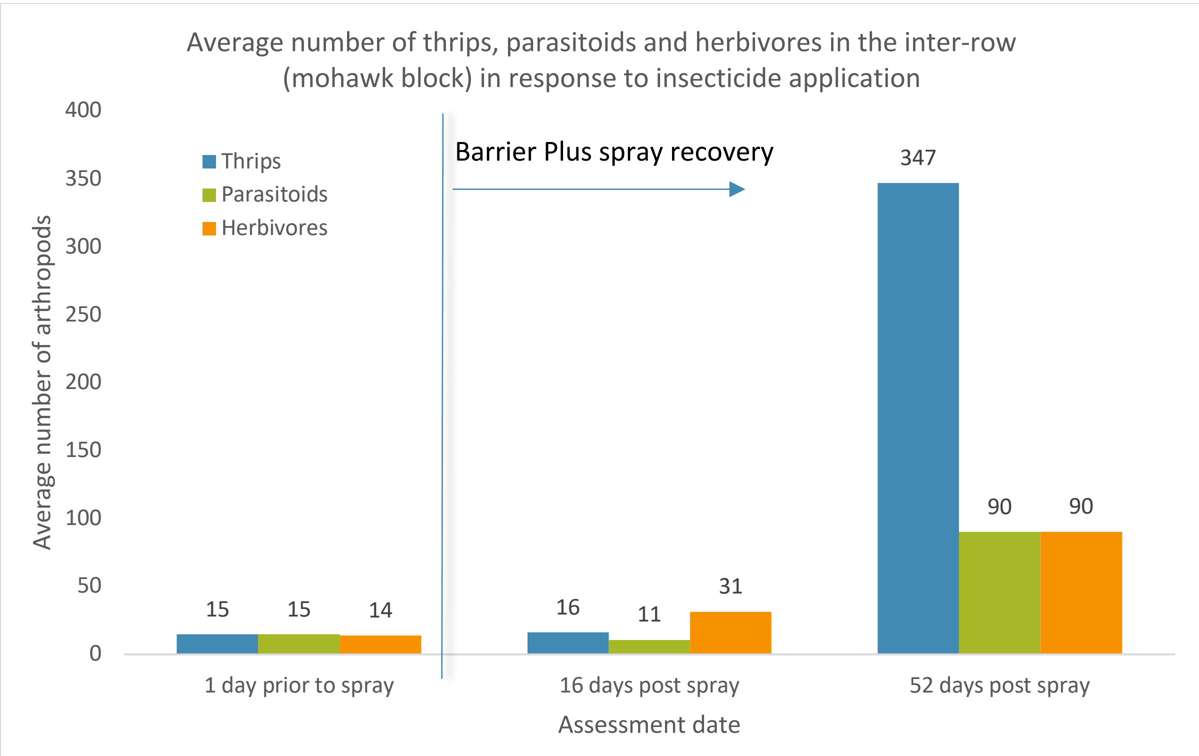


Chart 9: Average number of thrips, parasitoids and herbivores (hemiptera, excluding aphids, and whiteflies) sampled in the inter rows of the mohawk block at 1 day prior to spraying Barrier Plus insecticide, 16 days post spray and 52 days post spray. This is an average number taken from the three assessment points in the mohawk block.

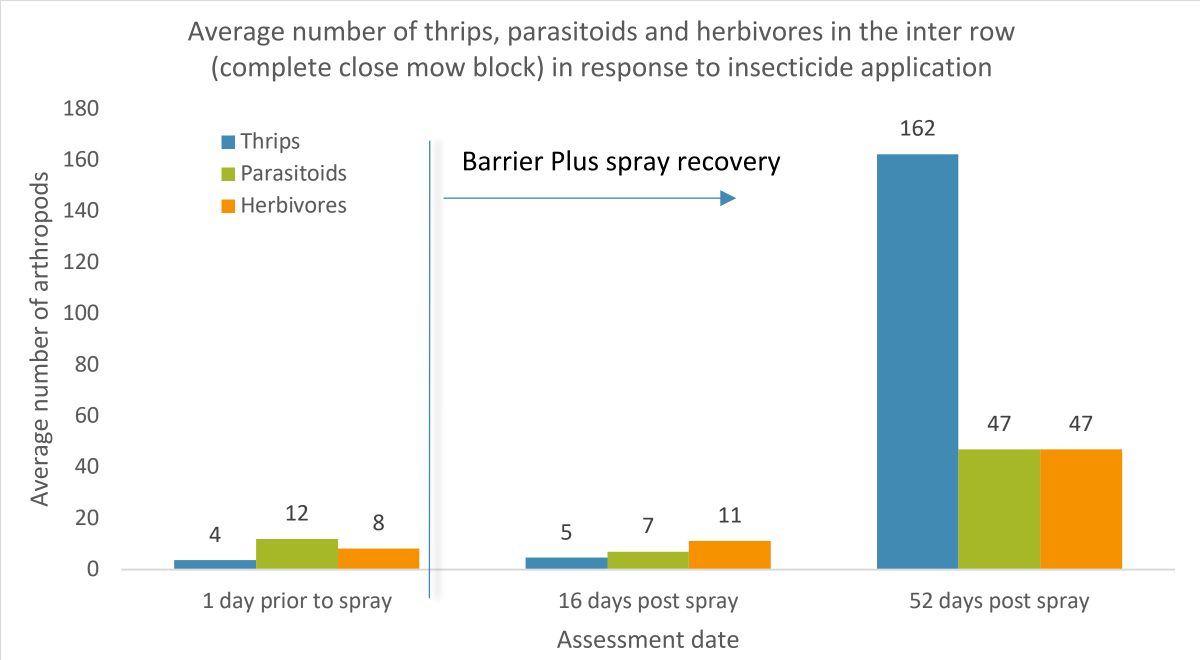


Chart 10: Average number of thrips, parasitoids and herbivores (hemiptera, excluding aphids, and whiteflies) sampled in the inter rows of the complete close mow block at 1 day prior to spraying Barrier Plus insecticide, 16 days post spray and 52 days post spray. This is an average number taken from the three assessment points in the complete close mow block.

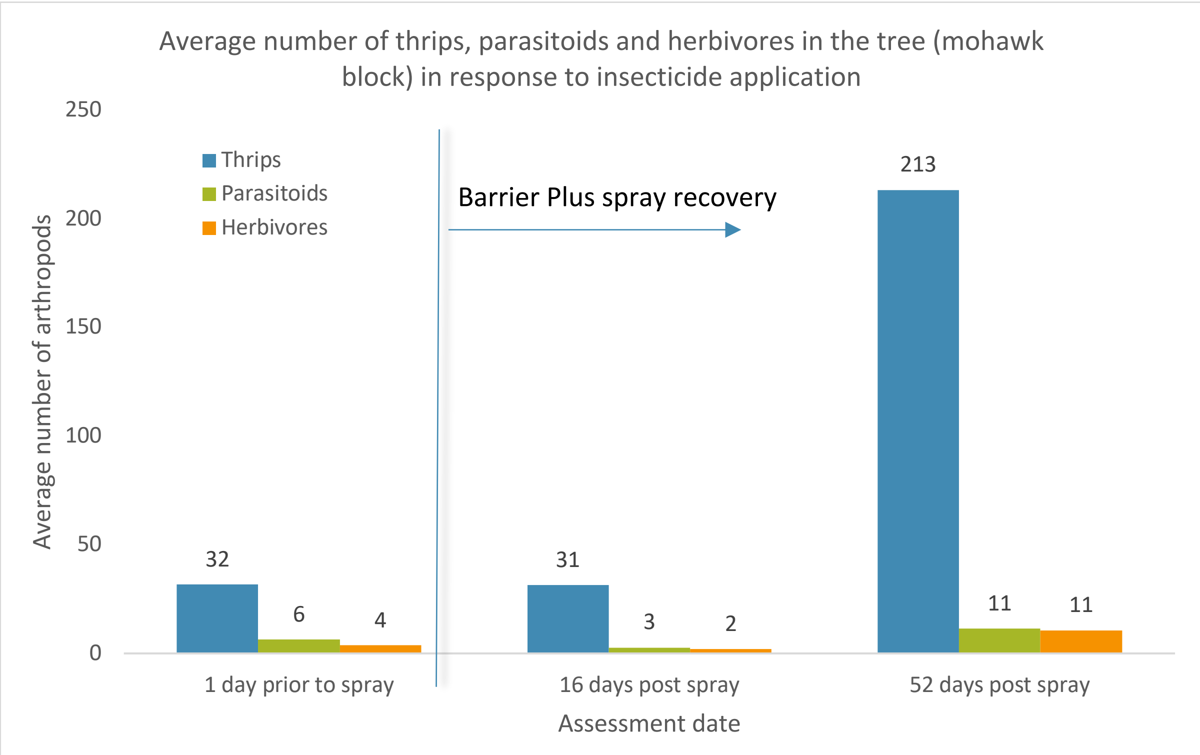


Chart 11: Average number of thrips, parasitoids and herbivores (hemiptera, excluding aphids, and whiteflies) sampled in the trees of the mohawk block at 1 day prior to spraying Barrier Plus insecticide, 16 days post spray and 52 days post spray. This is an average number taken from the three assessment points in the mohawk block.

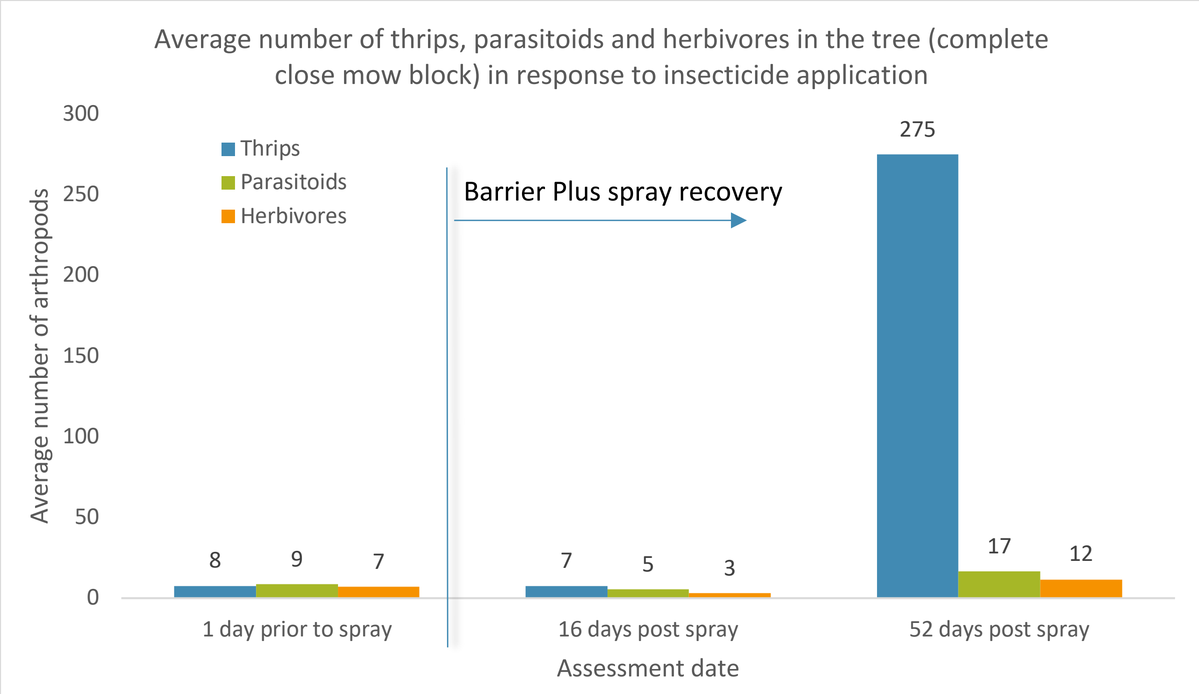


Chart 12: Average number of thrips, parasitoids and herbivores (hemiptera, excluding aphids, and whiteflies) sampled in the trees of the complete close mow block at 1 day prior to spraying Barrier Plus insecticide, 16 days post spray and 52 days post spray. This is an average number taken from the three assessment points in the complete close mow block.

A focussed look at parasitoids

Parasitoids were well represented in the YST catches, providing a meaningful indication of how the inter row treatments affect this important group of beneficial arthropods. Parasitoids were the most abundant of all the beneficial arthropods sampled by YSTs, and included MacTrix and Anastatus from previous releases.

In general, parasitoids were more abundant within inter rows compared to trees (see y-axis when comparing **Charts 13 and 14**). Within the inter row (**Chart 13**), parasitoid numbers were evidently higher within the complete close mown block in February and December of 2018. These results suggest that the releases of biocontrols along the orchard margin and in the adjacent rainforest area during these months contributed to the overall parasitoid abundance in the complete close mow block. There was 1 sampling period when parasitoid numbers were clearly higher within the mohawk block (September 2018). Within the tree (**Chart 14**), parasitoid numbers were evidently higher within the mohawk block at two sampling periods, September and December 2018, while there was 1 sampling period when parasitoid numbers were significantly higher within the complete close mow block (January 2017).

The lack of consistent distinction in parasitoid abundance between the two treatments in the inter row and tree indicate that perhaps there were a number of confounding factors within the experimental design that impeded a clear experimental distinction. For example, the release of biocontrol agents could have influenced numbers in either treatment, and the close proximity of the two treatment blocks makes it more difficult to separate immigration and migration of parasitoids. These factors were discussed within **Outcomes** (p. 5) and again within **Findings and recommendations** (p. 17).

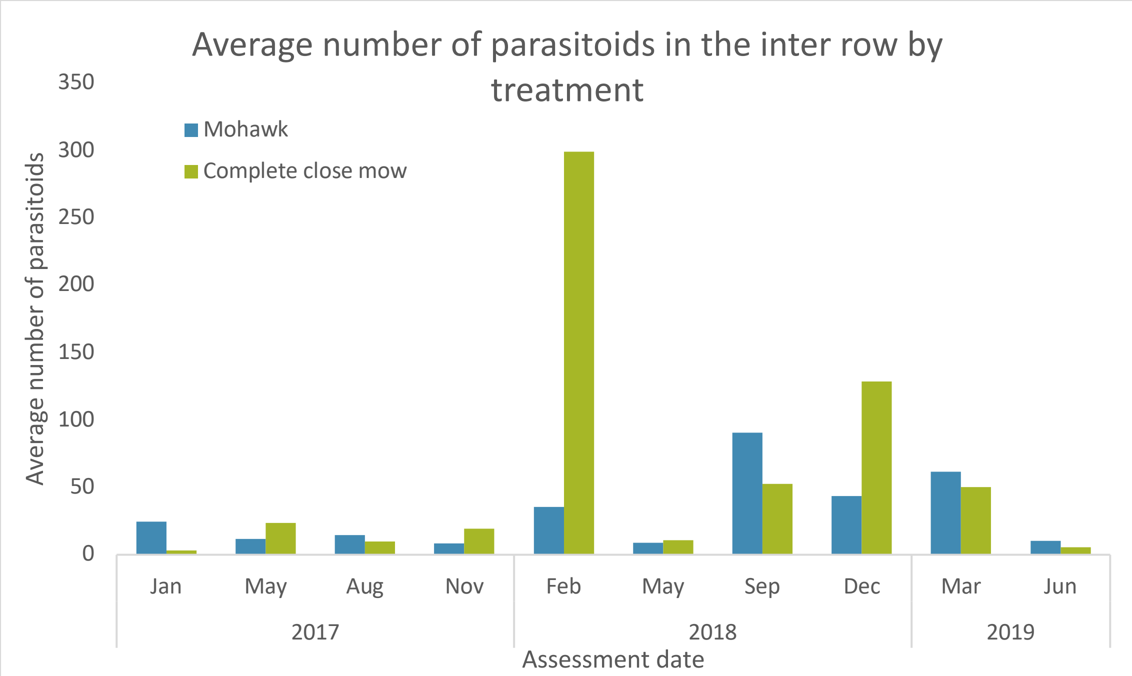


Chart 13: Average number of parasitoids by treatment through time – sampled in the inter row. This is an average number taken from the three assessment points on each block.

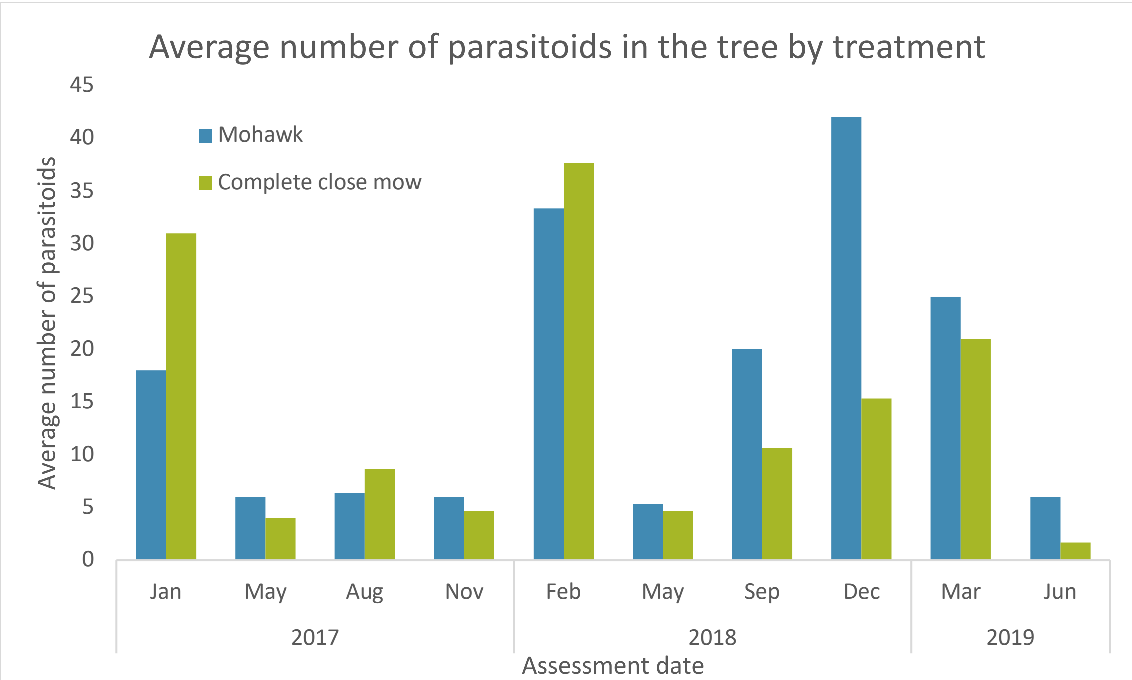


Chart 14: Average number of parasitoids by treatment through time – sampled in the tree. This is an average number taken from the three assessment points on each block.

Findings and recommendations

The mohawk worked very well on your farm, given the row width and availability of machinery of a suitable configuration. Retaining a mohawk year-round, including during harvest, proved to be relatively straight-forward. Likewise, it was straight-forward to conduct intermittent mowing, as required for row access, management of Cobbler’s Pegs, preparation for harvest and so on. The principal advantage of the mohawk reduced mow approach is that it can be sustained during harvest. This can be especially advantageous during winter and particularly in dry years, because it keeps an insectary viable during slow growth periods. Farms that removed the mohawk during harvest took many months to re-establish insectary vegetation when compared to your farm. Optimal benefits from insectaries are possible when they are in place before macadamia flowering and the increase in crop pest pressure.

The characteristics of the species mix of naturalised weeds, native perennials and grasses already present on your farm make reduced mowing a great low-effort management strategy for you to incorporate insectaries for beneficial arthropods. Your areas of native vegetation for arthropod habitat will also add value here.

Options for increasing the plant species diversity with seeding were discussed broadly during site visits. You trialled planting out seedlings with limited success given dry conditions. Seeding with hardy species can be considered for more targeted insectary flowering that compliments crop season and additional ecosystem services for soil and so on. There is strong interest in the industry for seeding of the inter row and cover cropping and an extensive range of seed options is emerging.

It is worth noting that findings from other trial farms and other industries indicate that alternate row mow may be a better management option than the mohawk for many growers outside of harvest. This involves mowing every second row on a rotating schedule, allowing all rows to "grow out" somewhat across the year but providing opportunities for mow management as required. This reduces the overall disturbance of beneficial arthropods, ensuring a refuge remains in place at all times for them. Your own approach to mow some but not all areas, as required, follows a similar principle. It ensures that beneficial arthropods will always have undisturbed areas around your farm for habitat.

Findings for your farm in terms of the benefits for beneficial arthropods in a mohawk as distinct from complete close mow in your orchard were confounded by difficulties with experimental design. This is not an unusual outcome with field experiments where there are so many unpredictable and uncontrollable factors in play.

When the findings from all of the farms that participated in this project are taken into consideration, it is clear that insectaries have meaningful influence on orchard ecology when growers can commit to inclusion of the insectary in the orchard in terms of space allocation and long-term management. The inter row worked very well for you given row width. There are other areas on-farm worth considering, including headlands, field margins and so on where changes to management can allow for habitat suitable for beneficial insects. Decisions to improve plant diversity with seeding, well-timed seeding and mowing to limit dominance of one species while encouraging new growth and flowering and so on are very influential.

Finally, the BioResources team encourages you to read the final report for the *Macadamia IPDM Program - Inter Row Project (MC16008)*, which is available via *Hort Innovation*. Here you will find out more on the benefits of insectaries for macadamia orchards and also the experiences of other trial farms in implementing and managing insectaries. There is also an exploration of the multiple ecosystem services known to flow from reduced mow inter row management practices along with improved arthropod biodiversity, including benefits for soil organic matter, nutrient cycling, water management, erosion control, weed suppression, soil carbon storage, soil microbiology and more.

Acknowledgements and thanks

The project team wishes to thank Sue Wiley for her participation, contributions and support.