Final Report

Strengthening cultural and biological management of pests and diseases in apple and pear orchards

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Victorian Department of Energy, Environment and Climate Action

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AP19002

Project:

Strengthening cultural and biological management of pests and diseases in apple and pear orchards (AP19002)

Disclaimer:

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Public summary

The objective of this project is to provide growers and advisors with increased confidence in Integrated Pest and Disease Management (IPDM) decision making by building on the achievements of previous PIPS programs. In particular, the project aimed to demonstrate the efficacy of biological control methods and address gaps in knowledge currently hindering adoption of practices that support biodiversity and soil health, both of which are essential for low input pest and disease management, without sacrificing plant health, fruit yield and quality.

Conservation biological control experiments conducted in orchards in Victoria and Tasmania highlighted the potential for habitat manipulation in apple and pear IPDM systems. Our conservation biological control orchard experiments demonstrated potential gains that can be made by manipulating arthropod abundance and diversity through altering ground cover within orchards. We also found that vegetative groundcovers within the tree line encouraged predators such as earwigs and spiders. These gains have the potential to both promote nutrient cycling and suppress ground dwelling pest species and canopy borne pests during the production season. However, our experiments have also identified practical barriers to implementation, particularly of native vegetation within orchard blocks, that, if not addressed, could deter widespread adoption in Australian orchards. Principal among these barriers is the difficulty in establishing native groundcover forbs and grasses within conventionally managed apple and pear orchard production systems.

In research specifically focused on the contribution of Trichogrammatidae parasitoids, we confirmed that the pest codling moth is a suitable host for *Trichogramma carverae* under laboratory conditions. Furthermore, our results indicate that *T. carverae* has considerable potential for control of codling moth in orchard situations, and that further ecological studies are warranted. We also discovered previously unrecorded diversity amongst the beneficial Trichogramma taxa occupying an experimental pear orchard. These findings highlight the importance of understanding the role of existing parasitoids in apple and pear orchards and how habitat manipulation and IPM can support their populations.

We found no evidence that the codling moth parasitoid *Mastrus ridens* has established permanent populations in Australia. However, we found evidence that *M. ridens* used in previous releases were impacted by low genetic diversity, probably as a result of undergoing several genetic bottlenecks over the decades it was maintained in laboratory culture. We therefore imported a new, genetically-diverse strain of *M. ridens* that is predicted to establish more readily in Australian orchards. Six releases of this new strain were conducted in orchards in four states in 2022/23. While it was too soon to conduct impact assessments for these releases in this project, follow-up monitoring commencing 2024 is recommended.

Based on preliminary scenario analyses using a prototype discounted cash flow model, we also found that biological control of codling moth with *M. ridens* is a worthwhile investment, especially if parasitoid populations prove to be sustainable without ongoing releases (Benefit to Cost Ratio of 5.5:1). The model is a valuable tool for planning future codling moth management priorities. It is recommended that the model and scenario analyses be further developed.

Communication and adoption outputs were substantial throughout the project, despite COVID-19 related movement restrictions. The project produced seven YouTube videos and contributed to others, convened 15 Community of Practice (CoP) meetings and seminars, published 49 articles by 12 CoP members on the ExtensionAus Australian Apple and Pear IPDM website, including seven case studies on IPDM from around Australia, and published 11 articles in the industry publication *Australian Fruit Grower*. The ExtensionAus Australian Apple and Pear IPDM website recorded 53,099 pageviews between 1 July 2020 and 30 June 2023.

The immediate outcome of this work is expected to be the availability of high-quality information on IPDM practices and technologies that are easily accessible to all sectors of the apple and pear industry. This will lead to higher level outcomes related to greater confidence by advisors and consultants in their ability to provide IPDM advice to growers, and increased grower confidence in the advice provided to them and their own ability to make informed IPDM decisions.

Keywords

Integrated Pest Management, conservation biological control, apple, pear, *Mastrus ridens*, codling moth, Community of Practice

Introduction

The objective of this project is to provide growers and advisors with increased confidence in Integrated Pest and Disease Management (IPDM) decision making by building on the achievements of the previous two PIPS programs, and the Integrated Pest Disease and Weed Management program AP16007. In particular, the project aimed to demonstrate the efficacy of biological control methods and address gaps in knowledge currently hindering adoption of practices that support biodiversity and soil health, both of which are essential for low input pest and disease management, without sacrificing plant health, fruit yield and quality.

Hort Innovation also prioritised the need to demonstrate establishment of *Mastrus ridens*, a parasitoid wasp released by Agriculture Victoria through previous Hort Innovation-funded PIPS projects, and its efficacy as a biological control against codling moth. The parasitoid releases resulted in excellent control of codling moth to the extent that both codling moth and the wasps were difficult to detect in the following season. Poor detection of *M. ridens* in subsequent seasons could have been due to the parasitoid dispersing from the original release sites in search of prey, or failing to establish because of factors such as insufficient prey or nectar, or possible effects relating to suspected high levels of inbreeding, or the methods used to detect the wasps in the field may not have been sensitive enough. The research therefore prioritised methods for measuring and optimising the performance and long-term establishment of *M. ridens*.

The *Mastrus* program is also aligned with new research aimed at improving the orchard habitat to support a greater diversity of biological control agents that would assist management of codling moth and other pests, and organisms known to improve soil health.

The immediate outcome of the work is expected to be the availability of high-quality information on IPDM practices and technologies that are easily accessible to all sectors of the apple and pear industry. This will lead to higher level outcomes related to greater confidence by advisors and consultants in their ability to provide IPDM advice to growers, and increased grower confidence in the advice provided to them and their own ability to make informed IPDM decisions.

Methodology

The project addressed five key objectives aimed at supporting evidence-based adoption of IPDM practices in Australian apple and pear orchards:

1. Identify, address, and extend gaps in cultural practices that attract and support orchard biodiversity for low input pest and disease management.
2. Collaborate with the PIPS project “Improved Australian apple and pear orchards soil health and plant nutrition” to build soil biodiversity and health as a cultural practice for soil disease management and plant resilience.
3. Demonstrate efficacy of biological control of major pests and diseases, such as codling moth, LBAM, apple scab and root rot.
4. Identify and demonstrate tools for measuring impacts of orchard cultural management practices on plant health, yield and quality.
5. Communicate findings in a clear and practical format to growers and wider industry.

To address these objectives, the project team developed the following core activities:

Activity 1. Conservation biological control (Appendix 1, Appendix 2)

We aimed to trial the use of native and non-native vegetation within apple and pear orchards, either deliberately planted or resident vegetation, for their potential to provide conservation biological control. More specifically, the objectives of the study were to:

1. Determine whether native and/or exotic grasses and forbs could be easily established in the apple and pear orchard inter-row using seed or tubestock, and
2. Determine the effect of these plantings in the inter-row and tree line on the invertebrate community composition, and their impact on crop pest and beneficial arthropod abundance and fruit pest damage levels.

These experiments were conducted at an experimental pear orchard at Agriculture Victoria’s Tatura SmartFarm in the

Goulburn Valley, and a commercial apple orchard in Tasmania's Huon Valley.

In the Victorian experimental orchard, three treatments were tested consisting of combinations of native groundcovers and grasses, and different establishment methods (seed sowing or tubestock planting). These treatments were compared to the standard practice of maintaining bare ground beneath trees (herbicide strip) and a mown inter-row consisting of broadleaf weeds and grasses (grower sward). The Tasmanian experimental orchard treatments included an additional 'exotic' flowering meadow treatment within the inter-row and compost/mulch and legume-grass tree line treatments.

In another study, we assessed the host-range of the egg parasitoid *Trichogramma carverae* in relation to codling moth and light brown apple moth, and assessed the diversity of *Trichogramma* spp. in an orchard situation, specifically:

1. To determine the suitability of codling moth and LBAM eggs as hosts of *T. carverae*,
2. To assess resident *Trichogramma* species, including *T. carverae*, in a pear orchard that is subject to conservation biological control treatments.

Activity 2. *Mastrus ridens* impact assessment (Appendix 3)

We assessed previous *M. ridens* release sites in Victoria and Tasmania for agent establishment using sentinel bands containing codling moth larvae.

We also attempted to test a lure-based monitoring system for *M. ridens* for use in orchards where the parasitoid has been released, including assessment of dose-response of *M. ridens* to the codling moth larval aggregation pheromone. Chemical lures provide an alternative to sentinel bands for detecting and monitoring target insects such as *M. ridens*. Once developed and validated, chemical lures can be easy and cost-effective to use, and they eliminate the risk of accidentally introducing pest insects that emerge from sentinel bands. Previous research has shown that *M. ridens* is attracted to a pheromone produced by cocoon-spinning codling moth larvae, and the specific chemical blend of the pheromone was subsequently described in overseas studies. This provided an opportunity to develop a chemical lure that can be used to monitor *M. ridens* release sites for establishment and spread.

Activity 3. *Mastrus ridens* efficacy (Appendices 3, 4 and 5a-b)

We imported a new strain of the codling moth parasitoid, *M. ridens* from Chile and aimed to conduct two releases at selected field sites. Furthermore, we examined the genetic variation in the two Australian laboratory colonies of *Mastrus*. The "old" Australian colony imported from New Zealand, was derived from laboratory cultures that had been subject to repeated bottleneck events in the past, as *Mastrus* were imported through multiple countries prior to arriving in Australia. The "new" colony was derived from Chilean cultures collected directly from the original *Mastrus* geographic range in central Asia.

We also developed a stochastic spreadsheet model to provide industry decision-makers (growers and public and private sector investors, including funding agencies and commercial biocontrol agent producers) with the tools and resources they need to compare the costs and benefits of a more ecologically-benign IPM approach based on *M. ridens* to existing, pesticide-centric IPM programs.

Activity 4. IPDM communication and adoption (Appendix 6a-b)

We maintained and expanded an Apple and Pear IPDM Community of Practice (CoP) to provide opportunities for consultants, service providers, and researchers to share knowledge and learn from each other, with the aim of increasing grower confidence and improving uptake of Integrated Pest & Disease Management (IPDM) by the apple and pear industry. The CoP was supported by the Integrated Pest and Disease Management ExtensionAUS website, built to house IPDM resources, support CoP identity and communication and provide opportunities for two-way communication through the "ask an expert" feature available on the website, and regular articles and videos.

Results and discussion

Activity 1. Conservation biological control (Appendix 1, Appendix 2)

The orchard experiments conducted in Victoria and Tasmania, and studies of similar production systems elsewhere, have highlighted the potential for habitat manipulation in apple and pear IPDM systems. The study was able to demonstrate the importance of maintaining flowering non-crop vegetation, albeit with exotic broadleaf weeds and grasses, within orchards for the conservation of beneficial arthropods. We found a diversity of parasitic wasps; and predatory lacewings, ladybirds, and mites within the orchard canopy, which were also detected in the inter-row vegetation. A greater abundance of beneficial natural enemies within the orchard corresponded with peak flowering of the inter-row vegetation and were lowest when the vegetation was sparse. Other ground-dwelling predators, including earwigs, spiders and rove beetles were collected in pitfall traps placed beneath trees. These predators were more abundant where ground cover and mulch provided a safe place to hide.

However, our experiments have also identified practical barriers to implementation, particularly of native vegetation within orchard blocks, that, if not addressed, could deter widespread adoption in Australian orchards. Principal among these barriers is the difficulty in establishing native groundcover forbs and grasses within conventionally managed apple and pear orchard production systems. Criteria that we developed for plant species selection considered a range of attributes, including several related to availability, cost, provision of SNAP (shelter, nectar, alternative prey, and pollen), and likelihood of establishment. However, we were unable to demonstrate the contribution native plant species could have in enhancing CBC within an apple and pear orchard in south-eastern Australia. Any future attempts to establish native plant species in Australian orchards would most likely require the use of weed matting or mulches or at least two years of weed management to reduce resident weed seedbanks prior to sowing or planting native species. Even then, competition from annual weeds would be an ongoing problem due to the high fertility of the orchard soils, which favour exotics over native plant species. Furthermore, due to the higher costs associated with purchasing native seed and tubestock, the labour involved in seeding and planting, and high weed management input, it's unlikely that growers would readily adopt the use of native cover crop species in orchard rows unless a sufficient economic and environmental benefit could be demonstrated to justify the added costs.

Overall, the CBC trials were able to demonstrate:

- The potential gains that can be made by manipulating arthropod abundance and diversity through altering ground cover composition within Australian apple and pear orchards.
- Vegetative groundcovers within the tree line encouraged predators such as earwigs in tree canopies and spiders on the orchard floor.
- Vegetative tree lines were also observed to encourage the movement of beneficial fauna from the inter-row towards the tree lines where they have the potential to have a greater impact on economically important pest species.
- The use of compost within the tree line was demonstrated to improve non-pestiferous ground dwelling mite populations under the trees.
- These gains have the potential to both promote nutrient cycling and suppress ground dwelling pest species (i.e., LBAM during winter) and canopy borne pests such as woolly apple aphid during the production season.

In research specifically focused on the contribution of Trichogrammatidae parasitoids, we confirmed that codling moth is a suitable host for *Trichogramma carverae* under laboratory conditions. Furthermore, our results indicate that *T. carverae* has considerable potential for control of codling moth in orchard situations, and that further ecological studies are warranted. We also discovered previously unrecorded diversity amongst the *Trichogramma* taxa occupying an experimental pear orchard, including the parasitoid *Trichogrammatoidea cryptophlebiae*. To our knowledge, *T. cryptophlebiae* has not previously been recorded as naturalised in Victoria. The contribution of *T. cryptophlebiae* to general pest control within apple and pear orchards, and possible synergistic relationships with the other apple and pear orchard *Trichogramma* species (*T. pretiosum* and *T. carverae*), requires further investigation. These findings highlight the importance of understanding the role of existing parasitoids in apple and pear orchards and how habitat manipulation and IPM can support their populations.

Activity 2. *Mastrus ridens* impact assessment (Appendix 3)

Sentinel codling moth bands deployed in two previous release sites, in Victoria and Tasmania, did not recover *M. ridens*. These were sites where the original (NZ strain) of *M. ridens* was released. To date, there is no evidence that the NZ strain has established permanent populations at any Australian release site. Releases of the newly imported Chile strain of *M. ridens* were conducted in the 2022/23 production season however it is too soon to conduct impact assessments for these releases. Follow up monitoring commencing 2024 is recommended for these most recent releases.

We found no difference in the attractiveness of *M. ridens* lures compared to controls and were unable to demonstrate any benefits of a lure-based monitoring system for *Mastrus ridens* (data not shown). Given the demands of further lure experimentation on codling moth and *M. ridens* cultures and increasing evidence of inbreeding in the original Australian *M. ridens* culture (NZ strain; Activity 3), we prioritised resources toward importing and releasing a new, genetically-diverse population (Chile strain) of *M. ridens* in Australia.

Better monitoring tools for *Mastrus ridens* are still required, however further attempts to develop a chemical lure for *M. ridens* would require substantial investment. For example, it is not certain why the pheromone lure used in these studies failed to attract *M. ridens* in the field. It is possible that the chemical blend was deficient in some way, or the lure system deployed in our experiments did not emit sufficient chemical to attract *M. ridens*, or that the insects released were not receptive to the pheromone. This last possibility was particularly troublesome, because it became apparent during the project that the *M. ridens* culture being used in these experiments (the NZ strain) was inbred compared to those used in overseas experiments. Any further attempts to develop a chemical lure for *M. ridens* should only use insects from a population known to be genetically diverse (Appendix 4 provides a description of methods to assess molecular variation in *M. ridens* laboratory cultures).

Activity 3. *Mastrus ridens* efficacy (Appendices 3, 4 and 5a-b)

We conducted eight new releases (six more than contracted) of the codling moth parasitoid *M. ridens* in Victoria (2 releases), Tasmania (2 releases), NSW (3 releases) and South Australia (1 release). Of these, six releases were of the newly imported *M. ridens* “Chile” strain.

Examination of microsatellite variation in the two Australian colonies revealed that the new colony (imported from Chile in 2022) was much more genetically variable than the old (NZ strain) colony, which was found to be highly inbred. The new colony however showed strong evidence of increasing numbers of diploid males being produced within a relatively short period of time (three months), indicating severe inbreeding post importation. Past studies have revealed that the presence of diploid males will likely have major negative fitness consequences for the current new Australian *Mastrus* colony, increasing the proportion of males produced which is highly undesirable for future mass releases, and may even eventually lead to collapse of the laboratory culture. Strategies to prevent or slow inbreeding in lab cultures, including potential improvements to laboratory culturing practices and re-importing *M. ridens*, should be considered for future *Mastrus* mass rearing efforts.

Based on preliminary scenario analyses using a prototype discounted cash flow model, we also found that biological control of codling moth with *M. ridens* is a worthwhile investment, especially if parasitoid populations prove to be sustainable without ongoing releases (Benefit to Cost Ratio of 5.5:1). If classical biological control is broadly successful, then commercial production and sale of *M. ridens* would be unnecessary. The recent re-importation and release of an improved *M. ridens* population from Chile is an important step in maximising the chances of widespread establishment. Current research effort is therefore directed at implementing classical biological control of codling moth with *M. ridens*, and this effort is warranted based on our findings.

However, there is still uncertainty about the likelihood of establishing viable populations of *M. ridens* in all situations where codling moth occurs. Another important finding of our study is that, even under augmentative (i.e., commercial) biological control scenarios, the use of *M. ridens* is profitable (Benefit to Cost Ratio of 2.7:1) when compared to pesticide-centric IPM approaches.

The model is a valuable tool for planning future codling moth management priorities. It is recommended that the model and scenario analyses be further developed and published in an appropriate peer-reviewed journal (Appendix 5b, draft manuscript).

Activity 4. IPDM communication and adoption (Appendix 6a-b)

Communication and adoption outputs were substantial throughout the project, despite COVID-19 related movement restrictions. The project produced seven YouTube videos and contributed to others, convened 15 Community of Practice (CoP) meetings and seminars, published 49 articles by more 12 CoP members on the ExtensionAus Australian Apple and Pear IPDM website, including 7 case studies on IPDM from around Australia, and published 11 articles in the industry publication *Australian Fruit Grower*. The ExtensionAus Australian Apple and Pear IPDM website recorded 53,099 pageviews between 1 July 2020 and 30 June 2023.

An evaluation of the IPDM Community of Practice (CoP) found that the CoP is valued by those that attend, and that the CoP should continue. Participant satisfaction surveys were conducted for several meetings with the average satisfaction score varying from 8.2 to 9.4 out of 10. The IPDM community supported further activities, including an annual face to face event to showcase IPDM case studies in different regions, use of a different web platform or approach to engage more growers, and promoting resources to facilitate greater uptake of integrated pest and disease management and to find ways to encourage private agronomists to participate. The IPDM CoP meetings demonstrated a high level of sharing and interest amongst the participants. The more experienced members in the group would share information and clarification on how to deal with pests and diseases in different regions around Australia. Guest speakers at these meetings resulted in discussions on the topics that were presented, with topics well received by the CoP.

Outputs

The project delivered the following outputs (as listed in the research agreement) (Table 1):

Table 1. Output summary

Output and description	Detail/location
A program logic with linkage to Hort Innovation and industry objectives as part of a M&E plan	Appendix 7a
A project risk register listing how the risks will be managed	Appendix 8
A stakeholder engagement plan	Appendix 6b
Six monthly milestone reports, including a final report that meets Hort Innovation standards	All six-monthly milestones reports submitted on time.
Detailed tests of soil health (soil microbial diversity), nutrient availability and uptake and link with pest and disease levels and apple and orchard productivity	Appendix 1
At least one Soil Biodiversity and IPDM Training course conducted in each growing state	Appendix 6a
Establishment of a network and communication channels as part of a Communities of Practice	Appendix 6a
Presentations at Future Orchards demonstration walks	Appendix 6a
Case studies for growers and advisors to observe and experience the benefits of implementing IPM	Appendix 6a
A report of the benefit-cost of implementing IPM and recommendations for future research to fill knowledge gaps	Appendix 5a
Scientific papers and articles in industry journals	Appendix 5b, Appendix 6a
Posts and other communication activities for the Australian Apple and Pear IPDM website	Appendix 6a
Participation in the pool of experts providing answers to the “Ask an Expert” facility on the IPDM website	Appendix 6a
A commercialisation plan for production and sale of *Mastrus ridens*	Appendix 5a

Outcomes

The intended outcomes were articulated in the IPDM program logic (Appendix 7a) and Monitoring and Evaluation (M&E) Plan (Appendix 7b). The M&E plan outlined the metrics used to measure project outcomes in relation to effectiveness, relevance, process appropriateness and efficiency, and are reported in the following Monitoring and Evaluation section (see below).

Monitoring and evaluation

The independent PIPS3 Program Coordinator (Marguerite White, ICD Project Services) conducted the final evaluation of the AP19002 project against the Program Logic and Monitoring and Evaluation plan. Three researchers, four growers, and three service providers (consultants and advisors) were interviewed in June and July 2023. The interview process used quantitative and qualitative approaches to evaluate **effectiveness**, **relevance**, **process appropriateness**, **efficiency** and **legacy** KEQ's of the PIPS3 Program, and specific project questions underpinning these. A table of the interview questions used to assess performance of the program/ project against the Key Evaluation Questions (KEQs) is provided in the final report for AP19007 (Independent Coordination).

The evaluation found that AP19002 achieved a "**Strong**" performance rating across all Key Evaluation Questions (Table 2, Table 3).

Table 2. Stakeholder interview quantitative response ratings to determine final performance.

Stakeholder interview result	Evaluation criteria
Strong	Rating of between 3.8 to 5
Moderate	Rating of between 2.4 to 3.7
Weak	Rating of between 1 to 2.3

Table 3. AP19002 Key Evaluation Questions and performance results.

AP19002 Key Evaluation Questions	Project performance	Example Feedback from respondents.
EFFECTIVENESS: *To what extent has the PIPS3 Program addressed the objectives, research agreement achievement criteria and identified outcomes/ outputs?*		
• To what extent has the project improved knowledge and understanding of the role of *Mastrus ridens* for sustainable management of codling moth in Australia? • To what extent has the project demonstrated benefits to orchard pest management, soil health and tree health through new approaches to cultural and biological practices?	**AP19002 effectiveness rating achieved:** 4.2 (n=10) **Overall program effectiveness:** 4.3 (n=43) Respondents were confident that the project achieved its objectives and activities were executed as expected. It was acknowledged by respondents that although the conservation biological control trial at the Tatura SmartFarm did not establish as hoped, the research team had delivered a well-designed experiment and had consulted appropriately with local experts on species to 'best	***Researcher*** *Generally positive. Still a fair bit of work in general needed on grower IPDM knowledge- though this is not really project related.* *Original objectives were very aspirational, so we had to adjust. Establishment of native species and management of the site to allow them to persist was challenging. BUT the design was well done, but the reality to establish and monitor in three years was too aspirational. The disappointing part for me is that we have no clear guidance for growers at this time.*

	fit' criteria prepared to meet both grower/ hostile orchard environments, and IPDM outcomes. Longer-term preparation of the site prior to establishment was a key learning from the project. Across both the AP19002 and AP19006 sites, weed pressures hampered good establishment of native treatments. Both growers and advisors believe that IPDM is not well understood by industry and knowing how to commence transitioning to IPDM is a barrier adoption. Although not directly related to this project, it highlights the need for existing IPDM resources to be further extended to industry. The *Mastrus ridens* component of work has helped to demonstrate the importance of IPDM practices to support the establishment of biological control agents. There was also a strong sense that the team has managed this very well. The project's initiatives of the Community of Practice (CoP) and quarterly AFG articles "IPDM in Focus" are seen as important extension initiatives of the project that have assisting in filling an extension gap, to some extent.	***Grower*** *It's all really important and adds to the value of what we are doing.* *The research is great but getting the information out to farmers is really important- 2-pager that is linked to the detail. Also needs the economics approach- if you adopt this, then what's the economic advantage? e.g., IPDM predatory insect advantage and demonstrate the economic advantage.* *IPDM aspects of the project has been exceptional in Tas.* *The region wants to see the Mastrus succeed, but we need to know more about making sure this happens.* ***Service Provider*** *The work is getting done, no doubt about that.* *Greg has been really good and supportive. The CoP worked well most of the time.*
RELEVANCE: *How relevant were the research outcomes/ outputs to the needs of apple and pear growers, advisors, and industry stakeholders?*		
• To what extent has the project met the needs of growers and front-line advisors in providing step-change information on the multiple benefits of inter-row conservation biocontrol plantings?	**AP19002 relevance rating achieved:** 4.3 (n=10) **Overall program relevance:** 4.4 (n=43) AP19002 was rated as strong by the respondents, with most comments relating to the *Mastrus ridens* component of work. It was highlighted that the project needed to further support the release of the new population by providing resources to growers on appropriate spray programs and IPDM strategies	***Grower*** *Once I knew what it was all about, I really started to follow you guys. I am one to give something a go.* *Mastrus is really interesting. We need to work around this though with a spray program, as it's not a straightforward swap.* ***Service Provider*** *The Mastrus work is so relevant to all regions. Getting growers to think about the relationship with*

<table>
<tr><td></td><td>that will support establishment and spread.

Although the outcomes were not as successful as hoped, the respondents understood the relevance of creating environments more conducive to attracting beneficials within the orchard. The need to be practical was highlighted, but having the right conversations was a step in the right direction.

While the work of the CoP is seen as extremely important at providing a collegiate, supportive, and seasonal approach to IPDM in the field- across agency, commercial and private advisors, respondents were discouraged by efforts to have more advisors to join the group. Further work is needed to promote the value proposition to this stakeholder group.</td><td>the orchard floor management has been good, but we need to work through the 'how' more.

The Mastrus has been a real positive- they are all concerned about Codling Moth. There needs to be some good communication on the chemical interactions- need to get Dave Williams work out in PIPS4 but it may need to be looked at again- What's the difference with the new population vs the unfit population Dave Williams was working with?

The improvements to the pest monitoring were really good. We took what the manual "said" and then gave it a "voice", but then adapted to suit a research & reality check. We refined those tools for growers. The whole concept of conservation biocontrol is very relevant, we are getting there in terms of grower awareness (change is needed) but is the industry/consumer willing to change their expectations to suit possible quality decline- this is what it may take to reduce pesticide use.

Growers can undo everything with one hit (i.e., control response to Mealybug), so we need to make sure the next two sprays are soft as possible. Agronomic advice important. CoP is so important in providing that long-term industry experience in this space.</td></tr>
<tr><td colspan="3">APPROPRIATENESS:

How well have intended audiences been engaged in the project?

To what extent was the PIPS3 Program Communications and Extension Plan appropriate and had an impact upon the target audience?</td></tr>
<tr><td>• To what extent did the project engage growers and front-line advisors through the IPDM Community of Practice and ExtensionAus apple and pear website?</td><td>AP19002 appropriateness rating achieved: 4.5 (n=10)

Overall program appropriateness: 4.6 (n=43)

The project was considered strong in engaging with the industry by partnering with the regional AP19006 sites, and through the roadshow events</td><td>Researcher

It's pretty obvious that we need so much work in extension as people are interested but they do not know how to access the information. People don't even know about the manual- it's there but we need to get it out. Maybe a pocket guide rather than large</td></tr>
</table>

	where *Mastrus ridens* populations were released. Growers were very interested in the story around the process taken to have a new *Mastrus ridens* culture imported, quarantined and reared by the team, primarily as the efforts taken to introduce a biological control agent into the country were not well understood. The videos produced on this topic were mentioned as well constructed, easy to follow and succinct. General, seasonal information on IPDM strategies communicated through the 'IPDM in Focus' articles, and AFG articles on conservation biocontrol benefits and different types of biological control, were valued by respondents as they were well-written and simple in nature. They also assisted the audience to understand how IPDM can be implemented, using a single pest as an example to break-down the elements needed to control. The CoP is highly valued by the advisors who participate as it provides a platform for exchange with those in similar roles across the country, and the guest presenters provide new insight into R&D.	*manual?* *Orchard walks definitely worked. In April-June; there were peaks on the extensionAus website after each roadshow field day. The CoP targeted advisors and consultants- so we are targeting a number of levels. Our focus of the CoP has been quality rather than quantity of numbers- emphasis on key influencers who can discuss the tricky issues in a safe forum.* ***Grower*** *User friendly to my region and the data is relevant to our region. We have different growing environments, so the work needs to be done here to have influence.* *The research is great but getting the information out to farmers is really important- 2-pager that is linked to the detail in the final report.* *I can't think of a reason why they have not been exposed to the R&D. They have had the opportunity. If you haven't attended, read, watched, or not contacted researchers, then that's on them.* *The guys you had talk at the event were really fascinating. I pulled out what was relevant to me. Also, when we were in the orchard, those specialists were so knowledgeable, and I really paid attention to what they had to say. To have the specialists in the orchard who are experts in certain aspects is so good- nitrogen input, IPDM- a group in the orchard and available to ask questions. It was awesome to have that opportunity.* *Face to face is always most impactful. For me, the research is something I will seek-out.* *I read the articles, but it is more important that it comes from the advisors such as Paul [James]. More important they know this*

		and then it gets to me. ***Service Provider*** *I liked the fact that there was a coordinator to oversee everything and get the extension stuff happening. Especially considering half delivered during COVID. Videos reached people when we couldn't.* *Less communication has been occurring so not knowing what is going.* *The engagement with growers slowed a little in the middle of the project as there was nothing new in the research (tangible) so nothing new to extend. We need to keep them more engaged throughout.* *Some of the Facebook CoP not bad but each region has its own issues. More videos on IPDM- not just research but issues that are seasonal.* *The roadshow was certainly very important. Got to get the researchers out. Crucial. The research benefits and that's what needs to happen.* *It's hard as PIPS is research- but they want to know how it is going to work on their farm and this is about how the research is extended afterwards.*
EFFICIENCY: *What efforts did the PIPS3 Program partners make to improve efficiency?*		
• To what extent did collaboration across the PIPS3 Program improve efficiency of pest, natural enemy and soil/tree health measurements?	**AP19002 efficiency rating achieved:** 4.0 (n=10) **Overall program efficiency:** 4.1 (n=39) The AP19002 respondents rated the PIPS3 Program as strong on its performance to deliver an efficient approach to research, and communication and extension of the research. Issues were raised that need to be addressed for PIPS4. These are a greater commitment to the integration of PIPS IPDM and soils projects, especially the development and	***Researcher*** *I would have done some things differently- the way that the soils & IPDM projects worked together- site establishment I would not have done things that way. Like site establishment to deplete weed burden- not enough time put into this…The projects need to work much better together.* *It's more beneficial to industry as growers have a range of issues to contend with, so looking at the whole system improves integration. Communication*

	implementation of standard protocols for experimental sites, and a clear schedule and process for collection, management, and analysis of soil samples and IPDM monitoring. It is evident that growers and service providers valued the integrated, whole-of-system, messaging and advice provided by the research teams. This was particularly evident when research leaders were together in the field with growers and advisors ([roadshow events].	*between projects can be done a little better i.e., we need to connect more with the soil health project but (currently) rely on "good will."* *The relationship with TIA through Steve is really important.* *The project leaders interacted, which was great but needed to trickle down and little further down the team.* ***Grower*** *My experiences with the program showed that everyone seemed to be in sync and knew where the integration points are.* *Whole-of-system is what needs to be considered, so anything that addresses that is good.* *Makes a difference for the information to come out as whole.* ***Service Provider*** *With you [Program coordinator] coming onboard it was a godsend. This project has forced researchers to be more aligned and work together. Cross fertilisation of ideas is a must and has worked.* *It's good to talk about all system issues together- The roadshow day showed that the researchers are working together to consider the impacts across the whole system.* *Black Spot Management article at the time was good- need to be front footed.*
LEGACY: *Are there signs that the PIPS3 Program will influence apple and pear growers in the future?*		
• To what extent has the project improved knowledge and understanding of the role of *Mastrus ridens* for sustainable management of codling moth in Australia, and benefits to orchard pest management, soil health and tree health through new approaches to cultural and	**AP19002 legacy rating achieved:** 3.9 (n=10) (Improved knowledge & understanding of the concepts= 3.9 & Likelihood of adoption <10 yrs.= 3.8) **Overall program legacy:** 4.0 (n=43) (Improved knowledge &	***Researcher*** *Already getting phone calls from growers on what they should be planting. This is a real shift in thinking from three years ago [orchard floor management].* *Definite improvement but they are not kicking goals. They are thinking about it. Lack of extension in IPDM space- they*

biological practices? *PROGRAM* • Is there evidence that outcomes and outputs of the PIPS3 Program will continue to be adopted by growers and front-line advisors? • To what extent do stakeholders believe that outcomes/ outputs of the PIPS3 Program are likely to become "usual grower practice" within the next ten years?	understanding of the concepts= 4.1 & Likelihood of adoption <10 yrs= 3.8) AP19002 has reinvigorated the conversation and awareness of IPDM, using the new *Mastrus ridens* release and conservation-biocontrol management experiments to demonstrate what needs to be considered in an IPDM program, but not necessarily yet clear guidance on the 'how to'. Whilst a legacy rating of strong has been achieved, all respondents acknowledged there is more to be done, and that PIPS4 will provide the longevity needed. Whilst conservation biological control strategies in the orchard are seen as needed, the practicalities of implementation need to be further considered, and the thought is to look beyond the use of natives that are difficult to establish and maintain. Respondents see the need for more diversity in providing habitat and a food source for beneficials, and the criteria developed by the project are valued, however location of plantings and species selection needs more work. General information on biological and cultural practices was highly valued as all stakeholder groups identified the need for more IPDM extension by industry. AP19002 was seen as providing an avenue for filling this gap to an extent. While growers and advisors believed "softer" practices were needed, and to a certain level are 'base' practice in some regions [SA and WA identified], the issue of an IPDM program becoming "quickly unstuck" by the use of chemicals to address a pressing seasonal issue, was raised frequently. These stakeholder groups see a need for more extension on how best to proactively manage and	*understand it, but they don't know how to use the knowledge- getting started and the practical implementation.* *My thinking has changed- I was very focused on native species (within orchard rows), but now I understand that they mostly don't work and difficult to establish. We need to look at the broader landscape.* *The change is already on its way for new orchards, but we don't know the right advice yet. Underneath the tree is already.* *The message is starting to get across, but they need more evidence. Continuity of the PIPS program will certainly help with this. We can build on PIPS3 very quickly. Will be outcomes in five years.* ***Grower*** *Knowledge is gold. It's a lot of time and money, and sometimes there are only a couple of sentences in advice that come out of this, but it's worth it and can give you the confidence to act. There is no one solution, but if you give the full arsenal on what is available a go, which is what the program is providing, then we can give what is relevant a go. Growers want to be shown and won't look at many things until it is proven consistently over many years.* *The problem is not enough are exposed directly [e.g., as host farmers]. If there are more growers involved, they will share locally. Those who absorb this information are the ones that are going to be here in the long term. Growers need to adapt and move onwards overtime. Some are staying where their fathers were.* *There will be a level of adoption, but time will tell... It's always going to be about what the biggest pain is as to where they will spend their money.*

	appropriately respond to seasonal pressures. The economic proposition of biological and cultural practices needs to be further assessed and extended. Information provided at the roadshow events on the economics of *Mastrus ridens* was welcomed by the audience. It is acknowledged that the whole-of-system economics, long-term, would be complex, but more case studies (such as the *Mastrus ridens* example) would be valuable. Growers acknowledge that IPDM takes a very long-term approach, and they will often favour more immediate pressures to focus limited expenditure rather than plan for the years ahead. There are certainly examples of where growers have undertaken their own simple economic assessment to justify the longer-term value of certain IPDM strategies, such as "softer" chemical use.	*Can see that some people are taking it on, and some people will never take it on and will fall by the wayside.* *I have only been back on the farm for six years, so it is all helpful, especially in the IPDM space and thinking about beneficials and ways to use softer chemicals- or at the right time to protect beneficials, especially pollinators. Started to think about spending a little more to protect our beneficials to combat the mites. Dad used to buy the cheaper chemical to kill the mites, but then the issue just arose each season. I encouraged him to think about the long-term economics rather than seasonal economics- the more expensive, softer chemical meant that there was no issue in the second year as we had protected the beneficial insects.* *Have started to talk to machinery suppliers about mowers rather than sprayers.* ***Service Provider*** *They want to produce fruit with increased yield and quality sustainably with less pesticides. Growers had trouble grasping the benefits from soil health, but could really see the value to IPDM- reducing risks, increasing beneficial pollinators etc. More immediate benefit.* *Driven off the back of new chemistry- it's about becoming more beneficial friendly. Growers are aware of it and these projects help the conversation.* *In the reseller world, they are having these conversations with growers all the time. Growers not using our knowledge are doing the same thing- but they are also those not engaged in anything offered by industry. [CoP Member]* *How the final messages are distributed will be the thing for*

		growers. They need guidance on not only establishing the populations, but how to manage things so they are not lost during one reactive action. *Service providers have picked-up a lot, and then the growers pick-up from this. Especially IPDM.* *IPDM is base practice already in this region-so anything in that space is tweaking only. They will be looking for spread of Mastrus and will run with it.*

Recommendations

Recommendations for growers and advisors

- Conservation biological control be implemented that includes the conservation of resident natural enemies and where necessary, the deliberate release of biological control agents that target specific pests.
- Inter-row vegetation management that promotes biodiversity of orchard natural enemies, such as no-mow flowering strips, or adapting mowing schedules is adopted.
- The use of compost or mulch within the tree line to harbor ground-dwelling predators and detritivores be considered.
- IPDM uptake and dissemination of information for service providers and growers is supported.
- The IPDM Manual is highlighted as an important online resource by developing stories for industry publications magazine and events.
- Other online resources are supported, and website analytics usage peaks analysed and correlated with IPDM research presented at industry events, indicating interest in the topics while it was fresh in the minds of attendees.

Recommendations for further research

- Further research be conducted into the development of tailored inter-row cover crop species that provide SNAP for resident natural enemies and specific biological control agents against key orchard pests such as the codling moth parasitoid, *Mastrus ridens.*
- The role of extant and remnant bushland and deliberate plantings of native vegetation around orchards and block margins, in conserving natural enemy populations, be investigated.
- The economic value of conservation biological control and addressing barriers to adoption is quantified.
- There is continued effort to integrate conservation biological control with IPDM programs (especially IPDM-compatible pesticides and their application), and research into soil health, tree health and fruit quality.
- Follow up monitoring be conducted for the most recent (2022/23) *M. ridens* releases, commencing in 2024.
- Projects requiring establishment and evaluation of plants and arthropod responses are longer than 3-years, and ideally conducted on multiple orchards using large treatment areas.
- The contribution of *Trichogrammatoidea cryptophlebiae* to general pest control within apple and pear orchards, and possible synergistic relationships with the other apple and pear orchard Trichogramma species (*T. pretiosum* and *T. carverae*), is investigated.
- Any further attempts to develop a chemical lure for *M. ridens* should only use insects from a population known to be genetically diverse.
- Strategies to prevent or slow inbreeding in lab cultures, including consideration of re-importing *M. ridens*, be implemented.
- The cost benefit and adoption model and scenario analyses for *Mastrus ridens* be further developed and published in an appropriate peer-reviewed journal.

Intellectual property

No project IP or commercialisation to report

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Appendix 2_AP19002_Trichogrammatidae parasitoids

Appendix 3_AP19002_*Mastrus ridens* importation, field release and assessment

*Appendix 4_AP19002_Assessment of genetic diversity in *Mastrus ridens* laboratory colonies in Australia

Appendix 5a_AP19002_Cost-benefit analysis for codling moth biocontrol with *Mastrus ridens*

*Appendix 5b_AP19002_Draft manuscript including update to Potential Net Benefits of *Mastrus ridens*

Appendix 6a_AP19002_Communication and Adoption report

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*draft manuscript intended for journal publication

Appendix 1

Technical Report: Conservation Biological Control

AP19002 Strengthening cultural and biological management of pests and diseases in apple & pear orchards

July 2023

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VICTORIA State Government | Energy, Environment and Climate Action

AGRICULTURE VICTORIA

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Project Leader Name	Greg Lefoe

Acknowledgment

We acknowledge and respect Victorian Traditional Owners as the original custodians of Victoria's land and waters, their unique ability to care for Country and deep spiritual connection to it. We honour Elders past and present whose knowledge and wisdom has ensured the continuation of culture and traditional practices.

We are committed to genuinely partner, and meaningfully engage, with Victoria's Traditional Owners and Aboriginal communities to support the protection of Country, the maintenance of spiritual and cultural practices and their broader aspirations in the 21st century and beyond.

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Executive Summary

Conservation biological control (CBC) is a sustainable approach to pest management that can contribute to a reduction in pests using habitat manipulation to secure and enhance the performance of natural enemies (predators and parasitoids) as biological control agents. CBC is a key component of integrated pest and disease management (IPDM) that has been gaining adoption in horticultural industries worldwide. In this context, habitat manipulation generally refers to non-crop or cover crop vegetation, planted within or adjacent to orchards, that provide Shelter, Nectar, Alternative hosts or prey and Pollen (SNAP) to increase the survival, fitness and abundance of beneficial arthropods, pollinators, predators, and parasitoids. Typically, exotic annual flowering species are promoted for use in cover crop plantings for CBC, however in south-eastern Australia, native vegetation grown within and on the periphery of vineyards has also demonstrated potential for improved pest management, particularly against pest insects that are themselves native, such as light brown apple moth (LBAM).

In this project, we aimed to trial the use of native and non-native vegetation within apple and pear orchards, either deliberately planted or resident vegetation, for their potential to provide CBC. More specifically, the objectives of the study were to:

1. Determine whether native and/or exotic grasses and forbs could be easily established in the apple and pear orchard inter-row using seed or tubestock, and
2. Determine the effect of these plantings in the inter-row and tree line on the invertebrate community composition, and their impact on crop pest and beneficial arthropod abundance and fruit pest damage levels.

These experiments were conducted at an experimental pear orchard at Agriculture Victoria’s Tatura SmartFarm in the Goulburn Valley, and a commercial apple orchard in Tasmania’s Huon Valley.

In the Victorian experimental orchard, three treatments were tested consisting of combinations of native groundcovers and grasses, and different establishment methods (seed sowing or tubestock planting). These treatments were compared to the standard practice of maintaining bare ground beneath trees (herbicide strip) and a mown inter-row consisting of broadleaf weeds and grasses (grower sward). The Tasmanian experimental orchard treatments included an additional ‘exotic’ flowering meadow treatment within the inter-row and compost/mulch and legume-grass tree line treatments.

Compared to the exotic species, the native grasses and groundcovers sown into inter-row treatments either did not germinate or failed to persist within both orchards. The slow germination of the native seeds limited their ability to compete with the faster growing exotic annuals that proliferated in the high nutrient soils. Furthermore, orchard management practices such as periodic mowing, mulching and soil compaction from farm machinery, contributed to the reduced establishment of the native plant species.

Greater success was achieved in both Victoria and Tasmania with native tubestock, with many of the species flowering soon after planting. In Victoria, the tubestock were limited to planting along the tree line where they received irrigation and were less prone to mechanical damage. However, their survival was also influenced (negatively) by snail herbivory and competition from weeds. Similarly, herbivory from wallabies and excessive weed competition affected tubestock survival past the second year in Tasmania.

The study was unable to demonstrate the contribution native plant species could have in enhancing CBC within an apple and pear orchard in south-eastern Australia. Any future attempts to establish native plant species in Australian orchards would most likely require the use of weed matting/mulches or at least two years of weed management to reduce resident weed seedbanks prior to sowing/planting native species. Even then, competition from annual weeds would be an ongoing problem due to the high fertility of the orchard soils, which favour exotics over native plant species. Furthermore, due to the relatively higher costs associated with purchasing the native seed/tubestock, the labour involved in seeding and planting, and high weed management input, it’s unlikely that growers would readily adopt the use of native cover crop species unless a sufficient economic and environmental benefit could be demonstrated to justify the added costs.

Despite these challenges, the study was able to demonstrate the importance of maintaining flowering non-crop vegetation, even if exotic broadleaf weeds and grasses, within orchards for the conservation of beneficial arthropods. We found a diversity of parasitic wasps; and predatory lacewings, ladybirds, and mites within the orchard canopy, which were also detected in the inter-row vegetation. A greater abundance of beneficial natural enemies within the orchard corresponded with peak flowering of the inter-row vegetation and were lowest when the vegetation was sparse. Other ground-dwelling predators, including earwigs, spiders and rove beetles were collected in pitfall traps placed beneath trees. These predators were more abundant where ground cover and mulch provided a safe place to hide.

Overall, the CBC trials were able to demonstrate:

- The potential gains that can be made by manipulating arthropod abundance and diversity through altering ground cover composition within Australian apple and pear orchards.
- Vegetative groundcovers within the tree line encouraged predators such as earwigs in tree canopies and spiders on the orchard floor.
- Vegetative tree lines were also observed to encourage the movement of beneficial fauna from the inter-row towards the tree lines where they have the potential to have a greater impact on economically important pest species.
- The use of compost within the tree line was demonstrated to improve non-pestiferous ground dwelling mite populations under the trees.
- These gains have the potential to both promote nutrient cycling and suppress ground dwelling pest species (i.e., LBAM during winter) and canopy borne pests such as woolly apple aphid during the production season.

Recommendations to industry/growers:

1. CBC be implemented that includes the conservation of resident natural enemies and where necessary, the deliberate release of biological control agents that target specific pests.
2. Adoption of inter-row vegetation management that promotes biodiversity of orchard natural enemies, such as no-mow flowering strips, or adapting mowing schedules.
3. The use of compost or mulch within the tree line to provide harbour for ground-dwelling predators and detritivores.

Recommendations to R&D investment decision makers:

1. Further research into the development of tailored inter-row cover crop species that provide SNAP for resident natural enemies and specific biological control agents against key orchard pests such as the codling moth parasitoid, *Mastrus ridens.*
2. Investigations into the role of extant and remnant bushland and deliberate plantings of native vegetation around orchards and block margins, in conserving natural enemy populations.
3. Quantifying the economic value of CBC and addressing barriers to adoption.
4. Continued effort to integrate CBC with IPDM programs (especially IPDM-compatible pesticides and their application), research into soil health, tree health and fruit quality.
5. Projects longer than 3-years for conservation biocontrol research in agroecosystems, ideally on multiple private orchards using large treatment areas.

Introduction

Conservation biological control (CBC) is a sustainable approach to pest management that can contribute to a reduction in pests using habitat manipulation to secure and enhance the performance of natural enemies (predators and parasitoids) as biological control agents. CBC is a key component of integrated pest and disease management (IPDM) that has been gaining adoption in horticultural industries worldwide (Gurr *et al.,* 2017).

CBC can also increase the success rate of other biological pest control strategies, such as classical biological control or augmentative biological control. For example, CBC can provide necessary resources for recently introduced classical biological control agents and aid establishment success. This is currently a priority in Australian pome systems for the parasitoid *Mastrus ridens* (Hymenoptera: Ichneumonidae), which is being mass released for the control of codling moth, *Cydia pomonella* (Tortricidae) a serious economic pest in pome fruit (Williams, 2020).

The aim of CBC is to provide on-farm (e.g., Pandey & Gurr, 2019) and (where necessary) landscape-level non-crop vegetation (e.g., Tscharntke *et al.,* 2007; Jonsson *et al.,* 2015) that provides Shelter, Nectar, Alternative hosts or prey and Pollen (SNAP) to increase the survival, fitness, and abundance of beneficial arthropods- pollinators, predators, and parasitoids- specifically, and the food-web in general. CBC of pests is thus about reinstating a greater degree of complexity in both the immediate agricultural environment, as well as in regions of agricultural intensity or overly simplified landscapes where it is necessary to replenish a diverse natural enemy species pool (Beaumelle *et al*., 2019).

Within apple and pear orchards, non-crop vegetation for CBC of pests (sometimes called ‘insectaries’) can be positioned within the inter-row by means of perennial flower strips (Cahenzli *et al.,* 2019), cover crops (Bugg & Waddington, 1994), or simply the local seedbank under reduced mowing practices (García & Miñarro, 2014). Non-crop vegetation can also be positioned under the tree line using cover crops with specific traits that will enhance crop production as well as provide SNAP to beneficial arthropods. Native grass strips and/or hedgerows can be positioned around block edges which can serve as overwintering sites and refuges during periods of in-crop disturbance (e.g., Debras *et al.,* 2008; Peñalver-Cruz *et al.*, 2019). Each of these spaces within an orchard can be individually designed to maximise ecosystem services specifically for the crop. As covered in a review by Herz *et al.,* 2019, research on CBC of pests in apples and pears has increased exponentially since the beginning of the 21st century and there are several important success stories and insights, particularly from Europe and China (Cahenzli *et al.,* 2019; Cai *et al.,* 2021; Gontijo *et al.,* 2013; Zhou *et al.,* 2014; Ji *et al.,* 2022).

Within Australia, movement toward CBC of pests using non-crop vegetation has been slower due to difficulties finding appropriate plant species that are suitable for the local environmental and farm-management criteria (Bone *et al.,* 2009) but that do not host light brown apple moth, *Epiphyas postvittana* (Tortricidae), an economically important pome pest that is native to Australia (Danthanarayana, 1975). Common practice in many Australian pome orchards is to regularly mow the grass-dominated inter-row, whilst keeping the tree line area free of vegetation by means of herbicide application. Selective insecticides are now commonly used instead of broad-spectrum to reduce collateral killing of non-target invertebrates. Despite the difficulties with plant species selection, the potential is there in apple and pear crops to design a biodiverse ecosystem that encourages the presence of natural enemies of pests as well as pollinators.

Apples and pears are grown in all states (but not territories) of Australia, although Victoria currently produces most of both crops (Australian horticulture statistics handbook, 2021). In Victoria, the main apple and pear producing areas typically have a mean annual rainfall of less than 800 mm and irrigation is necessary and limited to the tree line, usually by drip feeders.

Pome pests in Australia include a diverse range of arthropods from a wide range of taxa, including mites, thrips, scale, mealybug, true bugs, crickets and grasshoppers, fruit flies and vinegar flies, caterpillars, weevils and other beetles (Malipatil *et al.,* 2009). Of the pests, the most economically important is the codling moth, which occurs in all growing regions except Western Australia. Insecticide sprays are commonly used to control codling moth, light brown apple moth, and apple dimpling bug, *Campylomma liebknechti* (Hemiptera: Miridae) or in Tasmania its close relative, *Niastama punctaticollis* (Hemiptera: Miridae).

The beneficial complex that attacks arthropod pests in Australian pome orchards (natural enemies) include predatory mites, the spined predatory shield bug, *Oechalia shellenbergii* (Hemiptera: Pentatomidae), green and brown lacewings, hover flies, ladybird beetles, spiders and a range of parasitic wasps (Malipatil *et al.,* 2009). Parasitic wasp natural enemies of pome pests include: *Trichogramma* wasps (*T. carverae, T. funiculatum, T. brassicae*) that parasitise budworms, codling moth, oriental fruit moth and light brown apple moth; *Tetracnemoidea sydneyensis* (Hymenoptera: Encyrtidae) that parasitise longtailed mealybug; *Aphelinus mali* (Aphelinidae), a parasitoid of woolly aphids; Braconid wasps that parasitise budworm and light brown apple moth larvae; and *Telenomus* (Scelionidae) wasps that parasitise budworm eggs (Malipatil *et al.,* 2009). Waterhouse and Sands (2001) have compiled a list of recorded parasitoids that attack codling moth in Australia; these include one tachinid fly and seventeen species of Hymenoptera from six families.

PIPS (Productivity, Irrigation, Pests and Soils) programs were initiated in 2009 to establish and develop new tools and knowledge for use by apple and pear growers. The Integrated Pest and Disease Management (IPDM) subproject team introduced a parasitoid, *Mastrus ridens* as a classical biological control agent for codling moth, to supplement existing management approaches such as pheromone mediated mating disruption.

PIPS2 project *Integrated pest and disease management –Phase II (Child of AP14014)* (AP15001) ran from 2015-2019 with an IPDM component tasked to complete field releases of *M. ridens* in pome fruit orchards in eastern Australian states and to evaluate its effectiveness as a biological control agent against codling moth (Williams, 2019). These releases resulted in significant reductions of codling moth populations the following season (Williams, 2019), however, since the completion of PIPS2, there had been no evidence to show that *M. ridens* has established permanent populations in the release sites or surrounding areas.

The current PIPS3 project, *Strengthening cultural and biological management of pests and diseases in apple and pear orchards* (AP19002) aims to assess establishment of *M. ridens* and identify reasons for the apparent low establishment in Australia. One aspect of this work targets the genetic diversity of the imported colony (Lefoe, 2022), while another aspect aims to provide SNAP in the crop environment for conservation of beneficial arthropods including *M. ridens* and trichogrammatid wasps.

Selecting non-crop plant species to enhance the fitness of selected natural enemies plus a complex of generalist natural enemies whilst not providing host plants for pests; and adhering to the particular agronomic and environmental criteria in terms of plant selection, is a complicated task. Fortunately, plant selection to increase the fitness of trichogrammatid species has received a relatively high amount of research attention. White cultivars of sweet alyssum, *Lobularia maritima*, have been identified as being particularly beneficial for improving the survival and fecundity of *T. carverae*, whilst not being used as a host by larval and adult *E. postvittana* (Begum *et al.,* 2004; Begum *et al.,* 2006). Importantly, for trichogrammatid wasps, the need for within-crop nectar sources is particularly acute because of their small size and relatively weak flight (Glenn & Hoffmann, 1997). In contrast, larger parasitoids such as *M. ridens* (Ichneumonidae) can fly further (e.g., Dyer & Landis, 1997), however, corolla aperture and depth can be limiting for access to nectar (e.g., Vattala *et al.,* 2006). Alternatively, extrafloral nectar, which is formed on some plants, can significantly prolong the duration of nectar availability for parasitic Hymenoptera (Pemberton & Lee, 1996).

Native plants have evolved alongside local invertebrate populations, providing native beneficial insects with suitable SNAP requirements. Including native plants within agricultural ecosystems has potential to support a more diverse range of invertebrates compared to exclusively non-native species (Retallack *et al*., 2019), creating a more resilient and balanced ecosystem that is less likely to have pest outbreaks. Inclusion of flowering native vegetation in agricultural ecosystems can increase crop pollination (Potts *et al.,* 2010), because native flowering plants evolved alongside local pollinators, including native bees, butterflies, and other insects. Another important reason for choosing native vegetation wherever possible is to reduce the possibility of accidentally introducing exotic plants that become environmental weeds. However, there is a lack of information about the suitability of native versus exotic vegetation in apple and pear orchards in Australia in terms of establishment costs, agronomic characteristics and impacts on invertebrate populations. We therefore conducted orchard experiments in two states utilising either native (Victoria) or mixed native and exotic (Tasmania) vegetation within orchards to:

1. Determine whether native and/or exotic grass and forbs can be easily established in the apple/pear inter-row using seed and/or tubestock, and

2. Determine the effect of planting native and/or exotic grass and flowering forbs in the inter-row and tree line on the invertebrate community composition in both the inter-row and the tree crop, as well as its function in terms of crop pest and beneficial arthropod abundance and fruit pest damage levels.

Materials and Method

Conservation biological control experimental plots were established in Victoria (netted experimental pear orchard) and Tasmania (commercial apple orchard). The sites were monitored during the two seasons of 2021-2022 and 2022-2023.

Selection criteria for tree line and inter-row plant species for the experiments in both states were developed in an online workshop. The agreed criteria considered a range of desirable attributes including ease of establishment, the provision of SNAP resources for beneficial invertebrates, and soil health amelioration, as summarised in Table 1.

Table 1. Simplified criteria used to select native species for planting within the orchard inter-rows.

Criteria	Rationale
Endemic to the bioregion, easily sourced and reasonably priced	More likely to be adapted to local climates and soil types. Large quantities of seed/tubestock required.
Low growing, herbaceous but hardy	Able to withstand disturbance from machinery and trampling but not be a hazard for orchard personnel.
Flowers and pollen available year-round	Pests and their natural enemies can be active at different times of the year. Adults of the codling moth parasitoid, *Mastrus ridens*, would benefit from pollen and nectar throughout winter.
Plants with different flower shapes and colours	Beneficial insects have specialised mouth parts and may require specific types of flowers as a nectar source. For instance, tiny parasitic wasps require small, shallow flowers.
Potential contribution to soil health	Different plant species each have attributes that contribute to improving the physical, chemical and biological soil environment. A species mix that has a variety of characteristics will increase nutrient availability, improve soil structure and deliver natural protection from pathogens.
Low weed risk	Certain species, whilst otherwise providing ideal attributes, have potential to prolificate or spread without control. These may also compete for water in the orchard.

Plant species for inter-row and tree line treatments in Victoria (Table 2, Table 3, Table 4, Table 5, and Table 5) and Tasmania (Table 7) were selected using these criteria.

Victoria: experimental pear orchard

Conservation biological control plots were set up at the experimental pear (cv. 'Rico') orchard within the Agriculture Victoria SmartFarm at Tatura (-36.439012, 145.265909). This netted orchard is approximately 2 ha with rows running north-south. Soils in the experimental pear orchard are red sodosol (Isbell, 2002), which has a strong texture contrast between the red topsoil and the subsoil, which is sodic. Red Sodosol is known locally as Lemnos loam (Skene & Poutsma, 1962).

Experimental design and vegetation establishment

Eight rows within this orchard were used for the experiment with two rows left unused between each to reduce edge effects. Each of the eight rows were split into four plots, 42 m x 4 m (**Error! Reference source not found.**). Each plot consisted of three panels (physical divisions along the trellis) on each of the east and west sides. The following four treatments were allocated to plots in a replicated split plot design:

TR1: “Grower Sward” (i.e., control or standard practice) – mown grass/weeds

TR2: “Native grass/groundcover mix” species including grasses and flowering ground covers sown in the inter-row (Table 22)

TR3: “Native grass” species sown in the inter-row (Table 3)

TR4: “Native tubestock and grass” (Table 4 & Table 5)

All seed and tubestock were purchased from the Euroa Arboretum (http://euroaarboretum.com.au) using seed supplied by the Goulburn Broken Indigenous Seedbank and sourced from stands of remnant vegetation and designated Seed Production Areas within the local (Goulbourn Broken) catchment. Collections, cleaning, seed viability testing, and tubestock propagation were conducted by the Euroa Arboretum under a Flora and Fauna Guarantee Act (1988) permit.

A replicated glasshouse experiment was conducted to measure seed germination rates for three native grass species: 1) *Microlaena stipoides*, 2) *Bothriochloa macra*, and 3) mix of *Rytidosperma setaceum* and *R. erianthum*. Seeds were sown on the 1/07/2022 into trays (35 x 30 cm) containing either (1) commercial potting mix, or (2) orchard soil taken from TR4 (native tubestock and grass) plots at a rate of 4g per m^2. Each treatment was replicated five times. All trays were kept in a glasshouse and watered twice per week. The number of seedlings that had survived in each of the soil treatments were counted on 21/09/2022.

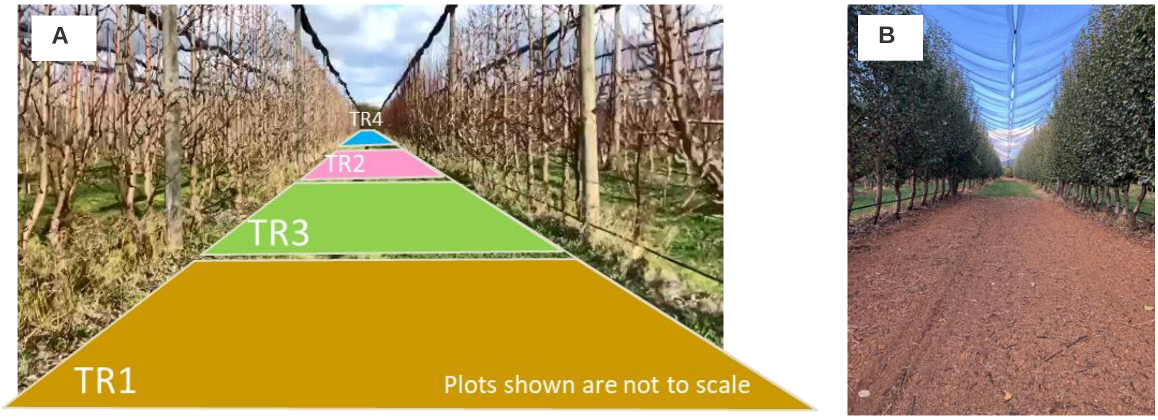

Figure 1. Overview of experimental plot layout at the Victorian experimental site a) illustration of a row (replicate) with four plots (treatments) randomly assigned, b) all treatment plots were lightly tilled prior to sowing (plot in foreground of photo), except for TR1 – standard practice plots which were mown (plot in the background).

Preparation of inter-row plots for TR2, TR3 and TR4 commenced during autumn 2021 using repeated herbicide application (Glyphosate 360), interspersed with soil tilling, with the aim of reducing the weed seed bank prior to sowing treatments. The soil was then lightly tilled again just prior to sowing, and seed of selected native species were hand-broadcast within the inter-rows of TR2 and TR3 plots on 25 May 2021 (**Error! Reference source not found.**a, Table 3 & Table 3). A turf roller was used to firm the seed down on the soil. Heavy rain occurred within hours of sowing TR2 and TR3. Supplementary irrigation of the inter-rows was not used, as it is the general practice in Victorian pome orchards. TR4 plots received an extended (12 months) site preparation including herbicide application, tilling and follow-up herbicide control for seeding emergence to account for competition from non-native grasses and broadleaf weeds. Seed for TR4 was hand-broadcast on 11/05/2022 using the same method as for TR2 and TR3.

Six native plant species were propagated as tubestock for the experiment by the Euroa arboretum (Table 5). A total of 32 plants of each species (except *Kennedia prostrata*) were planted directly in front of the tree line in each TR4 plot (Figure 2b). Thus 16 of each species were planted on either side of the rows. The allocation of species to each spot on one side of the row was randomised. For *K. prostrata*, only three plants were planted per plot. These were planted within the tree line of the centre panel of each of the native tubestock and grass (TR4) plot. Tree guards were placed around each seedling and snail bait put inside the tree guards at regular intervals. Planting of tubestock occurred over several weeks, commencing on 25 May 2022.

Following the sowing of native seeds in the treatment plots, limited follow-up weed control using herbicides was undertaken in the inter-rows apart from periodic mowing. Weed suppression continued beneath the trees along the irrigation drip lines using Basta® but discontinued for the native tubestock and grass plots after the tubestock was planted.

Figure 2. Applying native species treatments at the Victorian experimental site A) hand sowing native grass seeds in TR3 plots, B) tubestock of native flowering species planted on the edge of the tree line in TR4 - native tubestock and grass plots.

Table 2. TR2: native grass/groundcover mix planted in the inter-row at the Victorian experimental site.

Species	Common name	Quantity required (at 4g/m2)	Quantity required per plot
Chrysocephalum apiculatum	Common everlasting	504 g	63.0 g
Calocephalus citreus	Lemon beauty heads	504 g	63.0 g
Vittadinia cuneata	Fuzzweed	504 g	63.0 g
Kennedia prostrata	Running postman	504 g	63.0 g
Enchylaena tomentosa	Ruby salt bush	504 g	63.0 g
Bothriochloa marca	Red leg grass	504 g	63.0 g
Rytidosperma caespitosum / R. setaceum	Common wallaby grass	504 g	63.0 g
Microlaena stipoides	Weeping grass	504 g	63.0 g

Table 3. TR3: native grass seed planted in the inter-row at the Victorian experimental site.

Species	Common name	Quantity required (at 4g/m2)	Quantity required per plot
Bothriochloa marca	Red leg grass	1344 g	168 g
Rytidosperma caespitosum	Common wallaby grass	1344 g	168 g
Microlaena stipoides	Weeping grass	1344 g	168 g

Table 4. R4: native grass seed planted in the inter-row at the Victorian experimental site after extended (12 months) site preparation.

Species	Common name	Provenance (Revegetation zone)	Quantity sown (at 4g/m2)
Bothriochloa marca	Red leg grass	Devonish provenence (Victorian Riverina	1344 g
***Rytidosperma setaceum* (seed and chaff)**	Bristly Wallaby-grass	Euroa (Southern Riverina)	155 g
***Rytidosperma* species mix (seed and chaff)**	Bristly and lobed wallaby-grass	Euroa (Southern Riverina)	540 g
***Rytidosperma setaceum* (seed and chaff)**	Bristly Wallaby-grass	Devonish provenence (Victorian Riverina)	649 g
Microlaena stipoides	Weeping grass	Hilldene (Sugarloaf)	1344 g

Table 5. TR4: native tubestock planted directly in front of the tree line at the Victorian experimental site.

Species	Common name	Quantity planted per plot
Rhodanthe anthemoides	Chamomile sunrays	32
Vittadinia cuneata	Fuzzweed	32
Pelargonium australe	Austral stork's bill	32
Chrysocephalum apiculatum	Common everlasting	32
Calocephalus citreus	Lemon beauty heads	32
Kennedia prostrata	Running postman	3

Monthly assessment of the hand-sown inter-row and tree line vegetation was conducted in every second row of the experimental pear orchard during the 2022/23 growing season, between September 2022 and February 2023. The orchard could not be assessed in November due to extensive rainfall and waterlogging of the orchard. A 50 cm square quadrat was used to record the identity of all plant species present, as well as the proportion of bare earth and leaf litter in each quadrat. For each plant species, the percentage cover and whether they were in flower at the time was recorded.

The native tubestock was assessed in December 2022 and March 2023 to get an indication of their resilience in the orchard and their potential contribution to SNAP during this period. Each individual plant was recorded as either dead/alive and flowering/not flowering.

A soil analysis was conducted on the 3 November 2021 using the protocol provided by *AP19006 - Improved Australian apple & pear orchards soil health and plant nutrition*. Using a soil corer, six cores from each treatment (4 inter-row and 4 tree line samples) were collected from depth of 0-15 cm from four of the rows (1, 3, 5 and 7). The cores from each treatment were mixed thoroughly and oven dried at 50°C, ground if required, and sieved to 2mm. 250g of sieved soil was placed into a labelled plastic snap-lock bag. Samples were sent to CSBP Soil and Plant Analysis Laboratory for chemical analysis.

Throughout the trial, pre-existing orchard pest and disease monitoring and management practices continued and were used to inform appropriate chemical applications. Existing practice in this orchard prioritised, where possible, softer insecticides aimed at minimising damage to beneficial arthropods. A summary of the pesticides and fungicides applied within the Victorian experimental site throughout the duration of the trial is available upon request.

Arthropod and disease monitoring

Monitoring was conducted during the apple/pear growing season (Aug/Sep - April/May) in 2021/22 and 2022-23. The timing of monitoring visits aligned with the phenology of the tree crop as well as the seasonal activity of the main pests, diseases, and beneficial species.

Arthropod monitoring methods used at the Victorian experimental site are summarised in **Error! Reference source not found.**. Monitoring protocols were developed based on a literature review and expert advice from departmental entomologists who have experience in pome fruit production systems. Information about diagnostics, biology, damage and symptoms of the pests and diseases mentioned in this protocol can be found in the manual “Integrated Pest Disease and Weed Management manual for Australian Apple and Pears” published by Hort Innovation (Williams & Villalta, 2017). Some of the monitoring protocols were modified over time to address specific research questions within the project. To maintain consistency in monitoring and avoid any edge effects, one, two or three middle trees in each panel were flagged (depending on the canopy size of the trees) and used for most of the monitoring (Ridland, 2006; Williams & Villalta, 2017).

Flower-pest inspection

Flowers were monitored mainly for apple dimpling bug (ADB) and thrips during the flowering season, starting from mid-September to mid-October at the Victorian experimental site until two weeks after petal fall. Sampling was done once a fortnight in the morning. Four flower clusters from each of the two middle panels in each plot were selected and tapped from above 3-4 times in quick succession over a white tray or container. The number of ADB and thrips found were counted and recorded across the two panels in each plot.

One-minute canopy inspection

Tree canopies were visually inspected approximately once per fortnight from November 2021 until May 2022. Flagged trees in the middle panels of each plot (i.e., 2 panels per treatment) were visually inspected for one minute for evidence of the following pests and diseases; budworm (*Heliothis*), looper, pear slug, light brown apple moth (LBAM) larvae, weevils, scab, powdery mildew, Alternaria on leaves and fruit, and bitter rot on fruit. The presence of lacewings (brown and green), hoverflies, parasitoids, and ladybirds were also recorded. Count data from the two middle panels of each plot were summed for each arthropod, giving one value per plot in each block for every sampling occasion.

Infestations of woolly apple aphid and long-tailed mealybugs were categorised as: 0 (no colonies observed); 1 (<5 % of the shoots/leaves infested); 2 (5-10 % of tree infested); 3 (10-25% of tree infested with large colonies); and 4 (>25 % of tree infested with large colonies). The approximate number of mummified woolly apple aphids was recorded.

Table 6. **Overview of the vegetation and arthropod monitoring methods used for the conservation biological control experiment at the Victorian experimental site. ADB = apple dimpling bug; LBAM = light brown apple moth; Qfly = Queensland fruit fly.**

Monitoring method	Aim	Timing
Vegetation assessment	Record both inter-row and tree line vegetation in the experimental plots in the various treatment over time.	Monthly from September – April during 2022/23 season.
Flower-pest inspection	Record both ADB and thrips during the flowering season	Fortnightly from around mid-September to mid-October
One-minute canopy inspection	Visual inspection of common pest and beneficial arthropods in the crop canopy to determine their relative abundance in the various treatments over time.	Approximately once per fortnight from November 2021 until May 2022l.
Aerial mite assessment	Assess the relative abundance of main mite species present in the crop canopy in the various treatments over time.	Monthly from early November to April; 2021/22 and 2022/23 seasons.
Yellow sticky trap	Assess the relative abundance and diversity of winged arthropods (primarily thrips, flies and parasitic Hymenoptera) present in the crop canopy in the various treatments over time.	Monthly from October to April; 2021/22 season.
Pheromone trap	Record relative abundance of codling moth, LBAM and Qfly in the experimental pear orchard over time (not compared between treatments).	Weekly from Dec to April 2021/22 and from Aug to Nov 2022.
Earwig trap	Assess the relative abundance of earwigs in the tree crop in the various treatments over time.	Fortnightly or monthly from November to April; 2021/22 and 2022/23 seasons.
Pitfall trap	Determine relative abundance of ground-dwelling arthropods in the various treatments over time.	Monthly from November to April; 2021/22 season and once in March 2023
Sweep-net sampling	Determine the relative abundance of invertebrates residing in the inter-row vegetation in the various treatments over time.	Monthly from November to April; 2021/22 season.
Fruit damage assessment	Record the relative fruit damage from invertebrates in the various treatments at the end of each season.	Two assessments each season (2021/22 and 2022/23) in December and February.

Aerial mite assessment

Mites were monitored fortnightly or monthly from early November through to end of April 2021-22. Initially, leaf samples were collected to determine the first occurrence of mites from the first bloom on pears. Leaves were sampled from about 1.5-1.8m above ground on the outer parts of the canopy (for European red mite and *Bryobia* spp.), as well as the inner canopy (for two-spotted spider mite). Early-season monitoring concentrated on the inner, lower part of the tree, as this is where infestations often begin.

Several methods have been proposed for monitoring mites in Australian orchards, mainly based on examining leaves in situ to determine the percentage of leaves infested with mites. Three methods of sampling were compared to assess the suitability of each for measuring treatment effects in this experiment. For each flagged tree we randomly selected leaves to examine for mite species occurrence and prevalence:

(1) non-destructive visual examination of 10 leaves per panel/tree with a 10x hand lens (recommended method for routine orchard monitoring as per Williams & Villalta 2017) (**Error! Reference source not found.**a),

(2) destructive lab-based examination of 4 leaves per flagged tree(s)/panel using a stereo microscope, and

(3) destructive lab-based examination of 2 leaves per flagged tree(s)/panel using a stereo microscope.

The presence and prevalence of pest mites and the previously released predatory mite, *Neoseiulus californicus,* were recorded. The number of predators including *Stethorus* beetle (mite-eating ladybird) and other phytoseiid mites were also recorded if seen.

In methods (2) and (3), each sampled leaf was placed into a separate plastic snap-lock bag, and all leaves belonging to a plot were placed in a larger snap-lock bag with a label indicating sampling date, row, and treatment numbers. The leaf samples were kept in a cool room (4°C) for up to several weeks, during which time they were examined under a dissecting microscope.

Besides tetranychid mites, we looked for the presence and damage of eriophyid mites/blister mites. Eriophyid mites and immature stages of tetranychid mites are hard to see clearly with a 10× hand lens in the orchard, and detection requires a microscope. At the early stages of the monitoring, we realised that relying on the hand lens caused underestimation of the mites' population/presence. Raised blisters or pimples on the underside of leaves on new shoots and branches (sometimes on the stems and fruits) were considered as presence of eriophyid mites/blister mites. For other tetranychid mites and predatory mites (phytoseiids), observation of the actual mites was required to confirm their presence.

During the 2022/23 season, we modified mite sampling methods and examined eight leaves in each plot of five rows (used the same rows each time for sampling) = 160 leaves. Therefore, late spring and mid-summer populations of mites were assessed using this method.

Yellow sticky trap monitoring

Monitoring with yellow sticky traps is useful for determining the presence or absence of thrips, fruit flies and adult stage of beneficial flying predators and parasitoids (such as lacewings, hoverflies, different families of parasitoid wasps and tachinid dipterans). Each yellow sticky trap was installed in the lower third of the tree (at an approximate height of 1.5 m between branches, Ridland, 2006) in the middle panel of each plot for 5-7 days (**Error! Reference source not found.**b). This was repeated e very month from October to April. A total of 32 sticky traps were deployed every month (1 trap per plot x 32 plots) during the first season.

No insecticides were used in the orchard for 1-2 weeks prior to and during the installation period of the yellow sticky traps. After collecting from the orchard, the labelled traps were put separately in plastic laminating covers in the lab and stored at 4°C in the cool room for microscopic examination.

Pheromone trap monitoring

Owing to the small area of the orchard (and each plot) and the broad spectrum of the pheromone traps for codling moth (CM), LBAM and Queensland fruit fly (QFLY), it was not possible to measure the effect of native vegetation treatments on the abundance of these two pests. Hence, general pheromone monitoring data using the existing orchard pheromone trapping approach was used.

Two series (1 series in each end of pear orchard) of pheromone/fly traps were placed out in December 2021 until April 2022 and again from August to November 2022. The following pheromone traps were used in the orchard:

- CM pheromone traps (Codling Moth Duo Lure Max 10 mg): to monitor Codling moth, 2 series of 5 traps in each series were placed in the top third of the canopy or upper 30 cm to 1 m canopy of the trees on long stakes; distance between each two of the CM traps was the length of a panel. So, they were placed in the middle of 5 consecutive panels in each series.
- LBAM traps (LBAM 1 mg): two LBAM traps at both end of each series of CM traps; The LBAM traps were hung at a height of 1.5 m.
- QFLY traps (Cue lure wafer as attractant and Dichlorvos as insecticide): one trap in each of the 2 rows at one end of series. The buckets of QFLY traps were hung at about head height (1.5-1.8m) and about two-thirds of the way out from the trunk and in semi-shade and well clear of foliage (**Error! Reference source not found.**c). This allows easy access for the flies t hrough the entry holes of the trap.

Overall, there were 10 CM traps, 4 LBAM traps and 2 QFLY traps in the Victorian experimental orchard. The sticky plate/mats as well as lures were replaced monthly for both CM and LBAM traps. The lure inside the QFLY buckets was replaced every 3 months.

Earwig trap

Earwig traps were made of one strip of single-walled corrugated (depth of corrugation 0.3 mm) cardboard, about 9 x 9 cm rolled tightly with the corrugations facing inwards. The trap was secured either against the trunk or a branch so that the cardboard was in contact with the tree. A total of 32 cardboard rolls were spread out 30 cm above ground level (one in each plot on the tree trunk of the flagged trees in one of the middle panels of the plot; selection of one of the two middle panels was random) (**Error! Reference source not found.**d). They were monitored from November 2021 to April 2 022 on a fortnightly or monthly basis and old rolls were replaced. The traps were shaken vigorously into a tray/bucket, and the corrugations were ripped apart to ensure all earwigs fell out. After counting, the earwigs were released at least 5 m away from the location of the traps in the same plot. If the population was low, the exact numbers were recorded. If the population was high, earwig numbers were categorised as <15, 15-25, 25-50, >50 (Orpet *et al.*, 2019).

Pitfall trap

Pitfall traps were used to capture ground-dwelling arthropods such as spiders, weevils, centipedes, rove (staphylinid) beetles and ground (carabid) beetles present near the pear tree trunks. Ants, woodlice and Orthoptera (e.g., grasshoppers and crickets) were not counted because they are not considered important in terms of crop protection/damage of apples and pears. Samples were conducted monthly from November 2021 to April 2022 and then once in March 2023.

The traps consisted of several parts; disposable plastic cups (275 ml; 9 cm diameter) that were put into PVC pipes (10 cm diameter and 10 cm height) buried in soil in a middle panel (randomly chosen east or west panel) of each plot with the top at ground level (Yu-Hua *et al*., 1997). The pitfall holes were dug about 50 cm away from the trunk of the randomly selected flagged trees towards the inter-row. A plastic “roof” was installed to prevent the pitfalls from filling with debris and rain (**Error! R eference source not found.**e). The roofs were made of plexiglass plastic (20 x 20 cm) and 4 bamboo sticks of 20 cm lengths were inserted into the 4 corners of the plastic. A total of 32 pitfall traps/cups (one in each plot) were filled to one third with a solution of 20-30% antifreeze. Traps were collected after 5-7 days, and the contents emptied into lidded, labelled jars before morphological identification.

Sweep net sampling

This monitoring was done to collect arthropod pests and beneficials flying on/around the inter-row vegetation. including hoverflies, ladybirds, lacewings, thrips and parasitoid wasps. Samples were conducted monthly from November to April during the 2021-22 season and were taken from the middle section of each plot to avoid edge effects. One netting covered 180º from left to right or vice versa with one sweep for each of 10 steps (**Error! Reference source not found.**f). The collected a rthropods were emptied into a large snap-lock bag and stored in a cool room before being transferred into 80% ethanol. Morphological identification was done to family level, and all invertebrates were assigned to a functional feeding guild.

A functional feeding guild can be defined as any group of arthropods that exploit the same type of resource for food, based on the longest stage of their feeding lifecycle i.e., adult or nymph/larvae. We assigned each arthropod family to a broad functional guild, such as predator, parasitoid, herbivore, gall former, detritivore, nectarivore, fungivore or pome pest. Assigning functional feeding groups to arthropods at the family level is prone to some error, because there are often deviations from the general biological ground plan within a family. Despite this uncertainty, categorising arthropods into functional feeding guilds is an efficient way of understanding the broad balance between the different guilds in an ecosystem and whether this changes with regard to treatment.

Fruit damage assessment

Two assessments for fruit damage were conducted at the Victorian experimental site in each of the 2021/22 and 2022/23 seasons. Sampled fruit were inspected for the presence of damage by codling moth, LBAM, scab, apple dimpling bug, brown rot, leaf black spot and Heliothis. The first assessment of each season was a non-destructive sample in which the fruit were assessed directly on the tree; this was done the week before Christmas and after natural fruit-drop at the Victorian experimental site. Twenty fruit per panel (six panels per plot) from different heights, and from different sides of the flagged trees, were examined *in situ* and damage recorded. The second assessment used destructive sampling in which the fruit were picked just prior to harvest (i.e., mid-February) and examined in the laboratory to assess external and internal damage.

Data analysis

The Microsoft Excel Data Analysis toolkit was used to conduct one-way ANOVA comparison of means for the analysis soil phosphorus. Repeated measures analyses of variances were used to detect statistical differences between treatments and sample dates for only the fruit damage assessment and the inter-row arthropods sampled by sweep net (using GenStat for Windows 22nd edition (VSN, International Hempstead, UK) (Payne *et al*., 2022)

Figure 3. Several arthropod monitoring methods were used during the conservation biological control trial at the Victorian experimental site: A) aerial mite monitoring using a 10x hand lens; B) yellow sticky trap; C) Queensland fruit fly pheromone trap; D) earwig trap using a rolled-up piece of corrugated cardboard; E) installation of rain covers over a pitfall trap; and F) sweep netting inter-row vegetation.

Tasmania: commercial apple orchard

The field trial was established in a commercial orchard owned by R&R Smith's, Ranelagh Tasmania (43° 1.077' S, 146° 59.191' E). At the beginning of the experiment, the block was entering its third year of organic certification. The CBC experimental block consisted of 12-year-old 'Jazz' apples on M26 rootstocks. The trees were planted with a 1 m tree spacing and a 3.5 m row spacing in a north-south orientation (Figure 4). At the time of the trial's establishment, the inter-row contained a commercially available blend of clovers and rye grass (Huon #2) with a herbicide spray strip under the trees maintained using a certified organic herbicide, Slasher (Organic Crop Protectants, product code: 55761).

Experimental design and vegetation establishment

Separate treatments were established using a factorial split plot design to compare tree line and inter-row interactions**Error! Reference source not found.**. Each tree was spaced 1 m apart within rows, w ith the rows themselves spaced 2.5 m apart. Each inter-row treatment included 72 trees per main plot, and each of the three tree line sub-plot treatments consisted of 24 trees. There were 5 replicates per treatment.

The tree line treatments included a grower's standard practice herbicide strip (bare ground) that acted as the control treatment, a compost/mulch application, and a legume-grass cover crop mix. Likewise, for the inter-row treatments, growers practice made up the control using an existing, commercially available rye grass/ white clover mix. This was then compared to a native species mix containing *Microleana stipoides*, (weeping grass), *Viola hederacea* (Nat. violets), *Chrysocephalum apiculatum, Einardia nutans* (Climbing saltbush), *Goodenia elongata* (Lanky goodenia), *Arthropodium milleflorum* (Vanilla lily), *Calocephalus lacteus* (Milky beauty-head), and *Rhodanthe anthemoides* (everlasting daisy), and a consistent year-round flowering meadow species mix containing *Phacelia*, *Calendula* (marigold), Buckwheat, Coriander, *Plantago lanceolata* (plantain), *Lotus corniculatus* (birdsfoot trefoil), and *Chamaemelum nobile* (Lawn Chamomile). Species composition for each treatment and seeding rates are provided in Table 7. The native flowering plant species that were sourced as established tubestock from Plants of Tasmania, Ridgeway, Tasmania.

Prior to planting, all plots were prepared using an organic herbicide, Slasher, and subsequent compost mulch application in early spring, followed by seed sowing of the cover crop treatment. All tree line treatments were established in September 2020. Throughout the establishment and monitoring periods, the herbicide spray strips, and composts treatments were maintained using a certified organic herbicide, Slasher, (Organic Crop Protectants, Harris Park, NSW) and hand weeding, with additional sowing applied when required to ensure adequate coverage.

All plots were treated to control disease and pests, including twice weekly applications of sulphur during spring for the control of *Alternaria* leaf blotch during the 2021-22 production season, three applications of Dipel© (Sumitomo Chemical Australia, Epping, NSW), and Madex© (Sumitomo Chemical Australia, Epping, NSW) for codling moth in December, each one week apart, and a single application of Entrust© (Corteva Agriscience Australia, Chatswood, NSW) in December 2021 for the control of light brown apple moth (*Epiphyas postvittana*).

Table 7. Experimental treatment plant species composition and tubestock planting/seeding densities utilised in the establishment of the conservation biological control site at the Tasmanian experimental site.

Treatment name	Species Composition	Common Name	Planting/seeding density
Grower sward (Huon #2)	*Lolium perenne*	Victorian ryegrass	8 kg/ha
	Lolium perenne	Kingston ryegrass	12 kg/ha
	Trifolium pratense	USA red clover	5 kg/ha
	Trifolium repens	USA white clover	2 kg/ha
	Trifolium repens	'Apex' white clover	1 kg/ha
Flowering meadow mix	*Phacelia tanacetifolia*	Lacy phacelia / blue tansy	4 kg/ha
	Fagopyrum esculentum	Buckwheat	5 kg/ha
	Coriandrum sativum cv. Santo	Coriander	3 kg/ha
	Plantago lanceolata cv. Tonic	Buckhorn plantain	4 kg/ha
	Trifolium michelianum	Balansa clover	2 kg/ha
	Brassica sp.	BQ mix	2 kg/ha
	Avena sativa	Oats	3 kg/ha
	Raphinus sativus acanthiformis	Daikon radish	3 kg/ha
	Cichorium intybus cv. Commander	Chicory	2 kg/ha
Native flowering mix	*Microleana stipoides*	Weeping grass	2 kg/ha
	Viola hederacea	Native violet	0.5 plants /m^2
	Einardia nutans	Climbing saltbush	0.5 plants /m^2
	Goodenia elongata	Lanky goodenia	0.3 plants /m^2
	Arthropodium milleflorum	Vanilla lily	0.3 plants /m^2
	Calocephalus lacteus	Milky beauty-head	0.3 plants /m^2
	Rhodanthe anthemoides	Everlasting daisy	0.3 plants /m^2

Figure 4. Inter-row plantings showing the flowering meadow mix (foreground) and the standard grower mix, Huon #2 (background) at the conservation biological control field site during the ground-cover establishment phase (May 2021) at the Tasmanian experimental site.

Arthropod, disease and vegetation monitoring

The presence and quantification of invertebrates within the tree canopies within each sub-plot were monitored using yellow sticky traps (Figure 5Figure 5) placed among the tree canopies from 29/10/2021 to 4/04/2022 and 18/11/2022 to 22/03/2023. The sticky cards were placed within each treatment for one week each month giving an overall total of 225 traps each season. The insects caught on the sticky traps were then quantified under a Nikon microscope to morphologically identify and count the insect orders *Diptera, Hymenoptera, Thripidae, Arachnida, Coleoptera, Hemiptera, Neuroptera, Lepidoptera, Dermaptera*; the families *Coccinellidae, Asilidae, Dolichopodidae;* and the species *Aphelinus mali, Edwardsiana froggatti*, and *Anagrus armatus*. Earwig numbers were monitored using rolls of corrugated cardboard that acted as daytime refuge sites as described by Quarrell *et al*. (2017). The earwig traps were visually counted and re-released under the trees fortnightly in season 1. In season 2, earwigs were monitored fortnightly for the first month of the observation period and monthly thereafter. Codling moth (*Cydia pomonella*) and light brown apple moth (*Epiphyas postvittana*) flights were monitored using pheromone traps checked weekly.

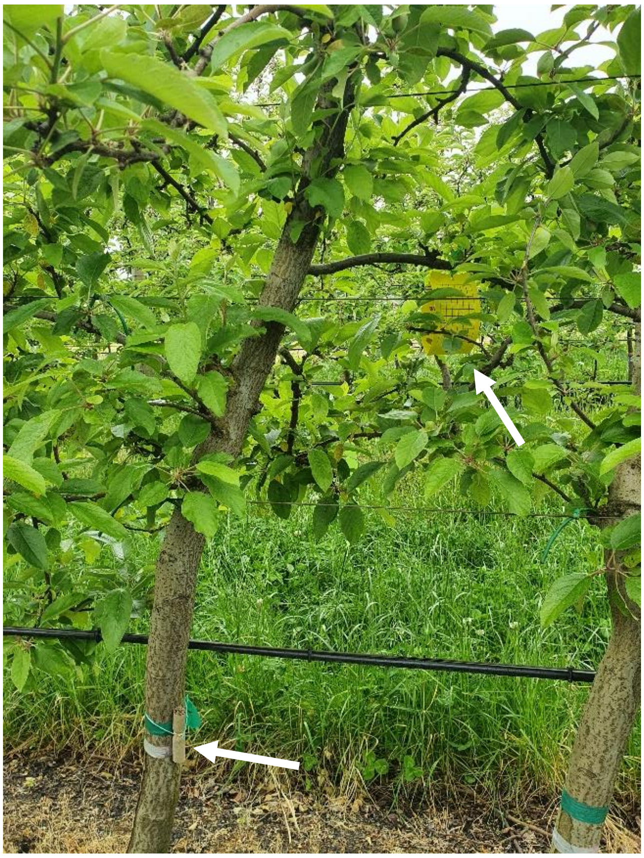

Figure 5. 'Jazz' apple tree at the Tasmanian experimental site with standard orchard ground-cover blend (Huon #2) (background) and herbicide 'spray strip' (foreground). Arrows indicate yellow adhesive 'sticky trap' for flying insect monitoring within the tree canopy and cardboard roll located on the tree trunk for European earwig (*Forficula auricularia*) monitoring.

Ground dwelling arthropods were monitored using pitfall traps. The pitfall traps were located in the centre of both the inter-row of each main plot and within the tree line of each subplot each month for one week during each season. Each pitfall trap consisted of a 100 mm round hole with a depth of ca. 120 mm. Each hole was lined with a sleeve of 100 mm poly pipe, which prevented the hole from collapsing and protected a 250 ml polyethylene jar (Bacto Laboratories, product code SJP8067UU) used to collect the trapped arthropods. Each jar was partially filled with ca. 75 ml of radiator coolant (SCA Long Life Green Coolant Premix, product code 591868) to preserve the captured insects. Each jar was then covered with a 100 mm plastic funnel (Figure 6) and covered with a 100 mm square of corflute ca. 1 cm above ground level to allow arthropod entry but prevent rain or irrigation water ingress into the beaker. Upon collection, each beaker and its contents were decantated into a sample collection vial with 70% EtOH to prevent sample spoilage prior to sample processing.

To determine the impact of the groundcover treatments on fruit quality, fruit damage assessments were conducted within one week of fruit harvest. Assessments were conducted by physically inspecting 100 fruits within each tree used during earwig monitoring and sticky trap collections (n = 45). Where individual trees possessed insufficient fruit numbers (< 100 apples), fruit on the neighbouring trees were inspected. The number of fruits inspected per treatment, the number of damaged fruit and the causal agent (i.e., apple scab, codling moth stings etc.) of any damaged fruit were recorded.

Figure 6. Pitfall trap at the conservation biological control experimental site at the Tasmanian experimental site: A) showing exposed funnel trap entrance, and B) pitfall trap with rainfall cover

Data analysis

Insect community data was analysed using a range of analyses in R Version 3.5.1 (R Core Team, 2022) and the Vegan package (Oksanen *et al*., 2022). We used the diversity function in Vegan to calculate Shannon-Weiner diversity indices for sticky trap catches. Generalised linear mixed models with a negative binomial distribution with a log link function were used to analyse the effects of date, tree line and inter-row treatments on insect species abundance, insect diversity and the total numbers of insects caught for both production seasons data. Time series data were analysed using linear mixed models. Fruit damage data were analysed using Kruskal-Wallis tests. Finally, Nonmetric Multidimensional Scaling (NMDS) Ordination was done in Vegan to visualise the overall dissimilarity of insect communities across orchard treatments, specifying a Bray–Curtis dissimilarity metric.

Results

Victoria: experimental pear orchard

Vegetation establishment

The native seed sown across all treatments mostly failed to germinate and/or establish within the orchard environment. For some of the grass species, the lack of germination may have been due to low seed viability or prolonged dormancy. In the glasshouse trial, only the *Rytidosperma* (wallaby grass) seeds germinated in both the potting mix and orchard soil, whereas there was little germination in either soil type for *Microlaena stipoides* and *Bothriochloa macra* (Figure 7).

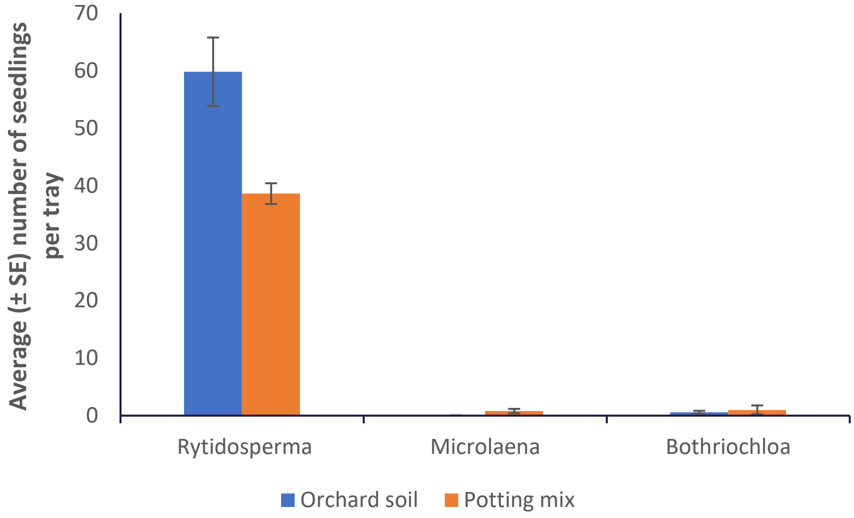

Figure 7. Germination success of three grass species (*Rytidosperma* species mix, *Microlaena stipoides* and *Bothriochloa macra*) sown into two soil types (soil from TR4 plots of the Victorian experimental site, and commercial potting mix) (mean ± standard error).

Tubestock plantings directly in front of the tree line in the native tubestock and grass plots were the only native vegetation that persisted for an extended period, Error! Reference source not found.with tree guards a nd snail bait to protect them. *Pelargonium australe* was the best performer in terms of survival and flower availability during the growing season (Figure 8). *Calocephalus citreus* and *Chrysocephalum apiculatum* were also relatively resilient and flowered well during the growing season (Figure 8). However, in terms of suitability to the crop environment, the native tubestock wasn't well suited for planting in the tree line because of their upright growth habit. The tree line needs to be managed to reduce the growth of weeds around the tree and irrigation piping, and weedy species were difficult to manage when growing around tubestock that was being protected (Figure 9b-c).

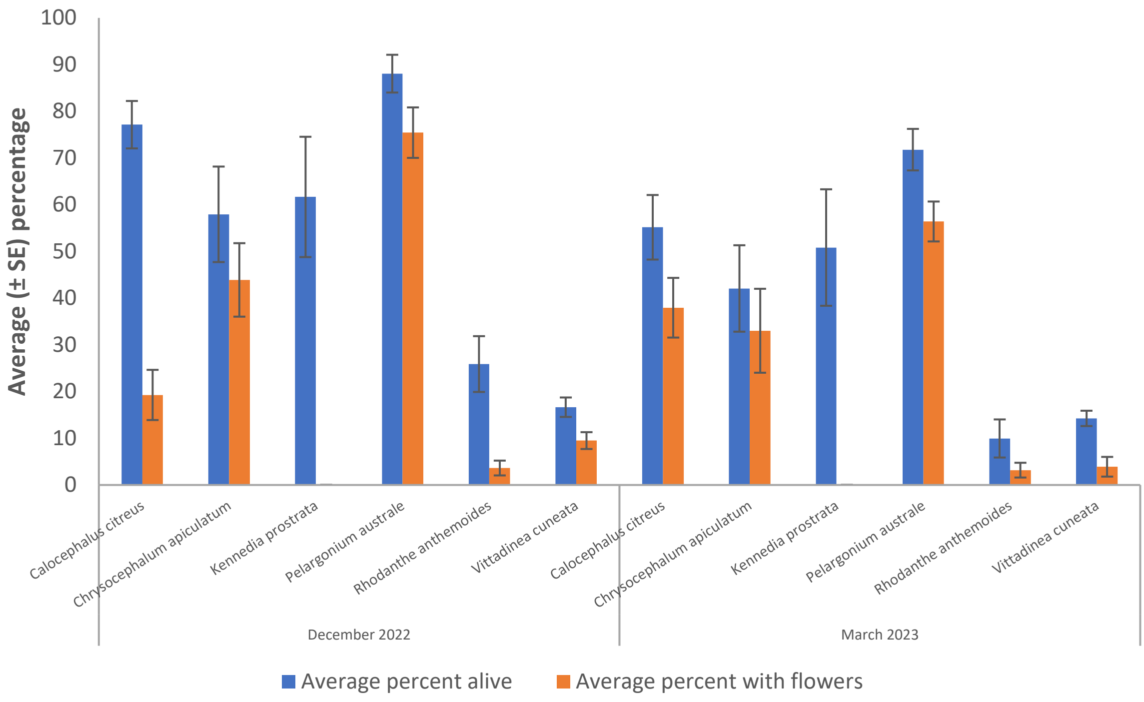

Figure 8. Average (mean ± standard error) percentage of tubestock alive (blue) and in flower (orange) at two dates in the 2022/2023 season at the Victorian experimental site.

Figure 9. TR4 (native tubestock and grass) at the Victorian experimental site: A) Flooding within the inter-row during October/November 2022; B) weedy species growing around the native tubestock in the tree line; C) native tubestock in plant guards, surrounded by weedy non-crop vegetation.

Existing weedy vegetation species that dominated the inter-row and tree line included burr medic *(Medicago polymorpha*), mallows *(Modiola caroliniana* and *Malva sylvestris*), broadleaf plantain (*Plantago major*), dock *(Rumex* spp.), wireweed (*Polygonum aviculare*), sedges (Cyperaceae), mouse-ear chickweed (*Cerastium glomeratum*) and grasses (Poaceae).**Error! Reference source not found.** During spring, the inter-row v egetation was largely dominated by the broad-leaf weeds and grass (Figure 10a-b; Figure 11). In subsequent hotter months, the vegetation became sparse across all treatments with over 50% of the ground present as either dead plant matter (leaf litter) or bare earth (Figure 10c-d; Figure 11) during 2022/23.**Error! Reference source not found.**

Figure 10. Inter-row vegetation at the Victorian experimental site in 2022/23: A) September, B) October, C) December and D) February.

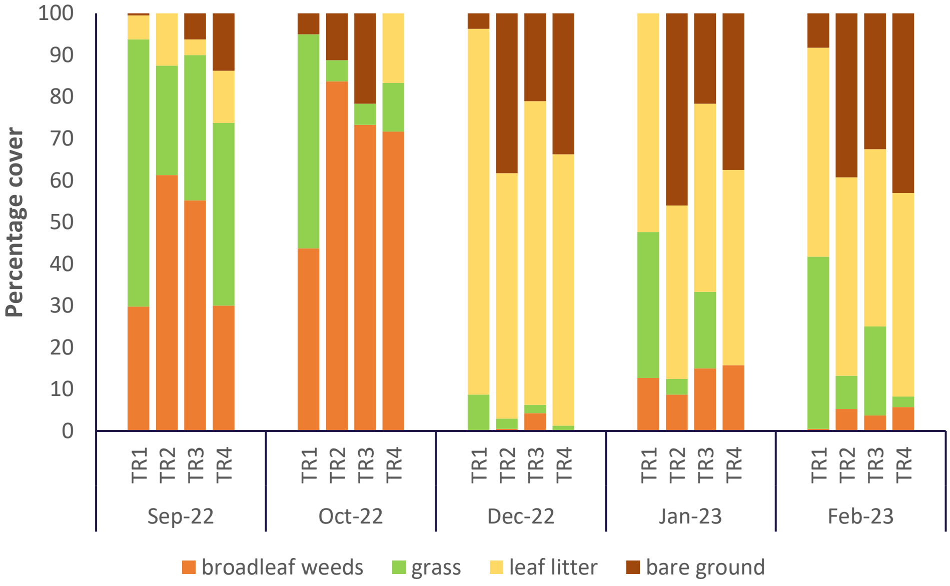

Figure 11. Percentage cover of inter-row vegetation, mulch and bare ground in the Victorian experimental site per 0.5 m^2 quadrat (n=4) in each of four treatments between September 2022 and February 2023. Treatment codes: TR1 (grower sward), TR2 (native grass/groundcover mix), TR3 (native grass) and TR4 (native tubestock and grass)

As expected, the diversity of plant species and prevalence of flowering was greatest during the spring months in both the inter-row and tree line, and lowest during December 2022 (Figure 12).

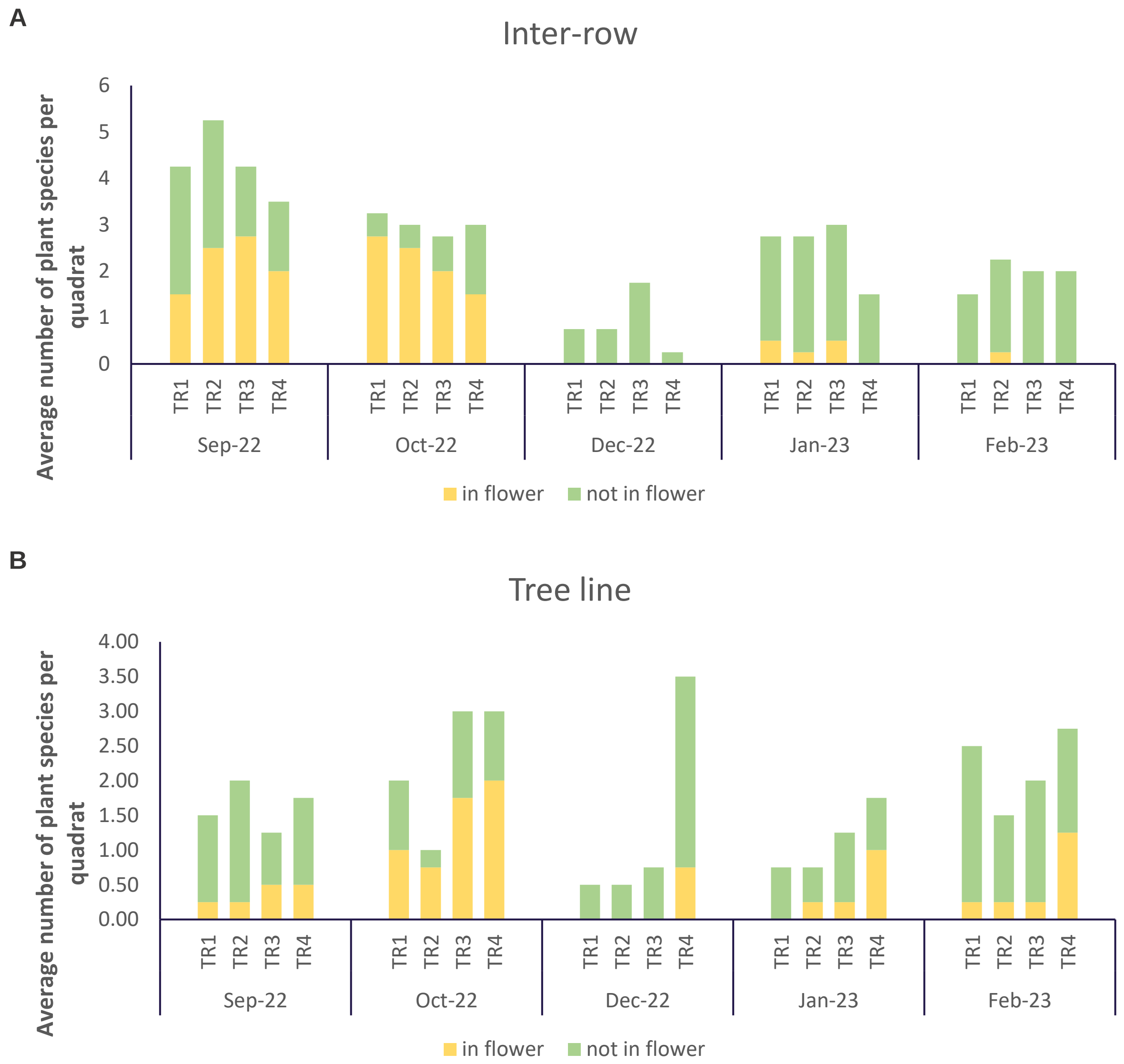

Figure 12. Average number of flowering and non-flowering species per 0.5 m^2 quadrat (n=4) in each of four treatments at the Victorian experimental site in: A) inter-row, and B) tree line between September 2022 and February 2023. Treatment codes: TR1 (grower sward), TR2 (native grass/groundcover mix), TR3 (native grass) and TR4 (native tubestock and grass).

Results for the soil analysis are only presented in this report for levels of phosphorous (Colwell P), due to its relevance to the establishment of native vegetation within the trial. The full soil analysis is available on request. There was no detectable gradient in phosphorous levels across the pear orchard (i.e., in an east-west direction) for samples from the tree line ($F_{3,12}$ = 3.48, P = 0.05) or inter-row ($F_{3,12}$ = 2.02, P = 0.16); or along the rows (i.e., north-south) for tree line ($F_{3,12}$ = 0.12, P = 0.94) or inter-row ($F_{3,12}$ = 0.42, P = 0.74). Hence, all tree line samples were pooled and compared with pooled samples from the inter-row to compare differences in phosphorus. Tree line soils were twice as high in Colwell P (mean ± SE; 138 mg/kg ± 6.9) compared to the inter-row (mean ± SE; 73.43 ± 56.68), (P < 0.05).

Arthropod community response to treatment

Flower-pest inspections

Apple dimpling bug was not found during flower inspections, only thrips were recorded. On average, more thrips were sampled from flowers in TR4 compared to the other treatments (Figure 13).This may be influenced by the lack of inter-row vegetation and resulting reduced natural enemy presence in TR4 during the 2022 flowering season (see Figure 19 for functional arthropod groups from the inter-row).

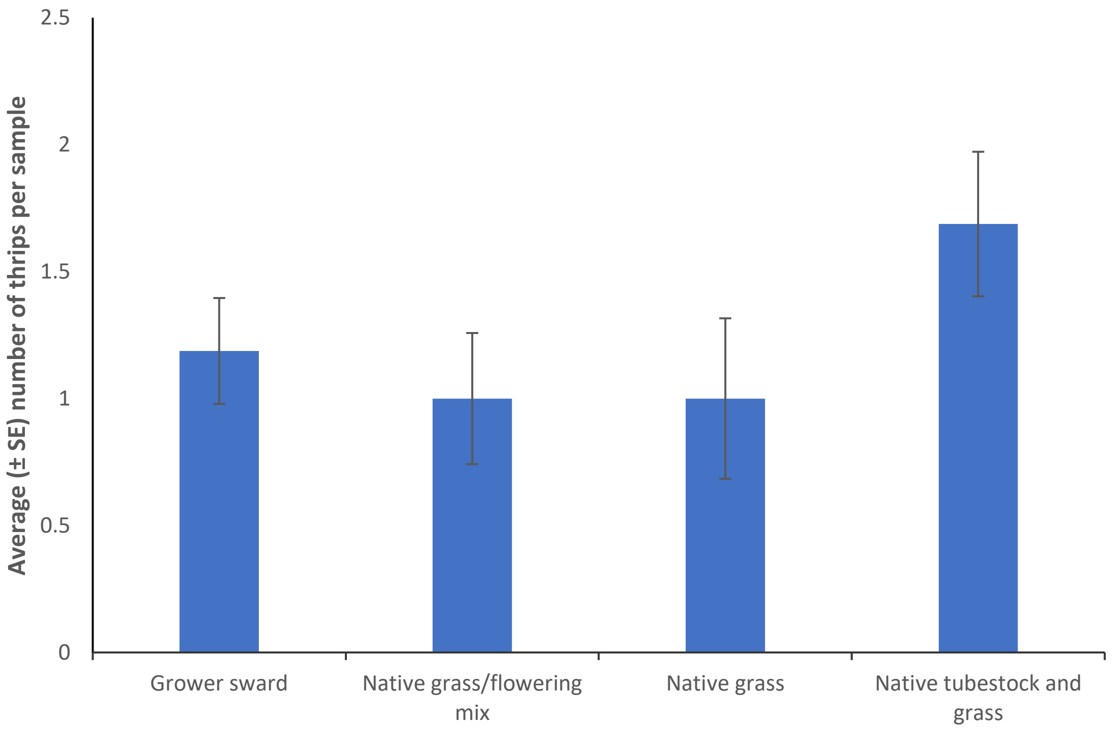

Figure 13. The average number of thrips collected per flower sample in the four treatments at the Victorian experimental site during the flowering season of 2022 (± standard error).

One-minute arthropod inspections

One-minute inspections of the pear canopy recorded long-tailed mealybug populations building up throughout the 2021/22 growing season (Figure 14). Lacewings, both brown and green, were also commonly recorded during one-minute canopy inspections, as well as parasitoids and fungal feeding beetles (family Lathridiidae) (**Error! Reference source not found.**). None of the commonly recorded arthropods showed a d ifference in abundance with regard to treatment.

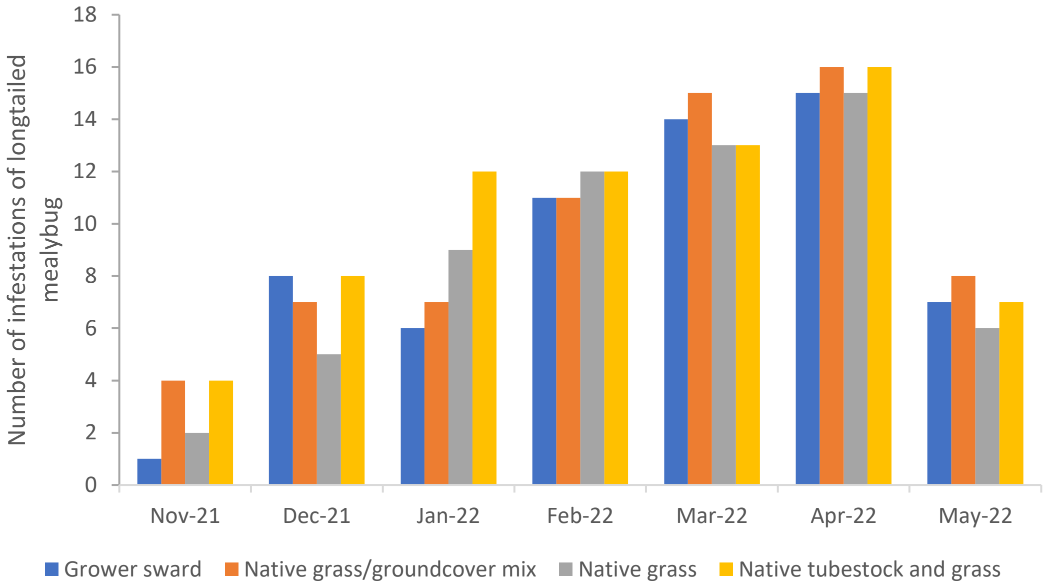

Figure 14. The total number of longtailed mealybug infestations per month in the four treatments at the Victorian experimental site. All infestations were less than 5% of the shoots/leaves.

Table 8. Total number of commonly sighted arthropods (lacewings, parasitoids and fungal feeding beetles) during one-minute canopy inspections in the four treatments at the Victorian experimental site, sampled approximately once per fortnight from November 2021 until May 2022.

Treatment	Lacewings	Parasitoids	Fungal feeding beetles
Grower sward (TR1)	54	14	54
Native grass/groundcover mix (TR2)	84	14	43
Native grass (TR3)	68	7	37
Native tubestock and grass (TR4)	50	8	23

Mites from the crop canopy

Throughout the 2021-23 seasons, various pest mites were observed in the orchard including two-spotted spider mite (*Tetranychus urticae*), European red mite (*Panonychus ulmi),* pear leaf blister mite (*Eriophyes pyri)*, *Bryobia rubrioculus* and the predatory mite *Neoseiulus californicus*. The blister mites were the first mite species that were detected in the orchard based on their symptoms on shoots and young leaves. They were first seen around mid to late September. The next species of mite seen in the orchard were *Bryobia* mites which were seen from the end of September onwards. Around the end of November and in December, two-spotted spider mites and European red mites started to be seen. In the orchards where generalist predatory mites (i.e., *Typhlodromus* spp. and *Neoseiulus* spp.) have established, different prey species are available during these months and predatory mites can switch food resource.

At the Victorian experimental site, predatory mites were released in the orchard around mid-December in the first season and their population built up and peaked by the end of December.

There were no treatment effects on mite abundance at the Victorian experimental site, however, methods for standardised mite sampling procedures were tested and refined. The number of mite species detected and the prevalence of detected species on leaves were dependent on sampling method used. Both destructive sampling methods, method (2) and method (3), performed better than the routine non-destructive standard in terms of species detection and prevalence (Table 9). The largest differences were seen during the early stages of infestation for mite species other than *E. pyri*. Early detection of certain mite species may be important because it can provide a more accurate estimate of the starting point for Cumulative Leaf Infested Days (CLIDs) calculations. Detection and prevalence results were similar for methods (2) and (3) despite the greatly reduced sampling effort (time required) for method (3), and overall sampling effort for method (3) was similar to that required for method (1). Therefore, in terms of both accuracy and sampling effort for this experiment, method (3) outperformed the other two methods.

Table 9. Apparent percentage of leaves infested with (at least one individual of) different pest and predator mites when using 3 different monitoring methods.

	Two-spotted spider mite	European red mite	Pear leaf blister mite	*Bryobia*	Overall pest mite infestation*	*Neoseiulus californicus* (predator)
Method 1	<4%	0	<1%	0	<5%	<2%
Method 2	10%	15%	10%	<1%	30%	>22%
Method 3	11%	13%	12%	3%	28%	>20%

During season 2022-2023, results showed that numbers of two-spotted spider mites in late spring were almost double than in mid-summer. In contrast, populations of European red mite rose to 41% infestation of the leaves in mid-summer, while no signs of European red mite were seen in late November. Total pest mite infestation was twice as much in summer compared to spring. In January, 16% of the leaves contained the released predatory mite (*Neoseiulus californicus*) (Table 10).

Table 10. Percentage of leaves infested with (at least one individual of) different pest and predator mites in spring (Nov 2022) and summer (Jan 2023).

Monitoring date	No. Leaves checked	Two-spotted spider mite	European red mite	Pear leaf blister mite	Bryobia	Total pest mite infestation*	*Neoseiulus californicus* (predator)
23/11/2022	160	11	0	27	0	39	1
20/01/2023	128	6	41	35	0	83	16

Yellow sticky trap collections

Yellow sticky traps attracted abundant numbers of thrips, parasitic wasps, flies and leaf hoppers, as well as smaller numbers of beetles, aphids and other Hemiptera (Figure 15). Parasitoids from the family Trichogrammatidae were trapped in the crop canopy, which indicates that these were most likely attacking arthropods in the pear trees.

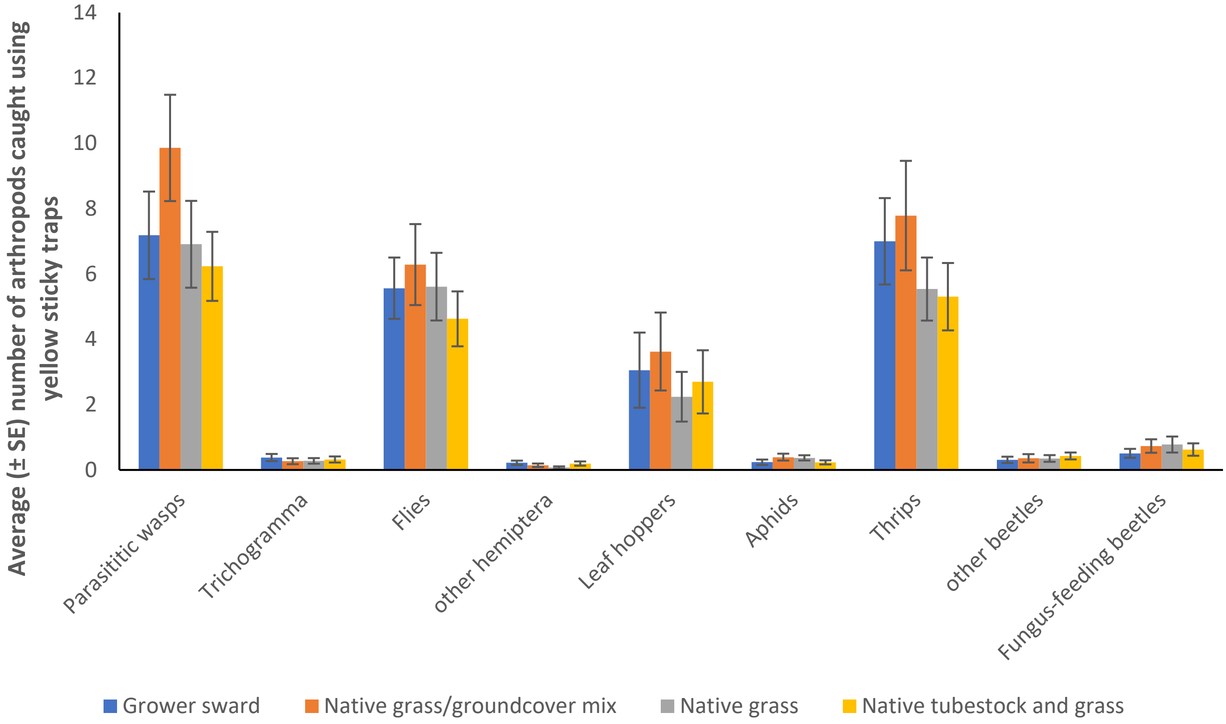

Figure 15. The average number (± standard error) of arthropods collected in the tree canopy of the four treatments at the Victorian experimental site using yellow sticky traps from October 2021 to April 2022

Pheromone trap collections

Pheromone trap data began at the start of December in 2021 and saw 10-14 codling moths between the two traps during the start of December (Figure 16). Numbers of codling moth decreased after mid December 2021 and remained very low until the end of the season. In 2022, codling moth numbers began to increase at the start of October and did so until insecticides for codling moth were applied in early, mid, and late November, which caused their numbers to fall (Figure 17).

In the 2021/22 season, Qfly were first seen during the first week of February and their population gradually increased until a peak of 52 flies between the two pheromone traps mid-March, after which the numbers markedly declined (Figure 16).

Light brown apple moth (LBAM) was caught each week in pheromone traps. The highest numbers were recorded between August and November 2022, with up to 45 between the four pheromone traps (Figure 17). Numbers of LBAM were a lot lower during the 2021/22 season, with up to 20 caught between the four pheromone traps (Figure 16).

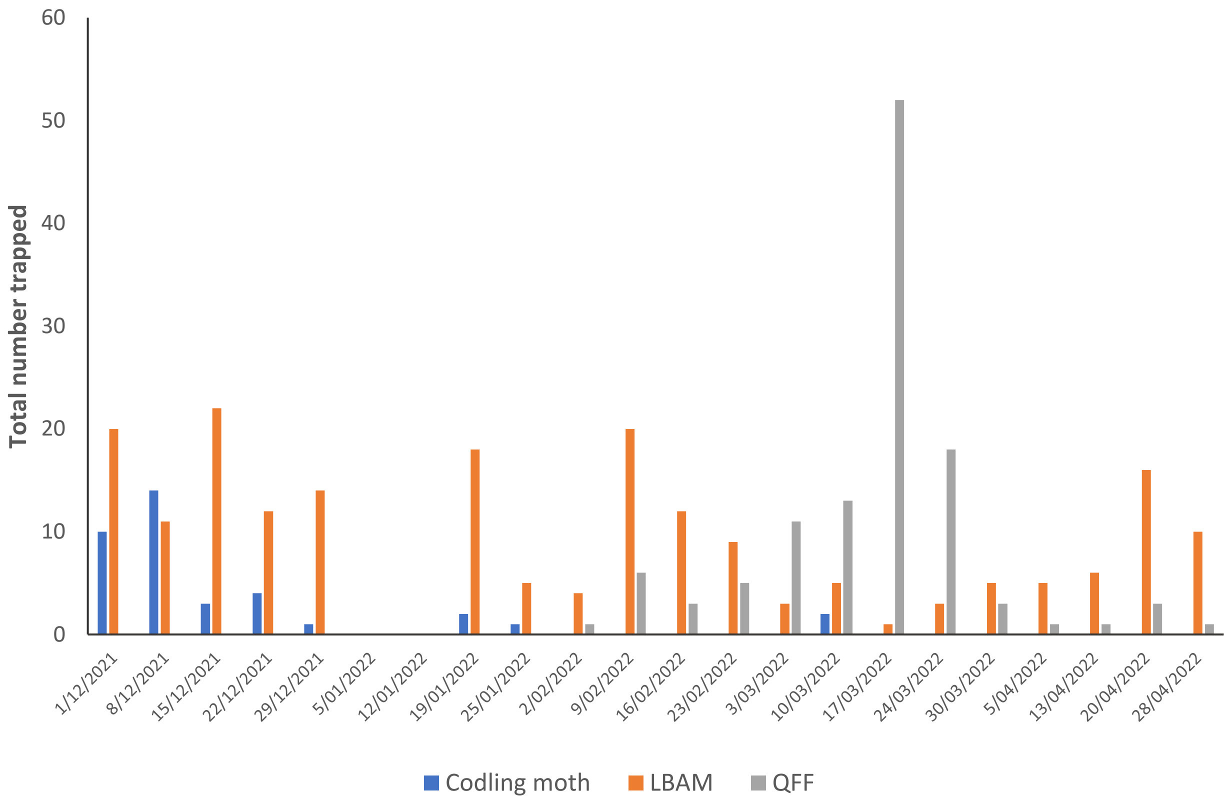

Figure 16. Weekly pheromone trap catches of codling moth, light brown apple moth (LBAM), and Queensland fruit fly (QFLY) at the Victorian experimental site throughout 2021-22 season. Two dates (5/1/2022 and 12/1/2022) have no data because traps were unable to be checked.

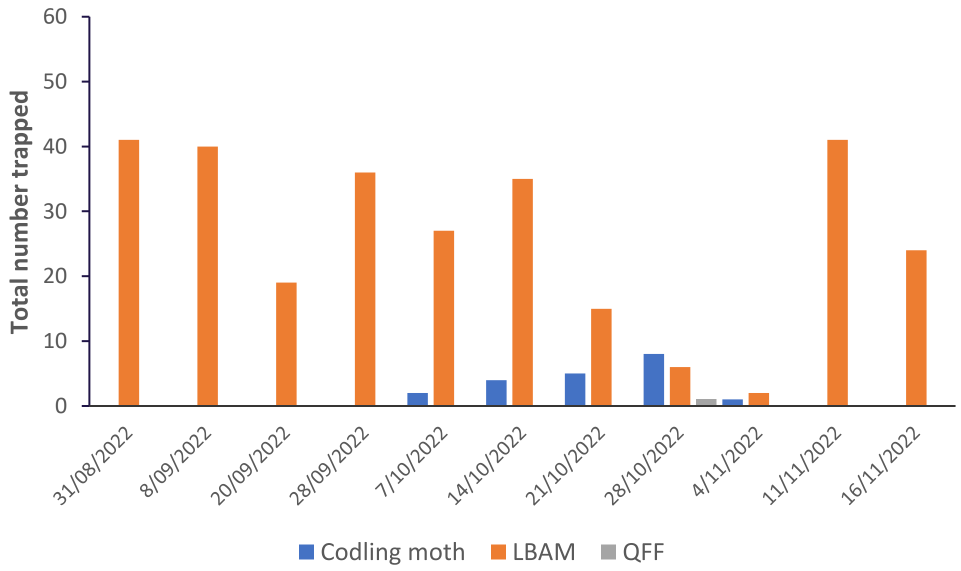

Figure 17. Weekly early season pheromone trap catches of codling moth, light brown apple moth (LBAM), and Queensland fruit fly (QFLY) at the Victorian experimental site throughout the 2022-23 season (sampling conducted up to 16 November 2022 only).

Earwig activity

Earwig numbers were very low in all treatments throughout the study in the Victorian orchard, hence data are not shown.

Pitfall trap arthropods
Pitfall traps collected large numbers of woodlouse (Isopoda; Oniscidea) and ants (Hymenotpera: Formicidae), crickets (Orthoptera) (numbers were not recorded for these groups) and smaller numbers of predators/beneficials such as spiders (Figure 19), centipedes and very few staphylinid or carabid beetles and weevils (Table 11).

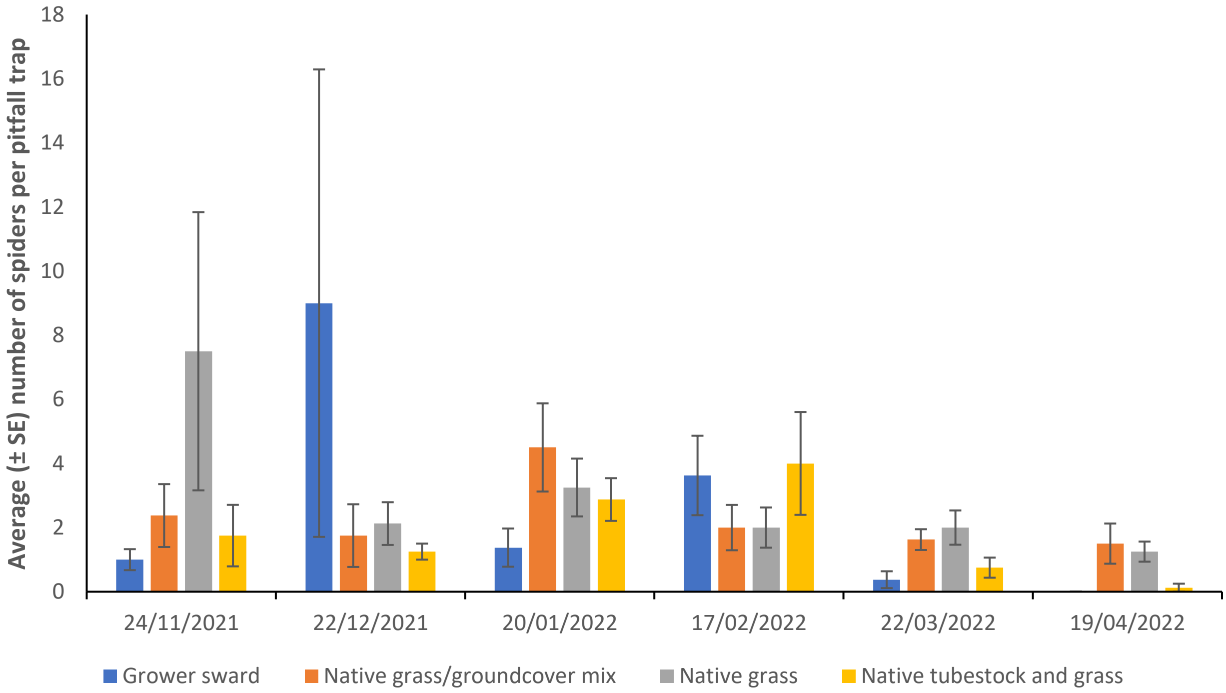

Figure 18. Temporal abundance of spiders collected from pitfall traps in the tree line of the four treatments at the Victorian experimental site from November 2021 to April 2022 (average ± standard error per monthly interval).

Table 11. Total sum of arthropods collected from all pitfall traps the Victorian experimental site.

Treatment	Spiders	Centipedes	Staphylinidae	Carabidae	Weevils
Grower sward (TR1)	124	28	21	12	4
Native grass/groundcover mix (TR2)	112	36	16	25	4
Native grass (TR3)	150	25	35	11	6
Native tubestock and grass (TR4)	89	29	22	7	3

Sweep net sampling

Sweep net samples from the inter-row at the Victorian experimental site collected a total of 1665 invertebrates over the 5-month sampling period. This is a relatively low number of invertebrates compared with the Tasmanian experimental site and reflects both the disturbed environment (mowing and insecticide use on the trees) and the lack of complexity in the inter-row vegetation. There would have been movement of arthropods between treatments due to the small pear block and trial design, however, there were still some differences in arthropod abundance and assemblage between treatments. The abundance of arthropods from the grower swards (TR1) was the same as the native grass/groundcover mix (TR2), both representing 32% of the total collected, while the native grass plots (TR3) yielded 21% and the native tubestock and grass plots (TR4) had the lowest arthropod abundance (15%).**Error! Reference source not found.**

Gall formers, made up entirely of flies from the family Cecidomyiidae, were the dominant arthropod feeding guild in the inter-rows at the Victorian experimental site (Figure 19). Cecidomyiidae are phytophagous and form galls in their larval stage. Herbivorous arthropods, including leafhoppers, flies (especially Agromyzidae), aphids and thrips, also made up a large proportion of the sweep net samples from the inter-rows, particularly in the grower sward and the native grass/groundcover mix plots. Parasitoids were the only functional feeding guild that differed significantly in their abundance between treatments (F_3=8.34, $p < 0.05$). The grower sward plots had significantly more parasitoids than the native grass plots and the native tubestock and grass plots (Figure 19). The striking difference in parasitoid abundance particularly between grower sward plots and native tubestock and grass plots reflects the differences in available vegetative habitat. Grower sward plots provided a more complex and stable environment where other arthropods were abundant as hosts, and nectar and pollen were more readily available, whereas native tubestock and grass plots were largely devoid of habitat during the sampling period.

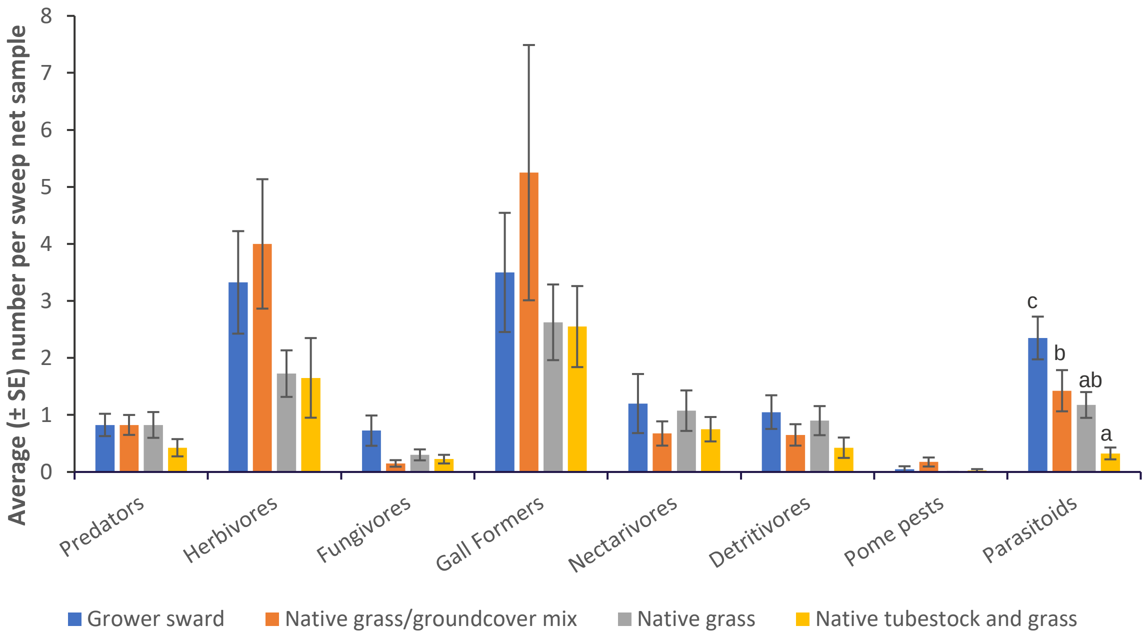

Figure 19. Abundance of arthropods (per sweep net sample) from main broad functional feeding guilds collected in the inter-rows of the four treatments at the Victorian experimental site using sweep netting from November 2021 to April 2022 (mean ± standard error). For the parasitoid data only, averages not sharing any letter are significantly different (p<0.05).

A total of 17 families of parasitic Hymenoptera were collected from inter-rows using sweep net sampling, however, only 10 families had 5 or more individual specimens in total (Figure 20). Most of the hymenopteran wasp families were collected in higher abundance in grower sward plots, and lowest from native tubestock and grass plots (Figure 20).

Of the encyrtid wasps, several were identified morphologically as *Tetracnemoidea sydneyensis,* which are parasitoids of longtailed mealybug. Trichogrammatids are important egg parasitoids of holometabolous insects such as Lepidoptera. Scelionidae are endoparasitoids whose members specialize in egg parasitisim of insects and arachnids (several species are commercially reared for biological pest control). Eulophidae are important parasitoids of concealed larva, particularly of leaf mining arthropods. Diapriidae are known as parasitoids of flies, and Aphelinidae are predominantly parasitoids of aphids, leafhoppers, psyllids and coccids. Most of the figitid wasps were morphologically identified as *Anacharis zealandica*, which parasitises brown lacewing larvae that were abundant at peak aphid season.

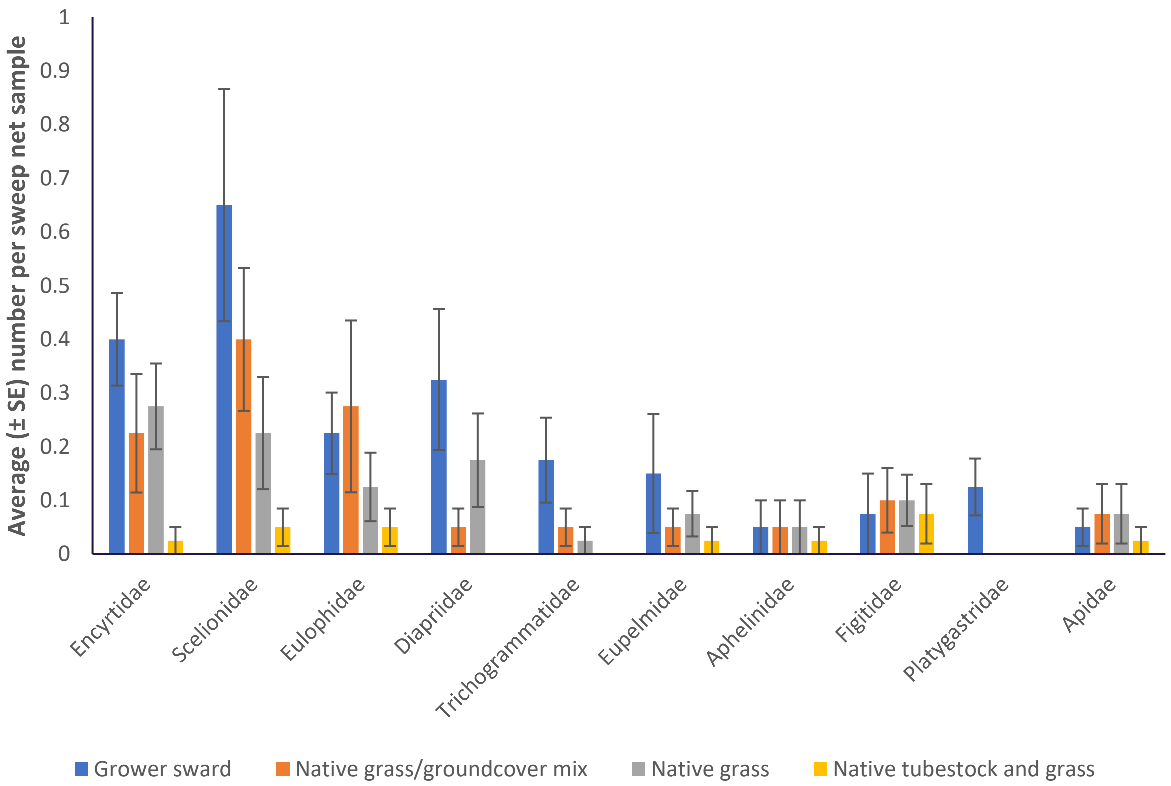

Figure 20. Average number of parasitic hymenopteran wasps (per sweep net sample) collected in the inter-rows of the four treatments at the Victorian experimental site using sweep netting from November 2021 to April 2022 (± standard error).

Interestingly, the seasonal abundance of parasitoids fluctuated markedly throughout the season and did not always coincide with the relative abundance of their hosts (Figure 21). For example, fewer parasitoids were collected during Feb-March 2022 despite high numbers of longtailed mealy bugs recorded during the visual inspections (see Figure 14). It is possible that orchard management practices, such as the mowing of inter-row vegetation affected the parasitoid abundance during these months.

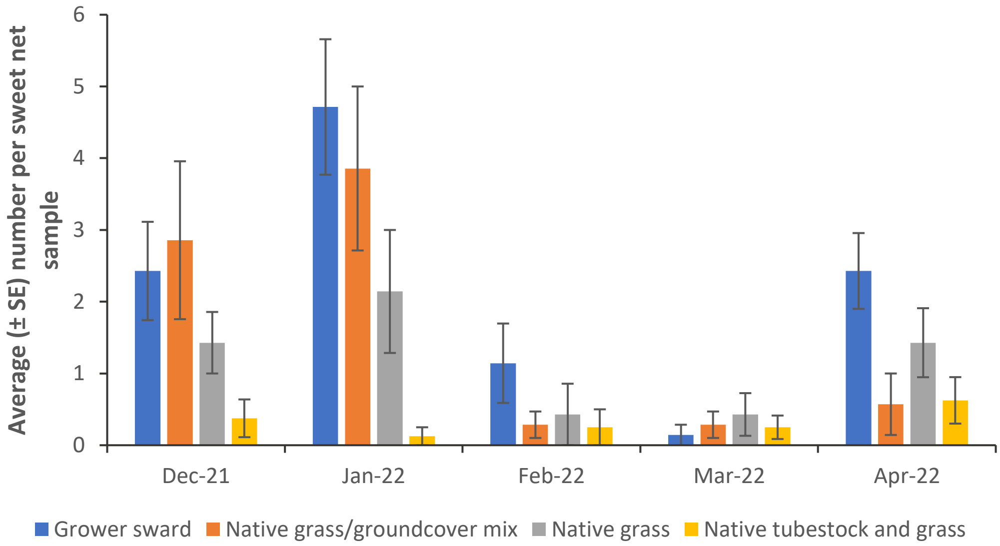

Figure 21. Temporal abundance of parasitoids collected from sweep net samples in the inter-rows of the four treatments at the Victorian experimental site from December 2021 to April 2022 (average ± standard error per monthly interval).

A total of 16 families of flies were recorded in the sweep net samples, with the most abundant families including the Cecidomyiidae, Drosophilidae, Heleomyzidae and Agromyzidae (Figure 22). The larvae of Cecidomyiidae are predominantly gall-forming and feed on the plant tissue; Drosophilidae larvae often breed in rotting fruit material; Heleomyzidae are detritivores that recycle nutrients; and Agromyzidae are well known as leaf miners in their larval stage, feeding on plant tissue. Very few 'beneficial' flies were sampled from the inter-row, except for the predatory Anthomyiidae (10 individuals), which were mostly found in grower sward plots and native grass/groundcover mix plots (Figure 22). For these commonly sampled fly families there was no clear effect of treatment on their abundance, which can be partly attributed to the lack of dependency on the non-crop vegetation for hosts/alternate prey for these fly families.

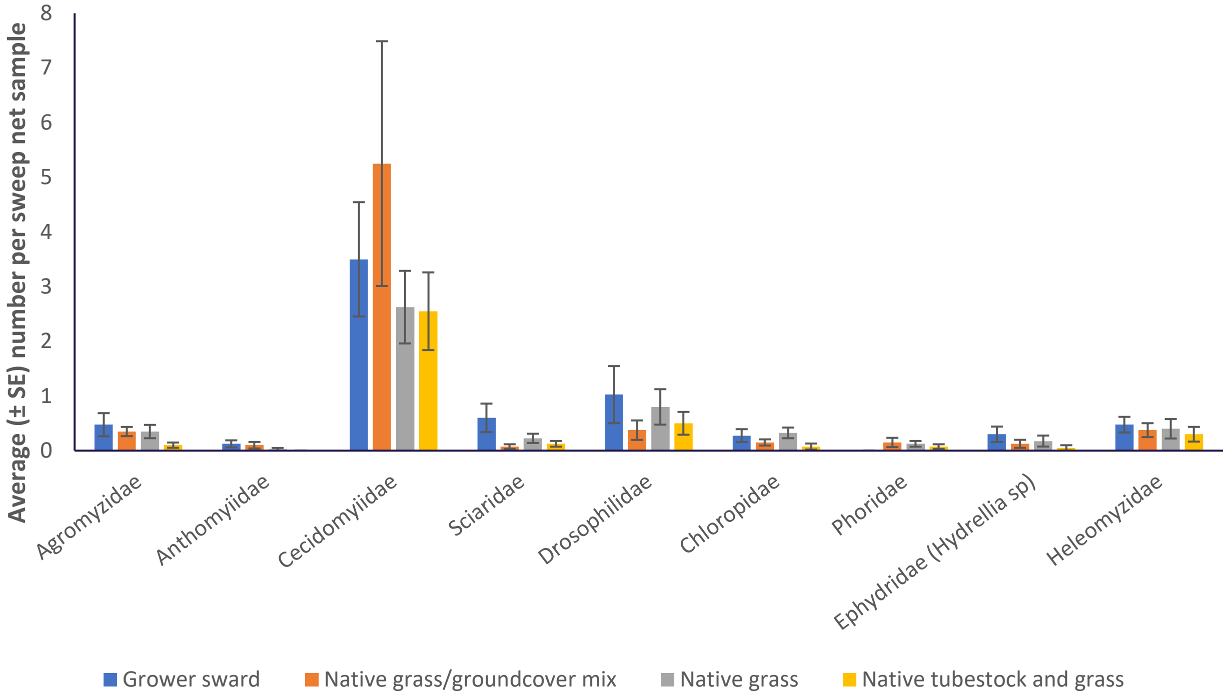

Figure 22. The average number (± standard error) of the most abundant families of flies (per sweep net sample) collected in the inter-rows of the four treatments at the Victorian experimental orchard using sweep netting from November 2021 to April 2022.

Fruit damage assessment

Fruit damage levels at the the Victorian experimental site did not appear to be influenced by treatment differences, but damage types and levels differed considerably between seasons (Table 12). In 2021/22 season there was very little insect damage, with some damage by light brown apple moth, but no apple dimpling bug and very little codling moth damage. The 2022/23 season showed a relatively high amount of apple dimpling bug damage, moderate levels of codling moth and light brown apple moth damage and some fungal disease associated with higher rainfall levels during the season.

Table 12. Total number of damaged fruits in the different treatments at the Victorian experimental site during 2021/22 and 2022/23 seasons caused by feeding by codling moth (CM), light brown apple moth (LBAM), apple dimpling bug (ADB) and Heliothis (Lepidoptera; Noctuidae).

Treatment	**2021/22 season**				**2022/23 season**			
	CM	LBAM	ADB	Heliothis	CM	LBAM	ADB	Heliothis
Grower sward (TR1)	0	4	0	0	11	6	57	0
Native grass/groundcover (TR2)	0	7	0	0	11	5	54	0
Native grass (TR3)	2	4	0	0	10	4	47	0
Native tubestock and grass (TR4)	2	3	0	0	10	2	45	1

Tasmania: commercial apple orchard

Vegetation establishment

The flowering 'meadow' mix established well, with some species flowering readily. However, prior to these species setting seed these plots were mowed causing issues with ongoing plant establishment. The only observable species to persist in these plots was plantain (*Plantago lanceolata* cv. Tonic) with rye grass and clover becoming the dominant species within these inter-row treatments.

The native field plots which were largely established using tubestock showed signs of establishment with some also in flower (Figure 23). Excessive rainfall throughout spring of 2021 in Tasmania impacted on the establishment and subsequent growth of some plantings within some of the experimental plots. It is currently unclear whether the native grass selected, *Microleana stipoides* (weeping grass) germinated within the native species plots due to the excessive number of weeds and exotic grasses within the inter-row plots despite each plot being hand weeded on three separate occasions. The native species were selected due to their spreading growth habit and/or high seed production and showed signs that they may outcompete many of the weed species present but failed to do so.

Similarly, issues post-planting with wallabies digging out native plantings subsided during the later stages of the production season. Additional tubestock was sourced (*Einardia nutans* and *Goodenia elongata*) and replanted to replace some of those lost during the establishment phase. While the wet spring in Southern Tasmania favoured the establishment of the natives in 2021, this was proceeded by the fourth driest summer on record (BOM 2022), which coupled with excessive weed competition induced elevated plant mortality and native inter-row plant establishment failure. By the beginning of spring 2022 none of the native plantings survived with these inter-row treatment plots reverting to being dominated by rye grass and white clover.

Figure 23. Native plant species establishment A) inter-row with chamomile sunray (*Rhodanthe anthemoides*) in flower during the spring of 2021, and B) dead native violet (*Viola hederacea*) that succumbed to drought stress during the summer of 2021-22.

Arthropod community response to treatment

2021-22 Production Season

During the 2021-22 production season a total of 52,156 insects were collected and identified via the sticky cards (Figure 24) and 5,472 earwigs were recorded in the cardboard rolls (max 105) and 6,745 were collected within the pitfall traps (Figure 25). Of the insects collected via the yellow sticky traps ca. 44% of the total insect collected were apple leafhoppers (*Edwardsiana froggatti*), 12% were their parasitoid *Anagrus armatus* and 9.5% were European earwigs.

Despite obvious differences in the total insect population sizes on the sticky traps, no significant difference was observed in total insect abundance between the inter-row treatments (P = 0.931), the tree line treatments (P = 0.639) or the interaction of the inter-row and tree line treatments (P = 0.986).

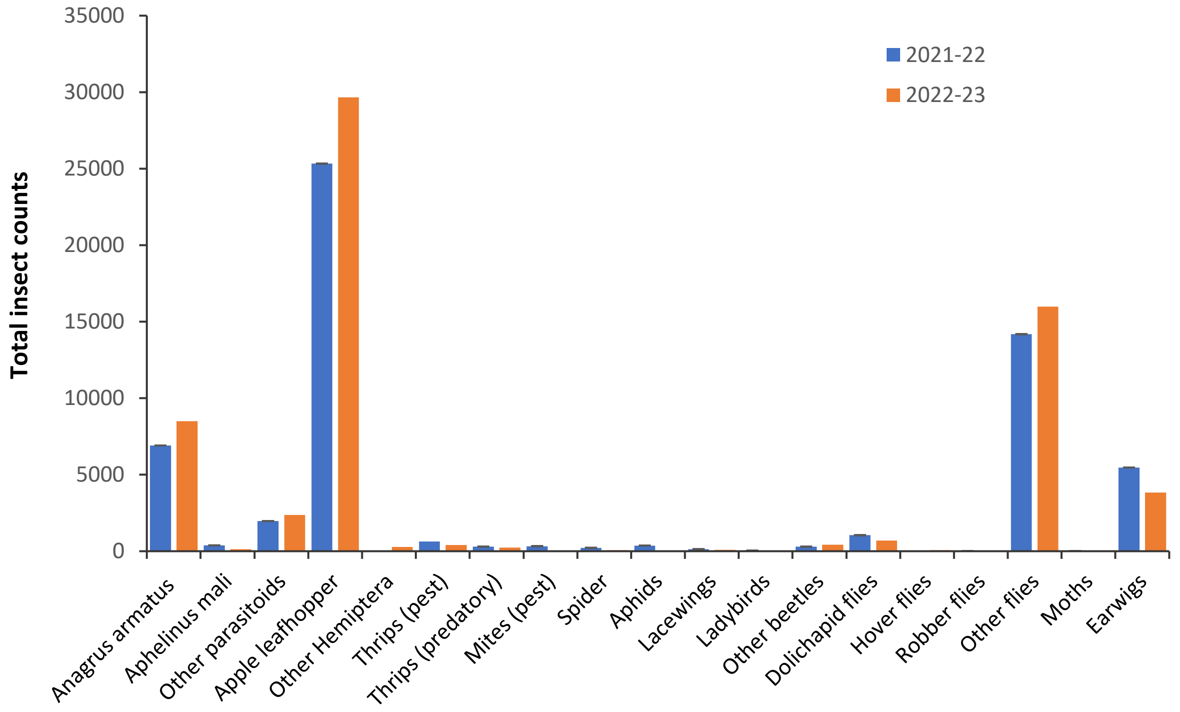

Figure 24. Total insect counts identified within apple tree canopies (n = 45) using both yellow sticky cards and cardboard rolls observed in 'Jazz' apples within the conservation biological control experimental block conducted at the Tasmanian field site during the 2021-22 and 2022-23 production seasons. Trapping occurred for 1 week per month during each production season.

Within the pitfall traps, total arthropod counts differed between the inter-row treatments (P = 0.046) but not between production seasons (P = 0.085) whereas the total number of arthropods differed both within the tree line treatments (P < 0.001) and between seasons (P = 0.05). Notable differences were observed among some ground-active taxa caught in pitfall traps. Dominant taxa were predatory spiders and edaphic mites, largely Oribatida. The number of juvenile spiders and Oribatida nearly doubled in the second season. In contrast, the omnivorous harlequin bug (*Dindymus versicolor*) declined from 844 to 19 individuals in the second season. Seasonally, mixed species of Coleoptera, dominated by ground beetles including predatory Carabids and Staphylinids (Rove beetles), were present in similar numbers, though they declined slightly in the second season. This seasonal trend was also evident among mixed species of flies, dominated by scuttle flies (Phoridae) that feed on dead matter; and springtails (Collembola) that occupy damp habitats where they mechanically break down organic matter.

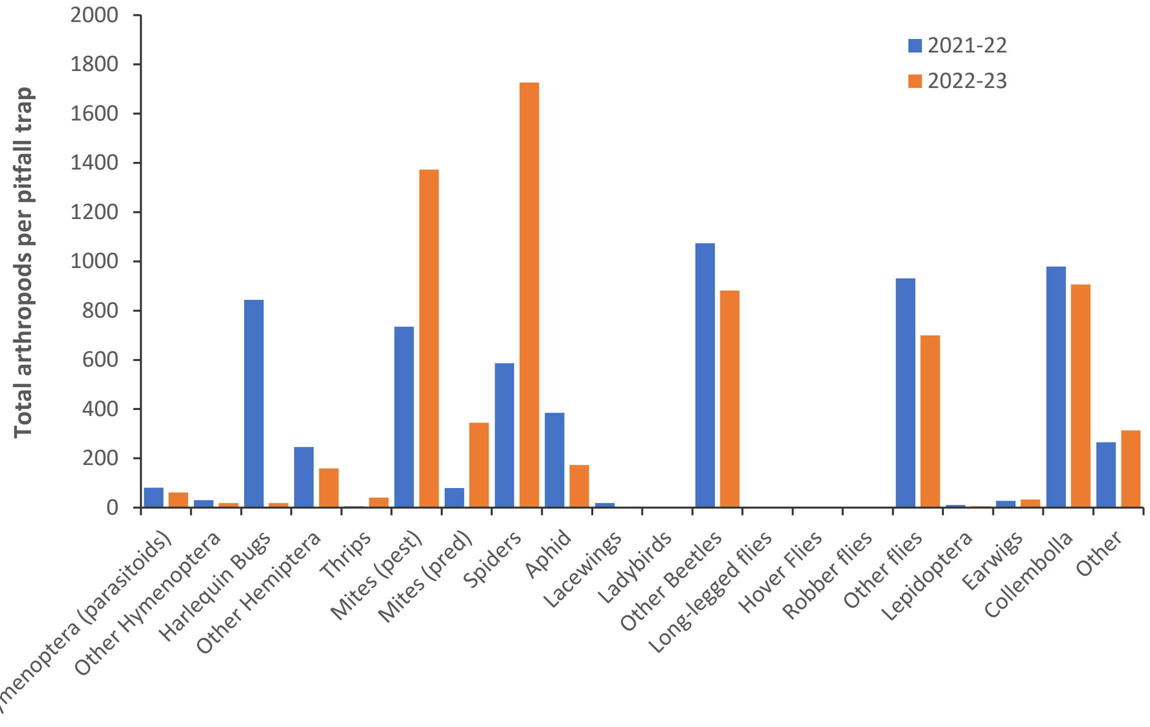

Figure 25. Total insect counts identified within pitfall traps within the Tasmanian conservation biological control experimental block during the 2021-22 and 2022-23 production seasons. Trapping occurred for 1 week per month during each production season.

Apple leafhopper and Anagrus armatus

Despite these differences in cumulative apple leafhopper population sizes within the various treatment combinations, no significant differences were observed in apple leafhopper population sizes over time between the inter-row ($P = 0.588$) treatments, the tree line treatments ($P = 0.253$) or the interaction between the inter-row and tree line treatments ($P = 0.321$). Similarly, no significant differences were observed in *A. armatus* populations between the tree line treatments ($P = 0.219$) and interaction between the inter-row and tree line treatments ($P = 0.278$). However, significantly fewer apple leafhopper parasitoids were observed in the native inter-row treatments (Figure 26).

Numerically higher cumulative apple leafhopper population sizes were observed in the grower sward (Huon #2) inter-row, and flowering meadow inter-row treatments compared to the native inter-rows (Figure 26). However, despite these higher population sizes being evident, no significant differences were observed in apple leafhoppers population sizes between the inter-row treatments ($P = 0.878$). Similarly, although higher populations were evident within the compost and legume-grass understory treatments no significant differences were observed between the tree line ($P = 0.240$, Figure 27) or within the interaction between the inter-row and tree line treatments ($P = 0.944$; Figure 28). Comparable patterns were observed within the apple leafhopper parasitoid populations with no significant differences observed within *A. armatus* populations between treatments (inter-row: $P = 0.435$; tree line: $P = 0.912$; interaction $P = 0.826$; Figure 28).

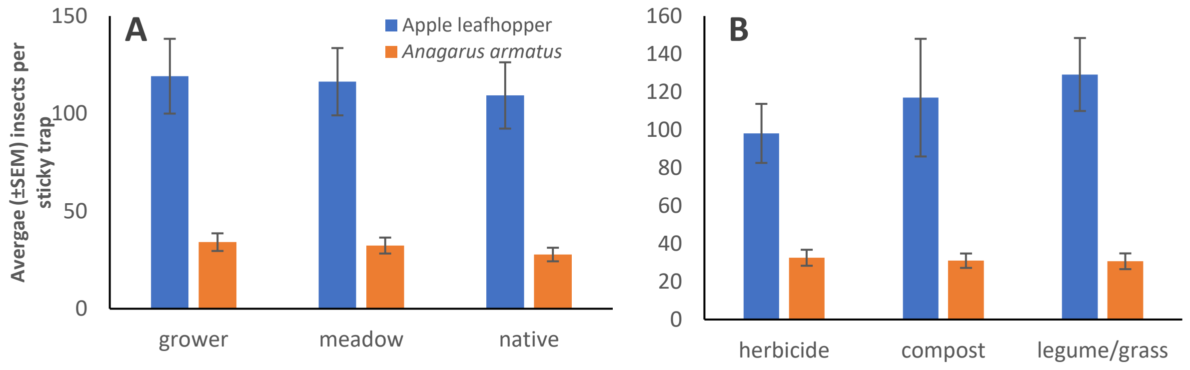

Figure 26. Mean (± SEM) apple leafhoppers (*Edwardsiana froggatii*) and its parasitoid, *Anagrus armatus* collected on sticky traps in Tasmanian CBC experiments during the 2021-22 production season. A) the inter-row treatments (grower sward (Huon#2), flowering meadow mix and native species plantings), and B) the tree line (herbicide spray strip, compost and legume-grass) treatments.

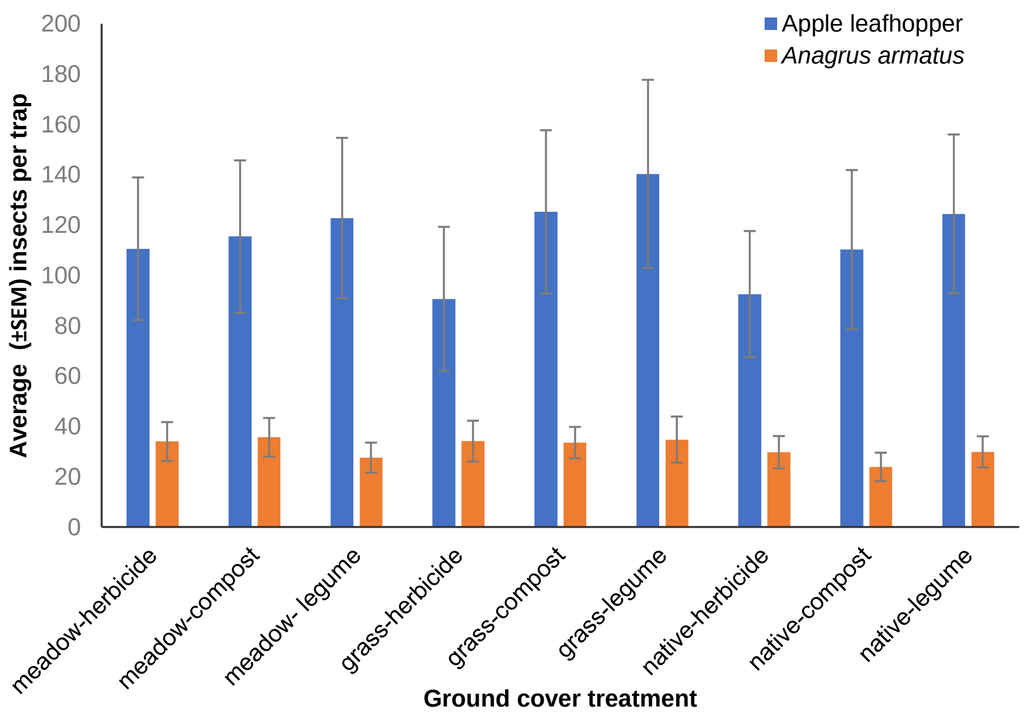

Figure 27. Mean (± SEM) apple leafhoppers (*Edwardsiana froggatii*) and its parasitoid, *Anagrus armatus* collected on sticky traps within the inter-row treatments (grower sward (Huon#2), flowering meadow mix and native species plantings) and the tree line (herbicide spray strip, compost, and legume-grass) treatment combinations during the Tasmanian conservation biological control experiments during the 2021-22 production season.

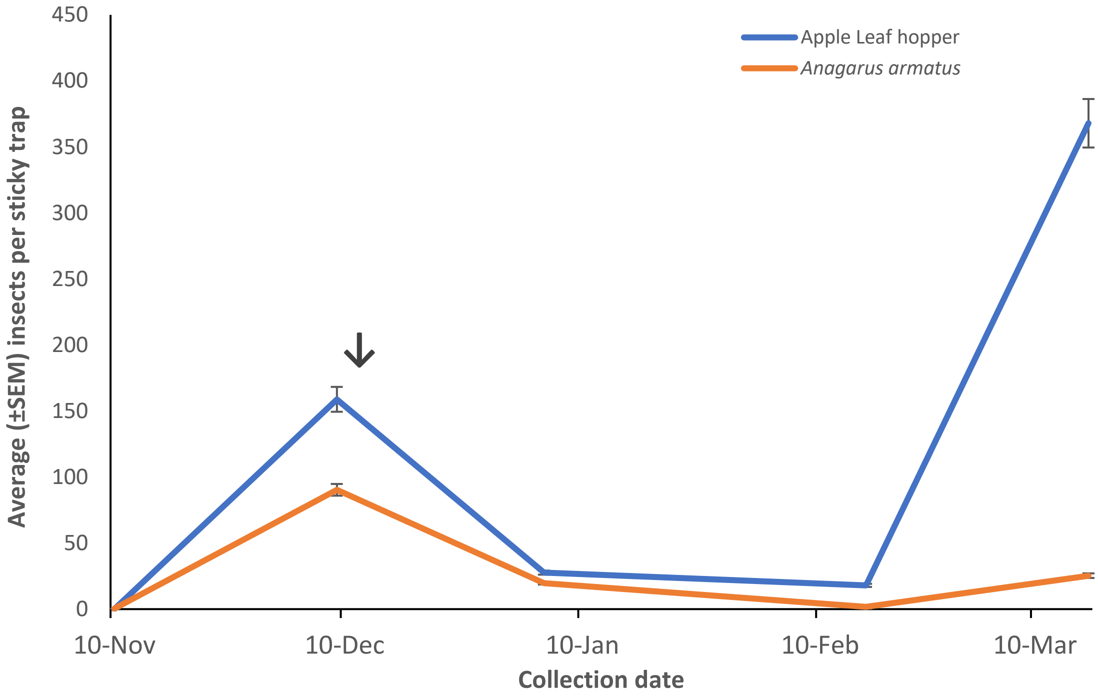

Figure 28. Mean (±SEM) apple leafhopper (*Edwardsiana froggatii*) its parasitoid (*Anagrus armatus*) counts observed in 'Jazz' apples tree canopies within the Tasmanian conservation biological control experimental block during the 2021-22 production season. Arrow indicates the timing of a Spinosad application for the control of Light Brown Apple Moth, *Epiphyas postvittana*.

European earwigs

Earwig population sizes declined significantly within all treatments over time across all treatments ($F_{8,16}$ = 80.932, P < 0.001; Figure 29 & Figure 30). No significant differences were observed in the total number of earwigs in the apples trees within the inter-row treatments ($F_{2,64}$ = 3.381, P = 0.060). A treatment effect was also observed within the tree line treatments ($F_{2,64}$ = 8.354, P = 0.001) with significantly more earwigs observed in trees with grass and legumes planted under the trees. However, no significant interaction was observed between the week of observations, inter-row or tree line treatments (P > 0.05).

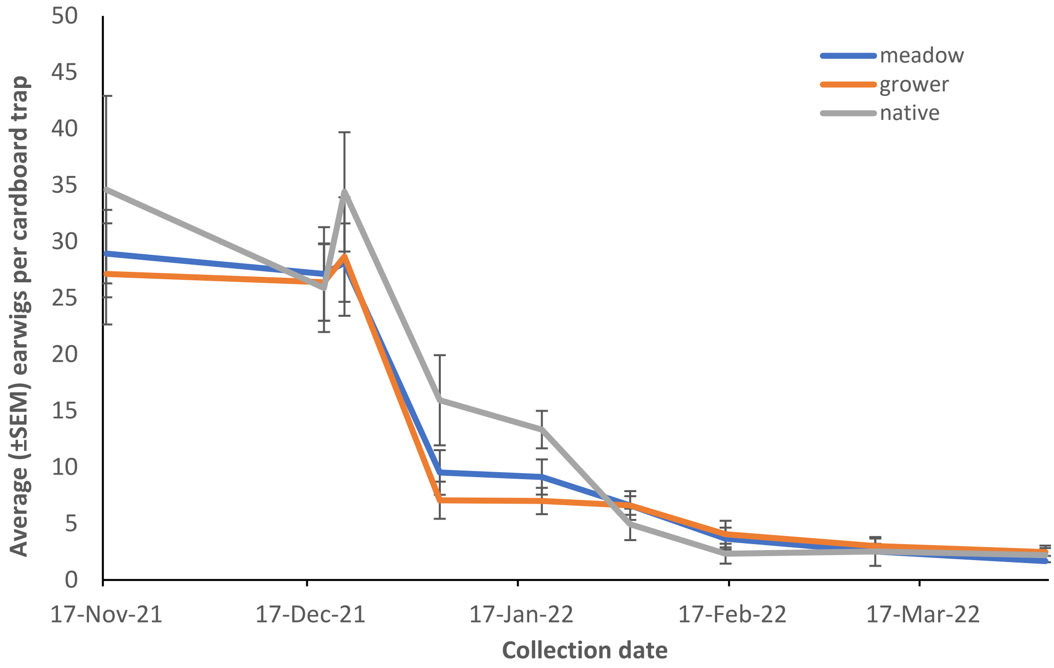

Figure 29. Mean (±SEM) earwig counts observed in 'Jazz' apples observed within the Tasmanian conservation biological control inter-row treatments (standard grower blend (Huon #2), flowering meadow mix and native species mix) throughout the 2021-22 production season. Earwigs were monitored using cardboard rolls located on the tree's trunk ca. 30 cm above the ground level.

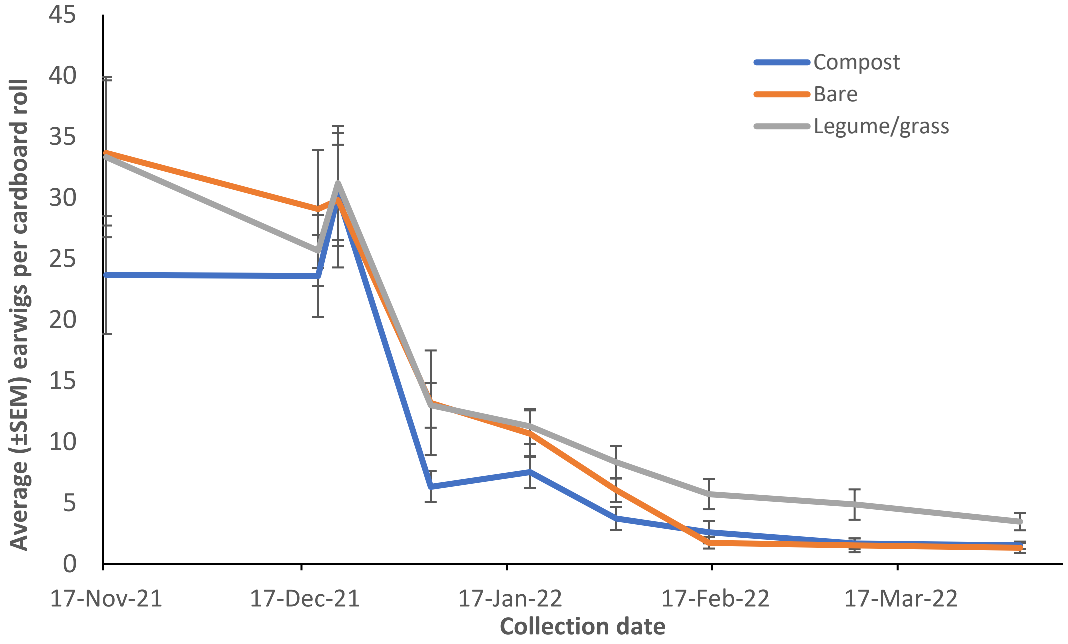

Figure 30. Mean (±SEM) earwig counts observed in 'Jazz' apples observed within the tree line treatments (herbicide spray strip, compost, or grass/legume green mulch) during the Tasmanian conservation biological control experiment throughout the 2021-22 production season conducted at R&R Smith's orchard Ranelagh, Tasmania.

Although differences were evident between the different ground cover treatments, how these changes in plant speciation and biodiversity altered insect pest and natural enemy interactions at a systems level become more evident using multidimensional scaling. Indeed, on a community level both the inter-row and tree line had little effect on overall arthropod abundance (Figure 31).

Parasitoids, *E. froggatti*, thrip, and spider populations demonstrated a greater association with the legume treatment when compared to the bare ground and mulch treatments. Greater population sizes of the predatory *Dolichopodidae* (long-legged flies) were associated with the compost amendment whilst a greater association with the bare treatment was observed with other Diptera, *A. armatus,* and *A. mali*. Diptera, *Dolichopodidae*, *E. froggatti*, thrips, parasitoids, spiders, and Hemiptera were similarly associated with the grass, meadow, and native inter-row treatments.

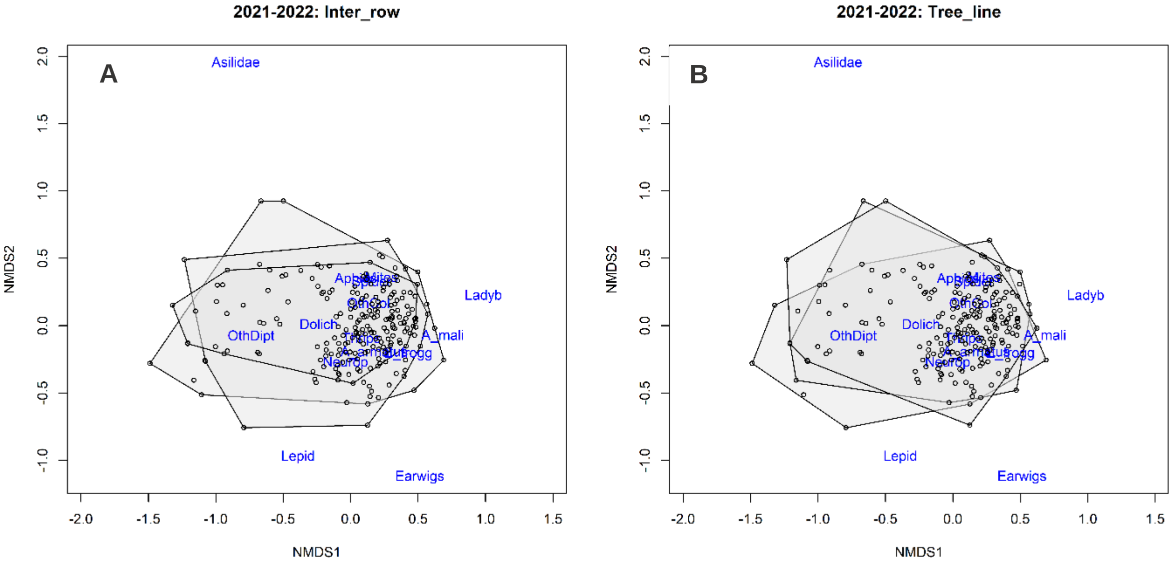

Figure 31. NMDS analysis of the insect fauna collected using sticky cards with the A) inter-row and B) tree line treatments within the Tasmanian conservation biological control experimental block during the 2021-22 production season. Each polygon (shape) indicates the insect diversity observed within each inter-row or tree line treatment. Overlapping polygons indicate little difference between treatment group insect communities.

Pitfall traps

When considering the total arthropod abundance within the various ground cover treatments, no significant differences were observed between the inter-row treatments (P = 0.411; Figure 32). However, a significant difference was observed between the tree line treatments (P = 0.004; Figure 33) with lower total arthropod counts were observed within the tree line pitfall traps located within the compost treatments (mean ± SEM: 48.1 ± 4.4). No significant difference (P = 0.352) was observed in total arthropod abundance between the herbicide strip and legume grass under stories (herbicide 32.1 ± 3.1; legume-grass 23.6 ± 2.5). Similarly, no significant interaction was observed in total arthropod abundance between the inter-row and tree line treatments was observed (P = 0.879) or between communities within the different treatments (Figure 34).

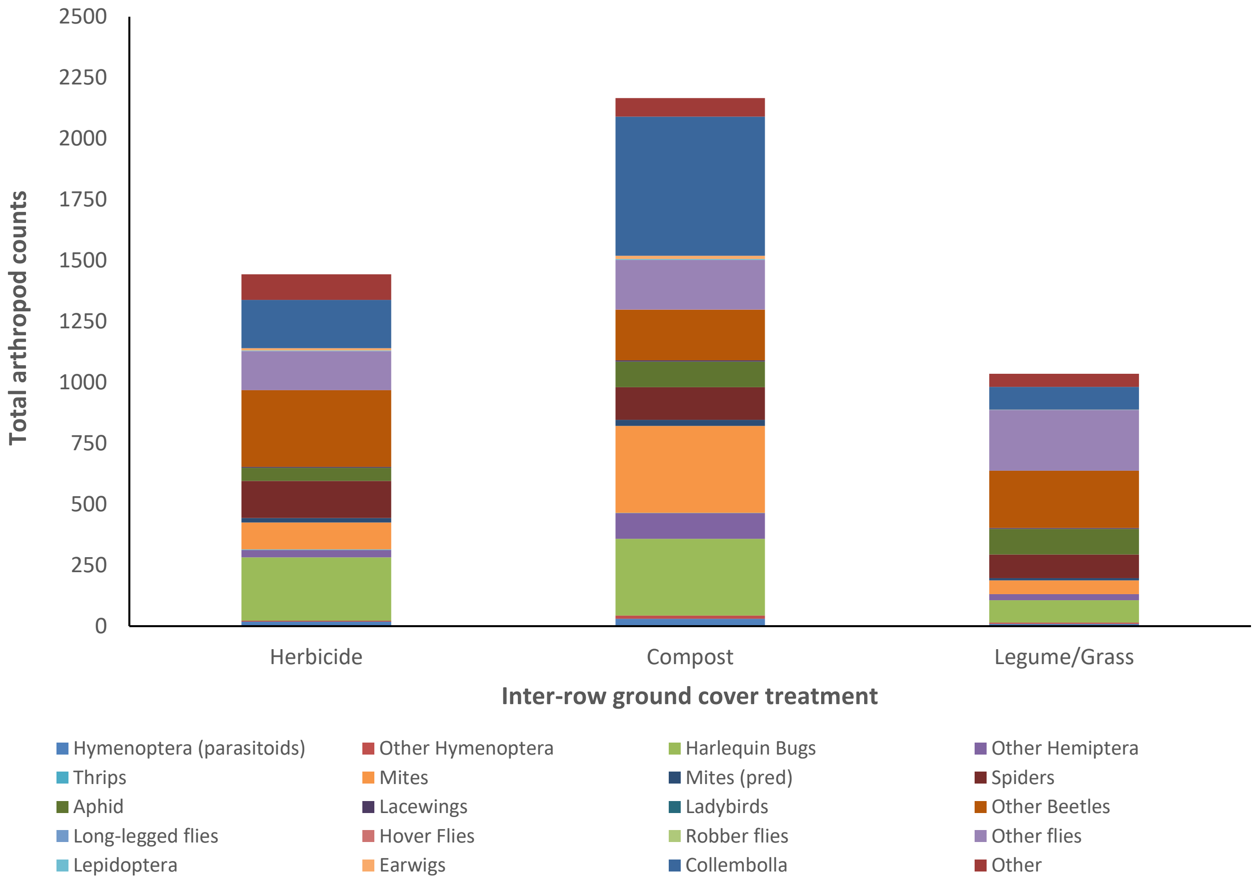

Figure 32. Total arthropod counts and faunal composition on the orchard floor during the Tasmanian conservation biological control experiment throughout the 2021-22 production season. All arthropods were collected using pitfall traps within the three inter-row treatments (Grower Huon #2, exotic meadow mix and native plants), n = 5.

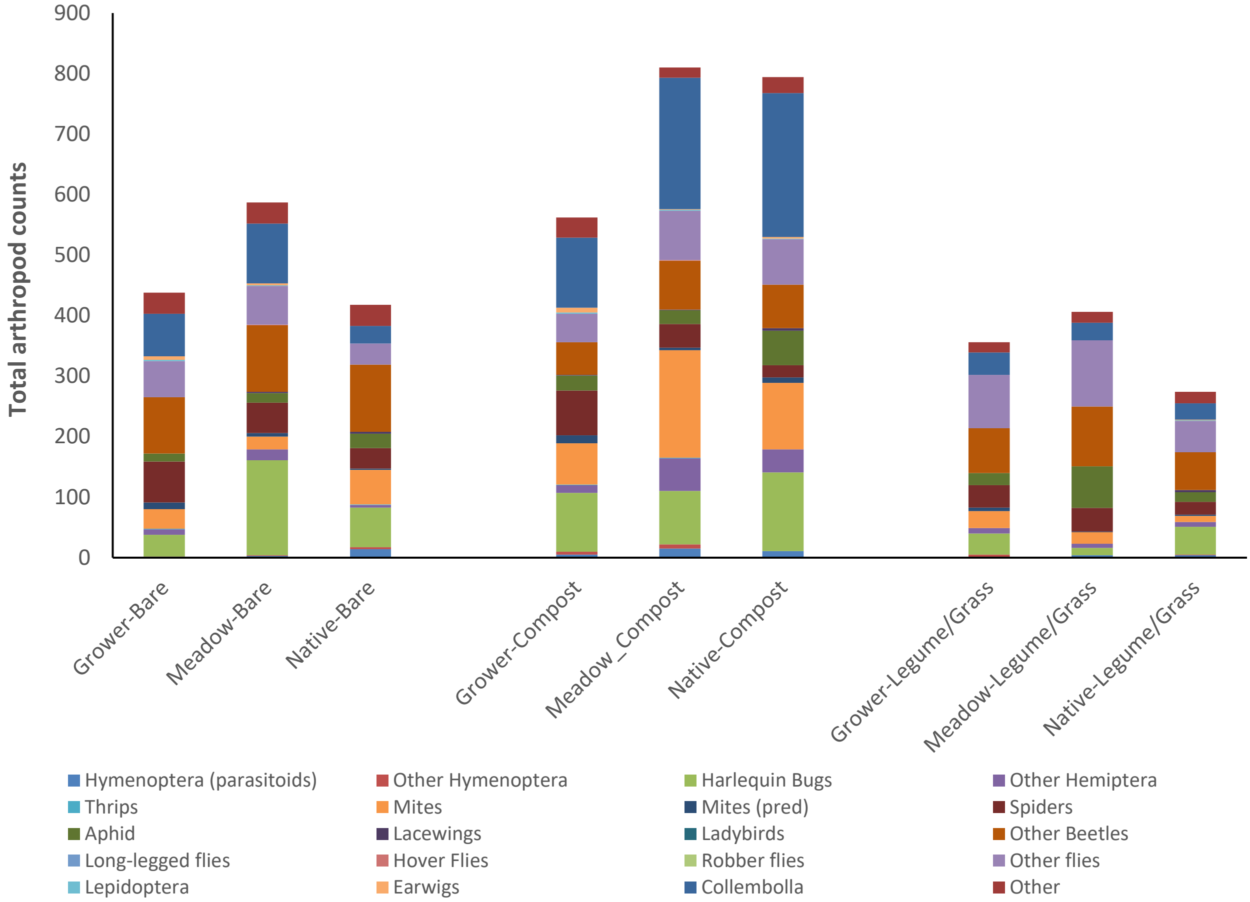

Figure 33. Total arthropod counts and faunal composition within the orchard floor during the Tasmanian conservation biological control experiment conducted during the 2021-22 production season. All arthropods were collected using pitfall traps within each sub-plot treatment consisting of either the herbicide spray strip, compost or green mature (legume-grass ground cover), n = 5.

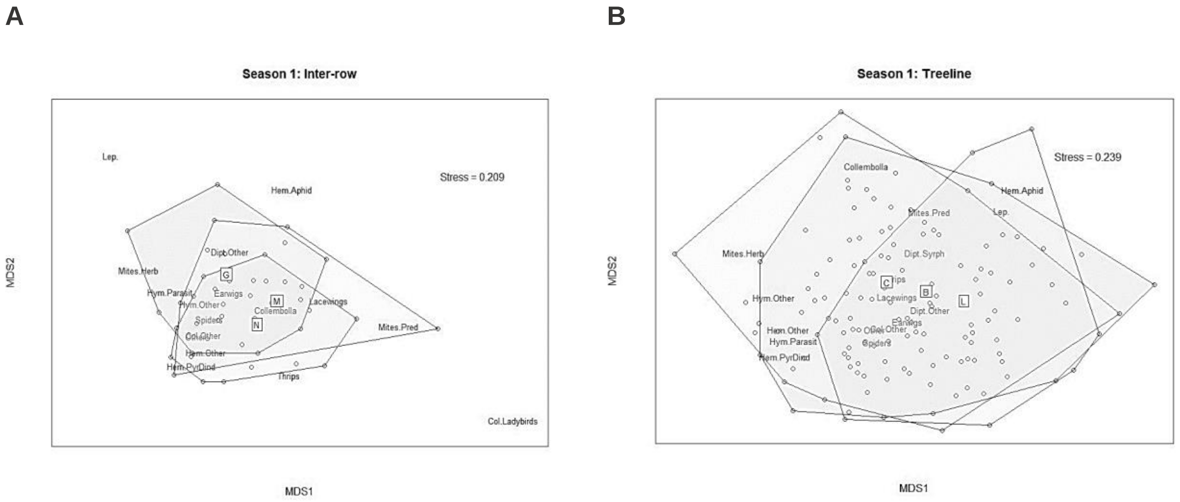

Figure 34. NMDS analysis of A) inter-row and B) tree line invertebrate communities observed in the Tasmanian conservation biological control experimental block during the 2021-22 production season. Each polygon (shape) indicates the insect diversity observed in each treatment within inter-rows or tree lines. Overlapping polygons indicate little difference between treatment group insect communities.

Fruit damage assessments

Fruit damage assessments were completed on the 4th of April 2022, approximately two days prior to harvest. Overall, fruit damage was relatively low across the experimental site (mean ± SEM, 4.48 ± 0.3%). The observed damage was largely caused by garden weevils (*Phlyctinus callosus*), apple scab (*Venturia inaequalis*), and codling moth (*Cydia pomonella*) with very low levels of thrip damage observed. Weevil damage was the predominant damage type (54.9%) followed by codling moth (20.5%) and apple scab (11.9%). No codling moth larvae were observed inside any of the fruit assessed, indicating the efficacy of the repeated organic insecticide applications (*Bacillus thuringiensis* & *C. pomonella granulovirus*) used in early December in preventing larval tunnelling but not fruit damage.

No significant difference in the total damage was observed between the three inter-row treatments (H = 11.780, P = 0.203), although some differences in damage type were. Significant differences in the levels of codling moth stings (H = 5.897, P = 0.024) and apple scab lesions (H = 9.000, P = 0.028) were observed between the three inter-row treatments, with higher damage levels observed within the exotic meadow inter-row treatment. No difference was observed between the standard grower sward (Huon # 2) and the native species mix.

No significant difference was observed in total damage (H = 5.048, P = 0.080), weevil damage (H = 3.140, P = 0.208) or codling moth stings (H = 3.849, P = 0.146) between the three tree line treatments. However, a difference was observed in apple scab incidence (H = 11.083, P = 0.004) with greater scab incidence in the compost tree line treatments. No significant interaction was observed between the inter-row and tree line treatments in any of the damage types observed or total damage occurrence.

2022-23 Production Season

A total of 58,074 insects were collected and identified via the sticky cards in the second season. A further 3,826 earwigs (mean 17.0 ± 0.9; max 75) were recorded within the cardboard rolls located on the trunks of the same trees and 6,298 arthropods were caught via the pitfall traps. The insect populations observed within the tree canopies during the 2022-23 production season mirrored the results of the 2021-22 production season with ca. 47.2% of the total insects collected were apple leafhoppers (*E. froggatii*), and

13.5% their parasitoid *A. armatus*. Large numbers (25.4%, mean = 64.5 ± 2.9 flies sticky trap^{-1}) of other Dipteran species (flies) that were deemed to have no deleterious effect on fruit damage were also recorded.

Approximately, 6.1% of the total insects collected within the tree canopies were European earwigs. Higher earwig numbers were recorded within trees located in the native species inter-row plots mid-season and then declined to become significantly lower than the populations sizes observed within the inter-row treatments despite little observable difference in plant species composition within these inter-row plots. In contrast, the earwig numbers within the growers blend declined mid-season but then increased in number towards seasons end.

Despite differences evident in the mean total insect population sizes within the tree canopies (Figure 35), no significant difference was observed between the inter-row treatments (P = 0.941), the tree line treatments (P = 0. 990) or the interaction of the inter-row and tree line treatments (P = 0.951).

Despite numerical differences evident between the apple leafhopper within the inter-row treatments (Figure 35) the tree line treatments or the interaction between the two treatment types (Figure 36), no significant differences were found between in population sizes between these insects (inter-row: P = 903; tree line: P = 0.201 and interaction: P = 0.692). Similarly, no differences were observed between apple leafhopper parasitoid *A. armatus* population sizes within the inter-row, tree line treatment or the interaction between the inter-row and tree line treatments (inter-row: P = 0.285; tree line: P = 0.111 and interaction: P = 0.213).

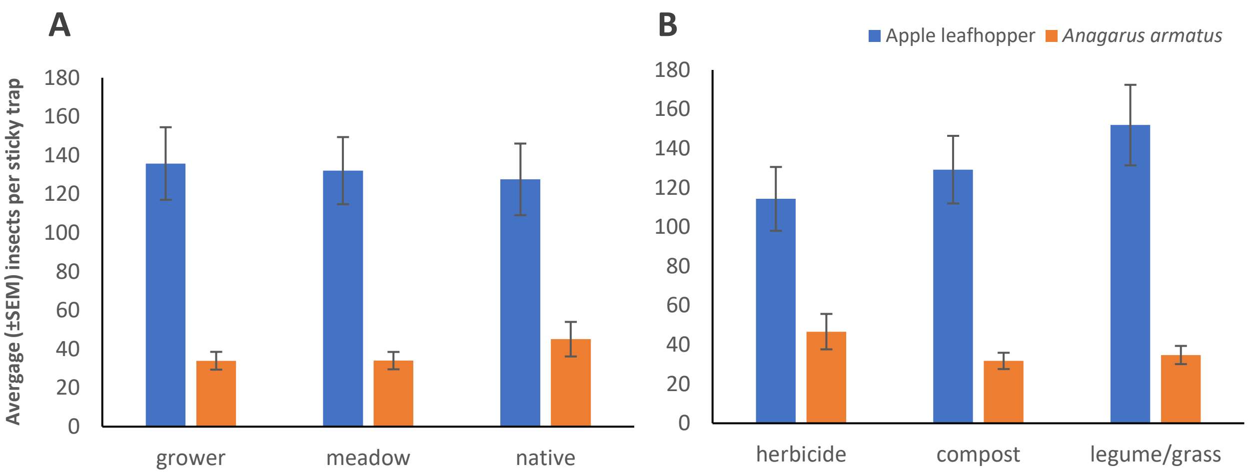

Figure 35. Mean (± SEM) apple leafhoppers (*Edwardsiana froggatii*) and its parasitoid, *Anagrus armatus* collected on sticky traps during the Tasmanian conservation biological control experiments during the 2022-23 production season within A) the tree line treatments (grower sward (Huon#2), flowering meadow mix and native species plantings), and B) the tree line (herbicide spray strip, compost, and legume-grass) treatments.

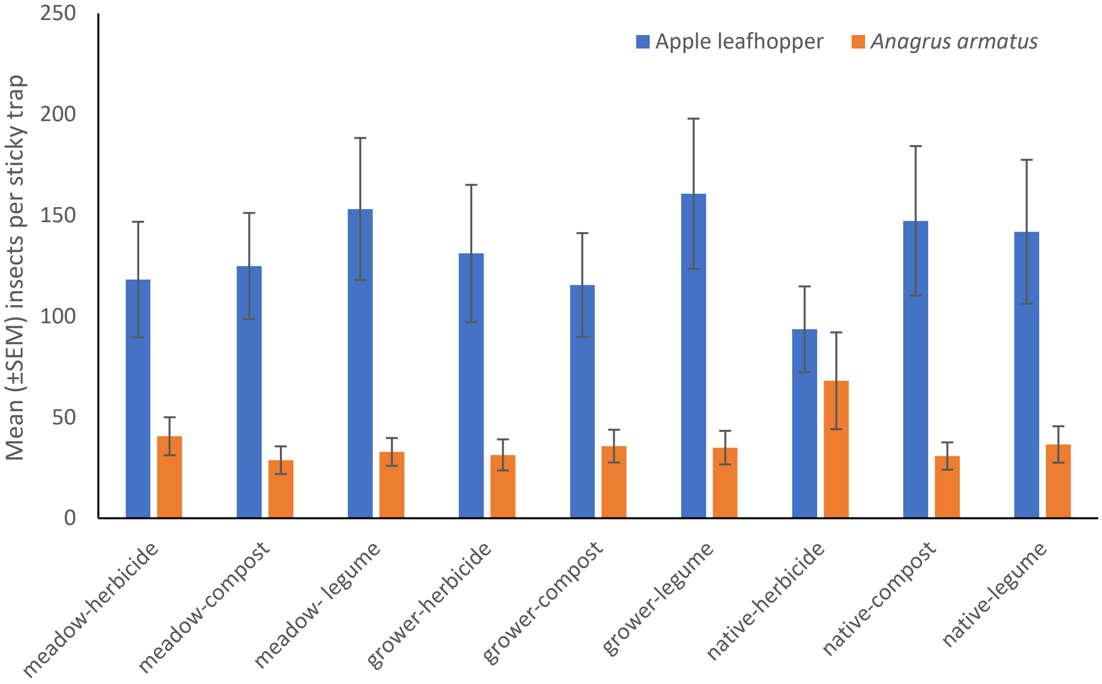

Figure 36. Mean (± SEM) apple leafhoppers (*Edwardsiana froggatti*) and its parasitoid, *Anagrus armatus* collected on sticky traps within the interaction between the tree line treatments (grower sward (Huon#2), flowering meadow mix and native species plantings) and the tree line (herbicide spray strip, compost and legume-grass) treatments during the Tasmanian conservation biological control experiments during the 2022-23 production season.

As observed during the 2021-22 production season, earwig numbers declined significantly over time across all treatments ($F_{4,8}$ = 74.468, P < 0.001; Figure 37 & Figure 38). No significant differences were observed in the total number of earwigs observed in the apple trees within the inter-row treatments ($F_{2,8}$ = 0.268, P = 0.268). Although higher earwig numbers were observed within the tree canopies that contained the legume grass tree line treatments these elevated population sizes were only observed at seasons end ($F_{2,24}$ = 2.111, P = 0.143). As was observed during the 2021-22 production season no significant interaction was observed between the week of observations, inter-row or tree line treatments (P > 0.05).

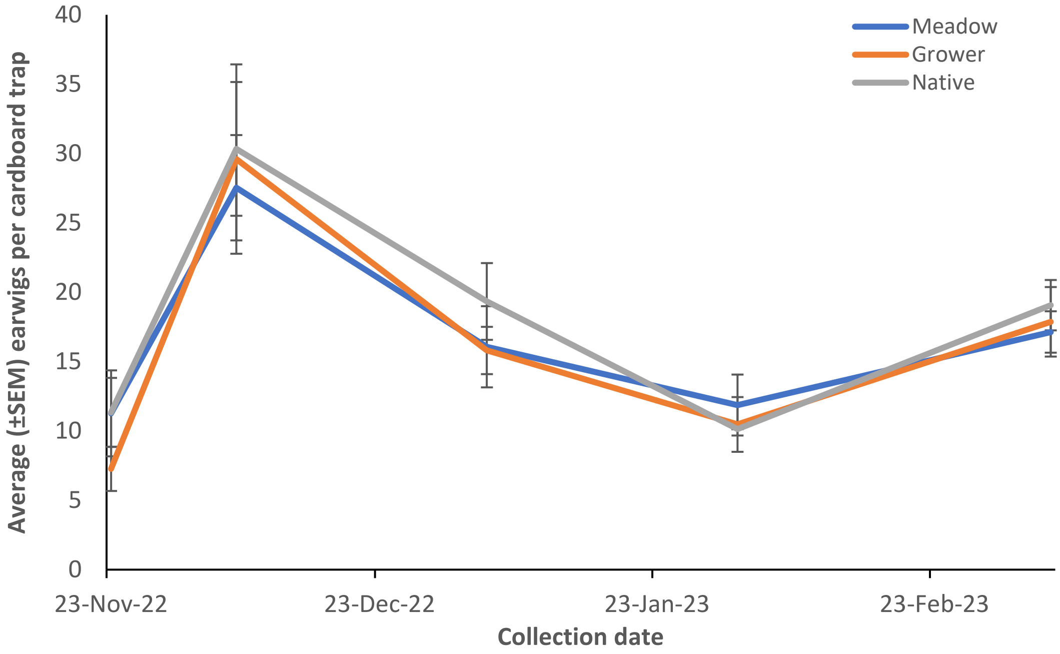

Figure 37. Mean (±SEM) earwig counts observed in 'Jazz' apples observed within the Tasmanian conservation biological control inter-row treatments (growers blend (Huon #2), flowering meadow and native species) during the 2022-23 production season. Earwigs were monitored using cardboard rolls located on the tree's trunk ca. 30 cm above the ground level.

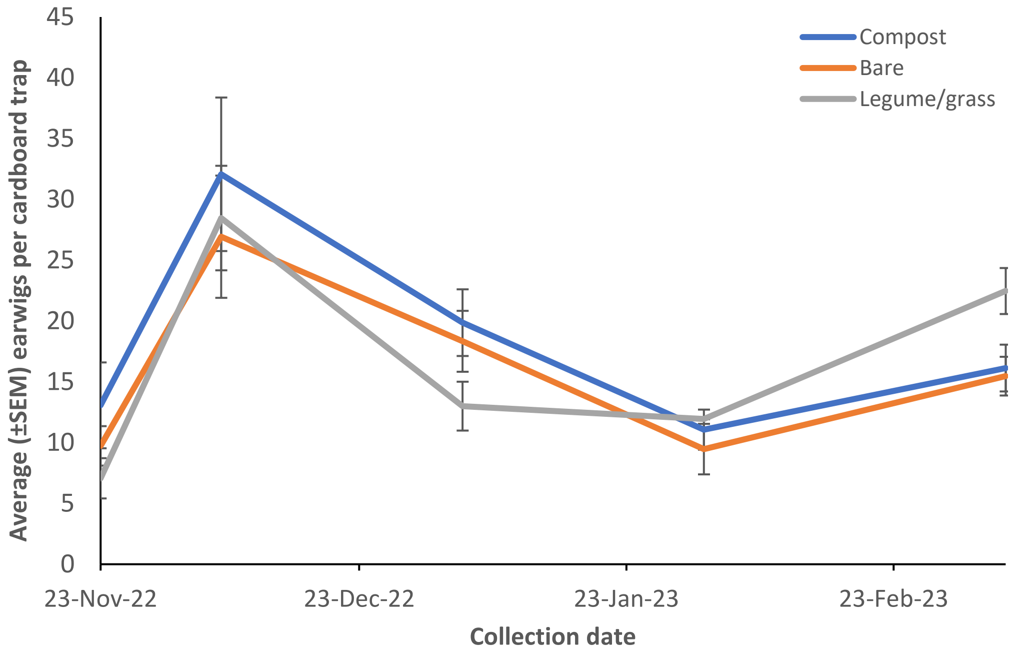

Figure 38. Mean (±SEM) earwig counts observed in Jazz apples observed within the Tasmanian conservation biological control tree line treatments (compost, herbicide spray strip and legume/grass green mulch) during the 2022-23 production season. Earwigs were monitored using cardboard rolls located on the tree's trunk ca. 30 cm above the ground level.

Despite these differences in cumulative apple leafhopper population sizes within the various treatment combinations, no significant differences were observed in the population sizes over time between the inter-row (P = 0.396) treatments or the interaction between the inter-row and tree line treatments (P = 0.798). However, a significant treatment effect was observed within the tree line treatments (P = 0.038) with great apple leafhopper populations observed within the trees that contained the grass-legume understory treatment (Figure 39). No significant differences were observed in *A. armatus* populations between the inter-row treatments (P = 0.798) the tree line treatments (P = 0.899) or the interaction between the inter-row and tree line treatments (0.798). Despite the lack of treatment effect within the *A. armatus* populations during the 2022-23 production season this species appeared more persistent in the second season possibly due to a lack of a Spinosad application for the control of light brown apple moth as observed during the 2021-22 production season (Figure 40 & Figure 41).

When considering the total insect diversity and abundance using multivariate analysis, no discernible difference was evident between either the inter-row or the tree line treatments (Figure 41).

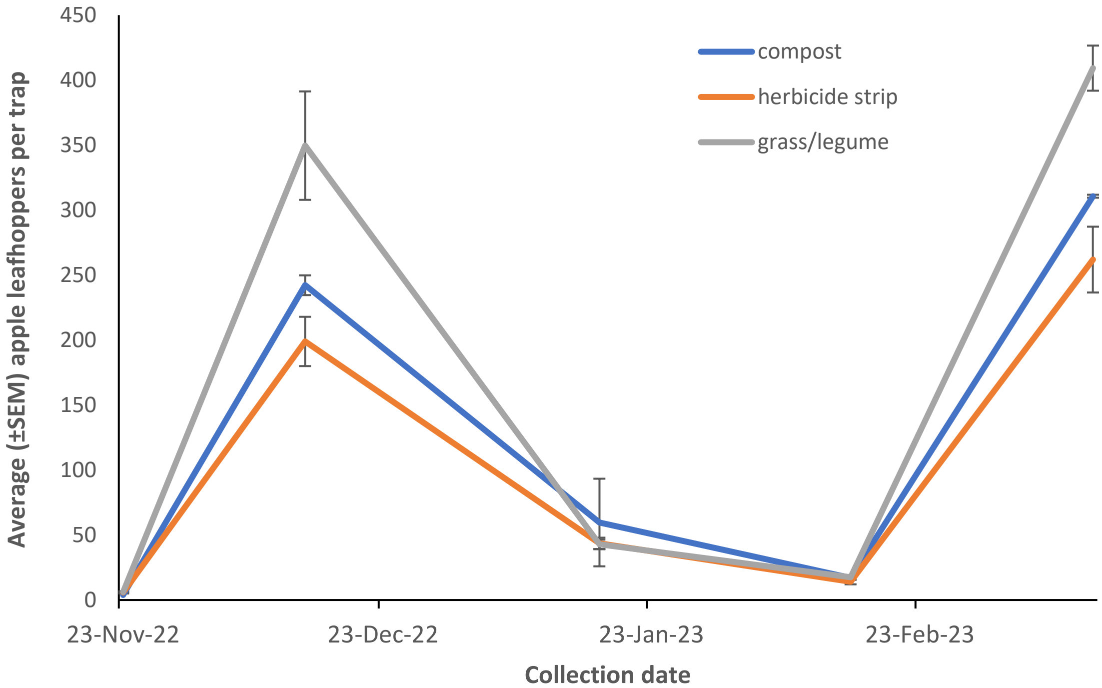

Figure 39. Mean (±SEM) apple leafhopper (*Edwardsiana froggatii*) counts observed in 'Jazz' apples tree canopies within the Tasmanian conservation biological control experimental block during the 2021-22 production season.

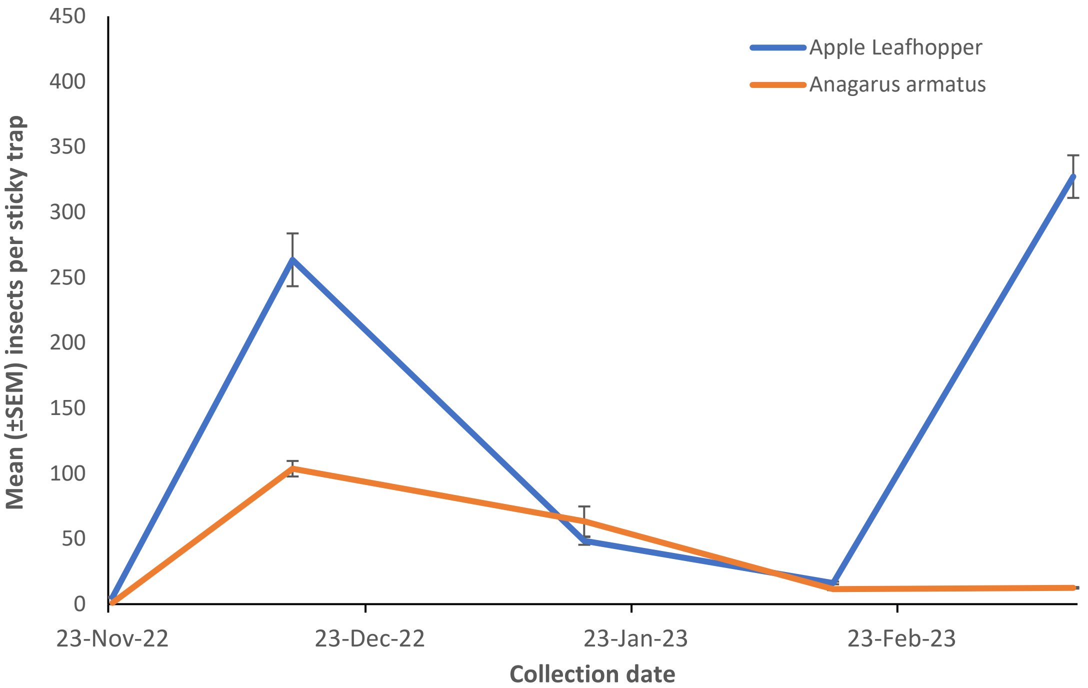

Figure 40. Mean (±SEM) apple leafhopper (*Edwardsiana froggatii*) and its parasitoid (*Anagrus armatus*) counts observed in 'Jazz' apples tree canopies within the Tasmanian conservation biological control experimental block during the 2022-23 production season.

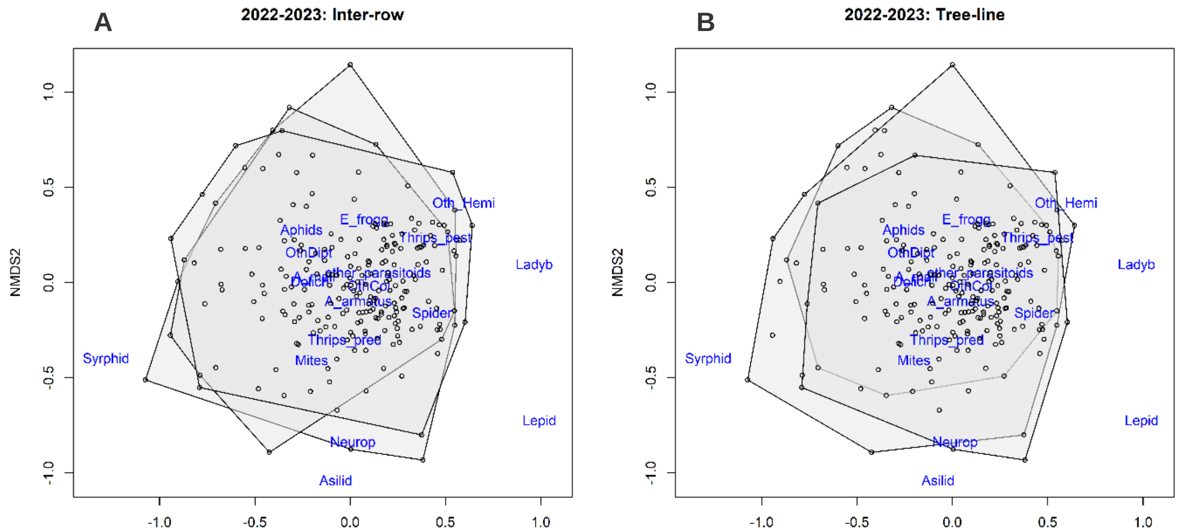

Figure 41. NMDS analysis of A) inter-row and B) tree line invertebrate communities by treatment within the conservation biological control experimental block during the 2022-23 production season conducted at R&R Smith's orchard Ranelagh, Tasmania. Each polygon (shape) indicates the insect diversity observed within each inter-row or tree line treatment. Overlapping polygons indicate little difference between treatment group insect communities.

Pitfall trapping

When considering the total arthropod abundance within the various ground cover treatments, significant differences were observed between both the inter-row (P = 0.050) and the tree line treatments (P < 0.001). Greater total arthropod counts were observed within the inter-row pitfall traps located within the native ground cover plots (44.8 ± 6.3 arthropods per pitfall trap), which due to plant establishment failure were largely newly established exotic rye grass and clovers in the second year. These elevated arthropod populations sizes were borne by increased spider, other (non-pest) beetles and collembola (spring tails) within the treatment plots. The lowest total arthropod abundance was observed within the exotic meadow inter-row mix (30.5 ± 4.6 arthropods per trap). Within the native plots, significantly more spiders (P < 0.001), but fewer collembola (springtails; P = 0.005; Figure 42) were observed.

Within the tree line treatments, higher total arthropod counts were observed in the compost tree line treatments (42.0 ± 6.2; Figure 44). The lowest total arthropod counts were observed in the legume-grass treatments (16.2 ± 3.4 per trap). A significant difference was observed in the number of other beetles between all three tree line treatments (P < 0.001) with fewer beetles observed in the legume-grass understory (mean: 2.1 ± 0.4; P < 0.001) compared to the other two treatments (compost: 4.8 ± 0.5; herbicide strip: 4.17 ± 0.4). No significant interaction was observed between the inter-row and tree line treatments (P = 0.985) in total arthropod abundance. However, elevated spider numbers were also observed within the native inter-row legume grass treatment combination most likely due to spider movement from the larger native inter-row treatment plots toward smaller tree line treatments (Figure 42 & Figure 43).

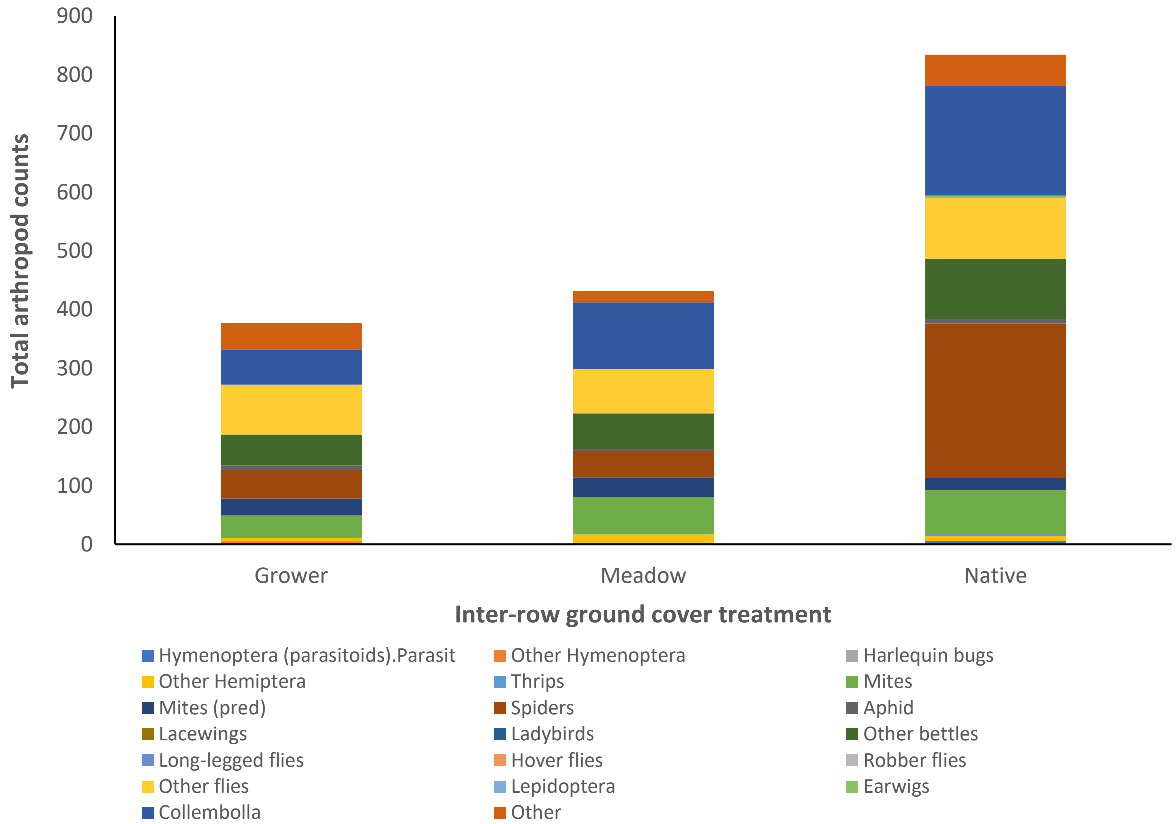

Figure 42. Total arthropod counts and faunal composition within the orchard floor during the Tasmanian conservation biological control experiment during the 2022-23 production season. All arthropods were collected

using pitfall traps within the three inter-row treatments (Grower Huon #2, exotic meadow mix and native plants), n = 5.

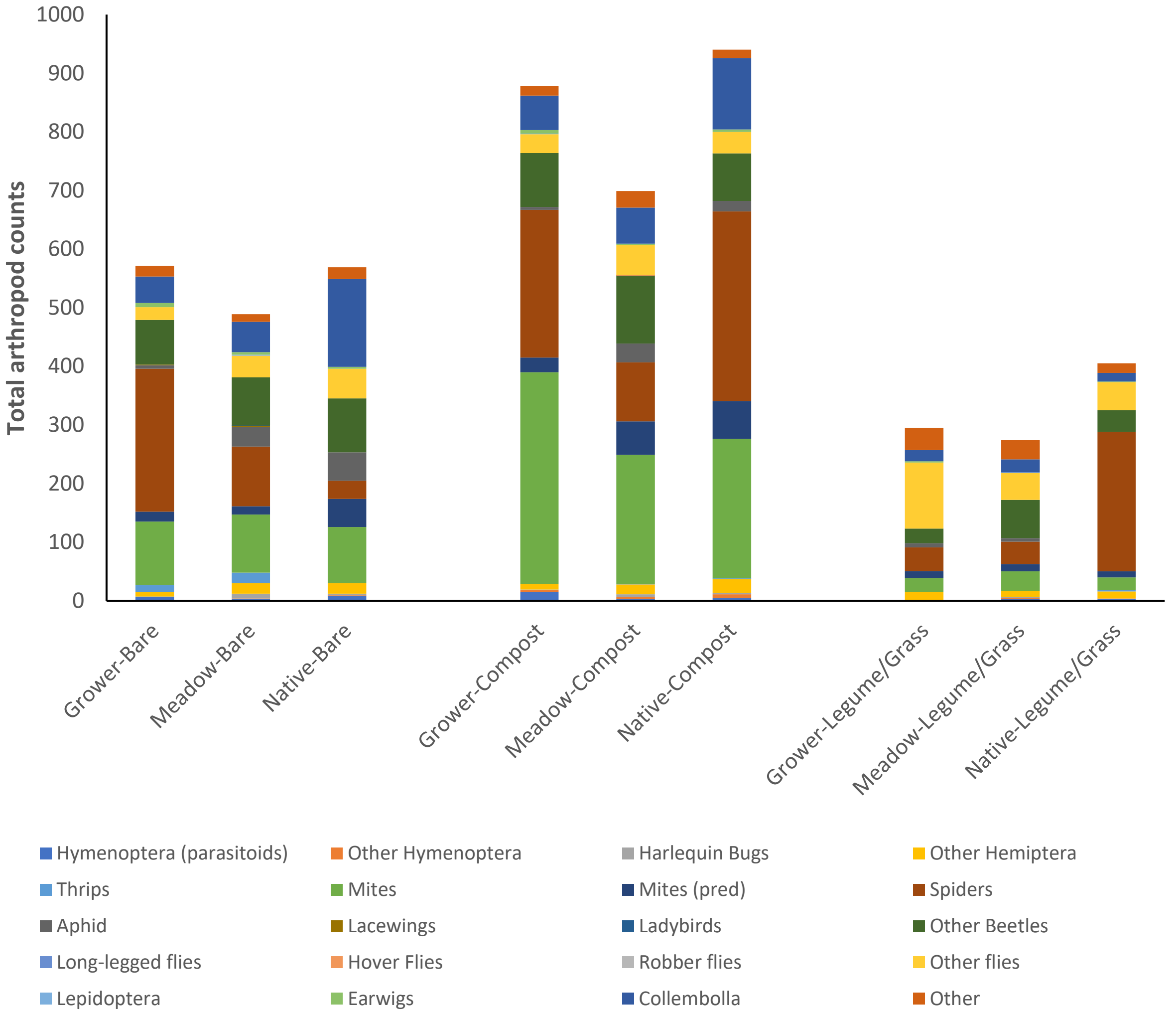

Figure 43. Total arthropod counts and faunal composition observed on the orchard floor within the Tasmanian conservation biological control experiment during the 2022-23 production season. All arthropods were collected using pitfall traps within each sub-plot treatment consisting of either the herbicide spray strip, compost or green mature (legume-grass ground cover), n = 5.

Despite these apparent differences between treatments regarding total arthropod abundance and preferences toward treatment types, when examined using multivariate analysis (Figure 44) no clear separation was evident between the different ground cover treatments with the exception of the elevated spider numbers within the native treatment plots.

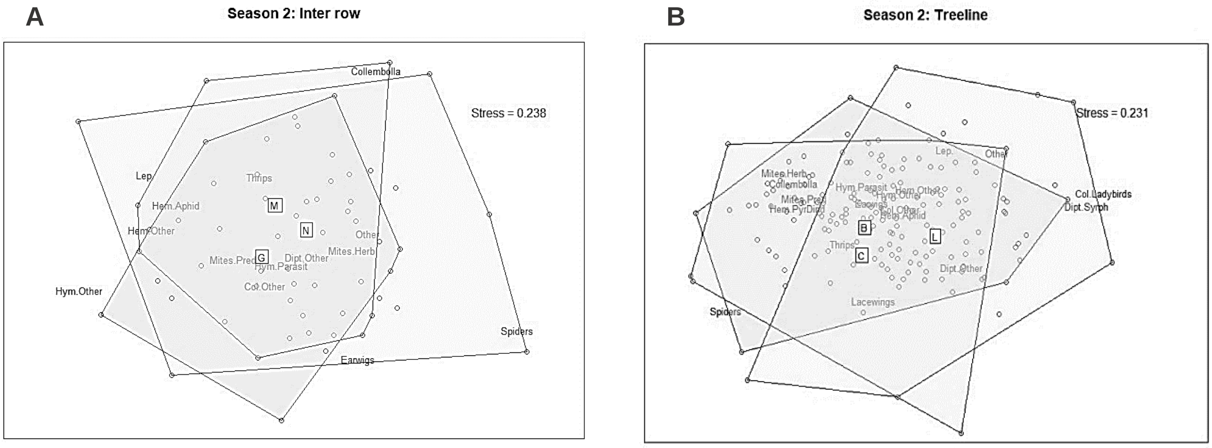

Figure 44. NMDS analysis of A) inter-row and B) tree line invertebrate communities by treatment observed within the Tasmanian conservation biological control experimental block during the 2022-23 production season. Each polygon (shape) indicates the insect diversity observed in each treatment within inter-rows or tree lines. Overlapping polygons indicate little difference between treatment group insect communities.

Fruit damage

Fruit damage assessments were completed on the 29th of May 2023, approximately five days prior to harvest. Overall, total fruit damage was relatively low (5.64%) across the trees assessed. However, the majority of the damage observed was the result of bitter pit - skin lesions that are initiated by a calcium deficiency during early fruit development. Indeed, only 1.21% of the total fruit damage observed could be attributed to pests or diseases.

Similar to the 2021-22 production season, the pest and disease damage observed was largely caused by weevils (57.8%), apple scab (20.9%), and codling moth (4.4%). Again, no codling moth larvae were observed inside any of the fruit assessed, indicating the efficacy of the repeated *Bacillus thuringiensis* & *C. pomonella granulovirus* insecticide applications. The weevil damage was again believed to have been initiated by garden weevils (*P. callosus*) as this was the only weevil species observed during the production season all be it in lower numbers than during the 2021-22 production season. Of the remaining fruit damage ca. 3 fruit showed damage that could be attributed to earwigs and 2 fruit that could be attributed to Harlequin bug (*Dindymus versicolor*, Figure 45), which were frequently observed aggregated on trestle posts but only rarely observed within the tree canopies. The causal agent for the remaining damaged fruit (n = 3) could not be attributed with certainty.

No significant difference was observed in total damage (H = 3.473, P = 0.176), codling moth stings (H = 0.000, P = 1.000) or apple scab incidence (H = 0.750, P = 0.687) within the inter-row treatments. Elevated weevil fruit damage was observed in the native species treatments (total = 16 damaged fruits; mean: 2.0 ± 0.5) however, not significantly so (H = 5.965, P = 0.051) with 5 damaged fruits observed in each the grower mix (Huon #2) and flowering meadow treatments.

No significant difference in the total damage was observed between the three tree line treatments (H = 1.978, P = 0.372), or in the number of codling moth stings (H = 0.000, P = 1.000) or apple scab (H = 0.750, P = 0.386) between the three inter-row treatments. No significant interaction was observed between the inter-row and tree line treatments in any of the damage types observed or total damage occurrence.

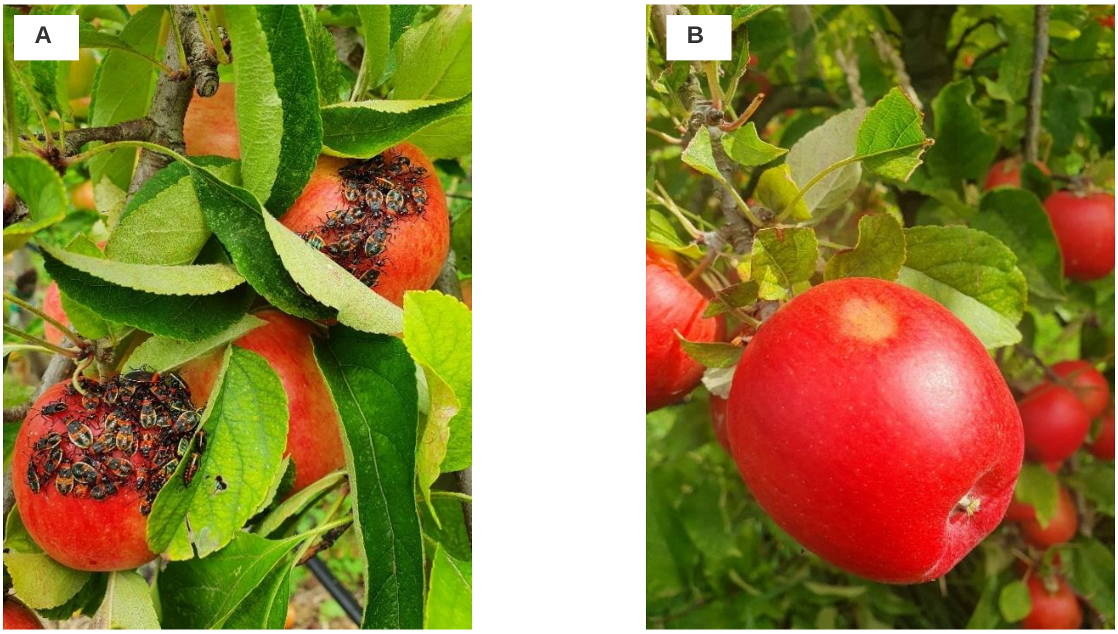

Figure 45. Jazz apple with A) aggregations of Harlequin bug (*Dindymus versicolor*) on the fruit B) characteristic fruit deformation initiated by Harlequin bug feeding during early fruit development.

Discussion

The orchard experiments conducted in Victoria and Tasmania, and studies of similar production systems elsewhere, have highlighted the potential for habitat manipulation in apple and pear IPDM systems. However, our experiments have also identified practical barriers to implementation, particularly of native vegetation within orchard blocks, that, if not addressed, could deter widespread adoption in Australian orchards. Principal among these barriers is the difficulty in establishing native groundcover forbs and grasses within conventionally managed apple/pear orchard production systems. In both States, we attempted to sow and plant cover crops of native (Victoria and Tasmania) and exotic (Tasmania only) plant species. Criteria that we developed for plant species selection considered a range of attributes, including several related to availability, cost, provision of SNAP (shelter, nectar, alternative prey, and pollen), and likelihood of establishment.

In determining which species may establish, we relied heavily on expert knowledge obtained from similar production systems. For the native species, we consulted native flora revegetation specialists and sourced seed and plants endemic to the bioregion. However, the environment within our two experimental orchards was particularly hostile to the cover crops we introduced, especially the native plant species.

In the Victorian trial, the establishment of native groundcover species by hand broadcasting of seed was the least effective method. Within only several months after sowing, the inter-row plots had already become a carpet of weeds, dominated by clovers and introduced grasses (Figure 46).

Figure 46. Weed establishment in treatment plots A) Rapid germination of weeds in the inter-row two months after the sowing of seeds of the native grass and groundcover species (TR2), B) close-up of weedy seedlings, consisting mostly of clover and annual ryegrass seedlings (15 July 2021).

The establishment of native grass seed was moderately successful, and we observed the occasional wallaby (*Rytidosperma*) and weeping grass (*Microlaena stipoides*) plant within the native grass/groundcover (TR2) and native grass (TR3) plots within the first season (2021/22). In the following year (2022/23), both species had persisted albeit at lower levels, while exotic broadleaf annual forbs, sedges and grasses had become abundant.

Australian native flora that are endemic to regions with nutrient-impoverished soils are extremely sensitive to phosphorus (P) due to a low capability to down-regulate their phosphate-uptake capacity (Durnin, 2021). They are also very poor competitors at higher P availability, giving way to more competitive species when soil P concentrations are increased (Lambers *et al.,* 2013). For native grasses, they are known to persist in soils of a median Colwell P of less than 21.3 mg/kg (Mitchell *et al.* 2019), while native flowering species persist better in soils with Colwell P less than 10 mg/kg (C. Olive personal communication June 7, 2022). The lack of establishment and persistence of the native species in the experimental orchards may be due to extremely high levels of P. Indeed, Colwell P levels were around 138 mg/kg beneath the trees, and 73 mg/kg in the inter-rows. It is uncertain whether such high P levels within the orchard prevented seedling establishment due to toxicity, or whether the seedlings of the native species were outcompeted by fast-growing annual weeds.

Despite the lack of establishment of native groundcovers sown into the inter-row of the Victorian experimental pear orchard, establishment of the native plant species using tubestock was more successful than the hand-broadcasting of seed. However, tubestock were far more expensive in terms of purchasing, planting and follow-up maintenance, and likely that over time, the introduced grasses and broadleaf weeds would potentially outcompete the natives (C. Olive personal communication, June 7, 2022).

In the Tasmanian experimental orchard, the unseasonal conditions observed during the 2021-22 production season, combined with an excessive weed burden and foot and machinery traffic, all impacted on the establishment of native species. Despite this, many of the plants appeared to survive their first season in the Tasmanian experiment but failed to persist through to the following winter. The plots subsequently became dominated by rye grass and clover, which eventually out competed the native plantings.

Unlike our apple and pear orchard experiences, the establishment of native perennial cover crops in vineyards in south-eastern Australia has been successfully demonstrated (Govender *et al*., 2010; Retallack *et al*., 2019). While careful site preparation of the vineyard is also required prior to and following the sowing of native species (Penfold & Collins, 2012), the success of native plant establishment in vineyards compared to apple/pear orchards is likely due to the fact that Australian vineyard soils are naturally low in phosphorus (Longbottom, 2010).

A common practice utilised in native habitat revegetation activities in temperate Australia, particularly where soil improvement has occurred, is to scalp off the topsoil to a depth of 10 cm followed by herbicide application for 2-3 years of treatment (Brown *et al.,* 2017). The optimum scalping depth removes the majority of soil seed bank and reduces available P to levels similar to indigenous areas (Morris & Charles, 2018). However, such strategies are likely to be impractical or undesirable in an orchard environment due to changes in soil structure, hydrology, removal of a large portion of soil organic carbon (Durnin, 2021), and potential damage to orchard tree roots.

The establishment of the exotic flowering meadow treatments in Tasmania also saw challenges, with mowing of these plots prior to seed set during the 2021-22 season, which prevented those species, with the exception of the plantain, from re-establishing during the 2022-23 season. Indeed, this highlights the need for changes in grower practice (i.e., mowing intervals) if CBC is to be adopted by the Australian apple/pear industry.

Despite these limitations, potential exists for the incorporation of native and/or exotic flowering species for CBC benefits that incorporates a landscape-scale approach across the orchard, rather than a “within-crop” approach. Several studies in Europe have demonstrated that margin strips (wildflowers, grass and hedgerows) adjacent to apple orchards provide floral resource provisioning (nectar and pollen), and habitat for the conservation of orchard pest natural enemies (Santos *et al*., 2018; Minarro & Prida, 2013). Such a strategy could be investigated for Australian orchards, whereby native vegetation is planted on the periphery, while suitably adapted vegetation (such as flower strips) consisting of species known to provide SNAP for natural enemies of key orchard pests is maintained within the orchard.

Whilst our treatments did not establish as intended, there were still results that can be highlighted for conservation biological control. In Victoria, the grower sward of resident broadleaf weeds and grasses hosted the highest number of beneficial parasitic Hymenoptera from important chalcidoid families, suggesting that these adventitious weeds still provided CBC benefits through the provision of floral resources. Interestingly, using DNA barcoding tools, we discovered considerable diversity amongst the *Trichogramma* taxa occupying the orchard, including, *Trichogramma cryptophlebiae*, not previously recorded from southern Australia. *Trichogramma cryptophlebiae* are minute wasps that parasitise the eggs of tortricid moths and are sold commercially for the biocontrol of macadamia nutborer, *Cryptophlebia ombrodelta*. This parasitoid has been shown to parasitise codling moth in laboratory experiments (Kaspi et. al 2019) but its impact in Australian apple and pear orchards is not known. Also, contribution of *T. cryptophlebiae* to general pest control within apple and pear orchards, and possible synergistic relationships with the other apple and pear orchard *Trichogramma* species (*T. pretiosum* and *T. carverae*) are unknown. This finding (more information in Appendix 2 of the Final Report for 19002) highlights the importance of the need for understanding the role of existing parasitoids and how CBC can support their populations.

Growers could strategically leave habitat and SNAP for beneficial insects wherever possible, which can be done in many ways depending on the inter-row width and available machinery. Where wider inter-rows exist, leaving a central strip down the centre of the inter-row maintains habitat for beneficial insects, or where narrow inter-rows exist, every second row can be mowed alternately (Llewellyn, 2021). Similarly, future research should investigate the replacement of the commonly practiced tree line herbicide strip with low growing mat-forming vegetation, as was investigated in the Tasmanian trials. These plantings have the potential to insulate the soil, protect it from erosion, increase soil structure and biology whilst providing habitat for beneficial arthropods for CBC.

Plant species selection for non-crop vegetation in pome orchards will depend on many factors and will differ from orchard to orchard. These factors include, but are not limited to, climate, soil type, access to irrigation, position within or around the orchard (e.g., tree line, inter-row, block perimeters, shelterbelts), available space, access to machinery such as mechanical seeders and/or mulchers/roller crimpers, and available finances/time for plantings and ongoing management. As well as these requirements for plant species suitability, any non-crop vegetation that is selected for CBC and/or pollination services should be chosen for their competitive advantage with weeds and their ability to regenerate soil health. From this perspective, future trials should be conducted on multiple commercial orchards so that these complexities can be addressed on a case-by-case basis.

At the Victorian experimental site, the conservation biological control experiment was designed as a replicated split plot, with three treatments and a control, allocated randomly to 42 x 4 m plots along each of 8 rows. Having several treatments adjacent to one another along the rows, plus a “buffer row” either side, the potential movement of arthropods into and of the plots may have confounded results leading to difficulties in detecting treatment effects. Ideally, CBC experiments would be designed with considerably larger plots with more replication across multiple orchards. Conducting trials on multiple orchards also helps mitigate the risk of losing an entire experiment to factors which are out of the control of the researcher, such as a trial site being flooded, or grower/management decisions to remove trees within the trial site.

Another learning from the conservation biological control experiments was that future experiments should carefully consider the number and frequency of arthropod monitoring techniques undertaken, because morphological identification of arthropods is especially time consuming. At the Victorian experimental site, we used eight arthropod monitoring techniques at a relatively high frequency, as well as the bi-annual fruit damage inspections and vegetation monitoring, which proved excessive. As a result, many of the arthropod collections were not able to be taxonomically diagnosed at an adequately low level due to time limitations. When selecting arthropod monitoring techniques for future conservation biological control work, concentration should be on functional and taxonomic groups of interest, the habitat being sampled, as well as the logistical aspects such as time investment, cost and available personnel.

For small arthropods (such as mites), monitoring techniques might need some adjustments. Preliminary observations in our study showed that the destructive method and lab-based examination for mites performed better than the non-destructive industry method in terms of species detection and prevalence. However, an obvious limitation of the destructive methods when compared to current practice, is the requirement for a stereo microscope, access to a laboratory or similar facility, and training in mite identification. Therefore, the destructive method may be more useful in the research context, or for appropriately trained consultants/scouts who monitor pests in orchards on behalf of growers. Another limitation with our study on mite monitoring techniques, was that it was limited to a single growing season in one pear orchard.

The most abundant parasitic wasp family collected at the Victorian experimental site were the Scelionidae. These are egg parasitoids whose characteristics are considered desirable for natural enemy conservation programs. They have positive host-density responsiveness, with simple adult diets, can be reared easily and can be considered in re-distribution or inundative release programs (Orr, 1988).

Conservation biological control is an integral tool within an IPDM system in horticulture because, alongside its own benefits, it supports and improves the efficacy of many inter-related ecosystem services and pest control tools, including soil health, crop pollination, augmentative biological control and classical biological control (Gurr *et a*l., 2017). This suite of ecosystem services and pest control tools are now needed by growers more than ever to alleviate some of the impending challenges that all Australian horticultural industries now face, including the need to reduce pesticides, high fertiliser costs, top soil loss as a result of bare soil in flood events, reduced soil health as a result of compaction and synthetic chemical use, the arrival of *Varroa destructor* which could impact pollination ability/costs, and continually changing weather and climate patterns (Calicioglu *et al.,* 2019; Australian horticulture statistics handbook, 2021).

Consumer demands, for example, are increasingly placing pressure on the production sector to minimise chemical use. The adoption of IPM-focused initiatives including CBC may well provide the opportunities required to meet these consumer expectations. However, if these initiatives are to be successful, greater consideration is needed regarding how to incorporate CBC into extant production systems including appropriate plant selection, CBC plot size and ongoing maintenance requirements. It is also commonly understood that the implementation of any IPDM activities can take several years to fully establish and become impactful, CBC is no different. On this basis, any future CBC trials should be given sufficient time to allow the plantings whether they be exotic or native to fully establish and the beneficial arthropod fauna time to respond to these enhanced floral resources.

Finally, conservation biological control projects need to be integrated with work on soil health, crop pollination and where possible augmentative and/or classical biological control programs to see the benefits that such a suite of practices can have on productivity and sustainability in comparison to existing approaches. While each practice on its own can be highly effective, the result of truly integrated practices can amplify farm productivity and cost effectiveness when compared to conventional practices. Ecosystems take time to change, and trials need to run for at least 5 years to establish the changed ecosystem and monitor the resulting changes to soil health, pollination, and pest damage.

Conclusion and Recommendations

In conclusion, the CBC trials were able to demonstrate:

- The potential gains that can be made by manipulating arthropod abundance and diversity through altering ground cover composition within Australian apple and pear orchards.
- Vegetative groundcovers within the tree line encouraged predators such as earwigs in tree canopies and spiders on the orchard floor.
- Vegetative tree lines were also observed to encourage the movement of beneficial fauna from the inter-row towards the tree lines where they have the potential to have a greater impact on economically important pest species.
- The use of compost within the tree line was demonstrated to improve non-pestiferous ground dwelling mite populations under the trees.
- These gains have the potential to both promote nutrient cycling and suppress ground dwelling pest species (i.e., LBAM during winter) and canopy borne pests such as woolly apple aphid during the production season.

Recommendations to industry/growers:

1. CBC be implemented that includes the conservation of resident natural enemies and where necessary, the deliberate release of biological control agents that target specific pests.
2. Adoption of inter-row vegetation management that promotes biodiversity of orchard natural enemies, such as no-mow flowering strips, or adapting mowing schedules.
3. The use of compost or mulch within the tree line to provide harbour for ground-dwelling predators and detritivores.

Recommendations to R&D investment decision makers:

1. Further research into the development of tailored inter-row cover crop species that provide SNAP for resident natural enemies and specific biological control agents against key orchard pests such as the codling moth parasitoid, *Mastrus ridens.*
2. Investigations into the role of extant and remnant bushland and deliberate plantings of native vegetation around orchards and block margins, in conserving natural enemy populations.
3. Quantifying the economic value of CBC and addressing barriers to adoption.
4. Continued effort to integrate CBC with IPDM programs (especially IPDM-compatible pesticides and their application), research into soil health, tree health and fruit quality.
5. Projects longer than 3-years for conservation biocontrol research in agroecosystems, ideally on multiple private orchards using large treatment areas.

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Appendix 2

Technical Report: Biological Control of Key Apple and Pear Pests using Trichogrammatidae parasitoids

AP19002 Strengthening cultural and biological management of pests and diseases in apple & pear orchards

July 2023

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VICTORIA State Government | Energy, Environment and Climate Action

AGRICULTURE VICTORIA

External Project Code Reference	AP19002
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Author	Greg Lefoe

Acknowledgment

We acknowledge and respect Victorian Traditional Owners as the original custodians of Victoria's land and waters, their unique ability to care for Country and deep spiritual connection to it. We honour Elders past and present whose knowledge and wisdom has ensured the continuation of culture and traditional practices.

We are committed to genuinely partner, and meaningfully engage, with Victoria's Traditional Owners and Aboriginal communities to support the protection of Country, the maintenance of spiritual and cultural practices and their broader aspirations in the 21st century and beyond

Contents

Introduction

Codling moth, *Cydia pomonella*, and light brown apple moth (LBAM), *Epiphyas postvittana*, are pests of pome fruits in Australia. LBAM is a native insect that has a wide host range, does not diapause, and survives on weeds and other vegetation in or near orchards and then infests apple and pear trees after foliage appears in spring. Codling moth is an introduced pest that diapauses as 5th instar larvae, and moths begin to emerge and commence oviposition in spring around flowering time in pome fruits.

Egg parasitoids of the family Trichogrammatidae have been successfully utilised world-wide as biocontrol agents that parasitise eggs of pests from different orders, including Lepidoptera (Hassan, 1993; Desneux *et al*., 2010; Tabone *et al*., 2010). Among Lepidoptera, the family Tortricidae is one of the main hosts of these parasitic wasps (Falcon and Huber, 1991). Considerable research has been conducted on augmentative use of Trichogrammatidae against codling moth in other countries (McDougall and Mills, 1997; Cossentine and Jensen, 2000). *Trichogramma* species have been recorded parasitising codling moth eggs in various parts of the world, including Turkey (Iren and Gurkan, 1971), Canada (Bloem *et al.*, 1998) and the USA (Pinto *et al.,* 2002).

Species of the genus *Trichogramma* that have been reported as potential biocontrol agents for control of codling moth include *T. platneri* (Mills *et al*., 2000), *T. minutum* and *T. pretiosum (*Yu *et al.,* 1984), and *T. dendrolimi* and *T. cacoeciae* (Hassan et al., 1987). McDougall & Mills (1997) investigated *T. platneri* against codling moth in the USA. Mass release of the species was demonstrated to be effective in a reduction of codling moth population by 60% (Mills *et al*., 2000). Other species of *Trichogramma* (*T. evanescens* and *T. cacoeciae*) contributed to a significant reduction of codling moth in organic apple orchards in Denmark (Sigsgaard *et al.*, 2017). Both species have been recorded from Australia but are not commercially produced.

In Australia, several species of Trichogrammatidae have been recorded parasitising codling moth eggs (Waterhouse and Sands 2001). Commercially reared species of Trichogrammatidae include *Trichogramma carverae*, *Trichogramma pretiosum*, and *Trichogrammatoidea cryptophlebiae*. *Trichogramma carverae* is known to parasitise LBAM eggs (Paull and Austin, 2006). Parasitism of codling moth eggs by *T. carverae* has not been published, to our knowledge, although it is frequently mentioned without supporting citations. These claims may have arisen from mistaken identity due to contamination of *T. carverae* cultures by *T. pretiosum* and subsequent distribution as *T. carverae*. *Trichogramma pretiosum* is known to out-compete *T. carverae* in laboratory cultures. *Trichogramma pretiosum* is a polyphagous egg parasitoid that is mass released as a biological control agent against various insect pests on different plants (Li, 1994). *Trichogramma pretiosum* was introduced from North America to control *Helicoverpa* in cotton and is now widely distributed in Australia (Rukmowati Brotodjojo and Walter, 2006).

Biocontrol agents such as *Trichogramma* could provide valuable pest management services during flowering and subsequent fruit development by parasitising pest eggs. This may require the release of multiple species to control the pests. The efficacy of parasitoids is affected by several factors including host acceptance, host size, density, shape, color, and cues such as kairomones contained in moth scales (Lewis and Nordlund, 1985; Miura *et al*., 1994). Species of the *Trichogramma* genus possess different host preferences and performances when facing their variable hosts (Godfray, 1994; Roriz *et al*., 2006; Desneux *et al*., 2012). Therefore, it is essential to investigate host ranges of parasitoids such as *Trichogramma* for possible use in biological control programs (Paraiso *et al*., 2013).

Our objectives in this study were to assess the host-range of *T. carverae* in relation to codling moth and LBAM, and assess the diversity of *Trichogramma* spp. in an orchard situation, specifically:

1. To determine the suitability of codling moth and LBAM eggs as hosts of *T. carverae*,
2. To assess resident *Trichogramma* species, including *T. carverae*, in a pear orchard that is subject to conservation biological control treatments.

Materials and Methods

Parasitism performance of *Trichogramma carverae* on codling moth and light brown apple moth eggs

Laboratory experiments were conducted in controlled environmental conditions 25 °C ± 2 °C, 60-65% ± 5% relative humidity, 16:8 L. Lepidopteran eggs (*Sitotroga cerealella*) parasitised by *T. carverae* were received from Bugs for Bugs (https://bugsforbugs.com.au/) and egg strips with approximately 100 parasitised eggs were prepared. Each egg strip was examined under the microscope to ensure eggs were in good condition and, where necessary, phytoseiid mites were removed. Codling moth and light brown apple moth eggs were collected over 4 days before the experiment and stored in the cool room (4 °C).

The experimental unit consisted of a sentinel card of 20 host eggs placed inside a plastic cup (70ml) with a lid. Treatments were as follows and were replicated 20 times.

T1: Codling moth eggs + egg strip parasitised by *T. carverae*.

T2: Light brown apple moth eggs + egg strip parasitised by *T. carverae.*

T3: Codling moth eggs only (Control).

T4: Light brown apple moth eggs only (Control).

T5: Lepidopteran egg strip parasitised by *T. carverae* only (Control).

The experimental units were checked for larval emergence of the hosts. After *T. carverae* had been emerging from lepidopteran eggs strips for three days, *T. carverae* and *Sitotroga* eggs were removed from all cups. The cups were checked under a dissecting microscope on the 6th, 8th, 13th, 15th and 23rd day after the experiment commenced and the following parameters were observed and recorded:

- Number of codling moth and light brown apple moth eggs parasitised in T1 and T2 (parasitised eggs turn blackish),
- number of intact black eggs without emergence holes to calculate the number of *T. carverae* that failed to emerge,
- number of eggshells with signs of *T. carverae* emergence (eggs where Trichogramma emerged have an irregular emergence holes),
- number of adult *T. carverae* emerged within each cup (more than one individual may emerge from one egg),
- number of emerged codling moth larvae in T1 and emerged light brown apple moth larvae in T2 (there is generally no larval emergence from parasitised eggs),
- number of emerged codling moth larvae in T3 and emerged light brown apple moth larvae in T4,
- number of *T. carverae* emerged from T5 as an indicator of parasitoid numbers on each lepidopteran egg strip.

Orchard assessments of resident trichogrammatid species (Hymenoptera: Trichogrammatidae)

Orchard assessments were conducted at Tatura experimental pear orchard to assess resident trichogrammatid populations:

a) Attracting resident trichogrammatid species using sentinel light brown apple moth eggs and yellow sticky traps

Light brown apple moth eggs were deployed in the experimental pear orchard in March 2022, and again in November 2022 and March 2023. Eggs were collected from a lab culture daily prior to deployment and stored at 4° C until there were enough eggs to prepare egg cards. This was necessary because

Trichogramma species do not parasitise eggs if they are not fresh. A microscope was used to count approximately 15-20 eggs per egg card. Eight sentinel eggs cards were clipped onto pear leaves in random positions within each of four experimental rows (every second row) (see *Appendix 1. Technical report: conservation biological control* for a description of the orchard experiment layout). 32 egg cards were also clipped to the back of pear leaves on the east and west sides of the middle panels in each plot. Trichogrammatid wasps prefer the shady side of the tree so egg cards were placed where they would be in shade and between 1.5- 1.8 m in height for easy access. Nb: in a pilot study, the sentinel egg cards were checked after three days for any signs of predation by generalist predators such as earwigs, but predation was negligible.

After 3-4 days, the egg cards were retrieved and placed individually into labelled plastic cups (70 ml) with lids; cups were kept in a CER at 25 °C. The egg cards were examined twice a week for signs of parasitism and/or emergence of light brown apple moth larvae or adult trichogrammatid wasps over the following two weeks. Parasitised eggs generally turn blackish within 3-4 days after parasitism.

Yellow sticky traps were put out monthly in the experimental pear orchard within the tree canopy to monitor invertebrates as part of a conservation biological control experiment (see *Appendix 1. Technical report: conservation biological control*). These yellow sticky traps were also used to monitor any trichogrammatid wasps present in the orchard.

b) Suction sampling for local Trichogrammatidae species identification

Suction sampling of the crop and non-crop vegetation in the experimental pear orchard was done using a Stihl SH56 vacuum shredder (27.2 cc displacement), fitted with tailor-made voile sleeves to catch invertebrates. Ad hoc (in terms of specific location) suctioning was done at various times in the 2022/23 production season, with the aim of sampling trichogrammatid species (Hymenoptera: Trichogrammatidae). Suction samples were sieved to remove larger invertebrates and samples were stored in 100% ethanol before morphological examination. Any trichogrammatid specimens collected were placed individually into vials containing 100% ethanol before DNA analyses.

Statistical analysis

For the parasitism performance of *T. carverae* on codling moth and light brown apple moth eggs, binomial percentage data, as required to meet the ANOVA assumptions, were transformed to angular scale, and subjected to analysis of variance (ANOVA) in accordance with a completely randomized design (CRD), which was the experimental design used in the study. Since the results from the angular scale and the original (binomial %) scale were similar, with ANOVA assumptions reasonably met in both cases, results from original scale are presented. Statistical significance of differences between treatments were tested using least significant difference (LSD) at 5% level of significance. All analyses were conducted using GenStat for Windows 22nd edition (VSN, International Hempstead, UK) (Payne et al., 2022)

Results

Parasitism performance of *Trichogramma carverae* on codling moth and light brown apple moth eggs

Parasitism of both codling moth and light brown apple moth eggs by *T. carverae* was high under laboratory conditions. Percent parasitism was slightly higher on light brown apple moth eggs (mean 85%) compared to codling moth eggs (mean 83.6%), however, there was no significant difference between host percent parasitism (Table 1). Based on the control samples of *T. carverae* in lepidopteran eggs (treatment 5), there was a mean of 67 *T. carverae* adults emerged from each egg strip. The percentage of dead or un-emerged *T. carverae* were also similar in both cases, 41.4% and 46.9%, respectively from parasitised codling moth and light brown apple moth eggs (Table 1). The number of emerged adult *T. carverae* from parasitised codling moth and light brown apple moth eggs were also similar with 492 and 303 individuals respectively in total (remembering that more than one individual can emerge from a host egg). Only two codling moth and four light brown apple moth larvae emerged in total.

Table 1. Percentage of codling moth (CM) and light brown apple moth (LBAM) eggs parasitised by *Trichogramma carverae*. In each replication approximately 20 host eggs were supplied to approximately 100 adult *T. carverae*.

	Treatment Mean				
Variate	CM	LBAM	F Prob	SEm	LSD (5%)
% Eggs parasitized	83.6	85.0	0.627	2.05	5.86
% Un-emerged and dead *T. carverae*	41.4	46.9	0.225	3.16	9.03

In the control samples where codling moth and light brown apple moth eggs were not exposed to *T. carverae*, the number of larvae that emerged from light brown apple moth eggs (mean 90.5%) was significantly higher (<0.001) than codling moth larval emergence (mean 69.7%) (Table 2). The number of viable eggs produced by light brown apple moth was also significantly higher (<0.001) than was produced by codling moth (Table 2).

Table 2. Percentage larvae emerged from codling moth (CM) and light brown apple moth (LBAM) eggs used as controls. Percent viable CM and LBAM eggs counted when eggs reached the black head stage. In each replication approximately 20 CM or LBAM eggs were used.

	Treatment Mean				
Variate	CM	LBAM	F Prob	SEm	LSD (5%)
% Larvae emerged	69.7	90.5	<0.001	1.75	5.51
% Viable eggs	69.8	91.2	<0.001	1.97	8.07

Orchard assessments of resident trichogrammatid species (Hymenoptera: Trichogrammatidae)

a) Attracting resident trichogrammatid species using sentinel light brown apple moth eggs and yellow sticky traps

Sentinel LBAM eggs deployed during both 2021-22 and 2022-23 production seasons did not catch any resident Trichogrammatidae specimens. Only one incident of parasitism of sentinel LBAM eggs occurred, and this was identified as a species from the hymenopteran family Eulophidae.

Yellow sticky traps, deployed monthly in the tree line of the pear orchard, caught approximately 70 specimens from the family Trichogrammatidae from the period November 2021 to March 2022 in the Tatura experimental pear orchard. These were unable to be identified by genetic analyses, probably due to the degradation of DNA.

b) Suction sampling for local Trichogrammatidae species identification

Three species of Trichogrammatidae were identified from 12 Trichogrammatidae specimens collected using suction sampling from vegetation around the pear orchard (and an adjacent almond block) at Agriculture Victoria's SmartFarm at Tatura between November 2022 and March 2023. Genetic sequencing (Figure 1) identified one species as *Trichogrammatoidea cryptophlebiae* (Hymenoptera; Trichogrammatidae), and the other two as unidentified species that are closely related on the phylogenetic tree to *Trichogramma carverae* and *Trichogramma pretiosum* (Figure 1).

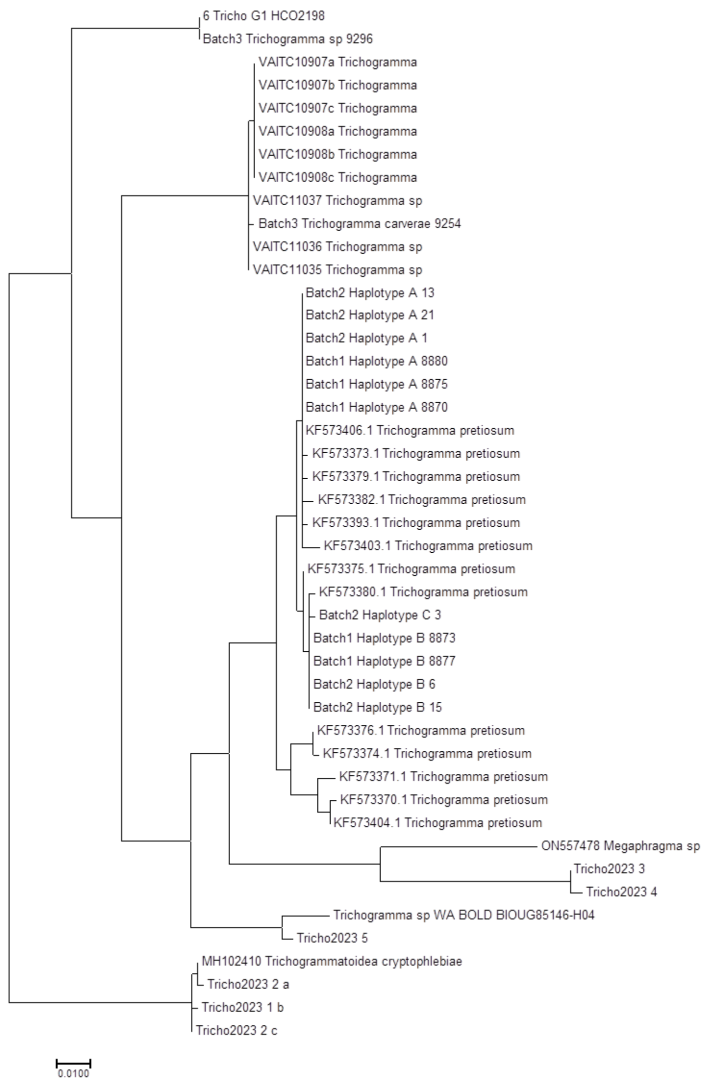

Figure 1. Dendrogram showing specimens suction-sampled from the Tatura experimental pear orchard (suctioned specimens are labelled "Tricho2023 #") and the closest genetic matches available from the BOLD and GenBank databases.

Discussion

This study confirmed that codling moth is a suitable host for *T. carverae* under laboratory conditions. Indeed, percent parasitism of codling moth eggs and those of LBAM, a known host, were not statistically different. Furthermore, the number of emerged codling moth or light brown apple moth larvae from eggs exposed to *T. carverae* was almost zero. *Trichogramma* are known to use egg contents as a food source as well as for parasitism, hence, a combination of parasitism and egg feeding may have contributed to the very low larval emergence from both host species.

The results indicate that *T. carverae* has considerable potential for control of codling moth in orchards situations, and that further ecological studies are warranted. For example, the survival and performance of parasitoids is known generally to benefit from availability of nectar and/or pollen. Fecundity and greenhouse survival of *T. carverae* was enhanced in the presence of flowering *Lobularia maritima* which can also be used as a selective food plant and weed suppressant under certain crops (Begum *et al.*, 2006). The impact of flowering ground cover vegetation on survival, performance, and biodiversity of biocontrol agents in orchards is important in an Integrated Pest Management (IPM) framework. Provision of suitable nectar and protein sources in orchards may improve survival of not only *Trichogramma* (Shearer & Atanassov, 2004; Gurr & Nicol, 2000) but also *Mastrus ridens* and generalist predators such as predatory beetles, hover flies, lacewings, and predatory mites, and enhance pollination by bees and other beneficial insects (Ratnadass *et al*., 2012).

Using DNA barcoding tools, we discovered previously unrecorded diversity amongst the *Trichogramma* taxa occupying the experimental pear orchard, including the parasitoid *Trichogramma (Trichogrammatoidea) cryptophlebiae*. To our knowledge, *T. cryptophlebiae* has not been recorded in Victoria. *Trichogramma cryptophlebiae* are minute wasps that parasitise the eggs of tortricid moths and are sold commercially for the biocontrol of macadamia nutborer, *Cryptophlebia ombrodelta*. This parasitoid has been shown to parasitise codling moth in laboratory experiments (Kaspi et. al 2019) but its impact in Australian apple and pear orchards is not known. The contribution of *T. cryptophlebiae* to general pest control within apple and pear orchards, and possible synergistic relationships with the other apple and pear orchard *Trichogramma* species (*T. pretiosum* and *T. carverae*), requires further investigation.

We also detected a eulophid parasitoid using sentinel egg cards in the pear orchard. Eulophidae is one of the largest chalcidoid families, and their host range is extremely diverse. They are considered one of the most important chalcidoid families from a biological control perspective. Many Eulophid species are internal parasitoids of concealed larvae, for example in mines, stems, rolled leaves or other places. These findings highlight the importance of understanding the role of existing parasitoids in apple and pear orchards and how habitat manipulation and IPM can support their populations.

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Appendix 3

Technical Report: *Mastrus ridens* importation, field release and assessment

AP19002 Strengthening cultural and biological management of pests and diseases in apple & pear orchards

July 2023

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VICTORIA State Government | Energy, Environment and Climate Action

AGRICULTURE VICTORIA

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Acknowledgment

We acknowledge and respect Victorian Traditional Owners as the original custodians of Victoria's land and waters, their unique ability to care for Country and deep spiritual connection to it. We honour Elders past and present whose knowledge and wisdom has ensured the continuation of culture and traditional practices.

We are committed to genuinely partner, and meaningfully engage, with Victoria's Traditional Owners and Aboriginal communities to support the protection of Country, the maintenance of spiritual and cultural practices and their broader aspirations in the 21st century and beyond

Contents

Introduction

Classical biological control uses highly specialised natural enemies, such as certain parasitoids, to control pests. The introduction of *Mastrus ridens* for the control of codling moth in Australia is an example of classical biological control. *Mastrus ridens* is a host-specific parasitoid of codling moth that is native to parts of central Asia. The parasitoid was originally collected from Kazakhstan in the 1990s and has been introduced to several countries to control codling moth, including the USA, Argentina, Chile, and New Zealand (Devotto et al., 2010; Sandanayaka et al., 2011). *Mastrus ridens* was imported into Australian quarantine as part of a classical biological control program for codling moth and approved for release in Australian orchards in 2013 (Lefoe et al. 2013).

Establishing a biocontrol agent in a new country, and demonstrating its impact, are challenging and critically important components of any classical biological control program. *Mastrus ridens* has been shown to be an efficient biocontrol agent, using codling moth aggregation pheromones to locate host larvae beneath the bark. *Mastrus ridens* females then deposit their eggs and the emerging parasitoid feeds on its host and eventually kills it. Field releases of *M. ridens* commenced in Australia in 2014, and more than 280,000 *M. ridens* were released in orchards in Victoria, New South Wales, Queensland, Tasmania and South Australia, up to 2020. Releases of *M. ridens* in Australian orchards have aimed to optimise both the number of release sites and number of individual parasitoids released at each site. This approach maximises the likelihood of establishing permanent populations of *M. ridens* at multiple locations, as is the case in other countries where the parasitoid has been introduced.

Subsequent monitoring of *M. ridens* release sites showed that codling moth numbers declined, sometimes dramatically, following release of the parasitoid in Australian orchards. However, permanent establishment of *M. ridens* has not been detected. One possible explanation for the lack of detection in the field is that *M. ridens* has not established in Australia. There is now evidence from overseas studies that genetic bottlenecks, combined with many years of rearing in a lab, may have reduced the insect's ability to establish viable populations in certain contexts (see Appendix 4). The aim of this study is to:

1. Monitor previous *Mastrus ridens* release sites in Victoria and Tasmania for agent establishment,
2. Re-import *Mastrus ridens* from a more genetically diverse population,
3. Pending approval to release insects from quarantine, conduct two releases of *M. ridens* from the newly imported population.

Materials and method

Monitoring past *Mastrus ridens* releases

Two orchards where *M. ridens* were previously released were selected for monitoring. The orchards were in Merrigum, Victoria, where 50,000 *M. ridens* were released in 2014, and the Huon Valley, Tasmania, where 32,000 *M. ridens* were released in 2017 (Williams, 2019).

Monitoring at the orchards was conducted in autumn 2021 and 2022 using the two methods described by Williams (2019), specifically (1) sentinel corrugated cardboard rolls containing non-parasitized diapausing codling moth larvae from the culture at the Tatura SmartFarm, and (2) cardboard trunk bands (Charles et al., 2013) deployed in autumn to capture wild codling moth larvae seeking cocooning sites, which would then attract *M. ridens*.

Re-importing *Mastrus ridens* from Chile

Permits for the re-importation *M. ridens* were obtained from Australian government regulatory authorities. The Pontifical Catholic University of Chile (PCUC) was sub-contracted to rear and ship *M. ridens* to the Agriculture Victoria insect quarantine laboratory because researchers at PCUC had re-collected *M. ridens* from its native range in central Asia and had undertaken genetic studies (microsatellites) on all existing PCUC colonies to assess their diversity and mixed several *Mastrus* lines to maximise culture diversity and overcome inbreeding.

Conducting new *Mastrus ridens* releases

Following approval of release from quarantine, *M. ridens* were transferred to the Agriculture Victoria Tatura SmartFarm for mass-rearing and orchard release. Rearing and release methods for *M. ridens* are described in Williams (2019).

Initially two orchards were prioritised for releases using criteria such as high codling moth populations, and no or minimal use of insecticides for at least three growing seasons. Additional releases were conducted as *M. ridens* culture numbers increased and as suitable orchards became available.

Results

Monitoring past *Mastrus ridens* releases

Cardboard bands deployed in 2021 and 2022 in the two orchards, using both monitoring methods, were destroyed by snails or failed to recover *M. ridens*.

Re-importing *Mastrus ridens* from Chile

A new *M. ridens* culture was imported from the Pontifical Catholic University of Chile on 13 May 2022 and maintained in quarantine at Agriculture Victoria's insect quarantine laboratory for a complete generation to ensure freedom from contaminants such as parasites and pathogens (Figure 1). Approval to release the culture from quarantine was granted on 23 June 2022.

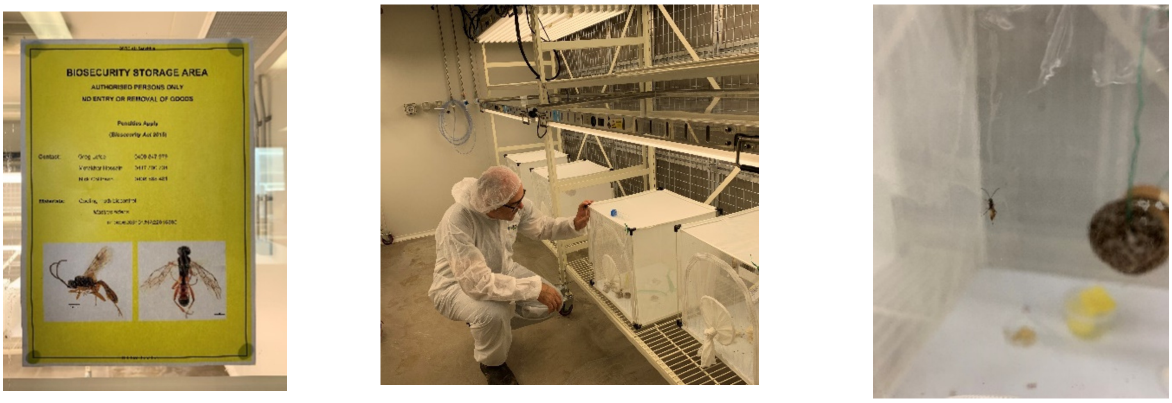

Figure 1. *Mastrus ridens* culture, imported from Chile, undergoing mandatory quarantine at Agriculture Victoria's AgriBio insect quarantine laboratory, Melbourne.

Conducting new *Mastrus ridens* releases

Field releases of *M. ridens* were conducted in orchards with existing codling moth populations in four states (Table 1, Figure 2).

Table 1. *Mastrus ridens* releases in Australian apple orchards, 2022-2023

Date	Year	*Mastrus ridens* strain[A]	Number released	Site	State	Latitude	Longitude

17 May	2022	NZ	2000	Merrigum	VIC	-36.38346	145.13360
15 June	2022	NZ	<10000[B]	Huon Valley	TAS	-43.02456,	146.98888
6 Sep.	2022	Chile	5000	Merrigum	VIC	-36.38346	145.13360
1 Dec.	2022	Chile	1900	Batlow 1	NSW	-35.480856	148.122136
1 Dec.	2022	Chile	800	Batlow 2	NSW	-35.51085	148.129481
24 April	2023	Chile	1850	Orange	NSW	-33.28090	149.01739
24 May	2023	Chile	1000	Huon Valley	TAS	-43.02456,	146.98888
30 May	2023	Chile	1000	Lenswood	SA	-34.94112,	138.81412

A. Strain refers to the source of the original importation to Australia; either New Zealand (NZ) or Chile.
B. Sufficient parasitized codling moth larvae were shipped to Tasmania for a release of up to 10,000 *M. ridens*, however a small number of emerged *M. ridens* were used in a laboratory experiment at the University of Tasmania.

Figure 2. Releasing *Mastrus ridens* in modified traps at Merrigum, Victoria, 17 May 2022.

Discussion

Codling moth bands deployed in two previous release sites, in Victoria and Tasmania, did not recover *M. ridens*. These were sites where the original (NZ strain) of *M. ridens* was released (in 2014 and 2017 respectively). To date, there is no evidence that the NZ strain has established permanent populations at any Australian release site.

In total we conducted eight new releases (six more than contracted) of the codling moth parasitoid *M. ridens* in Victoria (2 releases), Tasmania (2 releases), NSW (3 releases) and South Australia (1 release). Of these, six releases were of the newly imported *M. ridens* “Chile” strain. Releases of the newly imported Chile strain of *M. ridens* were all conducted in the 2022/23 production season; hence it is too soon to conduct impact assessments for these releases. Follow up monitoring commencing 2024 is recommended for these most recent releases.

Acknowledgment: Neil Penfold, Sudath Ekanayake and Joanne Dawson provided technical support for insect rearing. Tanya Zaviezo (Pontifical Catholic University of Chile) reared and shipped *M. ridens* and David Perovic (NSW DPI) provided valuable assistance transporting the shipment to Australia under quarantine. Project Community of Practice members and apple and pear growers in four states helped to select orchards suitable for *M. ridens* and conducted and/or hosted *M. ridens* releases.

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Appendix 5a

Technical Report:

Potential benefits and adoptability of *Mastrus ridens* for biological control of codling moth

AP19002 Strengthening cultural and biological management of pests and diseases in apple & pear orchards

July 2023

Greg Lefoe, Kerry Stott, David Williams, and Raelene Kwong

Energy, Environment and Climate Action

External Project Code Reference	AP19002
RCT No.	6471
Author	Greg Lefoe

Acknowledgment

We acknowledge and respect Victorian Traditional Owners as the original custodians of Victoria's land and waters, their unique ability to care for Country and deep spiritual connection to it. We honour Elders past and present whose knowledge and wisdom has ensured the continuation of culture and traditional practices.

We are committed to genuinely partner, and meaningfully engage, with Victoria's Traditional Owners and Aboriginal communities to support the protection of Country, the maintenance of spiritual and cultural practices and their broader aspirations in the 21st century and beyond

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Executive Summary

There remains considerable uncertainty surrounding the establishment, spread and efficacy of the codling moth parasitoid *Mastrus ridens* in Australia, and the potential for its broader adoption and commercialization. Given this uncertainty, and the impact of codling moth control on all other orchard integrated pest management (IPM) programs, we developed a model that provides industry decision-makers (growers and public and private sector investors, including funding agencies and commercial biocontrol agent producers) with the tools and resources they need to: (1) assess appropriate classical and/or augmentative biological control strategies, and (2) compare the costs and benefits of a more ecologically-benign IPM approach to existing, pesticide-centric IPM programs.

Based on preliminary scenario analyses using a prototype discounted cash flow model, we found that biological control of codling moth with *M. ridens* is a worthwhile investment, especially if parasitoid populations prove to be sustainable without repeated releases (Benefit Cost Ratio of 5.5:1). If classical biological control is broadly successful, then commercial production and sale of *M. ridens* would be unnecessary. The recent re-importation and release of an improved *M. ridens* population from Chile is an important step in maximising the chances of widespread establishment. Current research effort is therefore directed at implementing classical biological control of codling moth with *M. ridens*, and this effort is warranted based on our findings.

However, there is still uncertainty about the likelihood of establishing viable populations of *M. ridens* in all situations where codling moth occurs. Another important finding of our study is that, even under augmentative (i.e., commercial) biological control scenarios, the use of *M. ridens* is profitable (Benefit Cost Ratio of 2.7:1) when compared to pesticide-centric IPM approaches.

The model is a valuable tool for planning future codling moth management priorities. It is recommended that the model and scenario analyses be further developed and published in an appropriate peer-reviewed journal.

Figure 1. ***Mastrus ridens*** **female produced at Agriculture Victoria's Tatura SmartFarm.**

Introduction

Project Objectives

As part of the project AP19002 *Strengthening cultural and biological management of pests and diseases in apple and pear orchards* Hort Innovation requested that Agriculture Victoria investigate options to produce and distribute the codling moth parasitoid *Mastrus ridens*, specifically:

Output 15. A commercialisation plan for production and sale of *Mastrus ridens.*

However, there remains considerable uncertainty surrounding the establishment, spread and efficacy of *M. ridens* in Australia and the potential for its broader adoption and commercialisation. Given this uncertainty, and the impact of codling moth control on all other orchard integrated pest management (IPM) programs, we also address the following:

Output 11. A report of the benefit-cost of implementing IPM and recommendations for future research to fill knowledge gaps.

In doing so, we aim to provide industry decision-makers (growers and public and private sector investors, including funding agencies and commercial biocontrol agent producers) with the tools and resources they need to: (1) assess appropriate classical and/or augmentative biological control strategies, and (2) compare the costs and benefits of a more ecologically-benign IPM approach to existing, pesticide-centric IPM programs.

Background

Codling moth *Cydia pomonella* is the key pest of apples and pears in most pome fruit growing regions of Australia (except Western Australia) and, left uncontrolled, can damage up to 100% of the fruit crop. Codling moth management is achieved through combinations of orchard hygiene, monitoring, insecticide application (synthetic insecticides and granulosis virus), mating disruption, and biological controls such as egg parasitoids and predators. However, these programs often rely on multiple applications of synthetic insecticides to maintain damage at acceptable levels, resulting in control programs that are largely pesticide-centric. Management programs that rely on synthetic pesticides can cause secondary pest outbreaks through direct effects on biological control agents, and by creating an orchard environment that is hostile to beneficial organisms.

Mastrus ridens (**Error! Reference source not found.***)* is an important biological control of codling moth in many parts of the world (Charles et al., 2019; Mills, 2005), and has potential for the control of codling moth in Australia. *Mastrus ridens* can provide area-wide management of codling moth through reductions in: (i) overwintering codling moth populations, (ii) codling moth populations in organic orchards, and (iii) infestations on host trees outside sprayed orchards. Between 2014 and 2018, more than 280,000 *M. ridens* individuals were released in Victoria, NSW, Queensland, South Australia and Tasmania (Williams, 2019). Despite evidence of control at release sites (infested orchards), follow up monitoring did not detect permanent field populations of *M. ridens*. It is not yet known whether *M. ridens* failed to establish viable populations in Australia, or whether it is present but at levels that are too low to detect.

To assess the potential for biological control of codling moth, important factors to consider include the likelihood of establishing permanent *M. ridens* populations in Australia, the necessity and feasibility of commercial rearing and augmentative releases of *M. ridens*, and the uptake or adoption of *M. ridens* as part of IPM. In this context, an outcome of successful adoption of *M. ridens* is the transition from existing conventional control programs or pesticide-centric IPM, to ecologically-benign IPM that is demonstrably profitable (Kogan and Bajwa, 1999).

Approaches to codling moth management

Current management programs for codling moth aim to reduce pest damage to less than 1% of fruit (Williams and Villalta, 2021). Monitoring of orchards where *M. ridens* was released found that codling moth damage was reduced to similarly low levels (as low as 0.01% damage in some cases), but damage rebounded after two years (David Williams, pers comm.). Therefore, while *M. ridens* could achieve the required levels of control, there was doubt about the long-term efficacy of a single release of *M. ridens*.

Improving *Mastrus ridens* establishment in Australia

Overseas researchers studied the genetic diversity of different populations of *M. ridens* distributed around the world. They found that *M. ridens* is prone to inbreeding in laboratory cultures, and inbreeding could impede field establishment (Retamal et al., 2016; Zaviezo et al., 2017; Zaviezo et al., 2021). Inbreeding could therefore be an important factor in the possible failure to establish *M. ridens* from previous releases. Long term establishment of an introduced species such as *M. ridens* relies on sufficient genetic variability to enable adaptation to the new environment. The original *M. ridens* colony introduced to Australia was sourced via New Zealand from a colony in Argentina, which in turn was derived from insects imported into California over 20 years ago. A shift in sex ratio from female-biased in the original Californian colony (Bezemer and Mills, 2003) to male-biased in the NZ colony (Sandanayaka et al., 2011) has been demonstrated, together with a loss of genetic diversity over time in the laboratory colonies, with the NZ colony having the lowest diversity (Retamal et al., 2016). Inbreeding of *M. ridens* results in shorter-lived females, lower production of daughters, higher proportion of males and higher proportion of diploid males (Zaviezo et al., 2017) but it is relatively easy to increase genetic diversity by crossing a small number of wild-collected females with males from a low diversity colony (Retamal et al., 2016). Maintaining greater genetic diversity in the Australian culture of *M. ridens* by accessing females from more diverse colonies may lead to better performance of the laboratory culture and improved chances of successful establishment in the field. In Chile, *M. ridens* underwent (1) genetic studies (microsatellites) on all existing Chilean colonies to assess their diversity, and (2) mixed several Chilean Mastrus lines to maximise culture diversity and overcome inbreeding.

As part of the PIPS3 project AP19002 *Strengthening cultural and biological management of pests and diseases in apple and pear orchards*, a new *M. ridens* colony was imported from Chile and is now undergoing limited field release in Australia. The recent reimportation of *M. ridens* to Australia aims to improve the field fitness of the agent and its establishment success (Figures 2 and 3). The PIPS3 project is also testing a chemical lure for *M. ridens* to improve field detection of the agent and is trialling flowering cover crops that provide food and shelter to natural enemies such as *M. ridens*. The multi-pronged approach of importing a new *M. ridens* culture for rearing and release, and improved methods of supporting and detecting the agent in the field, will improve the chances of: (1) establishing *M. ridens* as a classical biological control agent in Australia, at least in some situations, and (2) demonstrating establishment, spread and impact on target pest populations.

Figure 2. Imported population of *Mastrus ridens* held in Australian quarantine.

Figure 3. Releasing *Mastrus ridens* in a commercial orchard.

Biological control options

Use of an improved population of *M. ridens* as part of IPM could substantially reduce pesticide use in pome fruit orchards. The potential benefits and costs of *M. ridens,* compared to current management practices, will depend on its efficacy and on the strategy adopted for *M. ridens*, which could be classical biological control, augmentative biological control, or a combination of the two (Figure 4).

Classical biological control

The importation of specialised natural enemies of a pest, and their release into areas where the biological control agent can establish permanent populations, is known as **classical biological control**. The aim of classical biological control is to exert sustained control on the pest for many years, without the need for further releases (van Lenteren, 2012). Successful classical biological control programs are the result of many years of intensive research to identify suitable agents from the pest's native range, assess the risk to non-target species in the area of introduction, undertake widespread releases to maximise the likelihood of establishment, and monitor and assess agent establishment, spread, and impact.

New agents for classical biological control can only be released once risk analysis has demonstrated, to the satisfaction of regulatory authorities, that the agent poses a negligible or very low risk to non-target species (Department of Agriculture and Water Resources, n.d.). The Australian risk assessment for *M. ridens* commenced in 2009 and benefitted from earlier overseas research. *Mastrus ridens* was approved for release in Australia in 2013, with the first releases occurring the following year (Aldred, 2013; Lefoe et al., 2013; Williams, 2019).

In most countries where *M. ridens* has been introduced, the parasitoid has behaved as a classical biological control agent by establishing permanent field populations that have controlled the pest in subsequent years (Retamal et al., 2016; van Lenteren, 2012). Commercial production and sale of the parasitoid has therefore not been necessary or feasible because, once released, classical biological control agents such as *M. ridens* establish and spread across the landscape, providing a non-excludable public good (Victorian Government, 2010).

Augmentative biological control

Commercial production and sale of biological control agents typically involves mass-rearing and (usually repeated) release of large of numbers of agents for immediate or short-term control (van Lenteren, 2012). This commercial approach is a feature of **augmentative biological control**. Begum et al. (2017) reviewed the commercial biological control industry in Australia. They identified delays and costs incurred in testing and importing exotic natural enemies as major barriers to Australian companies sourcing new agents for augmentative biological control.

Successful classical biological control impedes adoption of augmentative biological control because the benefits of classical biological control are not restricted to those who pay (Victorian Government, 2010). For this reason, biological control agent species are generally either classical or augmentative, but rarely both (although exceptions can occur, for example biological control of silverleaf whitefly with *Eretmocerus hayati* (CSIRO, 2021; De Barro, 2005)). Whether commercial production and sale of *M. ridens* is a necessary or commercially feasible activity in Australia will therefore depend on the success of efforts to establish permanent field populations of the agent, its impact on codling moth populations in different situations, and other factors such as production costs and adoption by growers.

Augmentative biological control is technically feasible in Australia because methods for rearing both *M. ridens* and its host are documented and available (Williams, 2019). If it was determined that augmentative biological control was feasible and necessary, then it is possible one or more commercial producers could access existing cultures (if available), or import new cultures, of *M. ridens*. While importing new agents is usually cost-prohibitive for Australian companies, the process would be greatly simplified for this agent compared to many other potential biological control agents. For *M. ridens*, the costs of biosecurity import risk assessment and associated research have already been met. Therefore, future importations could be streamlined as they would only require Australian commercial producers to:

(1) obtain import permits from the Department of Agriculture, Fisheries and Forestry (DAFF),

(2) source a *M. ridens* culture from a certified overseas laboratory,

(3) rear the imported culture through one generation in an Approved Arrangement (insect quarantine) laboratory, and

(4) obtain DAFF approval for release from quarantine.

However, augmentative biological control of *M. ridens* has not been implemented anywhere in the world. Recommendations for growers that would allow them to implement augmentative biological control as part of IPM would need to be developed.

Combined classical and augmentative biological control

A combination of classical biological control and augmentative biological control may be appropriate in some situations. For example, *M. ridens* may establish in some geographic areas but not others or may establish on unmanaged or neglected trees but not in orchards. In this scenario, commercial producers would need to determine whether the augmentative biological control market was large enough to be profitable.

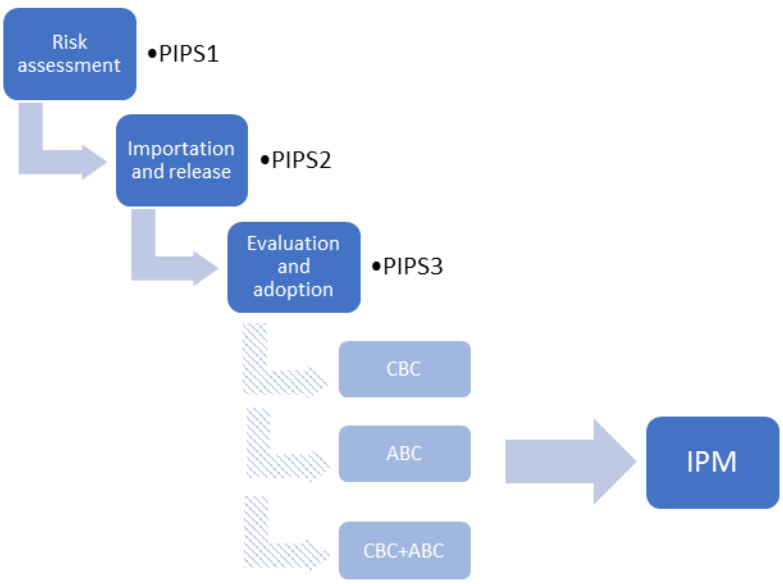

Figure 4. Process for implementing biological control of codling moth with the parasitoid *Mastrus ridens*, as part of an ecologically-benign integrated pest management (IPM) program. Hatched arrows represent potential strategies under consideration (CBC)

Current practice

Management programs that aim for 1% fruit damage or less typically rely on multiple applications of synthetic insecticides, with or without mating disruption using Isomate C. In our preliminary analyses we have assumed the following current practice management scenarios:

1. One application of Isomate C plus one application of Novaluron 100 g/L + Acetamiprid 80 g/L (e.g., Cormoran®).
2. One application of Novaluron 100 g/L + Acetamiprid 80 g/L (e.g., Cormoran®) plus three applications of Tetraniliprole 200 g/L (e.g., Vayego®).
3. One application of Isomate C plus one application of Novaluron 100 g/L + Acetamiprid 80 g/L (e.g., Cormoran®) plus three applications of Tetraniliprole 200 g/L (e.g., Vayego®).

Modelling IPM scenarios

Given continued uncertainty of the likelihood of *M. ridens* establishment, we developed a tool to guide decision making by investors and research agencies (spreadsheet available on request). The prototype Benefit Cost Analysis (BCA) tool assesses the production and release of M. *ridens* in apple and pear orchards under different biological control/IPM scenarios. We define biological control of codling moth as either:

(a) classical biocontrol involving once-off releases with wasps becoming established and providing ongoing suppression of CM populations, or

(b) augmentative biological control, whereby wasp populations fail to establish or "crash" necessitating periodic re-releases on adopting orchards.

The tool is a deterministic discounted cash flow model built in Excel on orthodox farm management economic analysis principles (Malcolm *et al.* 2005). It can be used to quantify changes in aggregate, industry-level, net benefits. Changes in net benefits are quantified in real $A2021/22 dollars using a real 5% discount rate (7% nominal, adjusted for 3% inflation).

For simplicity, polar demand and supply elasticities are assumed (Alston *et al.* 1995, p 55). That means the extra production (e.g., from improved control) was valued at a single market price and the value of any inputs saved (cost reduction) was calculated at the current level of production. Furthermore, any regional and international price effects that are due to the change in management of codling moth, as well as the distributional effects, were ignored. Aggregate industry apple and pear production was set at 405,000t, and unit values set at $A1,880/t (Hort Innovation 2022).

Economic performance metrics used are the Net Present Value (NPV) and the Benefit-Cost Ratio (BCR):

- The NPV is the difference between the present values (PV) of the stream of future benefits (i.e., reduced grower costs plus reduced production losses) and the PV of the stream of future costs (i.e., *M. ridens* production costs).
- The BCR is the PV benefits divided by the PV costs.

The tool can also be used to calculate a break-even charge for *M. ridens*, should they be sold commercially to growers.

Adoption of *M. ridens* in preference to synthetic pesticides was predicted using CSIRO's ADOPT – the "Adoption and Diffusion Outcome Prediction Tool" (Kuehne *et al.* 2017). Peak adoption was estimated at 30% of the target population, and time to peak adoption was estimated at 13 years. The major determinant of peak adoption was the profit benefit to growers in the years when *M. ridens* was released. A 'small' profit advantage was assumed; a moderate profit advantage could increase adoption substantially to 57%. The time to peak adoption was most sensitive to the proportion of the target population that would need to develop substantial new skills and knowledge. It was assumed that the majority would; but if about half would, then the time to peak adoption would decrease by one year to 12 years. Based on these findings, the time horizon for the analysis was set to 15 years.

Technical assumptions used in the tool were based on the scientific literature, where available, and the expert opinion of experienced research scientists working on IPDM and biological control projects within Agriculture Victoria (David Williams, Greg Lefoe and Raelene Kwong). Key amongst these are damages without and with *M. ridens*.

Without *M. ridens*, yield losses attributable to codling moth are assumed to be kept at the economic threshold of about 1% using synthetic pesticides (see Current practice). At label rates and list prices, on-farm management costs without *M. ridens* are estimated at about $895/ha (including machinery and labour). With *M. ridens*, production losses are expected to be much reduced, and are assumed to fall to just 0.01% (David Williams, pers comm). The cost of control is also much reduced, falling to about $450/ha to cover the associated cost of pheromone-mediated mating disruption using Isomate C.

At current levels of codling moth infestation (1%) and assuming 13 codling moth larvae are parasitised by each female *M. ridens* (Sandanayaka *et al* 2011), the number *M. ridens* required amounts to about 266 parasitoids per hectare (Table 1). This number would be released on a once-off basis as adoption grew amongst the target population, should *M. ridens* be sustainable without augmentation. Alternatively, should *M. ridens* populations “crash” and fail to recover, then it is assumed the parasitoid must be re-released every three years.

Table 1. *Mastrus ridens* parasitoids required to maintain damages at 1% the value of production (no. per hectare).

Crop	Quantity (t)	Yield (t/ha)	Average fruit weight (g)	Fruit per ha (no.)	Infested fruit per ha (no.)	*M. ridens* required per ha (no. males and females)
Apples	280,273	30	195	153,312	1,533	236
Pears	124,338	39	180	217,564	2,176	335
Sum/Average	404,611					266[1]

[1]Weighted average based on production volumes for apples and pears.

Agriculture Victoria production costs for *M. ridens* are about $168,000 p.a. This total includes staff costs and overheads of approximately $138,000, and operating costs (including releases) of about $30,000. The total covers rearing and maintenance of the parasitoid and the codling moth host in separate cultures, as well as annual releases, but excludes ancillary costs associated with research, extension, and related activities.

Agriculture Victoria currently has capacity to release 60,000 parasitoids per year, at unit production costs are about $2.80 per parasitoid released. Under the classical biological control scenario, this capacity is sufficient for releases over an area of 1,369 ha by the end of the 15-year planning horizon. In contrast, under the augmentative release scenario, capacity is sufficient for a much smaller area of 685 ha. Therefore, economic outcomes depend on persistence of *M. ridens* in the field, and the size of the assumed reduction in production losses (Table 2, Figure 5).

Table 2. Summary results of the BCA evaluated over 15 years with a 5% real discount rate.

Scenario	Present Value (PV) of AVR's rearing costs	Present Value (PV) of changed on-farm management costs	Present Value (PV) of changed on-farm gross income	Net Present Value	Benefit/ Cost Ratio	Break-even parasitoid price for growers
Classical biological control						
1. Cost savings to growers, production losses maintained at 1%	-$1.754m	$4.079m	0	$2.323m	2.3:1	$14.65/ parasitoid
2. Cost savings to growers and production losses fall to 0.01%	-$1.754m	$4.079m	$5.495m	$7.818m	5.5:1	$34.38/ parasitoid
Augmentative biological control						
3. Cost savings to growers, production losses maintained at 1%	-$1.754m	$2.039m	0	$0.285m	1.2:1	$4.60/ parasitoid
4. Cost savings to growers and production losses fall to 0.01%	-$1.754m	$2.039m	$2.747m	$3.032m	2.7:1	$10.80/ parasitoid

With classical biological control and a substantial reduction in production losses to 0.01% (Table 2, Scenario 2), the NPV (i.e., addition to growers' wealth), evaluated over a 15-year time horizon using a real discount rate of 5%, was $7.8m. The BCR was 5.5:1. With the stated assumptions, growers' break-even price would be a very substantial $35/parasitoid.

In contrast, with augmentative biological control and a similar reduction in production losses (Table 2, Scenario 4), the NPV was $3.0m and the BCR was 2.7:1. The break-even price to growers would fall to $10/parasitoid.

The tool considers the most tangible benefits arising from a reduction in grower's control costs and fruit losses. Further developments involve reviewing technical assumptions in light of findings from field trials and embedding uncertainty and risk in the analysis for detailed sensitivity analysis using the Monte Carlo simulation technology of @Risk (Palisade, 2022).

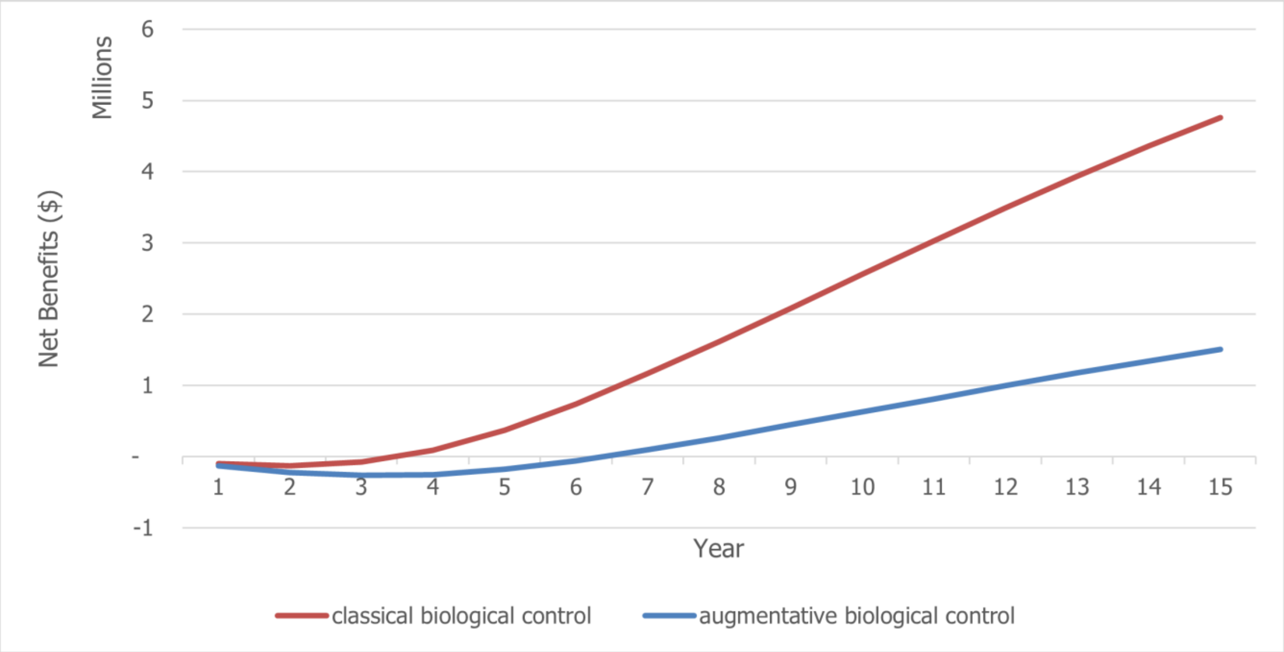

Figure 5. Cumulative annual net benefits for biological control of codling moth with *Mastrus ridens* (present value ($2021/22), 5% discount rate).

Conclusion

Based on preliminary scenario analyses, using a prototype discounted cash flow model, we found that biological control of codling moth with *M. ridens* is a worthwhile investment, especially if parasitoid populations prove to be sustainable without repeated releases (Benefit Cost Ratio of 5.5:1). If classical biological control is broadly successful, then commercial production and sale of *M. ridens* would be unnecessary. The recent re-importation and release of an improved *M. ridens* population from Chile is an important step in maximising the chances of widespread establishment. Current research effort is therefore directed at implementing classical biological control of codling moth with *M. ridens*, and this effort is warranted based on our findings.

However, there is still uncertainty about the likelihood of establishing viable populations of *M. ridens* in all situations where codling moth occurs. Another important finding of our study is that, even under augmentative (i.e., commercial) biological control scenarios, the use of *M. ridens* is clearly profitable (Benefit Cost Ratio of 2.7:1) when compared to pesticide-centric IPM approaches.

The model is a valuable tool for planning future codling moth management priorities. It is recommended that the model and scenario analyses be further developed and published in an appropriate peer-reviewed journal.

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Appendix 6

Technical Report: Communication and Adoption

AP19002 Strengthening cultural and biological management of pests and diseases in apple & pear orchards

July 2023

Mark Hincksman, Emily Crawford

VICTORIA State Government
Energy, Environment and Climate Action
AGRICULTURE VICTORIA

External Project Code Reference	AP19002
RCT No.	6471
Author	Greg Lefoe

Acknowledgment

We acknowledge and respect Victorian Traditional Owners as the original custodians of Victoria's land and waters, their unique ability to care for Country and deep spiritual connection to it. We honour Elders past and present whose knowledge and wisdom has ensured the continuation of culture and traditional practices.

We are committed to genuinely partner, and meaningfully engage, with Victoria's Traditional Owners and Aboriginal communities to support the protection of Country, the maintenance of spiritual and cultural practices and their broader aspirations in the 21st century and beyond

Contents

Introduction

The Integrated Pest & Disease Management Community of Practice (COP) meetings provided opportunity for consultants, service providers, and researchers to share knowledge and learn from each other, with the aim to increase grower confidence and improve the uptake of Integrated Pest & Disease Management (IPDM) by the apple and pear industry.

The COP was supported by the Integrated Pest and Disease Management ExtensionAUS website, built to house IPDM resources, support COP identity and communication and provide opportunities for two-way communication through the "ask an expert" feature available on the website. The platform is a key component of the project, *Strengthening cultural and biological management of pests and diseases in apple and pear orchards* (AP19002) and part of the PIPS 3 program. Agriculture Victoria is the key research provider and working with the University of Tasmania to deliver the project.

IPDM extension role

The Agriculture Victoria Horticulture Services team (HS) were responsible for engagement and practice change within the Apple and Pear IPDM community of practice, part of the *Strengthening cultural and biological management of pests and diseases in apple and pear orchards* (AP19002) project. The objective was to use the learnings from the research and IPDM COP to develop educational materials, tools, and resources to support uptake of IPDM practices by the community and industry. To achieve this the project officer coordinated and facilitated the COP meetings, organised key speakers, managed the ExtensionAUS IPDM website, responded to 'ask an expert' questions and facilitated responses via the COP, posted relevant PIPS3 IPDM material and awareness articles on ExtensionAUS and Facebook, and developed information for publications in the APAL grower magazine, AFG.

Community Of Practice meetings

There were several online meetings held for the community of practice, dependent on the availability of speakers and the community. Although the engagement and extension program was challenged by the restrictions of COVID-19, and reduced the number of online COP meetings, along with restrictions around research outputs, the online meetings allowed for members to participate in 15 events. Table 1 provides a list of topics, the date it was held, and the number of COP participants that attended.

Table 1. List of activities associated with the IPDM Community of Practice.

Date	Topics	Number of participants
9/9/2020	Around the nation update Apple and Pear productivity, irrigation, pests and soils program (PIPS3) – Greg Lefoe	Not available
4/02/21	Around the nation update Speaker postponed to later meeting	10
1/04/21	Around the nation update Classical biological control with a focus on *Mastrus ridens* in Australia – Greg Lefoe	7
6/05/21	Around the nation update Post-harvest control of WAA and nematode control of codling moth – Elizabeth Mace	14
9/7/21	Around the nation update Fruit fly research update- Dr Paul Cunningham	10
5/8/21	Around the nation update Early season earwig numbers as a predictor of issues later in the season - Dr Stephen Quarrell	14

2/9/21	Around the nation update Scab resistance – Dr Andrew Taylor	13
25/10/21	Around the nation update	19
25/11/21	Around the nation update Clear wing tree borer and potential for IPDM - Elizabeth Mace Q&A session with David Williams	15
24/2/22	Around the nation update IPDM and Queensland fruit fly (QFF) – Bronwyn Koll	18
7/4/22	Around the nation update White fly – identification, pest status and control in apple IPDM systems – David Williams	15
19/5/22	Around the nation update Update on *Mastrus ridens* releases and research into improved Mastrus population genetics – Greg Lefoe Seasonal update on European wasps – Greg Lefoe	15
25/8/22	Around the nation update Predatory mites - Dr Hasan Rahmani	9
25/11/22	Around the nation update Project update (AP19002) Strengthening cultural and biological management of pests and diseases in apple and pear orchards – Greg Lefoe	15
2/3/2023	Around the nation update Growfruit crop monitoring app - Michael Crisera Evaluation of the COP, Aimee McCutcheon (Horticulture Services, Agriculture Victoria)	14

An example of a community of practice member presenting information to the community, can be seen in Figure 1.

Figure 1. COP member, Michael Crisera from Fruit Growers Victoria, introduces the Growfruit Crop Monitoring app to the IPDM Community of Practice, March 2023.

COP meeting participant surveys:

Participant satisfaction surveys were conducted for several meetings with the average satisfaction score varying from 8.2 to 9.4 out of 10.

COP Membership increased from 29 to 31, despite several members retiring or moving onto other roles. This increase was due to a couple of member advocating for the community of practice to colleagues and consultants in the industry.

About the Website

The Integrated Pest and Disease Management (IPDM) extensionAus platform (Australian Apple and Pear IPDM) was built to provide practical information and advice to growers and industry to develop skills, knowledge and implement strategies in apple and pear orchards to develop, maintain and improve pest-resilient farming systems.

Key topics on this site are presented as articles, which describe the topic and importantly link to other references, presentations or tools that may be of use to the reader.

Table 2 provides an overview on website data sourced from Google Analytics. The most viewed page was an introduction to IPDM called 'what is integrated pest and disease management?', and data has also been provided on the IPDM manual. This data suggests that the topic is still new to many producers and service providers, and the uptake or behavioural change may be around 1/5 of those learning about the topic highlighted by interest in the IPDM manual, based on views.

Table 2. Website Google analytics

Data sourced from Google Analytics - 1 July 2020 to 30 Jun 2023	Data
Website: https://extensionaus.com.au/ozapplepearipdm/home The average time spent on the page was 2 minutes 26 seconds which suggests users are reading content. Google Analytics has demographic data that indicates that 67% of the website traffic are users in Australia.	53,099 pageviews 36,335 sessions 31,550 Users Organic searches: 25,038 Direct URL: 4,022 Social media: 2,136
Most viewed pages	Page Views
Harlequin bug – Manage Hosts and Hideouts https://extensionaus.com.au/ozapplepearipdm/test-image_-harlequin-bug/	13,966
What is Integrated Pest and Disease Management (IPDM)? https://extensionaus.com.au/ozapplepearipdm/what-is-integrated-pest-management-ipm/	5,552
Brush up on good bugs https://extensionaus.com.au/ozapplepearipdm/brush-up-on-good-bugs/	1,086
Integrated Pest and Disease Manual for Australian Apple and Pears, second edition	Views
An important component of the project was the development of the integrated pest and disease management manual, developed as an interactive PDF downloadable from the website. IPDM Manual: https://extensionaus.com.au/ozapplepearipdm/wp-content/uploads/sites/15/2021/04/2020-final-accepted-version-Apple-and-Pear-IPDM_V3.pdf Content: • Introduction to IPDM • Developing an IPDM plan	1,081 page views since publication in May 2021. 4th most viewed page

• Key pests and diseases, their activity periods, and monitoring methods • Biosecurity and potential incursions of new pests • Integrated weed management • Pesticides and the Australian apple and pear industry • Mating disruption • Pest and disease fact sheet	

3.1 Website resources

Table 3 lists 49 articles published on the ExtensionAus Australian Apple and Pear IPDM website from 1 July 2020 to 30 June 2023. These articles were developed by more than 12 COP members including the project officer and published on the website. This list included 7 case studies on IPDM from around Australia.

Table 3. Information resources published on the ExtensionAus Australian Apple and Pear IPDM website.

Topic	Link	Page views
Earwigs are useful predators in pome fruit orchards	https://extensionaus.com.au/ozapplepearipdm/earwigs-are-useful-predators-in-pome-fruit-orchards/	4
Advances in the biological control of codling moth in Australia	https://extensionaus.com.au/ozapplepearipdm/advances-in-the-biological-control-of-codling-moth-in-australia/	42
Helicoverpa and Loopers	https://extensionaus.com.au/ozapplepearipdm/helicoverpa-and-loopers/	77
Armillaria root rot	https://extensionaus.com.au/ozapplepearipdm/armillaria-root-rot/	66
Bitter Pit	https://extensionaus.com.au/ozapplepearipdm/bitter-pit/	52
Woolly Apple Aphid	https://extensionaus.com.au/ozapplepearipdm/wooly-apple-aphid/	287
Alternaria	https://extensionaus.com.au/ozapplepearipdm/alternaria/	180
Root lesion nematodes	https://extensionaus.com.au/ozapplepearipdm/root-lesion-nematodes/	72
Proactive management for mites	https://extensionaus.com.au/ozapplepearipdm/proactive-management-for-mites/	24
Victorians to be on the lookout for Medfly	https://extensionaus.com.au/ozapplepearipdm/victorians-to-be-on-the-lookout-for-medfly/	27
Thrips	https://extensionaus.com.au/ozapplepearipdm/thrips/	17
Carpophilus beetle in the Goulburn Valley (Vic)	https://extensionaus.com.au/ozapplepearipdm/carpophilus-beetle-in-the-goulburn-valley-vic/	57
Pollination Considerations 2021	https://extensionaus.com.au/ozapplepearipdm/pollination-considerations-2021/	18
Do insecticides make mealybugs worse?	https://extensionaus.com.au/ozapplepearipdm/do-insecticides-make-mealybugs-worse/	48
Prepare hives and help hoverflies	https://extensionaus.com.au/ozapplepearipdm/prepare-hives-and-help-hoverflies/	84

Start planning for mealybug	https://extensionaus.com.au/ozapplepearipdm/start-planning-for-mealybug/	56
Establishing native vegetation in inter-rows	https://extensionaus.com.au/ozapplepearipdm/11106-2/	49
IPDM Manual for Apples and Pears (1081)	https://extensionaus.com.au/ozapplepearipdm/ipdm-manual-for-apples-and-pears/	1081
Post harvest Scab control	https://extensionaus.com.au/ozapplepearipdm/post-harvest-scab-control/	334
Earwig control of WAA	https://extensionaus.com.au/ozapplepearipdm/earwig-control-of-waa/	66
Soil testing to help measure native vegetation success	https://extensionaus.com.au/ozapplepearipdm/soil-testing-to-help-measure-native-vegetation-success/	25
Fruit fly management	https://extensionaus.com.au/ozapplepearipdm/fruit-fly-management/	96
PIPS3: Strengthening Cultural and Biological Management of Pests and Diseases	https://extensionaus.com.au/ozapplepearipdm/pips3-strengthening-cultural-and-biological-management-of-pests-and-diseases/	35
Summer Spot – a few cases being seen in Vic	https://extensionaus.com.au/ozapplepearipdm/summer-spot-a-few-cases-being-seen-in-vic/	9
Latest regulatory changes for ag chemicals	https://extensionaus.com.au/ozapplepearipdm/latest-regulatory-changes-for-ag-chemicals/	31
How to Calculate Cumulative Leaf Infested Days (CLID's)	https://extensionaus.com.au/ozapplepearipdm/cumulative-leaf-infested-days-clids/	249
Mite Management	https://extensionaus.com.au/ozapplepearipdm/mite-management-in-orchards/	109
WA pome and summer fruit spray guide for 2020-21	https://extensionaus.com.au/ozapplepearipdm/wa-pome-and-summerfruit-spray-guide-for-2020-21/	73
What's the ideal time to spray to control LBAM?	https://extensionaus.com.au/ozapplepearipdm/whats-the-ideal-time-to-spray-to-control-lbam/	44
Is Granulosis virus effective in controlling CM?	https://extensionaus.com.au/ozapplepearipdm/is-granulosis-virus-effective-in-controlling-cm/	60
Apple and Pear IPDM Factsheet – Codling Moth	https://extensionaus.com.au/ozapplepearipdm/apple-and-pear-ipdm-factsheet-codling-moth/	89
Apple and Pear IPDM Factsheet – Fruit Flies (495)	https://extensionaus.com.au/ozapplepearipdm/apple-and-pear-ipdm-factsheet-fruit-flies/	495
WATCHOUT in the Orchard	https://extensionaus.com.au/ozapplepearipdm/watchout-in-the-orchard/	16
Have you seen LBAM recently?	https://extensionaus.com.au/ozapplepearipdm/have-you-seen-lbam-recently/	20
Orchard plant protection guide for deciduous fruits in NSW	https://extensionaus.com.au/ozapplepearipdm/orchard-plant-protection-guide-for-deciduous-fruits-in-nsw/	127
Calling all IPDM advisors	https://extensionaus.com.au/ozapplepearipdm/calling-all-ipdm-advisors/	31
New IPDM research project funded	https://extensionaus.com.au/ozapplepearipdm/new-ipdm-research-project-funded/	16

Codling Moth emergence	https://extensionaus.com.au/ozapplepearipdm/codling-moth-emergence/	403
Biofix and spray predictions	https://extensionaus.com.au/ozapplepearipdm/biofix-and-spray-predictions/	372
Apple Powdery Mildew	https://extensionaus.com.au/ozapplepearipdm/apple-powdery-mildew/	394
Apple dimple bug monitoring	https://extensionaus.com.au/ozapplepearipdm/apple-dimple-bug-monitoring/	206
Case Study Update: Kirup WA – July 2020	https://extensionaus.com.au/ozapplepearipdm/case-study-update-kirup-wa-july-2020/	40
Case Study Update: Lenswood SA – July 2020	https://extensionaus.com.au/ozapplepearipdm/case-study-update-lenswood-sa-july-2020/	39
Case Study Update: Adelaide Hills SA – July 2020	https://extensionaus.com.au/ozapplepearipdm/case-study-update-adelaide-hills-sa-march-2019/	12
Case Study Update: Stanthorpe QLD – July 2020	https://extensionaus.com.au/ozapplepearipdm/case-study-update-stanthorpe-qld-july-2020/	40
Case Study Update: Yarra Valley VIC – July 2020	https://extensionaus.com.au/ozapplepearipdm/case-study-update-yarra-valley-vic-july-2020/	44
Case Study Update: Geeveston TAS – July 2020	https://extensionaus.com.au/ozapplepearipdm/case-study-update-geeveston-tas-july-2020/	54
Case Study Update: Batlow NSW – July 2020	https://extensionaus.com.au/ozapplepearipdm/case-study-update-batlow-nsw-july-2020/	40
Apple and Pear IPDM Industry Survey 2020	https://extensionaus.com.au/ozapplepearipdm/apple-and-pear-ipdm-industry-survey-2020/	53
Variable spray threshold for mainland Apple Dimpling Bug	https://extensionaus.com.au/ozapplepearipdm/variable-spray-threshold-for-mainland-apple-dimpling-bug/	403

3.2 Website statistics correlating with events

When an extension event covering IPDM topics was held, user numbers on the IPDM website increased, highlighting topics were of interest to attendees and the value of digital resources in supporting awareness of IPDM. The graph below (Figure 2) provides an example in interest in the topic, seen through Google Analytics data where a visible peak in users access the website correlated to an event. These peaks occurred numerous times after extension events or orchard biocontrol agent releases were held.

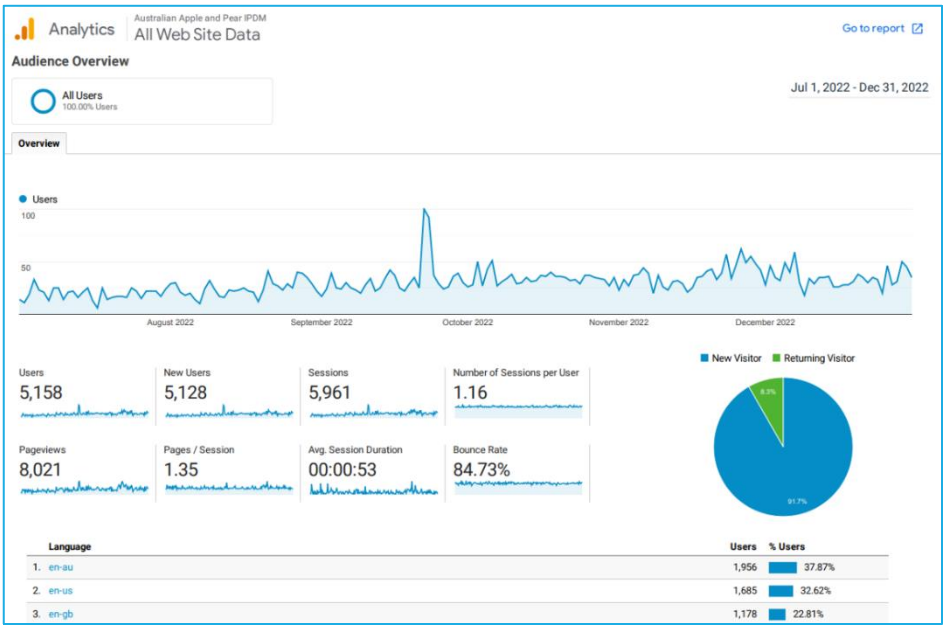

Figure 2. Graph from google analytics highlighting peaks by users interested in IPDM following a presentation at a grower event.

Ask and expert website function, and Facebook as interactive communication tools.

The ‘ask an expert’ function on the ExtensionAus Australian Apple and Pear IPDM website was not considered an effective tool as only 3 comments were posted during the time of the project - 1 request for information, and the other 2 as statements. This function was designed for growers and service providers to ask IPDM questions of experts about a particular issue relating to the topic on the webpage. The project officer and a couple of the COP members added comments to stories as a way to start conversations on a few of these topics. However, there was not much uptake of this function as well as few experts available to answer questions. COP members found that Facebook was a better tool for asking and answering questions. There are 150 members on the OzApplePear IPDM Facebook page (Figure 3), and a few of the COP members have used that platform for highlighting issues and answering questions from growers and other service providers with 47 posts since the project started.

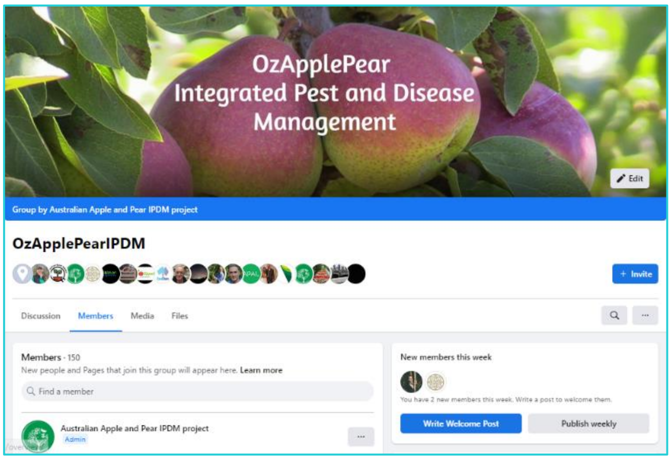

Figure 3. Facebook page (admin page) for OZApplePearIPDM community

3.3 Ensuring resource accessibility.

To ensure all resources on the ExtensionAUS Australian Apple and Pear IPDM website continue to be available to the apple and pear industry at the end of this project, assessment and management of these digital resources is being looked at, whether continue use of the IPDM ExtensionAUS or alternatives to house this information are being considered. As an example, it may be cost effective and a low risk to transfer resources to APAL for their website.

Articles developed for APAL industry magazine and APAL online web publication.

A number of articles, listed in table 4, were developed from the integrated pest and disease management manual for the APAL industry magazine, Australian Fruitgrower Magazines (AFG). The articles referred readers to the IPDM manual located on the ExtensionAUS Australian Apple and Pear IPDM website where they could access and download this onto their devices for future reference. The AFG circulation potentially exposed 970 recipients to these IPDM articles. Figure 4A and 4B show an example of material written for publication in the AFG magazine, Summer 2022 Vol 16 Issue 4.

A

B


IPDM in focus: bitter rot

Bitter rot is often the most serious fruit rot to affect apple orchards in warmer, humid growing conditions.

Identification and impact:

Prevention and management:

Figure 4. A) IPDM in Focus: front cover of magazine containing Bitter Rot IPDM information, B) story in AFG magazine - IPDM in Focus: Bitter Rot, page 40.

Table 4. Articles written for publications in APAL's seasonal Australian Fruitgrower Magazines.

Article	Publication
Conservation biocontrol of pests in pome fruit orchards - is it achievable with native ground cover species?*	Winter 2021
Optimising establishment and impact of the codling moth parasitoid *Mastrus ridens**	Winter 2021
IPDM Community of Practice provides platform for cooperative learning and upskilling	Winter 2021
IPDM in focus: Mite Management	Summer 2021
IPDM in focus: Alternaria	Autumn 2022
IPDM in focus: Woolly Apple Aphid management	Winter 2022
Advances in the biological control of codling moth in Australia*	Spring 2022
IPDM in focus: Helicoverpa and loopers	Spring 2022
IPDM in focus: Bitter Rot	Summer 2022
IPDM in focus: Black spot (apple scab and pear scab)	Autumn 2023
IPDM in focus: pear blossom blast*	Winter 2023

*Stories written by researchers / project team

The AP19002 project team contributed to web articles and videos for the APAL website that were published in the APAL Industry Juice e-newsletter. Table 5 provides a list of articles, links, publication dates and the number of times the pages were viewed. Table 6 provides a list of videos on the APAL YouTube channel that complement many of these articles. Table 7 provides a list of topics on social media such as APAL's Facebook, LinkedIn and Twitter channels that highlight some of these stories, and contain links directing readers to the APAL website.

Table 5: Industry articles published on the APAL website and sent through the Industry Juice e-newsletter (Source: APAL).

Article	Link	Date published	Page views
Strengthening cultural and biological management of pests and diseases in apple and pear orchards	https://apal.org.au/pips3-strengthening-cultural-and-biological-management-of-pests-and-diseases-in-apple-and-pear-orchards/	December 2020	49
Strengthening cultural & biological management of pests & diseases	https://apal.org.au/strengthening-cultural-biological-management-of-pests-diseases/	March 2021	54
Could native species improve your orchard?	https://apal.org.au/could-native-plant-species-improve-your-orchard/	June 2021	76
Making the most of the IPDM manual	https://apal.org.au/apple-and-pear-industry-benefits-from-revised-ipdm-manual/	August 2021	60
AP 19002 project update from Greg Lefoe (APAL 2021 R&D forum)	https://www.youtube.com/watch?v=iZSX7g0LDys	September 2021	16
IPDM monitoring of conservation biocontrol plots – PIPS Update	https://apal.org.au/ipdm-monitoring-of-conservation-bio-control-plots-pips3-update/	January 2022	20
IPDM in focus: Alternaria management	https://apal.org.au/ipdm-in-focus-alternaria-management/	July 2022	140
IPDM in focus: woolly apple aphid management	https://apal.org.au/ipdm-in-focus-woolly-apple-aphid-management/	August 2022	65

Advances in the biological control of coddling moth in Australia	https://apal.org.au/biological-control-of-codling-moth/	May 2022	142
IPDM in focus: Helicoverpa and loopers	https://apal.org.au/ipdm-in-focus-helicoverpa-and-loopers/	November 2022	30
Controlling coddling moth: Mastrus ridens research project	https://www.youtube.com/watch?v=4L_bL6HAWi0	December 2022	89
IPDM in focus: bitter rot	https://apal.org.au/ipdm-in-focus-bitter-rot/	Feb 2022	58
IPDM in focus: black spot (apple scab and pear scab)	https://apal.org.au/ipdm-in-focus-black-spot-apple-scab-and-pear-scab/	May 2022	60

Table 6: Videos published on the APAL YouTube channel (Source: APAL).

Video	Link	Date published	Views
Strengthening Cultural & Biological Management of Pests & Diseases - Apple & Pear Orchards (AP19002)	https://www.youtube.com/watch?v=vsQjJ5Y4G1o	October 2020	388
AP19002- Strengthening Cultural & Biological Management of Pests & Diseases in apple & pear orchards	https://www.youtube.com/watch?v=vsQjJ5Y4G1o	March 2021	319
Native Species in the Orchard - PIPS3 Program project AP19002	https://www.youtube.com/watch?v=kQuisqo61VE	June 2021	378
Using the new IPDM Manual - Emily Crawford	https://www.youtube.com/watch?v=k_AfjjZIhHQ	Aug 2021	129
AP19002 project update (PIPS3 Program) - APAL 2021 R&D Forum September 2021	https://www.youtube.com/watch?v=iZSX7g0LDys	September 2021	148
IPDM Monitoring of Conservation Bio-control Plots – Tatura SmartFarm Experimental Pear Orchard	https://www.youtube.com/watch?v=-GlwpCUp2M8	January 2022	391
Controlling codling moth: Mastrus ridens research project	https://www.youtube.com/watch?v=4L_bL6HAWi0	December 2022	143

Table 7: Social media articles published on the APAL Facebook, LinkedIn and Twitter channels (Source: APAL).

Topic	Date published	Facebook Reach / impressions / engagement	LinkedIn impressions / engagement	Twitter impressions / engagement
IPDM in focus: Alternaria management	July 2022	429 / 432 / 18	N/A	164 / 7
Advances in the biological control of codling moth in Australia	October 2022	235 / 248 / 17	1013 / 21	87 / 6
Controlling codling moth: Mastrus ridens research project	December 2022	465 / 459 / 25	164 / 5	1313 / 33
IPDM in focus: bitter rot	February 2023	458 / 446 / 33	2338 / 49	599 / 18
PIPS Mastrus release and soil health field walk in Tasmania (apal.org.au)	May 2023	555 / 621 / 27	494 / 20	89 / 3
IPDM in focus: black spot (apple scab and pear scab)	May 2023	350 / 366 / 26	2333 / 47	503 / 14

Evaluation of the Community of Practice and Australian Apple and Pear IPDM website

5.1 IPDM evaluation discussion, March 2023

Questions were put to the community of practice members at an online meeting to evaluate the benefits, challenges and continuation of this community and its support tools. There were 15 attendees at this meeting, with questions focused on 12 of the COP members who weren't a part of the project team.

Questions for the Community of Practice

Eight questions were asked of the community, using an ORID (objective, reflective, interpretive, decisional) evaluation extension approach (Figure 4). Table 8 captures comments from the community on each question.

Table 8: Comments captured through ORID evaluation.

What are key aspects of the COP or ExtensionAUS website that you can recall?
Seeing what pests or diseases were issues and accessing technotes if available.
Using the articles on ExtensionAUS website as a reference to sender growers.
IPM controls.
Regular meetings. Opportunities to hear from experts in other regions.
I came to the COP to have conversations with my peers. I also came to find new innovations or alternative control options.
Guest presentations on current issues..., ask an expert.
COP teams calls, regional roundabout and guest presentations.
Bringing in a guest speaker to each meeting.
Regional roundups of what is happening around the country, common issues.
COP: regional updates and open discussion about issues and management approaches. ExtensionAUS: one stop shop for extension materials.
One stop shop for resources.
The AUS websites case studies and being able to access an expert.

Extending our own thinking on IPDM strategies.		
Grower contact, an input via Facebook group.		
Guest speakers during COP meetings.		
Building the network.		
Variety of guest speakers was excellent. Also, like the whip around briefings on pest and disease issues.		
COP: regional updates and talks work. Challenge to keep it within one hour but people are busy so it can't be any longer. ExtensionAUS: easy to access. Ask the expert relies on two few people.		
It has lacked broad industry engagement. There are over 400 growers in Australia, plus service providers. We haven't seen that much engagement in COP.		
Brings out the share field observations and learn from each other so as to share with farmers more informatively.		
What resonates with you about the COP and ExtensionAUS website?		
COP gives good bang for buck.		
Some valuable experts cannot attend due to financial or availability issues.		
Great to have as a networking page, I think we could focus on getting key messages out at the key pest issues by growing times by state.		
The format of the meetings was great, being all the share screens and do presentations amongst ourselves was rewarding. Most technicians of IPDM are quite varied in their strengths and skills.		
Could you have all resources together on the ExtensionAUS website, but not sure how much it was accessed by growers.		
Building the network.		
There's a lot to fit into a meeting but people don't have time. Asking expert relies on people and too few people to respond.		
Ask an expert not used often. Can be used to seed ideas. Facebook - can be used to help brought a community. Was it actively advertised with growers? Needs constant monitoring and engagement. Exposure?		
What value do you see in the COP?		
Information	Prevention	
Centrally located	National network	
Sharing learnings	Connections	
Sharing	Export values	
Trust	Resources	
Network	Networking	
Learning	Info	
Relevance	Update	
Getting clues on IPDM	Like minded	
Export values	Connection	
What value do you see in the extensionAUS website?		
One stop shop	Tech info	
Experts	Details	
Interactive	Reach	
Ask expert	References	
Evidence	Knowledge	
IPDM manual	Networking	
Accessing resources	Accessibility	
Should the COP be continued?		
Yes – 11	No – 0	not sure – 0
Should the IPDM resources be available online?		
Yes – 12	No – 0	Not sure – 0
Is there anything that needs to be done differently moving forward?		
More promotion of resources to growers to get greater uptake.		
Help to source a meeting topic or guest speaker [expert].		
Look for platform that will create better engagement than the website for ask an expert.		
An app for what pest and disease is that?		

An annual face to face of the COP would be very good. It would allow more time to drill down on projects.
Extension by state or region by weekly notes from infield scouts will get more engagement.
Encourage private agronomists to be able to participate.
More practical answers.
Face to face meeting at an annual event.
Could APAL host COP and website when PiPS4 ends so they are not lost?
What's in the scope, there are many great works being done out there.
Do the face to face in a region so the team can see a successful IPDM case study.
I am recent to these meetings and so not aware of what resources are available in this space... promotion of resources would be good.

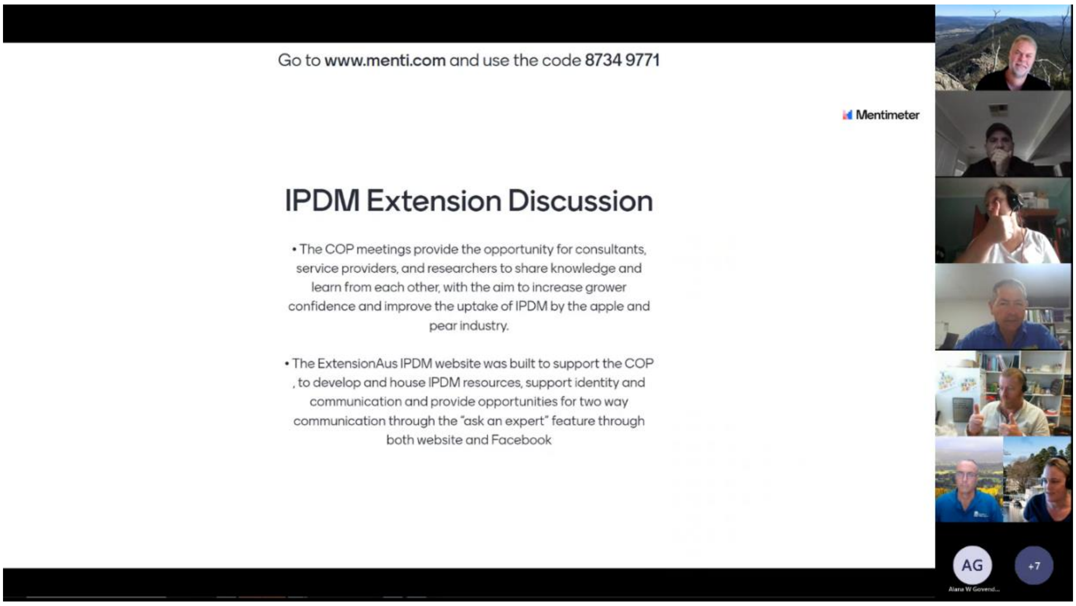

Figure 4: IPDM Extension Discussion - the ORID evaluation session with the IPDM Community of practice at the online meeting in March 2023. Evaluation run by Aimee McCutcheon, Program Manager – Horticulture Services (Agriculture Victoria).

5.2 Conclusion from the evaluation

It was clear from comments provided by the meeting attendees that the IPDM community of practice is valued by those that attend, and that it should continue. Eleven COP members voted yes to the COP continuing and 12 said yes to IPDM Extension information being available on a web platform to support the community. Recommendations were also made by the community such as an annual face to face event to showcase IPDM case studies in different regions, use a different web platform or approach to engage growers; and to promote resources for greater uptake of integrated pest and disease management and find ways to encourage more private agronomists to participate.

Key recommendations

IPDM Community of Practice meetings

The IPDM COP meetings demonstrated a high level of sharing and interest amongst the participants. The more experienced members in the group would share information and clarification on how to deal with pests and diseases in different regions around Australia. Guest speakers at these meetings resulted in discussions on the topics that were presented, with topics well received by the COP. It is also clear that there is more work to be done in supporting IPDM uptake and dissemination of information for service providers and growers.

IPDM manual

Continue to highlight the IPDM Manual as an important online resource by developing stories for the industry magazine and at industry events.

Highlight online resources

Website analytics highlighted peaks in searches correlating to IPDM research presented at industry events, indicating interest in the topics while it was fresh in the minds of attendees.

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AGRICULTURE VICTORIA

AP19002 Communications & Engagement Plan

PIPS3 Program and AP19002 communications are undertaken within sub-project teams (outline in table below) and between sub-projects (suggestions in table below) to foster information/ knowledge exchange, common understanding/ approach, integration of sub-project activities, and accelerate efficiency and effectiveness in delivery.

Project/ Program duration internal communications & collaboration

Strategy/ Activity	Implementation steps/ resources	Stakeholders	Responsibility	Monitoring/Evaluation	Timing/ frequency
What should be undertaken & why?	*How will it be executed?*	*Identify organisations/ personnel needed.*	*Who will manage the process start to end?*	*How will extent of impact be determined?*	*When will it happen?*
extensionAus contributor training	• On-line platforms	Project Team	Emily Crawford/Greg Lefoe	# contributed articles # expert responses	10 Sept 2020
Sub-project meetings to coordinate activities	• On-line platforms	Sub-project team members	Greg Lefoe		As required
AgriBio/AVR newsletter to promote the project internally	• Internally circulated newsletter	Sub-project team members	Greg Lefoe		Twice; at commencement and completion of project
AgriBio Science conference to promote Hort IPDM within Agriculture Victoria	• On-site or on-site conference	Agriculture Victoria	Greg Lefoe	# abstracts accepted and attendance	Once
Quarterly meetings/ project updates with all four PIPS3 projects	• Microsoft teams	All project team members in all 4 projects	Project leaders Marguerite to co-ordinate?		Quarterly?
	•				

AP19002 Communications & Engagement Plan

How will the sub-project undertake communications and extension to engage with growers and front-line advisors to increase knowledge, understanding and generate practice change? Importantly, how will this happen using a program approach?

External Communications & Engagement

THEME *	Strategy/ Activity	Target Audience	Implementation Steps/ resources	Stakeholders	Responsibility	Monitoring/Evaluation	Timing/ frequency
	What will be undertaken & why?	*Who do you want to be engaged?*	*How will it be executed?*	*Identify organisations/ personnel needed.*	*Who will manage the process start to end?*	*How will extent of impact be determined?*	*When will it happen?*
Biological and cultural management solutions- March 2022, March 2023,	ExtensionAus Apple and Pear IPDM webpage	Growers and advisors	• Written articles, photos, videos on webpage • Ask the Expert function	Project team And CoP	Greg Lefoe and Emily Crawford	Google analytics	Fortnightly Sept 2020 – June 2023
Biological and cultural management solutions- March 2022, March 2023,	Facebook IPDM group	Growers and advisor	• Posts, photos, videos on Facebook group page, with signposting to webpage	Project team And CoP	Greg Lefoe and Emily Crawford	Facebook analytics	Fortnightly Sept 2020 – June 2023
Biological and cultural management solutions- March 2022, March 2023,	IPDM Community of Practice (CoP)	Advisors	• CoP meetings (videoconferences)	Project team And CoP	Greg Lefoe and Emily Crawford	• Feedback from members • Contributions and engagement from members in project	Bimonthly / quarterly Sept 2020 – June 2023

AP19002 Communications & Engagement Plan

Biological and cultural management solutions- March 2022, March 2023,	APAL Industry Juice	Growers and advisor	• Written articles	Project team	Greg Lefoe and Emily Crawford		As appropriate Sept 2020 – June 2023
			•				

***Whole system approach** – December 2020, June 2022, June 2023, **Integrated management solutions** – March 2021, September 2022, **The role of advanced technologies in future orchard systems**- June 2021, September 2022, **Resource use efficiency** – September 2021, December 2022, **Biological and cultural management solutions**- March 2022, March 2023, **Performance indicators**- March 2022, March 2023, **Adaption and resilience in a more variable climate**- December 2021, December 2022

Project Logic Framework Project Code: AP19002

Relevant SIP Outcome(s)

Support Industry efficiency and sustainability

- **Outcome 1. Industry profitability and global competitiveness is improved by reducing the average cost per carton**
- Apple and Pear SIP 2017-2021

Intermediate Outcomes >5 years

- Informed understanding of interactions between cultural (incl. soil health), biological and chemical IPDM practices
- Increased grower confidence in integrated pest and disease management decision making
- Advisors and consultants more confident in providing IPDM advice to apple and pear growers
- More accessible high-quality information on IPDM practices, and economic benefits and costs
- Increased information sharing and integration amongst growers and advisors

Short-term Outcomes (achievable in project duration)

- Gaps in cultural practices that attract and support orchard biodiversity for low input pest and disease management addressed
- Important factors for improved soil biodiversity, soil health and plant resilience identified
- Improved efficacy of biological control of major pests and diseases, such as codling moth, LBAM, apple scab and root rot
- Tools for measuring impacts of orchard cultural mgt practices on plant health, yield and quality developed and demonstrated
- Research findings communicated in a clear and practical format to growers and wider industry

Sub-project Outputs (Tangible deliverables)

Results of tests of soil health (soil microbial diversity), nutrient availability and uptake linked with pest and disease levels and apple and orchard productivity
Decision criteria for selecting compatible native species for orchards

Scientific papers, technical articles and factsheets to support IPDM decisions.

Results of parasitoid field and laboratory experiments.
Assessment of genetic diversity of Australian *Mastrus ridens* populations and importation.
Effective monitoring tools for *Mastrus ridens* establishment and impact assessment.
Commercialisation plan for *Mastrus ridens*

Communication & engagement

- At least one Soil Biodiversity and IPDM Training course conducted in each growing state
- Establishment of a network and communication channels as part of a Communities of Practice.
- Soil Biodiversity and IPDM Training course conducted.
- Case studies for growers and advisors to observe and experience the benefits of implementing IPM

Sub-project Activities (Required to deliver outputs)

Conservation biocontrol
Determine species and establish plots with ground covers.
Tricho lab study on CM eggs.
Glasshouse/lab studies of Tricho and cover crop suitability.
Pest, disease, soil health and biodiversity field assessments

Mastrus monitoring and impact
Develop and test pheromone detection methods.
Implement large scale field detection and establishment study.

Mastrus efficacy
Import new Mastrus colony from USA.
Compare genetic diversity of Aust and overseas populations.
Supplementary releases of Mastrus.

Communication and adoption
Prepare and implement Communication and engagement plan

Start-up Outputs	Baseline *Mastrus* data, standardised IPDM protocols, Project reference group, PIPS3 Program meetings				
Start-up Activities	Project administration/ governance	Baseline orchard data collection	Establishing partnerships	Project planning	Investment/Support

Sub-project stakeholders		
Stakeholder Group	**What will they need to know about the sub-project as an audience?**	**What is their role in implementation of the sub-project activities and achieving the outcomes?**
Project Team/ Organisation	Individual roles and responsibilities, opportunities for collaboration and their contribution to the achievements of the project and program outcomes.	Implementing sub-project activities to achieve project outputs and short-term outcomes.
Hort Innovation	Alignment with relevant Hort Innovation and industry strategies and SIP. Milestone reporting, MER, Comms Plan, Risk Register. Project and program progress, issues and communications.	Proving funding & program level support, on-going access to the PIPS3 Program Co-Ordinator.
Sub-project Reference Group	Alignment with relevant Hort Innovation and industry strategies and SIP. Project and program progress, issues and communications.	Provide oversight, strategic direction and regular grower input.
Sub-project collaborators	Sub-project activities and areas for collaboration. Opportunities to share information and resources.	Ensuring sub-projects work collaboratively to achieve program outcomes.
Front Line Advisors & growers	Rationale for current research priorities and clear explanation of the sub-project's contribution to improved orchard management and productivity. Plain English advice and recommendations from the sub-project research outcomes in easy to access formats.	Facilitating communication and adoption objectives. Delivering outcomes of the sub-project and next-users and end-users of the research findings.

Extension Partners	Plain English advice and recommendations that flow from the sub-project research outcomes.	Facilitating communication and adoption objectives.

Provide at least one sub-project KEQ per logic hierarchy to assess the project's relevant objectives and outcomes at that level

Sub-project Key Evaluation Questions	
Key Evaluation Question	**Sub-project specific questions**
To what extent has the sub-project addressed the objectives and achieved the identified outcomes/ outputs?	*To what extent has the sub-project improved knowledge and understanding of the role of Mastrus ridens for sustainable management of codling moth in Australia?* *To what extent has the sub-project demonstrated benefits to orchard pest management, soil health and tree health through new approaches to cultural and biological practices?* *To what extent has the sub-project resulted in grower intention to adapt cultural and biological practices for sustainable pest management?*
How relevant was the sub-project to the needs of the identified stakeholders?	*To what extent has the sub-project met the needs of growers and front-line advisors in providing step-change information on the multiple benefits of inter-row conservation biocontrol plantings?*
How well have intended audiences been engaged in the project?	*To what extent did the sub-project engage growers and front-line advisors through the IPDM Community of Practice?*
To what extent were communications and engagement processes appropriate to the target audience/s of the sub-project?	*To what extent did the planned communications reach the target audience and influence IPDM practices?*
What efforts did the project make to improve efficiency?	*To what extent did collaboration between PIPS3 sub-projects improve efficiency of pest, natural enemy and soil/tree health measurements?*

Adjust template as required. Not all activities, outputs and outcomes need to be monitored - be selective. Refer to what the primary audience wants to know.

Sub-project Monitoring Plan

Sub-project Logic Level	What will be monitored	Key Performance Indicators (KPI)	Data Collection Methods/ Source	Timing/ frequency/ responsibility
Sub-project start-up				
Planning & management The underpinning structure and processes to guide and support project duration activities and outputs *What needs to be planned for and managed?*	Mastrus establishment and spread	# release sites monitored	Record keeping (lab book, form template, spreadsheet or field data capture software)	Seasonal (Sub-project Leader and inter-state collaborators)
	Standardized IPDM protocols	# orchards implementing IPDM protocols # timely data submissions	Record keeping (lab book, form template, spreadsheet or field data capture software)	Seasonal (Sub-project Leader and inter-state collaborators)
	Project reference group (PRG)	# grower representatives/States on PRG # PRG meetings	PRG minutes	Six-monthly (Program Coordinator; Sub-project Leaders)
	PIPS3 Program meetings	# meetings Increase in sub-project collaboration	PIPS3 meeting minutes	Quarterly (Program Coordinator; Sub-project Leaders)
Activities and Outputs				

Research, communication, and engagement *What will the sub-project deliver and produce?*	Conservation biocontrol plots	% efficacy of Tricho against codling moth eggs Suitability score for cover crop species for (1) orchard suitability, (2) Tricho & Mastrus abundance, (3) soil health, and (4) tree health.	Record keeping (lab book, form template, spreadsheet or field data capture software)	Seasonal (Sub-project leader, conservation biocontrol lab and field staff)
	Mastrus establishment and impact	Mastrus pheromone trap produced # Mastrus traps deployed and retrieved	Record keeping (lab book, form template, spreadsheet or field data capture software)	Year 1 (Sub-project leader, Mastrus lab and field staff)
	Mastrus efficacy	# Specimens analyzed for genetic diversity # supplementary Mastrus releases	Record keeping (lab book, form template, spreadsheet or field data capture software, import permits)	Year 1 (Sub-project leader, international collaborator, Mastrus lab and field staff)
	Communication and adoption	# Soil Biodiversity and IPDM Training courses conducted # New IPDM experts contributing to Community of Practice # IPDM enquiries addressed through Community of Practice # Articles submitted as detailed in the Commun. and Engagement plan. # peer-reviewed papers submitted	Evaluation questionnaires, analytics	Ongoing/intermittent (Sub-project leader, Extension officer, Program Co-ordinator)

Short-term outcomes (project duration)				
Achievable within the life of the project *What will result by project end from the sub- project research, communication, and engagement activities?*	Improved efficacy of biological control of major pests and diseases	% growers aware of IPDM practises % growers and advisors who understand requirements for viable long-term Mastrus and Tricho populations	Interviews, questionnaires	Ongoing/intermittent (Sub-project leader, Extension officer)
	Important factors for improved soil biodiversity, soil health and plant resilience	% growers and advisors aware of contribution of inter-row plantings to soil health	Interviews, questionnaires	Ongoing/intermittent (Sub-project leader, Extension officer)
	Communications to growers and wider industry	% growers and advisors aware of research findings	Evaluation questionnaires, analytics	Ongoing/intermittent (Sub-project leader, Extension officer, Program Co-ordinator)
Intermediate Outcomes (Post project 5-10 yrs)				
Legacy *What longer-term influence will outcomes of the sub-project have on industry?*	Informed understanding of interactions between cultural (incl. soil health), biological and chemical IPDM practices	% growers adopting conservation biocontrol practices % growers aware of biocontrol agent establishment and impact in their orchard	Interviews, questionnaires, industry reports	

	Increased grower confidence in integrated pest and disease management decision making	% growers routinely practicing IPDM % reduction in use of pesticides incompatible with biocontrol	Interviews, questionnaires, industry reports	
	More accessible high-quality information on IPDM practices, and economic benefits and costs	% growers regularly interacting with an IPDM Community of Practice	Interviews, questionnaires, industry reports	

APPLE AND PEAR

PRODUCTIVITY, IRRIGATION, PESTS AND SOILS PROGRAM (PIPS3)

pips
Apples & Pears
PRODUCTIVITY IRRIGATION PESTS AND SOILS

Monitoring & Evaluation Plan

2020-2023

AGRICULTURE VICTORIA

tia TASMANIAN INSTITUTE OF AGRICULTURE
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This project has been funded by Hort Innovation using the apple and pear research and development levy and funds from the Australian Government. For more information on the fund and strategic levy investment visit horticulture.com.au

CONTENTS

1 INTRODUCTION

The purpose of the Monitoring and Evaluation Plan (M&E Plan) is to outline the framework and work plan that will be implemented to appropriately evaluate the performance and effectiveness of the Apple and Pear industry's third *Productivity, Irrigation, Pests and Soils Program (PIPS3)*, funded by Hort Innovation using the apple and pear research and development levy and funds from the Australian Government.

The PIPS3 Program is a three-year (2020-2023) research and development effort encompassing five integrated projects, led by four organisations. These are:

- AP19002- *Strengthening cultural and biological management of pests and diseases in apple and pear orchards*, Project Lead: Agriculture Victoria, Dr Greg Lefoe
- AP19003- *Advancing sustainable and technology driven apple orchard production systems*, Project Lead: Agriculture Victoria, Dr Ian Goodwin
- AP19005- *Developing smarter and sustainable pear orchards to maximise fruit quality, yield and labour efficiency*, Project Lead: Agriculture Victoria, Dr Ian Goodwin
- Ap19006- *Improved Australian apple and pear orchards soil health and plant nutrition*, Project Lead: Tasmanian Institute of Agriculture (TIA), Dr Nigel Swarts & Dr Sally Bound
- AP19007- Independent Program Coordination for PIPS3 Program, Project Lead: ICD Project Services, Marguerite White

The M&E Plan will assist the individual projects to each deliver upon the milestones and achievement criteria of their relevant research agreements, in consultation with their partners and Project Reference Groups (PRG), whilst also contributing to overall program and industry objectives through the established avenues of the Independent Coordinator, PIPS3 Program Reference Group (PIPS3 PRG) and the *PIPS3 Program Communications and Extension Plan* (C&E Plan).

Projects of the PIPS3 Program have contributed to the preparation of this program level M&E Plan. It has been developed to provide a cascading roadmap, to ensure appropriate and timely monitoring, evaluation, reporting and continuous improvement processes at both the program and project levels to demonstrate immediate and intermediate performance and effectiveness, together with the valuable contribution the program will make towards the *Apple and Pear Strategic Invest Plan 2017-2021 (SIP)* and longer-term industry goals.

1.1 RELATIONSHIP WITH SIP STRATEGIES

Outcome 1	**Industry and global competitiveness is improved by reducing the average cost per carton**
Strategy 1.1	Drive orchard reworking with emphasis on preparedness for increased mechanisation/ automation/scale. Primary research projects: AP19003 & AP19005
Strategy 1.2	Continue to build the body of knowledge around pest & disease management & prevention, considering both biosecurity risk mitigation & cost reduction. Primary research project: AP19002
Strategy 1.3	Improve soil health & increase knowledge of beneficial microbes in orchard management. Primary research project: AP19006
Strategy 1.4	Improve labour productivity through greater adoption of technology and leadership training Primary research project: AP19003 & AP19005
Strategy 1.5	Research IT and data systems that enable better collection and connectivity of orchard and business data at every level of the supply chain. Primary research projects: AP19003 & AP19005
Outcome 3	**The value of the average bin has risen, resulting in improved industry profitability**
Strategy 3.1	Improve quality consistency and percentage of Class 1 fruit per hectare

2 PIPS3 PROGRAM LOGIC

Long-term Outcomes >10yrs

The apple and pear industry has adopted tools and management practices required to operate orchards that:

- Are resilient to climate variability and weather extremes;
- Use resources efficiently and sustainably;
- Apply biological and cultural solutions in the management of pests, disease and nutrients;
- Drive product quality and business profitability through use of automated/ mechanised advanced technologies along the supply chain; and
- Produce a low environmental footprint and sustainable product that meets consumer preference and expectations.

Intermediate Outcomes >5yrs

- Informed understanding of interactions between cultural/biological/chemical IPDM & soil health practices leading to implementation of recommended sustainable orchard practices.
- Accessible, high-quality information on IPDM practices, economic benefits & costs leading to increased adoption of biological controls.
- Apple orchard design & management practices adopted that improve crop loading, maximise fruit yield & quality, minimise impacts of extreme heat events & foster greater orchard system diversity.
- Improved pear crop load management recommendations adopted to avoid biennial bearing and maximise fruit quality.
- Rework recommendations of pear orchard design adopted, underpinned by research findings of the yield & fruit quality potential of new cultivars & benefits of a sustainable whole system approach.
- Sensing technologies adopted that improve informed decision-making, leading to efficient production of premium quality product.
- Decision support tools adopted by industry: Pear irrigation scheduling, SINATA for apples irrigation scheduling & nutrient budgeting & Apple crop-load tool.
- Industry platforms for greater collaboration on productivity, irrigation, pests and soils are valued by industry growers/advisors as trusted sources of scientifically robust information & recommendations.
- Advisors & consultants are confident in providing sustainable management practice advice to apple and pear growers developed from PIPS3.
- Growers have adopted recommendations and tools of the PIPS3 Program and are able to demonstrate benefit through yield/quality, profitability and resilience gains.

Short-term Outcomes (project duration)

- Developed recommendations for cultural practices that support orchard biodiversity for low input pest & disease management.
- Improved efficacy of biological control of codling moth, LBAM, apple scab & root rot.
- Effects of orchard design on yield & fruit quality of new pear cultivars measured and subsequent management practice options devised.
- Increased knowledge on the drivers of pear fruit colour development and degradation, and effectiveness of novel netting protection strategies.
- Commercial sensing technologies calibrated/ validated for industry to measure in situ fruit & tree parameters and establish orchard-specific crop load relationships.
- Relationship understood for apples between fruit position and light exposure on colour development, sunburn damage, fruit quality and floral initiation.
- Chemical signals identified for apples that determine impact of high crop load on floral initiation & differentiation, and fruit size in the subsequent season.
- Increased knowledge on sustainable orchard management practices & soil health, resilience, productivity/quality impact, incl. soil health indicators.
- Decision support tools developed, trialled & training of advisors/ grower conducted for improved decision-making & monitoring of orchard precision and sustainable management practice recommendation implementation.
- The PIPS Program has delivered as a high impact, collaborative and integrated research program.
- Stakeholders are effectively informed on research outcomes and the potential benefit of these for businesses profitability, industry sustainability, efficient resource management practices & local operating environments.

Outputs

- Decision criteria for selecting native species mixes for biological control & soil health.
- Determination of physical, biological & chemical soil health indicators.
- Developed knowledge on soil health, pest & disease, & productivity (tree size & fruit number, size & colour) relationships.
- *Matrus ridens* genetic diversity, establishment & impact assessment monitoring tools.
- *Mastrus ridens* commercialisation plan
- Developed & trialled decision support tools – Pear irrigation scheduling, SINATA for apples irrigation scheduling & nutrient budgeting & Apple crop-load tool

Outputs of the PIPS3 Communication & Extension Plan

- Peer reviewed science journal articles, conference papers and technical reports.
- Presentations at industry conferences/ events on research progress and findings.
- Guides & technical fact sheets- skills training to support these in sensing technology, sustainable orchard practices & IPMD.
- Case studies & videos: informational, peer exchange & on technology/decision support tool use.

Program-wide

- Websites established/ updated (APAL, ExtensionAus) & content maintained
- Broad media press releases
- *AFG* magazine & *Industry Juice* publications.
- Social media campaigns (APAL, AgVic, TIA)
- PIPS3 Future Orchards® event collaboration/ contributions
- PIPS3 specific field events and industry forums

Activities

AP19002 Project

- Conduct conservation biocontrol field, glasshouse & laboratory experiments (*Mastrus ridens* & *Trichogramma spp.*).
- Cover crop suitability assessment.
- Conduct *Mastrus ridens* release, detection, efficacy & impact studies. Includes development & testing of pheromone detection methods.
- Conduct soil health, pest/disease, & productivity relationship field sampling & analysis.

AP19003 Project

Collect, analyse & report field experiment data:

- Rootstock, row orientation, fruit position & light exposure effects on fruit quality and floral initiation (Sundial orchard Tatura).
- Crop load effects on fruit quality & floral initiation (commercial orchard).
- Metabolic analysis of bud samples to identify chemical signals that influence floral initiation.
- Field testing of sensors technologies
- Orchard specific crop load algorithm determination for crop load decision support tool.

AP19005 Project

Collect, analyse & report field experiment data:

- Continuation of planting system and rootstock experiments
- Crop regulation
- Functional yield relationships
- Sensing technology 'proof-of-concept' and calibration
- Decoupling heat and light
- Novel netting
- Undertake development of pear orchard irrigation scheduling tool (excel based)

AP19006 Project

Collect, analyse & report on sustainable floor management field experiment data across five growing regions:

- Inter-row treatments- native & general meadow cover-crops
- Tree-line treatments- legume mixes & mulches
- Physical, chemical & biological (microbial, carbon) indicators and parameters investigated.
- Develop data package and grower guide on recommended sustainable orchard managements.
- Undertake development of SINATA web app

Program Level

- Implement governance/ consultation process
- Six-monthly reporting on research/ activity progress
- Implement and monitor the PIPS3 Program Communications and Extension Plan, in collaboration with projects, PRG and industry stakeholders.
- Implement the PIPS3 Program M&E Plan to monitor, evaluate & undertake adaptive management processes, to continually improve, in collaboration with projects and PRG
- Coordinate mid-term and final evaluation processes & reporting.

Start-up Outputs

- Project Work plans/ preschedules, methodology & protocols developed &
- Literature reviews completed/ baseline data determined.
- Field and glasshouse experiments established
- Established communication platform with industry communications & extension (Website)
- Prepared mechanisms for collaboration & integrated planning - project leadership group, PRGs & program plans.

Start-up Activities

- ADMINISTRATION/ GOVERNANCE PROCESSES
- LITERATURE REVIEWS/ BASELINE DATA COLLECTION
- PARTNERSHIP DEVELOPMENT
- PROJECT/ PROGRAM PLANNING CONSULTATIONS
- INVESTMENT/ SUPPORT SECURED
- CONTRACTING CONDUCTED

3 M&E PLAN SCOPE

The M&E Plan has been prepared to address both internal and external monitoring, evaluation, reporting and improvement requirements. Primary stakeholder groups are those who will use the results of the M&E Plan to manage and make decisions about the PIPS3 Program. The secondary stakeholder groups are those that may be interested to know certain results of the PIPS3 Program's M&E processes, but do not have a management or decision-making role in relation to the program.

3.1 STAKEHOLDER AUDIENCE GROUPS

STAKEHOLDER GROUPS	ROLE IN ACHIEVING OUTCOMES	WHAT THEY NEED TO KNOW
PRIMARY AUDIENCE		
HORT INNOVATION	Program manager to ensure compliance with contract agreements and alignment with industry investment strategies and Hort Innovation processes.	• Consultative program/ project planning conducted and review/ approval processes undertaken (project workplans/ preschedules, risk management registers, Communications & Extension Plan, M&E Plan). • Program/ project reference groups established and ongoing input/feedback & actions from these industry consultations. • Reviewed project communications from Program Coordinator for approval. • Timely and quality six-monthly reports received on research progress. • Performance/ impact of integrated research, communication and extension activities. • Performance/ impact of project level levy payer communications and extension activities. • Early detection of project risks and identification of adaptive management solutions to be applied.
INDEPENDENT PROGRAM COORDINATOR	Coordination and implementation of program plans and facilitation of research integration and stakeholder collaboration opportunities.	• Schedule of key project research, communications and extension activities. • Target audiences and avenues for communications and extension. • Project progress and findings for appropriate, timely and accurate communications through C&E Plan identified methods. • Draft project communications for review & seek approvals from Hort Innovation. • Analytics and evaluation results from levy payer/ stakeholder communications and extension activities to report to Hort Innovation on extent of engagement and impact and identify/ implement opportunities for improvement.

		• Early detection of project risks and identification of adaptive management solutions to be applied.
AGRICULTURE VICTORIA RESEARCH LEADERS & TEAMS	Design, implementation and review of research activities in accordance with the Hort Innovation Research Agreement and project preschedule. Have farm use agreement in place with grower partners. Conduct planned activities to implement the risk management register, PIPS3 C&E Plan and PIPS3 M&E Plan. Timely project progress reporting to Hort Innovation and other supporters.	• Analysis of experimental site data collection activities. • Project progress in accordance with preschedules/ workplans and reportable milestone and final outputs/ outcomes. • Data findings from PIPS3 and sub-contractor collaborators • Early detection of project risks and identification of adaptive management solutions to be applied. • Evaluation outcomes of extension activities to assess performance, extent of impact and seek feedback on ways to improve. • Analytics on communication activities to evaluate level of engagement with target audiences and potential impact. • Preparation of peer reviewed manuscripts for publication in scientific journals.
TASMANIAN INSTITUTE OF AGRICULTURE RESEARCH LEADERS & TEAM	Design, implementation and review of research activities in accordance with the Hort Innovation Research Agreement and project workplan. Conduct planned activities to implement the risk management register, PIPS3 C&E PLAN and PIPS3 M&E Plan. Timely project progress reporting to Hort Innovation and other supporters.	• Analysis of experimental site data collection activities. • Project progress in accordance with preschedules/ workplans and reportable milestone and final outputs/ outcomes. • Data findings from PIPS3 and sub-contractor collaborators • Early detection of project risks and identification of adaptive management solutions to be applied. • Evaluation outcomes of extension activities to assess performance, extent of impact and seek feedback on ways to improve. • Analytics on communication activities to evaluate level of engagement with target audiences and potential impact.
PROGRAM REFERENCE GROUP	Strategic program level planning, input, feedback and advice pertaining to Hort Innovation investment in PIPS3 Program integrated research, communication, engagement and reporting activities. The PRG ensures industry need and sentiment is reflected, activities are well targeted and will result in high level industry impact.	• Progress of the research to provide timely grower/ extension advisor input into activities. • Evaluation outcomes of extension and communication activities to assess performance, extent of impact and provide input on ways to improve. • Forward plans for research, communications and extension activities to identify potential risks and provide grower/ extension advisor insight into potential adaptive management solutions.
SECONDARY AUDIENCE		
RESEARCH TEAM SUB-CONTRACTORS	Assist core project team in specific research component or locality relevant project research, communication and extension activities in accordance with the Hort Innovation Research Agreement and project workplan.	• Project preschedules/ workplans for appropriate resourcing and scheduling. • Collaboration opportunities with broader research activities as relevant to sub-contracted components. • Data findings of research activities as relevant sub-contracted components.

		• Evaluation outcomes of extension activities to assess performance, extent of impact and seek feedback on ways to improve.
PROJECT REFERENCE GROUPS	Project level grower/advisor perspective input feedback and advice pertaining to experimental design and treatments, extension and communications. The PRG ensures regional industry need and sentiment is reflected, activities are well targeted and will result in high level industry impact.	• Progress of the research to provide timely grower/ advisor input into activities. • Evaluation outcomes of extension and communication activities to assess performance, extent of impact and provide input on ways to improve. • Forward plans for research, communications and extension activities to identify potential risks and provide grower/ advisor insight into potential adaptive management solutions.
HOST GROWERS OF FIELD EXPERIMENTS	Provide access and maintain the integrity of research sites. Provide grower perspective on usual practice versus treatment experiments as well as insight into how research needs to be communicated and extended to peers.	• Research project workplans and schedules. • Risks and management requirements to maintain integrity of the research sites. • Progressive research finding to provide timely grower, formal and informal, input and feedback
APPLE & PEAR ADVISORS AND GROWERS	Input, feedback and practical advice pertaining to experimental design and treatments, extension and communications via extension events. Openness to consider and build knowledge in new orchard management and technology adoption options.	• Timely updates on the findings of the research and how these may address their needs and impact upon orchard management practices/ advice provided. • Develop new knowledge and skills to understand orchard/ business benefit and implement recommendations/ guidelines. • Develop confidence in new management options/ technologies using industry standard data metrics to demonstrate sustainability, yield, production and profitability outcomes.
COMMUNICATION COLLABORATORS **(Further details outlined in the PIPS3 Program C&E Plan)**	Assistance in engaging key audiences in the research activities and extending prepared program materials, resources, tools and videos to update and inform through industry or organisational avenues. Provider of analytics on extent of reach and engagement via these avenues.	• Planned PIPS3 Program communication activities via the PIPS3 C&E Plan. • Number of communication materials, reach and engagement (publication, social media and web-based platform analytics) • Influence of these activities on increased knowledge, understanding and skill development. • Influence of these activities on intent to adopt or newly adopted practices.
EXTENSION COLLABORATORS **(Further details outlined in the PIPS3 Program C&E Plan)**	Assistance in engaging key audiences in the research activities and extending prepared program materials, resources, tools and videos to update and inform through industry or organisational avenues, especially training and field walk events. Provider of analytics on extent of participation, reach and engagement associated with PIPS3 Program collaborations, and evaluation of metrics associated with increased knowledge, understanding and intent to adopt.	• Planned PIPS3 Program extension activities or intent to collaborate with industry events (e.g. FO) via the PIPS3 C&E PLAN. • Number of activities conducted, participation, reach and engagement. • Influence of these activities on increased knowledge, understanding and skill development. • Influence of these activities on intent to adopt or newly adopted practices.

3.2 KEY EVALUATION QUESTIONS

The key evaluation questions of the PIPS3 Program have been prepared in consultation with each of the partner projects. Where KEQ are relevant across the program, or have a whole of industry focus, these are presented as whole of program questions. It is anticipated that as the project progresses towards the mid-term point, the KEQ may be further defined in consultation with the PRG and the evaluation consultant.

KEY EVALUATION QUESTIONS	SPECIFIC PROGRAM/ PROJECT QUESTIONS
EFFECTIVENESS	
To what extent has the PIPS3 Program addressed the objectives, research agreement achievement criteria and identified outcomes/ outputs?	WHOLE OF PROGRAM • To what extent has the PIPS3 Program advanced the apple and pear industry's capabilities to achieve the overall objectives? • To what extent did the five projects of the PIPS3 Program meet research agreement achievement criteria and milestones according to the expectations and timeframes of Hort Innovation? AP19007 • To what extent has the independent program coordinator role delivered improved integration of R&D through greater collaboration across the projects of the PIPS3 Program? • To what extent has the independent program coordinator role delivered improved communication of R&D outcomes and outputs to growers by ensuring collaboration across the four projects, industry extension and communication providers, leading industry growers, service providers and regions? AP19002 • To what extent has the project improved knowledge and understanding of the role of *Mastrus ridens* for sustainable management of codling moth in Australia? • To what extent has the project demonstrated benefits to orchard pest management, soil health and tree health through new approaches to cultural and biological practices? AP19003 • To what extent has the project improved orchard design and crop load management in a variable climate by providing knowledge and tools to consistently deliver premium fruit that meets consumer expectations in domestic and export markets? • To what extent has the project developed, calibrated, validated and evaluated sensor technology to measure in flower number, tree size, fruit number, fruit size and fruit colour? AP19005 • To what extent has the project improved knowledge and understanding of orchard design and management to grow new pear cultivars to market specifications within the context of a changing and variable climate? • To what extent has the sub-project advanced sensor technology to enable/improve measurement of orchard parameters?

	AP19006 • To what extent did the project increase grower and front-line advisor knowledge and understanding of sustainable orchard management practices? • Did the project produce sustainable orchard management guidelines and the SINATA Irrigation & Nutrition web app?
RELEVANCE	
How relevant were the research outcomes/ outputs to the needs of apple and pear growers, advisors and industry stakeholders?	WHOLE OF PROGRAM • What outcomes/ outputs of the PIPS3 Program are most valued by growers and front-line advisors? • How, and to what extent, will these influence future business and management decisions? AP19002 • To what extent has the project met the needs of growers and front-line advisors in providing step-change information on the multiple benefits of inter-row conservation biocontrol plantings? AP19003 • Do identified stakeholders believe the project investment was worthwhile and would they invest in the project team and/or subject matter in the future? AP19005 • To what extent has the project met the needs of growers and front-line advisors to provide information on design and management of pear orchards and use of sensor technology? AP19006 • Is there evidence that outcomes/ outputs of the project have inspired growers to implement sustainable orchard management practices? • To what extent has the project met the needs of growers and front-line advisors to provide information and guidance on soil health management strategies and the impact of these upon soil health, production and profitability?
PROCESS APPROPRIATENESS	
How well have intended audiences been engaged in the project?* ***The PIPS3 C&E Plan, Section 9.1 outlines the Performance Indicators for assessment of this KEQ.**	WHOLE OF PROGRAM • To what extent did the PIPS3 Communications and Extension Plan succeed in engaging growers, advisors and service providers in the research? • What were the most successful mechanisms for engaging target audiences in the activities of the PIPS3 Program? • To what extent did partners of the PIPS3 Program engage in collaborative activities with relevant extension providers? • To what extent did the Program/Project Reference Groups provide opportunity for growers and front-line advisor input and feedback into activities? AP19002

	• To what extent did the project engage growers and front-line advisors through the IPDM Community of Practice and ExtensionAus apple and pear website?
To what extent was the PIPS3 Program Communications and Extension Plan appropriate and had an impact upon the target audience? * ***The PIPS3 C&E Plan, Section 9.1 outlines the Performance Indicators for assessment of this KEQ.**	WHOLE OF PROGRAM • To what extent has implementation of the Communications and Extension Plan resulted in increased knowledge, understanding and capability of growers and front-line advisors? • To what extent is there evidence that growers and front-line advisors have adopted or intend to adopt management practice outcomes of the PIPS3 Program? • To what extent did extension activities meet the expectations of the intended audience/ audiences and is there evidence that PIPS3 Program applied appropriate adaptive management in response to event evaluation results? AP19007 • To what extent has the independent program coordinator successfully coordinated/ delivered upon the PIPS3 Program Communications and Extension Plan? AP19002 • To what extent has the project resulted in greater confidence, intention to adopt, or adoption of IPDM cultural and biological practices for sustainable pest management? AP19003 • To what extent has the project resulted in greater confidence, intention to adopt, or adoption of new orchard design and the uptake of sensor technologies? AP19005 • To what extent has the project resulted in greater confidence, intention to adopt, or adoption of new orchard design and management, and improve utilisation of sensor technologies? AP19006 • To what extent has the project resulted in greater confidence, intention to adopt, or adoption of practices in sustainable orchard management practices?
EFFICIENCY	
What efforts did the PIPS3 Program partners make to improve efficiency?	WHOLE OF PROGRAM • Did projects of the PIPS3 Program address STOP/GO review recommendations to avoid project creep and budgetary overspend? AP19007 • To what extent did the governance, planning and collaboration activities implemented by the independent program coordinator improve efficiency across the program? If so, is there evidence that increased efficiency achieved additional value and impact? AP19002/ AP19006

	• To what extent did collaboration across the PIPS3 Program improve efficiency of pest, natural enemy and soil/tree health measurements? AP19003/ AP19005 • Did the project/s efficiently manage shared resources and utilise skills and knowledge within other PIPS3 Program projects?
LEGACY	
Are there signs that the PIPS3 Program will influence apple and pear growers in the future?	• Is there evidence that outcomes and outputs of the PIPS3 Program will continue to be adopted by growers and front-line advisors? • To what extent do stakeholders believe that outcomes/ outputs of the PIPS3 Program are likely to become “usual grower practice” within the next ten years?

4 PERFORMANCE EXPECTATIONS- PROGRAM MONITORING PLAN

The PIPS3 Program Monitoring Plan is a collated program level guide to what needs to be monitored, the Key Performance Indictors (KPI), and the data collection methods are to be used across all projects. It is supported by the detailed Monitoring Plans of each individual projects in Appendix 1. It is important to highlight that with regards to communications and extension, the Communications and Monitoring Plan of the PIPS3 Program C&E Plan, Section 9.1 is the primary source for KPI of both a qualitative and quantitative nature. The two plans complement one another and must be jointly considered in all monitoring, evaluation and reporting.

LOGIC LEVEL	WHAT WILL BE MONITORED	KEY PERFORMANCE INDICATORS	DATA COLLECTION	TIMING
Start-up Activities & Outputs *What foundational structures, plans and processes will be established to guide and support the PIPS3 Program activities and outputs over three years?*	**Execution** of research agreements & collaborator contracting.	Contracting process completed by all parties.	• Milestone 102 reporting demonstrates all collaborators have been contracted in accordance with Research Agreements.	Milestone 102
	Establishment of governance, consultation & collaboration. (Program & Project Reference Groups, Project Leadership Group, Project Team Meetings)	Terms of Reference (ToR) **prepared** and six-monthly meetings **conducted** **Effectiveness** of PRGs as primary consultative platform for stakeholder input and feedback. **Effectiveness** of the Project Leadership Group and Project Team Meetings in increasing collaboration and monitoring research progress to achieve research agreement milestones.	• Membership & ToR reviewed & approved by the Hort Innovation Program Manager. • Meeting attendance • Meeting agendas & minutes • Actions implemented (documented in following meeting minutes). • Mid-term and final evaluation key stakeholder questions.	PRGs 6-monthly (AP19002 & AP19006) PRG Annually (AP19005) AP19003 to form relationship with AP19006 PRG. PLGs 4 annually Team Meetings approx. monthly
	Prepared and approved risk registers	**Risk registered submitted** and approved in Milestone 102. **Evidence** that risk registers are reviewed and continuous improvement actions are undertaken.	• Risk registers submitted Milestone 102. • Six-monthly within research team meeting minutes. • Annually within PLG & PRG meeting minutes.	At least 6-monthly
	Adoption and execution of the PIPS3 Communications & Extension Plan (PIPS C&E Plan).	**PIPS3 C&E Plan prepared** in consultation with project, communication and extension stakeholders in Milestone 102. **Effectiveness** of the PIPS3 C&E Plan as the primary tool for executing program communications and extension activities	• PIPS3 C&E Plan prepared by Program Coordinator & review/ approval processes undertaken in Milestone 102 period. • PIPS3 M&E Table (Section 9.1) outlines specific quantitative and qualitative data collection to be undertaken.	6-monthly (milestone reports), mid-term & final project evaluation metrics.

		in accordance with Hort Innovation requirements and Research Agreements of all partners.	• Mid-term and final evaluation key stakeholder questions to evaluate impact.	
	Adoption and execution of the PIPS3 M&E Plan.	**Effectiveness** of the PIPS3 M&E Plan in assisting Hort Innovation and program partners to monitor Research Agreement obligations. **Effectiveness** of the PIPS3 M&E Plan as a tool to assess progress towards final program outputs and outcomes throughout implementation.	• M&E Plan prepared by Program Coordinator & review/ approval processes undertaken in Milestone 102 period. • Six-monthly reporting against the M&E Plan by the Program Coordinator. • Mid-term and final evaluation key stakeholder questions to evaluate impact.	6-monthly (milestone reports), mid-term & final project evaluation metrics.
	Prepared project preschedules/ workplans/ Gantt charts finalised and exchanged.	**Project plans prepared** & exchanged. **Extent** to which exchange of planning documents, together with providing progress updates as a part of governance/ consultation meeting structures, leads to **effective** collaboration and implementation.	• Documentation prepared and exchanged within Milestone 102. • Updates and discussion on these documented in PLG & Team meeting minutes. • Mid-term and final evaluation key stakeholder questions to evaluate impact.	PLGs 4 annually
	Prepared and agreed experiment protocols	**Evidence** that experiment protocols have been determined and agreed where collaboration between projects is required or regional demonstration sites are established.	• Documentation prepared, agreed and exchanged within Milestone 102. • Regional demonstration sites have been established with standardised trial design and protocols implemented (AP19006).	Milestone 102- 31st December 2020
	Established experimental sites	**Evidence** that experimental sites have been established in accordance with Research Agreements on both research and commercial properties.	• Research site locations specified- address, GPS Coordinates & collaborating farmer. • Experiment and treatment designs determined and documented. • AP19002- Tatura SmartFarm/ Tas (AP19006) Bio Control Plots & *Mastrus ridens* release sites • AP19003- Tatura Sundial Orchard & 1 commercial orchard. • AP19005- 1 Tatura experimental pear site & 1 commercial property	Milestone 102- 31st December 2020 Milestone 104- 31st October 2021

			• AP19006- In-depth Tasmanian trial sites (2) & regional demonstration sites (4)	
Project Activities & Outputs *What will the PIPS3 Program deliver and produce?*	Literature review	Literature review completed by AP19006.	• Internal peer review undertaken to finalise report. • "Healthy Soils" parameters determined.	Milestone 106- 15th December 2021.
	Field & glasshouse experiments/ technology validation & calibration.	**Extent to** which experiments are implemented in accordance with Research Agreement milestones. **Evidence** that the data collection is scientifically robust and can be used for baseline and comparison analysis purposes. **Extent** to which the research activities are valued and relevant to industry stakeholders and are generating increased knowledge and understanding.	• Site based data recording systems/ data capture software implemented. • Experiment data outputs & subsequent analysis outcomes progressively reported in 6-monthly Milestone Reports. • Peer reviewed science papers published. • Peer reviewed technical fact sheets and reports published. • Mid-term and final evaluation key stakeholder questions to evaluate impact.	6-monthly (milestone reports), mid-term & final project evaluation metrics.
	Laboratory based research, testing & analysis	**Extent to** which experiments are implemented in accordance with Research Agreement milestones. **Extent to** which testing and analysis activities inform field-based activities and support determination of decision support tool algorithms and soil health, IPDM, production, productivity and quality parameters/ scoring. **Evidence** that data sampling, testing and analysis results are scientifically robust and can be used for accurate baseline and comparison analysis purposes.	• Data recording systems/ data capture software implemented. • Experiment data outputs & subsequent analysis outcomes progressively reported in 6-monthly Milestone Reports. • Pheromone traps developed (AP19002) • Peer reviewed science papers published. • Peer reviewed technical fact sheets and reports published.	6-monthly (milestone reports), mid-term & final project evaluation metrics.
	Technical Reports	**Extent** to which the research has contributed to "adoption ready" new knowledge in orchard design and sustainable management practices.	• Technical reports delivered. • Refer to Section 9.1 of the PIPS3 C&E Plan.	Relevant milestone & final project reporting on technical reports.
	Grower Fact Sheets & Guidelines	**Extent** to which resources deliver increased appreciation for research outputs, grower confidence to adopt and knowledge/skills to implement outcomes.	• Case studies documenting grower experiences in using developed resources and production/ quality outcomes (AP19007).	Progressive updating of project *PIPS3 Program M&E Portal* (refer Section 5.1)

			• Refer to Section 9.1 of the PIPS3 C&E Plan. • Final evaluation key stakeholder questions to evaluate impact.	Relevant milestone & final reporting on resource development. Mid-term & final project evaluation.
	Decision Support Tools	**Extent** to which growers have confidence to use and implement recommendations of developed decision support tools. (AP19006 SINATA Web App, AP19003 Crop-load tool, AP19005 Irrigation planning & scheduling tool)	• Workshops conducted and evaluated to introduce and develop grower/ advisor confidence/ skills in use. • Case studies documenting use of the tools and subsequent decisions made/ advice provided by growers/ advisors. • Final evaluation key stakeholder questions to evaluate impact.	Progressive updating of project *PIPS3 Program M&E Portal* (refer Section 5.1) Relevant milestone & final reporting on workshops. Final project evaluation.
	Science Journal Papers	**Extent** to which activities are implemented in accordance with Section 8.1 of the PIPS3 C&E Plan.	Refer to Section 9.1 of the PIPS3 C&E Plan.	Progressive updating of project *PIPS3 Program M&E Portal* (refer Section 5.1) Final project reporting on manuscripts & publications.
	Workshops/webinars/ field days/ field walks	**Extent** to which activities are implemented in accordance with Section 8.1 of the PIPS3 C&E Plan.	Refer to Section 9.1 of the PIPS3 C&E Plan.	Progressive updating of project *PIPS3 Program M&E Portal* (refer Section 5.1) 6-monthly (milestone reports). Mid-term & final project evaluation
	Website content (including videos)/ published articles/ social media presence	**Extent** to which activities are implemented in accordance with Section 8.1 of the PIPS3 C&E Plan.	Refer to Section 9.1 of the PIPS3 C&E Plan.	Progressive updating of project *PIPS3 Program M&E Portal* (refer Section 5.1) 6-monthly (milestone reports). Mid-term & final project evaluation
	Industry conferences, forums and collaboration opportunities	**Extent** to which activities are implemented in accordance with Section 8.1 of the PIPS3 C&E Plan.	Refer to Section 9.1 of the PIPS3 C&E Plan.	Progressive updating of project *PIPS3 Program M&E Portal* (refer Section 5.1)

				6-monthly (milestone reports). Mid-term & final project evaluation
	Science conferences	**Extent** to which activities are implemented in accordance with Section 8.1 of the PIPS3 C&E Plan.	Refer to Section 9.1 of the PIPS3 C&E Plan.	Progressive updating of project *PIPS3 Program M&E Portal* (refer Section 5.1) 6-monthly (milestone reports). Mid-term & final project evaluation
Short-term outcomes (project duration) *What will result within three years from PIPS3 Program research, communication and engagement activities?*	**Effective** coordination, collaboration, communications and extension.	**Extent** to which activities of the Program Coordinator role (AP19007) has increased collaboration between research teams, project collaborators and industry stakeholders. PIPS3 Program has **effectively communicated and extended** research outputs/ outcomes in sustainable orchard management practices, biocontrol IPDM practices, orchard design and sensing technologies within the context of business resilience, productivity and profitability outcomes. **Extent** to which implementation of the PIPS3 C&E Plan has resulted in greater knowledge/ understanding of the impact of certain treatments/ managements upon orchard sustainability, production and fruit quality. **Extent** to which implementation of the PIPS3 C&E Plan has resulted in greater confidence to adopt research recommendations/ guidelines/ tools.	• Refer to Section 9.1 of the PIPS3 C&E Plan. • Results of publication analytics across electronic and print platforms (number, reach, engagement). • Attendance numbers at events • Event evaluation results (Appendix 2), • Effectiveness of PIPS3 Program speakers at third party events (i.e. Future Orchards) • Final evaluation key stakeholder questions to evaluate impact.	Milestone reports of AP19007 Mid-term & final project evaluation.
	Improved efficacy of biological control of major pests and diseases.	**Extent** to which growers are aware of the benefits of IPDM practices.	• Research outcomes reported in Milestone Reports.	Progressive updating of project *PIPS3 Program M&E Portal* (refer Section 5.1) per

		Extent to which researchers/growers/ advisors understand the requirements for viable long-term *Mastrus ridens* and *Trichogramma sp.* populations.	• *Mastrus ridens* commercialisation plan developed. • Event evaluation results (Appendix 2) • Final evaluation key stakeholder questions to evaluate awareness and understanding.	event conducted where AP19002 is involved in delivery. Final project evaluation.
	Increased knowledge and understanding of the critical factors within conservation biocontrol treatments, and the sustainable orchard management practices, that result in improved soil health, plant health, resilience, orchard productivity and fruit quality.	**Extent** to which researchers/growers/advisors have increased their awareness and understanding on how inter-row plantings and tree-line ameliorants (the sustainable practices) impact soil health, pest control, orchard sustainability and production outcomes. **Extent** to which growers aspire/ intend to adopt sustainable management practices.	• Combined research outcomes reported in Milestone Reports where multiple projects are contributing to this understanding. • Event evaluation results (Appendix 2) • Final evaluation key stakeholder questions to evaluate increased knowledge and understanding, and intent to adopt demonstrated practices.	Progressive updating of project *PIPS3 Program M&E Portal* (refer Section 5.1) per event conducted where AP19002/ AP19006 are involved in delivery. Final project evaluation.
	Evidence of the determination of relationship between fruit position and light exposure on colour development, sunburn damage, fruit quality and floral initiation.	**Extent** to which the apple orchard systems research experiments are completed and report upon the determination of relationship factors. **Extent** to which researchers/growers/advisors have increased their knowledge and understanding on the relationship between fruit position and light exposure on colour development, sunburn damage, fruit quality and floral initiation in apple orchards.	• Milestone & final reporting • Peer reviewed science papers published. • Peer reviewed technical fact sheets and reports published. • Website analytics on access to relevant resources. • Event evaluation results (Appendix 2) • Final evaluation key stakeholder questions to evaluate knowledge and understanding.	Progressive updating of project *PIPS3 Program M&E Portal* (refer Section 5.1) per event conducted where AP19003 is involved in delivery. 6-monthly (milestone reports). Mid-term & final project evaluation
	Evidence that chemical signals have been identified that determine the impact of high crop load on floral initiation and differentiation, and fruit size in the subsequent season.	**Extent** to which the apple orchard systems research experiments are completed and report upon chemical signals that impact upon key apple orchard production parameters. **Extent** to which researchers/growers/advisors have increased their knowledge and understanding on chemical signals that determine the impact of high crop load	• Milestone & final reporting • Peer reviewed science papers published. • Peer reviewed technical fact sheets and reports published. • Website analytics on access to relevant resources. • Event evaluation results (Appendix 2) • Final evaluation key stakeholder questions to evaluate knowledge and understanding.	Progressive updating of project *PIPS3 Program M&E Portal* (refer Section 5.1) per event conducted where AP19003 is involved in delivery. 6-monthly (milestone reports). Mid-term & final project evaluation

		on floral initiation and differentiation, and fruit size in the subsequent season.		
	Evidence that commercial mobile sensing technology is available to industry to measure in situ fruit and tree parameters and establish orchard-specific crop load relationships.	**Extent** to which apple orchard systems remote sensing technology calibration and validation work has been completed and reported. **Extent** to which growers/advisors have increased their knowledge and understanding on the benefits of using remote sensing technology and have built greater confidence to adopt tools.	• Milestone & final reporting • Peer reviewed science papers published. • Peer reviewed technical fact sheets and reports published. • Website analytics on access to relevant resources. • Event evaluation results (Appendix 2) • Final evaluation key stakeholder questions to evaluate knowledge, understanding and confidence/intent to adopt.	Progressive updating of project *PIPS3 Program M&E Portal* (refer Section 5.1) per event conducted where AP19003 is involved in delivery. 6-monthly (milestone reports). Mid-term & final project evaluation
	Evidence that the effects of orchard design on yield and fruit quality of new pear cultivars have been measured and management implications communicated to growers.	**Extent** to which the pear orchard systems research experiments are completed and report upon the effects of orchard design upon key pear orchard production parameters. **Extent** to which growers/advisors have increased their knowledge and understanding of the impact of orchard design on yield and fruit quality of new pear cultivars and the associated management implications.	• Milestone & final reporting • Peer reviewed science papers published. • Peer reviewed technical fact sheets and reports published. • Website analytics on access to relevant resources. • Event evaluation results (Appendix 2) • Final evaluation key stakeholder questions to evaluate knowledge, understanding and confidence/intent to adopt associated practice managements.	Progressive updating of project *PIPS3 Program M&E Portal* (refer Section 5.1) per event conducted where AP19005 is involved in delivery. 6-monthly (milestone reports). Mid-term & final project evaluation
	Evidence that proof-of-concept and/or calibration of sensing technology research has potential to provide data to support management decisions in pear orchards.	**Extent** to which the pear orchard systems remote sensing proof of concept / validation work has been completed and reported. **Extent** to which growers/advisors have increased their knowledge and understanding on the potential benefits of using remote sensing technology and have built greater confidence to adopt tools.	• Milestone & final reporting • Peer reviewed science papers published. • Peer reviewed sensor guidelines and videos completed. • Website analytics on access to relevant resources. • Event evaluation results (Appendix 2) • Final evaluation key stakeholder questions to evaluate knowledge, understanding and confidence/intent to adopt.	Progressive updating of project *PIPS3 Program M&E Portal* (refer Section 5.1) per event conducted where AP19005 is involved in delivery. 6-monthly (milestone reports). Mid-term & final project evaluation
	Evidence that pear orchard systems research has increased knowledge on the drivers of fruit	**Extent** to which the pear orchard systems experiments are completed and report upon the key drivers of fruit colour	• Milestone & final reporting • Peer reviewed science papers published.	Progressive updating of project *PIPS3 Program M&E Portal* (refer Section 5.1) per

	colour development and degradation, and the effectiveness of novel netting protection strategies have been determined.	development/degradation and the assessment of novel netting protection strategies. **Extent** to which growers/advisors have increased their knowledge and understanding on the drivers of fruit colour development and protection mechanisms.	• Event evaluation results (Appendix 2) • Final evaluation key stakeholder questions to evaluate knowledge and understanding.	event conducted where AP19005 is involved in delivery. 6-monthly (milestone reports). Mid-term & final project evaluation
	Evidence that soil health indicators for apple and pear orchards have been established and extended with consideration for regional differences.	**Extent** to which in-depth and regional experiments are completed and report upon the determination of soil health indicators. **Extent** to which growers and advisors are aware of the determined physical, biological and chemical soil health indicators for apple and pear orchards of their region.	• Milestone & final reporting • Event evaluation results (Appendix 2) • Final evaluation key stakeholder questions to evaluate knowledge and understanding.	Progressive updating of project *PIPS3 Program M&E Portal* (refer Section 5.1) per event conducted where AP19006 is involved in delivery. 6-monthly (milestone reports). Mid-term & final project evaluation
	Evidence that decision support tools (web app or excel based) have been extended and skills have been developed to aid adoption.	**Extent** to which growers and advisors have increased their knowledge and skills in using the developed decision support tools to manage irrigation, nutrients and crop-loads in the orchard.	• Combined research outcomes reported in Milestone Reports where multiple projects are contributing to this understanding. • Event evaluation results (Appendix 2) • Final evaluation key stakeholder questions to increased knowledge and capability to adopt decisions support tools.	Progressive updating of project *PIPS3 Program M&E Portal* (refer Section 5.1) per event conducted where AP19003/AP19005/AP19006 is involved in delivery. 6-monthly (milestone reports). Mid-term & final project evaluation
Intermediate Outcomes **(post project to ten years)**	Understanding of interactions between cultural, biological and chemical IPDM practices has led to practice change.	**Extent** of adoption of conservation biocontrol practices. **Measured** industry improvements in the suppression of codling moth and LBAM in orchards can be attributed to adopted conservation biocontrol practices.	• *Mastrus ridens* commercially available. • Industry annual survey includes IPDM practices. • CM, LBAM, *Mastrus* and *Trichogramma* surveys.	Annual Industry Survey Annual website analytics on access to relevant resources.
	Orchard design to maximise fruit yield and quality and minimise	**Extent** of adoption by growers of PIPS3 Program recommendations/ guidelines	• Industry annual survey includes how growers are using orchard design, technologies and practices to manage the	Annual Industry Survey Annual website analytics on access to relevant resources.

	the impact of extreme heat events.	on training and pruning systems to better manage light environment. **Extent** to which technology to measure light environment demonstrated/ developed by the PIPS3 Program is commercially available from industry service providers	light environment and the accessibility of advice/ technology from local service providers.	
	Improved crop load management by providing knowledge and tools to deliver premium fruit that meets consumer expectations.	**Extent** to which growers are using sensors to determine thinning requirements. **Evidence** that further research is investigating how to apply metabolites to stimulate floral initiation.	• Industry annual survey includes how growers are determining thinning requirements. • Review of further investment in apple orchard thinning technology projects.	Annual Industry Survey Annual website analytics on access to relevant resources.
	Sensing technology used in apple orchards to assist growers to produce fruit to market specifications.	**Extent** to which growers are using sensors to determine management intervention to increase fruit colour and manipulate fruit size.	• Industry annual survey includes technology adoption by growers.	Annual Industry Survey Annual website analytics on access to relevant resources.
	Decisions to rework pear orchards are informed by knowledge of yield and fruit quality potential of new cultivars and whole systems implications.	**Extent** to which growers are using different rootstocks, new blush cultivars, higher tree density and modern training systems. **Extent** to which growers demonstrate intent to adopt next generation rootstocks and cultivars.	• Industry annual survey includes components of the orchard system that have been reworked/ intend to be reworked associated with recommendations/ guidelines of the PIPS3 Program.	Annual Industry Survey Annual website analytics on access to relevant resources.
	Use of sensing technology in pear orchards to assist growers to grow fruit to market specifications.	**Evidence** that further research is/ has furthered capability (e.g. sensing fruit quality) for full adoption readiness. **Extent** to which growers are using sensors to provide flower and fruit load data to assist decision making. **Extent** to which growers that have adopted sensor technology have improved the percentage of fruit grown to market specification.	• Industry annual survey includes technology adoption by growers and impact upon percentage of fruit grown to market specification. • Review of further investment in pear orchard sensing technologies.	Annual Industry Survey
	Better crop load management in pears to avoid biennial bearing and maximise fruit quality.	**Extent** to which growers have adopted recommended fruit thinning techniques	• Industry annual survey includes thinning techniques used by pear growers and	Annual Industry Survey

		of the PIPS3 Program that consistently maximise fruit quality and yield.	impact upon yield and percentage of fruit grown to market specification.	
	Orchardists implementing sustainable orchard management practices	**Extent** of industry adoption of sustainable management practices recommended by the PIPS3 Program. **Measured** industry-wide soil health improvements evident through use of industry soil health indicators in industry surveys. **Extent** to which growers that have adopted sustainable management practices can demonstrate improved soil health, plant health, orchard productivity, fruit quality and increased resilience to climate variables.	• Industry annual survey includes what sustainable management practices have been adopted and measured improvements in productivity and fruit quality. • Industry soil health check campaign conducted using the determined soil health indicators.	Annual Industry Survey Industry Soil Health Check Campaign 5- & 10-years post PIPS3 Program completion.

5 EVALUATION

A summary of the minimum data requirements for both the mid-term and final evaluation demonstrates that both the KEQ and KPI can be assessed through a limited number of information sources.
Mid-term evaluation completed: December 31st, 2021 & Final evaluation completed: 30th May 2023.

DATA COLLACTION CATEGORY	QUANTITATIVE (MONTHLY REPORTING + ANALYSIS WITHIN MID-TERM & FINAL EVALUATIONS)	QUALITATIVE (MID-TERM & FINAL SURVEY)
Communications	☐ Number of materials/ publications produced ☐ Dissemination/ publication avenues. ☐ Reach & engagement analytics ☐ Metrics collected in the project *PIPS3 Program M&E Portal* (refer Section 5.1) per communication activity undertaken.	☐ Materials/ publications/ platforms are valued as a reputable source of information by stakeholders. ☐ Materials/ publications/ platforms have improved knowledge, understanding and skills. ☐ Materials/ publications/ platforms have resulted in adoption/ intention to adopt recommended practices and/ or technologies.
Extension	☐ Industry/grower/ service provider extension opportunities. ☐ Registered participation numbers ☐ PIPS3 Program event evaluation results or collaborating organisation evaluation results. ☐ Metrics collected in the project *PIPS3 Program M&E Portal* (refer Section 5.1) per extension event conducted/ co-operatively delivered.	☐ Improved knowledge & understanding on outputs & outcomes of the research and acquired skills to aid in implementation. ☐ Growers/ service providers believe research has responded to input/feedback leading to confidence in outputs/outcomes. ☐ Adoption/ intention to adopt recommended practices and/ or technologies.
Collaboration/ Consultation	☐ Collaborations conducted through governance and industry/ program forums. ☐ Agendas/programs and resultant meeting minutes/ forum proceedings prepared. ☐ Team meeting agendas/actions/ adaptive management documented. ☐ Metrics collected in the project *PIPS3 Program M&E Portal* (refer Section 5.1) per event conducted.	☐ Evidence of exchange, input & resource efficiency outcomes. ☐ Valued as vehicle for input/feedback on research by industry/ collaborator members. ☐ Research team members can identify increased knowledge and understanding benefits of networking and exchange opportunities.
Research	☐ Six-monthly reporting upon milestone achievement criteria. ☐ Final Reports ☐ Peer reviewed science journal publications, fact sheets & technical reports. ☐ Tested (validated & trilled) decision support tools available for use.	☐ Trial site activities are understood, supported and valued by industry/growers/ service providers.

5.1 PIPS3 PROGRAM M&E DATA-BASE AND PORTAL

The *PIPS3 Program M&E Portal* is designed to be centrally located, cloud-based file platform for the management and collection of data relating to communication, extension and collaboration activities, as well the publication of project materials. It will assist the Program Coordinator to generate six-monthly project and program level reports for all partners. These reports will contain quantitative graphs and tables for Project Leaders to provide as supporting appendices of Milestone Reports and for reporting to their own organisations and project collaborators.

Each PIPS3 Program project has access to their project folder only. The folder is comprised of a motherhood excel database named "AP1900*X* PIPS3 Program M&E Data-base" and individual folders for each activity delivered.

There are two-steps in fulfilling the requirements of the *PIPS3 Program M&E Drop Portal* for each activity delivered by the project:

(1) Input the activity into the *PIPS3 Program M&E Database* by completing each column of the spreadsheet.
(2) Create a new folder for each activity to upload evidence of the activity using the following naming protocol: Year_Month_Date_Event (2020_Nov_11_NSW Field Day).

In accordance with Section 9 of the PIPS3 Program C&E Plan, the following should be uploaded:

Ex**tension activities**:

- ☐ Copy of all promotions
- ☐ Copy of all presentations & hand-outs
- ☐ Collated summary of the *PIPS3 Program Event Evaluation* (Appendix 2) results
- ☐ Copies of photographs/ recordings

Communication activities:

- ☐ Copy of the article/ post
- ☐ Analytics evidence (web/ social media platform generated) relating to reach and engagement

Collaborations:

- ☐ Agenda/ Program
- ☐ Minutes/ Notes demonstrating completed & planned actions
- ☐ For larger forums: Summary of the *PIPS3 Program Event Evaluation* (Appendix 2) results

It is expected that project materials (fact sheets, technical reports, published science journal articles) will be submitted with the relevant Milestone Report and therefore is not required to be uploaded to the *PIPS3 Program M&E Portal* but an entry must be made into the data-base to record this activity.

Click the link to view the standard template for the AP1900*X* PIPS3 Program M&E Data-base template, including examples of the data collation potential of this reporting mechanism.

PIPS3 Program M&E Data-base Template

6 REPORTING AND CONTINUOUS IMPROVEMENT

The following reporting mechanism are being used to report upon the progressive and final research, collaboration, communications and extension activities, outputs and outcomes.

The PIPS3 Program C&E Plan provides extensive detail on how reporting will be undertaken to the broader industry through planned communications and extension activities. The details below concentrate on formal Hort Innovation requirements and governance/consultation/collaboration structures.

REPORT TYPE	TO WHOM & CONTINUOUS IMPROVEMENT ACTIVITIES	TIMING
Milestone Reports	**Hort Innovation/ Research Partner Organisation** ☐ Performance against milestone achievement criteria determined. ☐ Monitoring of project creep ☐ Project risk assessment	6- monthly
Final Reports	**Hort Innovation/ Research Partner Organisation** ☐ Performance against project milestones determined. ☐ Key outputs and outcomes for industry identified for final communication to levy investors. ☐ Communication to industry in relation to delivery against industry strategic investment plan.	End of project
Written, presentations and verbal updates	**Project Leadership Group** ☐ Update on project activity progress to Hort Innovation R&D Program Manager. ☐ Collaborate on project/program activities, scheduling and resource sharing across the five projects. ☐ Seek technical input/ feedback from peers. ☐ Review of risk registers across the program **Program/ Project Reference Groups** ☐ Present key results ☐ Discuss implications and communications of key results (could include anecdotal grower observations), gaps (e.g. knowledge, costs risks) for effective adoption of key results. ☐ Report upon the communications, communications, collaborations and project materials achieved for the six-month period (generated from the *PIPS3 Program M&E Drop-box*) ☐ Platform for collective research and industry input, feedback and design of adaptive management strategies (where identified as required). ☐ Collaborate on communication and extension methods to best extend progressive findings. ☐ Seek input into the composing of key messages for industry emanating from progressive research findings.	Quarterly 6-monthly Annually-AP19005

	☐ Review of the project risk register **Industry & PIPS3 Program team forums** ☐ Communicate project/program activity progress and the outcomes of collaborative research. ☐ Seek technical advice/ input ☐ Exchange information and ideas to assist in research delivery or the assessment/understanding of research data. ☐ Consult on communication and extension methods to best extend key outcomes/ messages emanating from progressive research findings. **Project Team Meetings** ☐ Update on project activity progress ☐ Review progress against the project preschedule/ workplan/ Gannt chart ☐ Allocate resources and schedule experimental work. ☐ Risk register review and design of adaptive management strategies quarterly (where identified as required).	At least annually Monthly

APPENDIX 1 PROJECT LEVEL PROJECT MONITORING PLANS

AP19002 PROJECT MONITORING PLAN

Sub-project Logic Level	What will be monitored	Key Performance Indicators (KPI)	Data Collection Methods/ Source	Timing/ frequency/ responsibility
Sub-project start-up				
Planning & management The underpinning structure and processes to guide and support project duration activities and outputs *What needs to be planned for and managed?*	Mastrus establishment and spread	# release sites monitored	Record keeping (lab book, form template, spreadsheet or field data capture software)	Seasonal (Sub-project Leader and inter-state collaborators)
	Standardized IPDM protocols	# orchards implementing IPDM protocols # timely data submissions	Record keeping (lab book, form template, spreadsheet or field data capture software)	Seasonal (Sub-project Leader and inter-state collaborators)
	Project reference group (PRG)	# grower representatives/States on PRG # PRG meetings	PRG minutes	Six-monthly (Program Coordinator; Sub-project Leaders)
	PIPS3 Program meetings	# meetings Increase in sub-project collaboration	PIPS3 meeting minutes	Quarterly (Program Coordinator; Sub-project Leaders)
Activities and Outputs				
Research, communication, and engagement *What will the sub-project deliver and produce?*	Conservation biocontrol plots	% efficacy of Tricho against codling moth eggs Suitability score for cover crop species for (1) orchard suitability, (2) Tricho & Mastrus abundance, (3) soil health, and (4) tree health.	Record keeping (lab book, form template, spreadsheet or field data capture software)	Seasonal (Sub-project leader, conservation biocontrol lab and field staff)

	Mastrus establishment and impact	Mastrus pheromone trap produced # Mastrus traps deployed and retrieved	Record keeping (lab book, form template, spreadsheet or field data capture software)	Year 1 (Sub-project leader, Mastrus lab and field staff)
	Mastrus efficacy	# Specimens analyzed for genetic diversity # supplementary Mastrus releases	Record keeping (lab book, form template, spreadsheet or field data capture software, import permits)	Year 1 (Sub-project leader, international collaborator, Mastrus lab and field staff)
	Communication and adoption	# Soil Biodiversity and IPDM Training courses conducted # New IPDM experts contributing to Community of Practice # IPDM enquiries addressed through Community of Practice # Articles submitted as detailed in the Commun. and Engagement plan. # peer-reviewed papers submitted	Evaluation questionnaires, analytics	Ongoing/intermittent (Sub-project leader, Extension officer, Program Co-ordinator)
Short-term outcomes (project duration)				
Achievable within the life of the project *What will result by project end from the sub- project research, communication, and engagement activities?*	Improved efficacy of biological control of major pests and diseases	% growers aware of IPDM practices % growers and advisors who understand requirements for viable long-term Mastrus and Tricho populations	Interviews, questionnaires	Ongoing/intermittent (Sub-project leader, Extension officer)
	Important factors for improved soil biodiversity, soil health and plant resilience	% growers and advisors aware of contribution of inter-row plantings to soil health	Interviews, questionnaires	Ongoing/intermittent (Sub-project leader, Extension officer)

	Communications to growers and wider industry	% growers and advisors aware of research findings	Evaluation questionnaires, analytics	Ongoing/intermittent (Sub-project leader, Extension officer, Program Co-ordinator)
Intermediate Outcomes (Post project 5-10 yrs)				
Legacy *What longer-term influence will outcomes of the sub-project have on industry?*	Informed understanding of interactions between cultural (incl. soil health), biological and chemical IPDM practices	% growers adopting conservation biocontrol practices % growers aware of biocontrol agent establishment and impact in their orchard	Interviews, questionnaires, industry reports	
	Increased grower confidence in integrated pest and disease management decision making	% growers routinely practicing IPDM % reduction in use of pesticides incompatible with biocontrol	Interviews, questionnaires, industry reports	
	More accessible high-quality information on IPDM practices, and economic benefits and costs	% growers regularly interacting with an IPDM Community of Practice	Interviews, questionnaires, industry reports	

AP19003 PROJECT MONITORING PLAN

Sub-project Logic Level	What will be monitored	Key Performance Indicators (KPI)	Data Collection Methods/ Source	Timing/ frequency/ responsibility
Sub-project start-up				
Planning & management The underpinning structure and processes to guide and support project duration activities and outputs *What needs to be planned for and managed?*	• Gantt chart and research preschedule			
	• Completion of Gantt chart and research preschedule, sharing with project team and PIPS3 projects.	Gantt chart and research preschedule approved by project team, statistician and collaborators and viewed by other PIPS3 projects. Synergies with other PIPS3 projects identified.	Direct communication at meetings led by AP19007.	Nov 2020, once, Project leader (Ian Goodwin)
Activities and Outputs				
Research, communication, and engagement *What will the sub-project deliver and produce?*	• Field experiments implemented, data collected and statistically analysed.	Peer reviewed science papers.	Submitted to journal.	One draft paper by Nov 2022 and 3 draft papers by May 2023, Project team
	• Industry articles.	Publication in AFG or other industry magazine.	Editor feedback.	Four articles (Nov 2020, Nov 2021, Nov 2022 and May 2023, Project team
	• Technical report, user guidelines, video and factsheet on new technology	Published on APAL web site.	Web statistics (APAL). PRG feedback.	Video May 2022, Factsheet Nov 2022, Technical report and user guidelines May 2023, Principal investigator

	and advanced management systems.			
	• Field walks and SmartFarm visitations.	Grower and industry service provider participation. > 300 visitors to SmartFarm.	Evaluation survey and feedback. Email thanks.	As required. Documented in milestone reports, Project team
	• PIPS3 Program reference group.	PRG provides advice to project leaders and industry context for communicating results	Meeting minutes	Once per year, documented in milestone reports, Project leader
Short-term outcomes (project duration)				
Achievable within the life of the project *What will result by project end from the sub- project research, communication, and engagement activities?*	Relationships established between fruit position and light exposure on colour development, sunburn damage, fruit quality and floral initiation.	Completion of experiments, results reported to industry and peer reviewed.	Documented in milestone reports and final report.	Six monthly milestone reports (Nov 2020 – May 2023) and final report (July 2023), Project leader
	Chemical signals identified that determine the impact of high crop load on floral initiation and differentiation, and fruit size in the subsequent season.	Completion of experiments, results reported to industry and peer reviewed.	Documented in milestone reports and final report.	Six monthly milestone reports (Nov 2020 – May 2023) and final report (July 2023), Project leader
	Commercial mobile sensing technology available to industry to measure in situ fruit and tree parameters and establish orchard-specific crop load relationships.	Completion of experiments, results reported to industry and peer reviewed. Completion of sensor	Documented in milestone reports and final report	Six monthly milestone reports (Nov 2020 – May 2023) and final report (July 2023), Project leader

		guidelines, factsheets and videos.		
Intermediate Outcomes (Post project 5-10 yrs)				
Legacy *What longer-term influence will outcomes of the sub-project have on industry?*	Orchard design to maximise fruit yield and quality and minimise the impact of extreme heat events.	Growers are adopting training and pruning systems to better manage light environment. Technology to measure light environment offered by commercial service providers and other researchers looking at management systems.	Industry survey or industry database.	
	Improved crop load management by providing knowledge and tools to deliver premium fruit that meets consumer expectations.	Growers are using sensors to determine thinning requirements. Researchers investigating how to apply metabolites to stimulate floral initiation.	Service/equipment providers. New projects to develop products to increase floral initiation.	
	Sensing technology used in apple orchards to assist growers to produce fruit to market specifications.	Growers are using sensors to determine management intervention to increase fruit colour and manipulate fruit size.	Service/equipment providers.	

AP19005 PROJECT MONITORING PLAN

Sub-project Logic Level	What will be monitored	Key Performance Indicators (KPI)	Data Collection Methods/ Source	Timing/ frequency/ responsibility
Sub-project start-up				
Planning & management The underpinning structure and processes to guide and support project duration activities and outputs *What needs to be planned for and managed?*	• Pre-schedule			
	• Completion of preschedule, sharing with project team and PIPS3 projects	Preschedule approved by project team, statistician and collaborators and viewed by other PIPS3 projects. Synergies with other PIPS3 projects identified.	Direct communication at meetings led by AP19007.	Oct 2020, once, Project leader (Ian Goodwin)
Activities and Outputs				
Research, communication, and engagement *What will the sub-project deliver and produce?*	• Field experiments implemented, data collected and analysed	Peer reviewed science papers	Submitted	Milestone 104 (Oct 2021), 106 (Oct 2022), 107 (Apr 2023), Project team
	• Industry articles	Publication in AFG or other industry magazine	Publication reference PRG feedback	Two per year, documented in milestone reports, Lead investigator (Lexie McClymont)
	• Irrigation guidelines and videos	Grower interest	Web statistics (APAL) PRG feedback	Once, end-of-project, Project leader
	• Sensor guidelines and videos	Grower interest	Web statistics (APAL) PRG feedback	Once, end-of-project, Lead investigator

	• Field walks	Grower participation	Attendance – sign in sheets Evaluation survey and feedback	Two per year, documented in milestone reports, Project leader
	• Project reference group	PRG provides advice to project team and industry context for experiment planning and interpretation of results.	Meeting minutes	Once per year, documented in milestone reports, Project leader/Lead investigator
Short-term outcomes (project duration)				
Achievable within the life of the project *What will result by project end from the sub- project research, communication, and engagement activities?*	Effects of orchard design on yield and fruit quality of new pear cultivars measured and management implications communicated to growers.	Completion of experiments, results reported to industry as outlined above, 10% of growers attend a field walk 20 % of growers access web resources	Documented in milestone reports and final report.	Six monthly milestone reports (Oct 2020 – April 2023) and final report (July 2023), Project leader
	'Proof-of-concept' and/or calibration of sensing technology to provide data to support management decisions in pear orchards.	Completion of experiments, results reported to industry as outlined above. Completion of sensor guidelines and videos. 10% of growers attend a field walk 20 % of growers access web resources	Documented in milestone reports and final report.	Six monthly milestone reports (Oct 2020 – April 2023) and final report (July 2023), Project leader
	Increased knowledge of drivers of fruit colour development and	Completion of experiments, results	Documented in milestone reports and final report	Six monthly milestone reports (Oct 2020 – April 2023) and final report (July 2023), Project leader

	degradation and effectiveness of novel protection strategies.	reported to industry as outlined above,		
Intermediate Outcomes (Post project 5-10 yrs)				
Legacy *What longer-term influence will outcomes of the sub-project have on industry?*	Decisions to rework orchards informed by knowledge of yield and fruit quality potential of new cultivars and whole systems implications.	Growers are using different rootstocks, new blush cultivars, higher tree density and modern training systems. Growers are interested in investigating next generation rootstocks and cultivars.	Industry survey or industry database.	
	Use of sensing technology in pear orchards to assist growers to grow fruit to market specifications.	Growers are using sensors to provide flower and fruit load data to assist decision making. Development of additional capabilities (e.g. sensing fruit quality) are further informing management decisions or integrating data with management systems.	Service/equipment providers	
	• Better crop load management in pears to avoid biennial bearing and maximise fruit quality.	Fruit thinning techniques developed to consistently maximise fruit quality and yield.		

AP19006 PROJECT MONITORING PLAN

Sub-project Logic Level	What will be monitored	Key Performance Indicators (KPI)	Data Collection Methods/ Source	Timing/ frequency/ responsibility
Sub-project start-up				
Planning & management The underpinning structure and processes to guide and support project duration activities and outputs *What needs to be planned for and managed?*	• Formation of sub-project team	Subcontracts in place	Sub-project records	**N Swarts** (30-9-2020)
	• Collaboration with growers providing trial sites	Trial sites confirmed	Sub-project records	**N Swarts** (30-9-2020) FLA's
	• Coordination with sub-project leads	Coordinated trial site plans	Sub-project records	**N Swarts** (30-9-2020) FLA's
	• Collaboration with contractor to provide web app	Subcontract in place	Sub-project records	**N Swarts** (30-9-2020)
Activities and Outputs				
Research, communication, and engagement *What will the sub-project deliver and produce?*	• Literature review	Review completed	Sub-project records	**S Bound** (15-12-2021)
	• Project (PIPS 3) update meetings	Meetings conducted; Action plans produced;	Sub-project records	**M White** 6 monthly

	• Sub-project trial planning meetings	Meetings conducted; Action plans produced;	Sub-project records	**N Swarts** Monthly
	• Detailed field trial plans	Field trial plans reviewed and produced	Sub-project records	N Swarts (30-9-2020) FLA's
	• Regional Field trials (NSW, SA, WA, Vic)	Demonstration sites established at minimum 4 sites	Sub-project records	**N Swarts** (annual) FLA's
	• In depth research trial (Tas sites)	Trial sites established at minimum 2 sites	Sub-project records	**S Bound** (annual)
	• Regional grower field days; Industry technical conferences	Field days conducted at field trial sites	Sub-project records	**N Swarts** (2022, 2023) FLA's
	• Industry communications	6 Industry journal articles; Web page produced updated bi-annually or as needed; Social media updates;	Sub-project records	N Swarts (ongoing) M White
	• Nutrient / irrigation management decision support tool - web app	Web app developed	Sub-project records	N Swarts (Update at 30-6-2022 and 30-6-23) S Green
	• Grower Guide	Grower guide reviewed and published	Sub-project records	N Swarts (30-6-23) S Bound, FLA's
	• Data Package	Data package published	Sub-project records	N Swarts (Updates 30-6-21; 30-6-2022; 30-6-23) S Bound

	•			
Short-term outcomes (project duration)				
Achievable within the life of the project *What will result by project end from the sub- project research, communication, and engagement activities?*	• Key soil health indicators for apple and pear orchards established	An increase in orchardists aware of key soil health indicators for apple and pear orchards	Sub-project records	N Swarts Project team
	• Orchardists & advisors with increased awareness & knowledge of sustainable orchard management practices and their impact on soil health, resilience, orchard productivity and fruit quality	An increase in orchardists/advisors in major apple & pear growing regions of Australia are aware of key sustainable orchard management practices	Event surveys and feedback. End of project survey	N Swarts Project team
	• Orchardists & advisors with increased awareness and skill in using web-based tools to manage water and nutrients in the orchard	An increase in orchardists in major apple & pear growing regions of Australia are aware of SINATA web-based tool for managing water and nutrients in the orchard; 10 % of orchardists/advisors have tested the web-based tool;	Web-data analytics; Start and end of project surveys.	N Swarts Project team
	• Orchardists aspire to implement sustainable orchard management practices	An increase in orchardists aspiring to implement sustainable orchard management practices	Start and end of project surveys;	N Swarts Project team

Intermediate Outcomes (Post project 5-10 yrs)				
Legacy *What longer-term influence will outcomes of the sub-project have on industry?*	• Orchardists implementing sustainable orchard management practices			
	• Orchardists confidently using web-based tools to help manage orchard irrigation and nutrition			

APPENDIX 2 PIPS3 PROGRAM EVENT EVALUATION TEMPLATE

The PIPS3 Program Event Evaluation package is available in the PIPS3 Program Template Drop-box: HERE

Link to online version for smartphones: https://www.surveymonkey.com/r/PIPS3 .

Also available via a QR code for scanning by event participants. Printable version example provided below.

pips Apples & Pears
PRODUCTIVITY IRRIGATION PESTS AND SOILS

Event Evaluation

Please complete this short evaluation so we can continue to improve!

NAME (Optional):

CIRCLE: Grower Service Provider/ Advisor Researcher

EMAIL ADDRESS (Optional):

Please provide a scale score: 1 (Strongly Disagree/ Highly Unlikely) **5** (Strongly Agree/ Highly Likely)

(1) Overall, today was worth attending: *1 2 3 4 5*

(2) Overall, the content was well presented: *1 2 3 4 5*

Tell us what worked well or needs improvement here.

(3) Today I increased my knowledge and understanding on how the research/ demonstrated practices, technologies or tools may assist my business and/ or industry.

1 2 3 4 5

(4) Attending today's event has given me greater confidence to adjust certain practices/ adopt new practices.

1 2 3 4 5

(5) Based on the outcome of your participation/ confidence, how likely are you to make changes to your management practices?

1 2 3 4 5

(6) If you are likely to make practice changes, briefly what might they be? If you are not likely to make practice changes, briefly what are the reasons/barriers?

Tell us here.

(7) How soon do you think you may investigate options to make the right practice changes for your business?

Within 6 months Within 12 months Within 2 years Within 5 years When the technology/practice is further proven

(8) What is the key message you will take home with you today?

For further information on the purpose and use of this evaluation, please contact:
Marguerite White, PIPS3 Program Coordinator: mwhite@icdprojectservices.com.au **www.apal.org.au PIPS3**

Hort Innovation | APPLE AND PEAR FUND

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AGRICULTURE VICTORIA tia

Privacy Policy on reverse side of the PIPS3 Program Event Evaluation printed version and stated at the commencement of the on online version.

The PIPS3 Program collects, stores, uses, discloses and otherwise handles your personal information in accordance with the *Privacy Act 1988 (Cth)* and as otherwise set out in the privacy policy available at Hort Innovation Privacy Policy. For project evaluation purposes, your response to rated questions is reported in an aggregated per event, per project or overall program format only, without disclosure of individual names, personal contact details or location. Long answers may be used for communication materials or project/program reporting to Hort Innovation as anonymous responses unless written consent is otherwise obtained from you. Provision of names, phone numbers and email addresses are entirely optional and are collected for post event PIP3 Program recommended practice follow-up information or grower/ advisor support by the relevant project team only. You may request that data provided by you is removed at any time.

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Abstract

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Monitoring mites in orchards: absence or non-detection?*

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Successful integrated pest management (IPM) programs rely on effective and efficient methods of monitoring pest and beneficial species, including mites. Several methods have been proposed for monitoring mites in Australian orchards, mainly based on examining leaves in situ. During the 2021–2022 growing season we flagged 1–2 pear trees *Pyrus communis* in each of 192 panels (a panel being trees in a 14 m length of a row) in a pear orchard at Tatura, Victoria, Australia. For each flagged tree we examined mite species occurrence and prevalence using three methods, (1) non-destructive visual examination of 10 leaves per panel using a 10x hand lens (current industry standard), (2) destructive lab-based examination of 4 leaves per flagged tree(s) using a stereo microscope, and (3) destructive lab-based examination of 2 leaves per flagged tree(s) using a stereo microscope. The presence and prevalence of pest mites and the previously released predatory mite *Neoseiulus californicus* were recorded. Throughout the season we observed various pest mites in the orchard including *Tetranychus urticae*, *Panonychus ulmi*, *Eriophyes pyri*, and *Bryobia rubrioculus* and the predatory mite *N. californicus.* However, the number of species detected and the prevalence of detected species on leaves were dependant on sampling method used. Both destructive sampling methods, method (2) and method (3), performed better than the current non-destructive industry standard in terms of species detection and prevalence. The largest differences were seen during the early stages of infestation for mite species other than *E. pyri*. Early detection of certain mite species is important because it can provide a more accurate estimate of the starting point for Cumulative Leaf Infested Days (CLIDs) calculations, resulting in better informed management decisions. Importantly, detection and prevalence results were similar for methods (2) and (3) despite the greatly reduced sampling effort (time required) for method (3), and overall sampling effort for method (3) was similar to that required for method (1). Therefore, in terms of both accuracy and sampling effort, method (3) outperformed the other two methods we trialled. An obvious limitation of method (3) when compared to current practice is the requirement for a stereo microscope and access to a laboratory or similar facility. Therefore, the method may be more useful for appropriately trained consultants who monitor pests in orchards on behalf of growers. Another limitation with our study was that it was limited to a single growing season in one pear orchard. We therefore recommend further research to validate our observations, and to support recommendations for growers and consultants.

Keywords: Pesticides, sampling, beneficial mites, pests, Acari, two-spotted spider mite

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