Hort Innovation

Final Report

The IPM program for the Australian macadamia industry

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Delivery partner:

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The IPM program for the Australian macadamia industry (MC16004)

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Contents

Public summary

Many pests significantly affect the Australian macadamia industry and sustainable management of these is crucial for continuing market access, productivity, profitability and maintaining industry viability. This research investigated a holistic pest management approach in Australian macadamias, with the aim of long-term and sustainable management, leading to orchard resilience.

The major pests in macadamias were examined as well as new and emerging pests. Monitoring was emphasised as the foundation of effective pest management. Cultural and biological controls, such as the integration of inter-rows to increase biodiversity and releasing biological control agents were implemented. In addition, more IPM compatible chemical controls were investigated as well as optimising pesticide use as part of the chemical rotation.

Key outcomes from this project were:

This project made many advances in integrated pest management for macadamias. To ensure the successful adoption of IPM, a 'one size fits all approach' cannot be taken. It is recommended that the results of this project need to be placed into the context of each grower's circumstances, location and farming system. Factors that need to be considered include location, varieties, spacings, tree height, adjoining vegetation and threshold tolerance.

Effective seed weevil management. When this project started, macadamia seed weevil (MSW) was a significant new pest causing up to 30% crop loss; it now causes little crop loss. A strategy for managing MSW was developed, reducing the pesticide applications required from 2 organophosphate sprays to one application of indoxacarb. Using indoxacarb stopped further egg-laying by the weevil and prevented breeding while the crop is susceptible. This strategy also removed the need for mulching, which suits the integrated orchard management (IOM) approach and reduced crop losses. It is estimated that this outcome alone has reduced crop loss by over $20 million per annum.

Adoption of IPM has increased in the industry. Regional case study sites comparing current practice and newer IPM strategies in the 4 major growing regions of Central Queensland, South East Queensland (Gympie/Glasshouse Mountains Region), Northern Rivers and Mid North Coast of NSW were evaluated in collaboration with consultants. All comparative trial sites practised IPM, albeit at different levels. Interestingly, the conventional trial sites in each region adopted findings from the higher level IPM site after they were shown to be effective.

More IPM compatible pesticides are now available to the industry. Trials at the Centre for Tropical Horticulture (CTH) at Alstonville in the Northern Rivers region of NSW evaluated more IPM compatible chemical options in combination with biological control. The trials showed that effective control can be achieved using these new insecticides and an additional benefit of these newer compounds is they do not induce secondary pest flare-ups.

Maintaining tree health is an important part of IPM, especially for boring pests such as beetles. For example, scolytid beetles are attracted to stressed trees, therefore, ensuring strong sap flow is a way to limit their potential for entry. As drought can be an issue in rain-fed environments, knowing when beetle pests are present in orchards is critical so that appropriate management strategies can be put in place. Using pheromone traps to monitor these beetle pests was a beneficial finding in this project and one that can be used by industry.

Investigating biological control for macadamia seed weevil. A PhD candidate investigated the biology and ecology of entomopathogens for MSW. Different strains of *Beauveria bassiana* and *Metarhizium anisopliae* were successful in controlling MSW in laboratory studies, but unfortunately, the entomopathogens were not successful in field conditions. This is most likely due to the instability (i.e. UV instability) of the entomopathogens.

Investigation of biological control for macadamia lace bug. A PhD study is investigating options for biological control of macadamia lace bug (MLB). A pilot study tested 12 commercially available biological control agents in laboratory conditions and found that the *Orius* bug (*Orius tantillus*) is a potential control agent. Field studies are now underway, but as this study is still in progress, results are pending.

Variations between extreme climatic conditions such as drought (2018–2019) and wet (2020–2021) favoured very different pests that needed to be managed. For example, during the drought, *Leptocoris* bugs were a first-time problem in macadamias in NSW and the incidence of different scolytid beetles increased. A lesson learned from this is the need to make an orchard more resilient to climatic effects, particularly drought. Cultural practices to conserve moisture, such as mulching and pruning would be important for this.

To support the findings of the research project, **numerous extension activities** were delivered to provide current and best practice information to the industry. This included articles in industry publications (e.g. AMS News Bulletin, NSW DPI Plant Protection Guide), factsheets (e.g. NSW DPI Primefact on macadamia seed weevil, life cycle and monitoring), presentations at MacGroups in all production regions, consultants workshops, processor field days and international conferences.

Future research should examine the following areas:

Fruit spotting bug (FSB) is the most significant pest in macadamias. Future research should continue to focus on managing it holistically, looking at cultural, biological and chemical control together. While parasites have been identified, as these are pest-specific and FSB is difficult to rear in captivity, future work should consider investigating mass-rearing systems for FSB so these parasites can be available for mass release.

As **IPM is not a stagnant system** and different pest pressures are observed between farms and regions, a system to benchmark IPM adoption and allow objective comparisons between the different strategies is required. This system would investigate the link between pest management strategies and productivity. This would allow individual growers the opportunity to assess their performance over time and also provide a way for the industry to measure the success of future research in achieving improved IPM outcomes while maintaining productivity.

Continue to provide research into new and emerging pests. In this project, new pests (e.g. *Leptocoris* spp. and bark boring beetles) emerged and there needs to be active research to react to these to ensure the industry remains viable. This approach would need to involve a step wise progression by providing an interim control strategy (e.g. minor use permit) while longer-term studies are undertaken to improve orchard resilience (e.g. adoption of resistant/tolerant cultivars). As the effects of climate change continue in all growing regions, the need to ensure pest management evolves with those changes will be required.

Further evaluations of new and emerging insecticides that are IPM compatible are required. Due to the long lead time between showing efficacy and registration, continual evaluation is needed. It is also recommended that the evaluations be handled independently and by service providers with a history of independence within the macadamia industry. This is to ensure grower confidence in using any new products released. As part of these evaluations, the effect of these chemicals on biological control agents such as MacTrix should be performed.

Using **cultural control strategies** to improve IPM outcomes should be evaluated, especially orchard design and cultivar selection to reduce pest susceptible environments. This has successfully been adopted in other crops and is considered an area currently lacking in the macadamia industry. This is particularly pertinent with the current rapid expansion of the industry and provides a great opportunity to reduce pest susceptibility and the need for intervention.

Breeding new macadamia cultivars with reduced susceptibility to pests would decrease the need for intervention. Within the context of breeding, consideration of drought tolerance as protection for beetle ingress and the effects of climate change should also be incorporated.

The full value of **increasing biodiversity in orchards** should be considered. This would include not only improving the biodiversity gained from planting inter-row crops, but also the effect on pest populations in the crop, the level of control achieved, yield and quality of production. This study should also look at the inter-row system in its entirety, for example, the potential to use inter-row biodiversity to increase pollination (and ultimately crop yield) should be considered.

Investigating potential parasites. Parasites were found in field populations of FSB and *Leptocoris* bugs. Parasites included a phorid fly (*Apocephalid* sp.) and *Trichopoda* sp. (possibly *T. pennipes*, a single specimen) and further work is required to investigate mass-rearing systems for these parasites.

Different commercially available **biological control agents** were released at various trial sites in different seasons. While all biological control agents have been shown to contribute to pest management, only MacTrix provided control at levels considered economically viable.

Keywords

Macadamias; integrated pest management; monitoring; cultural control; biological control; beneficials; biodiversity, inter-row plantings, insecticides; fruit spotting bug; macadamia seed weevil; case study sites

Introduction

Many pests significantly affect the Australian macadamia industry and sustainable management of these pests is crucial for continuing market access, productivity, profitability and maintaining industry viability. Pest management strategies have previously been developed for single pest species. These strategies, particularly for fruit spotting bugs (*Amblypelta* spp.) (Hort Innovation project MT10049) involved several approaches, including monitoring tools, chemical, biological and cultural controls, as well as a pilot study of an area-wide management approach. However, no truly integrated strategy has been developed for more than 1 or 2 of the key pests.

This project (MC16004) is part of a larger Macadamia IPM Program (MC18005) with different components (MC16003, MC16005, MC16007 and MC16008). The overall aim of the larger IPM program was to develop a pest-resilient farming system for the macadamia industry. Specifically:

- identify gaps in research for pest management in macadamias in Australia
- continue research as required on current key pests
- develop a truly integrated and sustainable management approach
- maintain and improve industry resources in pest diagnostics and IPM tools
- maintain and build the capability to respond to new and emerging pests
- build strong links to other macadamia industry programs.

The NSW DPI component of the project (MC16004) focused on assessing pest management strategies in the 4 major growing regions of Australia; Central Queensland (CQ), South East Queensland (SEQ), Northern Rivers of NSW (NRNSW) and the mid-North Coast of NSW (MNNSW). The objectives specific to this project were:

- develop an improved monitoring strategy for key pests
- develop a truly integrated management strategy for key pests in Australian macadamias
- reduce the input of chemicals through more strategic pesticide use
- foster more integration of biological and cultural controls throughout the industry
- increase awareness and identification of potentially new endemic and exotic pests of macadamias
- maintain access to current markets and contribute to access to new markets for Australian macadamias.

The pest complex affecting macadamias is summarised in Table 1. While this table lists the pests possible on macadamias, when the project commenced in 2016, there were specific pests significantly affecting the productivity of the macadamia industry in Australia. These included:

- flower and foliage pests such as macadamia lace bug (formerly *Ulonemia* spp.), felted coccid (*Acanthacoccus ironsidei*, formerly *Eriococcus ironsidei*), macadamia flower caterpillar (*Cryptoblabes hemigypsa*)
- mites and thrips species
- kernel and post-harvest pests such as fruit spotting bugs (*Amblypelta* spp.), macadamia seed weevil (*Kuschelorhynchus macadamiae,* formerly Sigastus weevil), macadamia nut borer (*Cryptophlebia ombrodelta*), banana fruit caterpillar (*Tiracola plagiata*) and kernel grub (*Assaria seminivale*)
- pests attacking the branches, trunk and nuts such as bark beetles (*Cryphalus subcompactus*, *Hypothenemus* spp. or *Xyleborus* sp.).

Table 1: List of macadamia pests and comparison to Ironside (1983) status.

1 = key pest; 2 = sporadic pest; 3 = induced pest; 4 = potential pest.

Common name	**Scientific name**	**Part of macadamia affected**	**Pest status according to Ironside (1983)**	**2022 comments**
Macadamia flower caterpillar	*Cryptoblabes hemigypsa*	Flower	1	A problem in dry districts
Macadamia lace bugs	*Cercotingis decoris* (formerly *Ulonemia* sp.), *Proteatingis howardi* (predominantly in NSW)	Flower	4	At least 4–5 species on commercial trees
Macadamia felted coccid	*Acanthacoccus ironsidei*, formerly *Eriococcus ironsidei*	Flower, nuts, branches, trunks	3	Secondary pest where SP insecticides have been used late or lack of nursery hygiene
Banana fruit caterpillar	*Tiracola plagiata*	Nuts (nutlets)	Not mentioned	A problem in Central QLD only due to mulch
Auger beetle	*Xylopsocus sp.* *X. gibbicollis*	Branches and trunks	Not mentioned	Severe on macadamia planted on flood plain branches and trunks after water logging
Pinhole borer	*Hypothenemus eruditus* *Hypothenemus seriatus*	Nuts	Not mentioned	*H. eruditus*, mainly NSW *H. seriatus*, mainly Bundaberg
Ambrosia beetles	*Xyleborus* spp. *Xylosandrus crassiusculus* *Cnestes solidus* *Euwallacea* nr. *fornicatus*	Branches and trunks	Not mentioned	Attacks hardwood Sap stain fungal associations *Dothriella* and *Botryosphaeria*
Bark beetles	*Cryphalus subcompactus*	Branches	Not mentioned	Ringbarks branches; attracted to trees signalling stress
Longicorn beetles	*Urocanthus* spp. and others	Branches	Not mentioned	Exacerbated by dry weather
Black citrus aphid	*Toxoptera citricida*	Flowers, young shoots	2	Incidental
Flower looper	*Gymnocelis subrufata*	Flowers	4	Incidental
Spotting bugs	*Amblypelta nitida* *Amblypelta lutescens lutescens*	Flowers, nuts	1	*A. nitida*, NSW and QLD *A. l. lutescens*, QLD only
Green vegetable bugs	*Nezara viridula*	Flowers, nuts	4	Problem near favourite hosts (i.e. soy beans)
Leptocoris bug	*Leptocoris tagalicus* *Leptocoris rufomarginatus*	Nuts	Not mentioned	Exacerbated by dry weather and proximity to foam bark and golden rain trees
Macadamia kernel grub	*Assara seminivale*	Nuts	4	Exacerbated in varieties with open micropyle
Nut petiole stem borer	*Paranepsa amydra*	Young nut	Not mentioned	Incidental
Macadamia leaf miner	*Acrocercops chionosema*	Foliage	1	A problem only in young trees
Macadamia nut borer	*Cryptophlebia ombrodelta*	Nuts	1	Only a problem if not correctly managed (i.e. possibly due to weather)

Table 1: List of macadamia pests and comparison to Ironside (1983) status (cont.)

1 = key pest; 2 = sporadic pest; 3 = induced pest; 4 = potential pest.

Common name	**Scientific name**	**Part of macadamia effected**	**Pest status according to Ironside (1983)**	**Comments**
Macadamia seed weevil (formerly Sigastus weevil)	*Kuschelorhynchus macadamiae*, formerly *Sigastus* sp.	Nuts	Not mentioned	Only a problem if not correctly managed
Macadamia twig girdler	*Neodrepta luteotactella*	Foliage, thin branches, twigs	1	A problem only in young trees
Broad mite	*Polyphagotarsonemus latus*	Foliage, young shoots	Not mentioned	Feeds on the upper side of foliage; young buds
Citrus flat mite	*Brevipalpus lewisi*	Foliage, young shoots	Not mentioned	
Red-shouldered leaf beetle	*Monolepta australis*	Flowers, foliage, young nuts	2	Incidental (weather dependent)
Latania scale	*Hemiberlesia lataniae*	Nuts, foliage, branches	2	Induced pest
Long soft scale	*Coccus longulus*	Leaves and twigs	Not mentioned	Incidental
Macadamia mussel scale	*Lepidosaphes macadamiae*	Leaves	4	Incidental
Macadamia white scale	*Pseudaulacaspis brimble*	Leaves and nuts	4	Incidental
Oleander scale	*Aspidiotus nerii*	Leaves	Not mentioned	Incidental
Argentinian scarab	*Cyclocephala signaticollis*	Roots	Not mentioned	Exotic pest, a problem with black soil
African black beetle	*Heteronychus arator*	Roots	Not mentioned	A possible issue on former cane land
Brown cockchafer	*Rhopaea magnicornis*	Roots	Not mentioned	A possible issue on red soil on former cane land
Tea mosquito bug	*Helopeltis* spp.	Flower panicles, young shoots, developing fruit	Not mentioned	A problem in Asian macadamia now in Brisbane QLD (endemic to northern QLD)
Scirtothrips	*Scirtothrips dorsalis*. *Scirtothrips albourmaculatus*	Foliage, young shoots, nuts	1	Induced pest
Greenhouse thrips	*Heliothrips haemorrhoidailis*	Foliage, young shoots, nuts	4	Induced pest
Red-banded thrips	*Selenothrips rubrocinctus*	Foliage, young shoots, nuts	4	Induced pest
Plague thrips	*Thrips imaginis*	Flowers, nuts foliage	Not mentioned	Induced pest
Western flower thrips	*Frankliniella occidentalis*	Foliage, young shoots, nuts	Not mentioned	Problem with proximity to primary host (i.e. vegetable)

Historically, most of these pests were controlled exclusively by applying broad-spectrum insecticides. Over the past 30–40 years, the negative effects on human and environmental health from a chemistry-only approach to control pests and diseases in agriculture systems have been recognised (Carson, 1962), resulting in a move towards 'softer' options. However, there is less tolerance for chemical management practices in agricultural systems due to increasing awareness of the effects of human-based activities on the natural environment and encroachment of urbanisation adjacent to agricultural production areas.

Integrated pest management (IPM) was first developed as a strategy in agricultural systems during the 1970s as a response to the growing knowledge and concern associated with pesticide use. As the name suggests, the approach was about transitioning away from the exclusive use of pesticides for pest control by integrating other elements such as cultural practices (e.g. manual and/or mechanical practices to alter the soil and crop environment) and biological control (i.e., using insect, fungal or bacterial species that kill or disrupt pest species life cycles). More broadly, IPM is seen by many as any practice that does not involve the use of pesticides. However, for an IPM strategy to be successful, it must allow the user to maintain an acceptable degree of revenue/profit from their enterprise, which is often not achievable without some use of chemical pest control. To that end, we define IPM as a 'sustainable approach to pest control meeting the social, economic and environmental expectations of stakeholders using a combination of methods including cultural control, biological suppression and targeted chemistry. Successful IPM is reliant on regular monitoring and intervention is made when economic damage thresholds are exceeded'.

Pest management strategies for macadamia in the past have been developed for single pest species. These strategies have varied in their scope; from partial to comprehensive. The use of broad-spectrum insecticides has meant that while strategies are pest-specific, any pest (target or non-target) has been controlled. As the system changes and we use more targeted chemistry, pests that were considered minor can become major, but others might also disappear as biological controls are also effective.

The current approach for fruit spotting bugs (*Amblypelta* spp.) in macadamia serves as the best example of an integrated pest management strategy as it incorporates several techniques, including monitoring tools for accurate life cycle identification and associated knowledge of when to use the range of chemical, biological and cultural controls available. The strategy for FSB continues to evolve with pilot studies into area-wide management monitoring. Enduring success for the Australian macadamia industry is reliant on the continued development and adoption of IPM strategies for all insect pests. MC16004 is a critical project to help achieve this success.

Successful pest management is influenced by the interplay of these factors and an orchardist's preference for biological, cultural and chemical controls that align with their social, economic and environmental (triple bottom line) expectations in orchard management. As such, it is beyond the scope of this project to provide prescriptive recommendations for pest control. Rather, the results from this work are aimed at providing a snapshot of different approaches and their relative success in achieving each pillar associated with triple bottom line outcomes underpinned by monitoring and evaluation (Figure 1).

The program was developed in a consultative way, with the project steering committee/project reference groups comprised of members from the industry, including growers and consultants, the industry peak body (Australian Macadamia Society, AMS), IPM consultants (IPM Technology) and Hort Innovation.

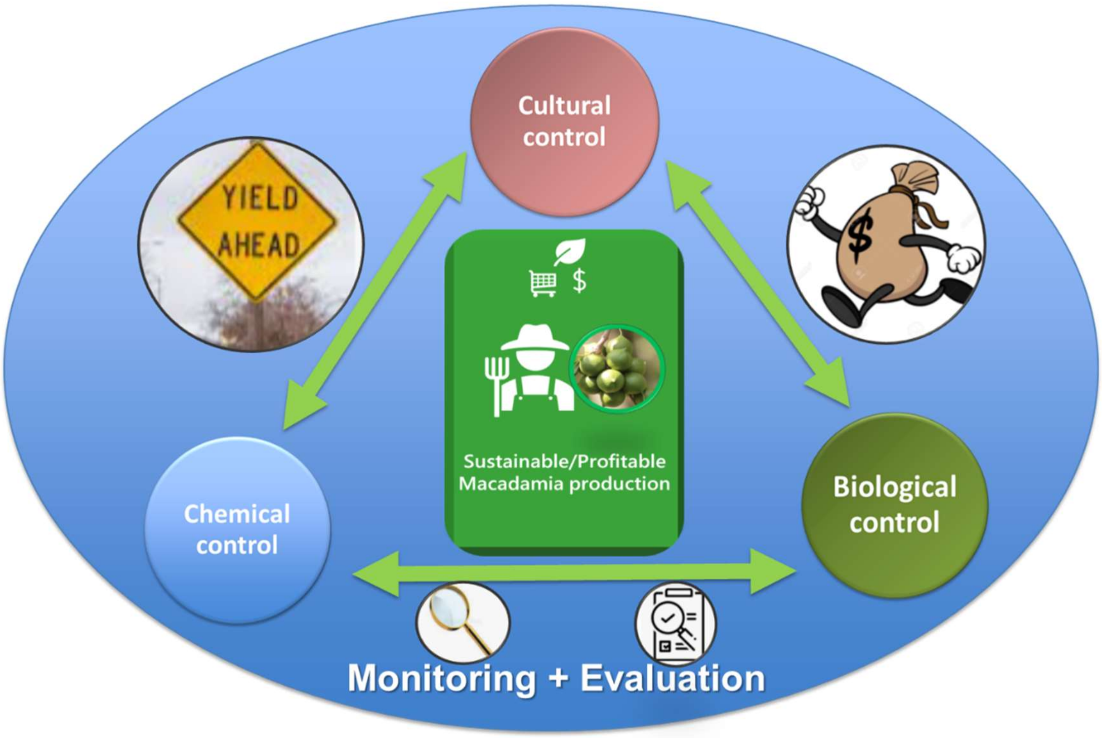

Figure 1: The aim of the project – sustainable macadamia production, based on cultural, biological and chemical control underpinned by monitoring and evaluation.

Methodology

This project (MC16004) focused on the following areas of investigation:

1. **Gap analysis**
2. **Ecology and biology studies**
3. **IPM strategies**
4. **Biological control**
5. **Monitoring strategies**
6. **Cultural control**
7. **Chemical screening**
8. **Industry adoption**
9. **Diagnostics and response**
10. **Linkage**

1. Gap analysis

A gap analysis was undertaken by performing a literature review (Appendix 1.1. and Appendix 1.1.1.) exploring 84 references, covering IPM in general, IPM in other tropical fruit and nuts and also previous research in macadamias. This was then combined with comments and input from industry representatives, leading growers and pest consultants to identify the key gaps and develop a wholistic gap analysis. The gap analysis results were used to refine and focus future research, for example, focusing ecology and biology studies on improving the understanding of macadamia seed weevil (as much is known about other key pests).

2. Ecology and biology studies

The ecology and biology of macadamia pests and beneficials were combined with other studies within this project, including the biodiversity trial at the Centre for Tropical Horticulture, case study sites in the IPM strategy trials (Appendix 1.2.) and using monitoring strategies for beetle pests (see Appendix 1.2.3.). Damage identification and direct monitoring, which included the following, were also used:

- Visual observation, counts of pests/beneficials, using magnifying glasses (hand lenses or Optivisor headband magnifiers)

- Pheromone trapping using commercially available traps and lures

  - Delta traps and pheromones for macadamia nut borer (MNB)
    - Delta traps were placed at the case study sites and also the trial blocks at CTH Alstonville
    - Numbers of ♂ MNB caught were checked weekly at CTH and fortnightly at case study sites and numbers recorded
    - Lures were changed fortnightly
    - Sticky plates in the trap were changed every 4 to 6 weeks

  - Intercept trap and lures for banana spotting bugs (BSB)
    - Pheromone traps for BSB were used at the case study sites in Queensland
    - Traps were changed fortnightly and numbers recorded
    - Lures were changed every 6 weeks

  - Panel traps (coffee berry borer traps (BOCAP®)), 'Ambro' lures and a methanol-ethanol mixture (3:1) for scolytid beetles
    - Panel traps were emptied fortnightly
    - The content from the collecting bottle of the trap was poured through a tea strainer and collected beetles were put into a specimen jar
    - Beetles were examined at Wollongbar Primary Industries Institute (WPII)

  - Lindgren funnel traps and INRA lures for cerambycid beetles
    - Cerambycid traps were used at CTH Alstonville and a commercial farm at Caniaba

      - Specimens were collected from the trap container and put into a specimen jar
      - Beetles were examined at Wollongbar WPII
      - Lures were changed every 3 weeks

- Monitoring hedges (including other hosts such as *Murraya paniculata* and *Macadamia ternifolia*) for spotting bugs (FSB and BSB)
    - Monitoring hedges were visually checked for spotting bugs weekly at CTH and fortnightly at case study sites
    - Numbers and life stages of spotting bugs were recorded
    - The percentage of 5th instar nymphs of the total number of spotting bugs seen was calculated
    - Numbers from monitoring hedges at CTH Alstonville were shared with a group of consultants, processors and growers via e-mail between November and the end of January
- Yellow sticky traps for intercepting general pests and beneficials
    - Yellow sticky traps were placed at the case study sites and the trial sites at CTH Alstonville
    - Traps were replaced every 2 weeks
    - Traps were examined at WPII for pests and beneficials
- Checking falling nuts fortnightly between October and February for
    - MSW (presence of eggs marks, eggs, larvae and adults)
    - FSB (presence of damage)
    - MNB (presence of eggs, tunnels)
    - At the trial sites at CTH Alstonville, nuts on the ground were collected and visually checked for MNB tunnels and MSW egg marks
    - Nuts were cut and checked for MSW eggs or larvae and FSB damage

For MSW ecology, a key component was monitoring nut size to determine if the threshold previously determined of 8 mm nut diameter for viable reproduction was valid. In addition, samples were collected and time taken for generation development was examined, along with the susceptibility of nut stages.

For MLB (*Cercotingis decoris* and *Proteatingis howardi*, formerly *Ulonemia* spp.), a PhD in collaboration with Southern Cross University (SCU) on its biology, ecology and biological control options was commissioned and started on 1 April 2020 and is expected to be completed by 1 April 2023.

The PhD study is exploring different aspects of MLB ecology and biology, specifically:

- Determining the number of generations and the life cycle of MLB in laboratory studies (details are in Appendix 4.6)
- Whether flowering triggers a rapid breeding response in MLB in a field trial (details are in Appendix 4.6)
- Determination of movement of MLB both within orchards and in the environment surrounding orchards, trapping MLB with yellow sticky traps (Appendix 4.6.)

MLB populations were monitored in different orchards with different management for 3 flowering seasons with yellow sticky traps that were changed monthly from April 2019 to December 2021. Traps were all placed in cv. 246 trees. The number of adults caught per trap was counted. Compared were the following:

- Four treatments in the main IPM trial (Entomology block) (Appendix 1.3.1.)
- Effect of tree density (3.5 × 10 m vs. 7 × 10 m vs. 10 × 10 m) (Density block) (Appendix 2.5.2.)
- Effect of different varieties and spread of flowering on MLB populations in an unsprayed block with continuous out of season flowering (Sink block) (Appendix 2.5.2.) vs. an unsprayed block with a single variety (Density block) (Appendix 2.5.2.) vs. a managed block (Entomology block) (Appendix 1.3.1)
- Cards were taken back monthly to WPII entomology laboratories and checked for MLB numbers. Details are described in Appendix 2.5.2.

Biodiversity trial at the Centre for Tropical Horticulture

A previously unsprayed block was used for biodiversity investigations. Inter-rows were planted with a mix of flowering species to act as a reservoir for beneficial insects. The plant species selected were made after discussions with Abigail Makim from BioResources and Tony Hodges from Williams, who have had significant experience in this area and have undertaken a complimentary study (MC16008). The block design is shown in Appendix 1.3.2. (Figure 1.3.2.1). Seeds were sown in February 2020 by hand, after the drought broke. Blocks were monitored between October and December 2020 for pests and beneficials using the standard monitoring program as described in Appendix 1.3.2., including visual observations, yellow sticky traps for general pests and beneficials, cutting nuts for MNB, MSW and FSB.

Harvest and kernel assessment

Harvest yields and samples for assessment were taken from each tree selected for monitoring (marked trees in Figure 1.3.2.1.). Samples were assessed for insect damage to the husk, de-husked and then dried and a kernel recovery assessment was carried out. Details of the methodology for harvest, nut in husk and kernel assessments are provided in Appendix 1.2.4.

3. IPM strategies

To investigate IPM strategies, different management practices were assessed and evaluated on 8 case study trial sites and at the Centre for Tropical Horticulture (CTH), Alstonville NSW.

Case study trial

In the 4 major growing regions (Central Queensland (Bundaberg), South East Queensland (Gympie Glasshouse Mountains region), Northern Rivers (Alstonville) and Mid North Coast of NSW (Nambucca Heads-Macksville region)), 2 sites with different management strategies were selected. Research on case study sites was managed in collaboration with commercial crop consultants. Farms used their management strategies and were reported on and measured throughout the project.

Two case study sites were set up in each of the 4 major macadamia growing areas by collaborating consultants as follows:

- Central Queensland, Bundaberg Region: Eddy Dunn
- Glasshouse Mountain/Gympie Region: Chris Fuller
- Northern Rivers Region: Jarrah Coates
- NSW Mid North Coast Region: Bob Maier

In each area, a site with a high level of IPM management and one with more reliance on broad-spectrum insecticides were chosen. An overview of the case study farm sites in the 4 different regions is shown in Table 1.2.1. and Figures 2 to 5. A description by the collaboration consultant for each of their case study sites is presented in Appendix 1.2.1.

Treatments, including cultural, biological and chemical controls, were common practice for each case study site using the consultant's recommendations. An overview of treatments applied at each site is shown in Figures 2–5. A detailed description of the treatments is given in Appendix 1.2.2. (Tables 1.2.2.1 to 1.2.2.8). Figures 2 to 5 show the differences in management at the different sites and over time. Each site used some level of IPM.

Monitoring

Case study sites were monitored fortnightly for pests and beneficials between July and March each season.

A monitoring protocol was developed at the beginning of the project in collaboration with the participating consultants. An example of a monitoring sheet and general information on monitoring and thresholds is shown in Appendix 1.2.3.

Monitoring techniques were as follows (also see monitoring in the ecology and biology studies section above):

- visual observations: pests and beneficials identified in functional groups
- yellow sticky traps: pests and beneficials identified in functional groups
- pheromone traps: macadamia nut borer, scolytid beetles, banana spotting bug in QLD (*Amblypelta l. lutescens*)
- monitoring hedges: FSB and BSB. This was a visual observation of the presence of FSB and BSB (adults and nymphs) on alternative host plants adjacent to the orchard.

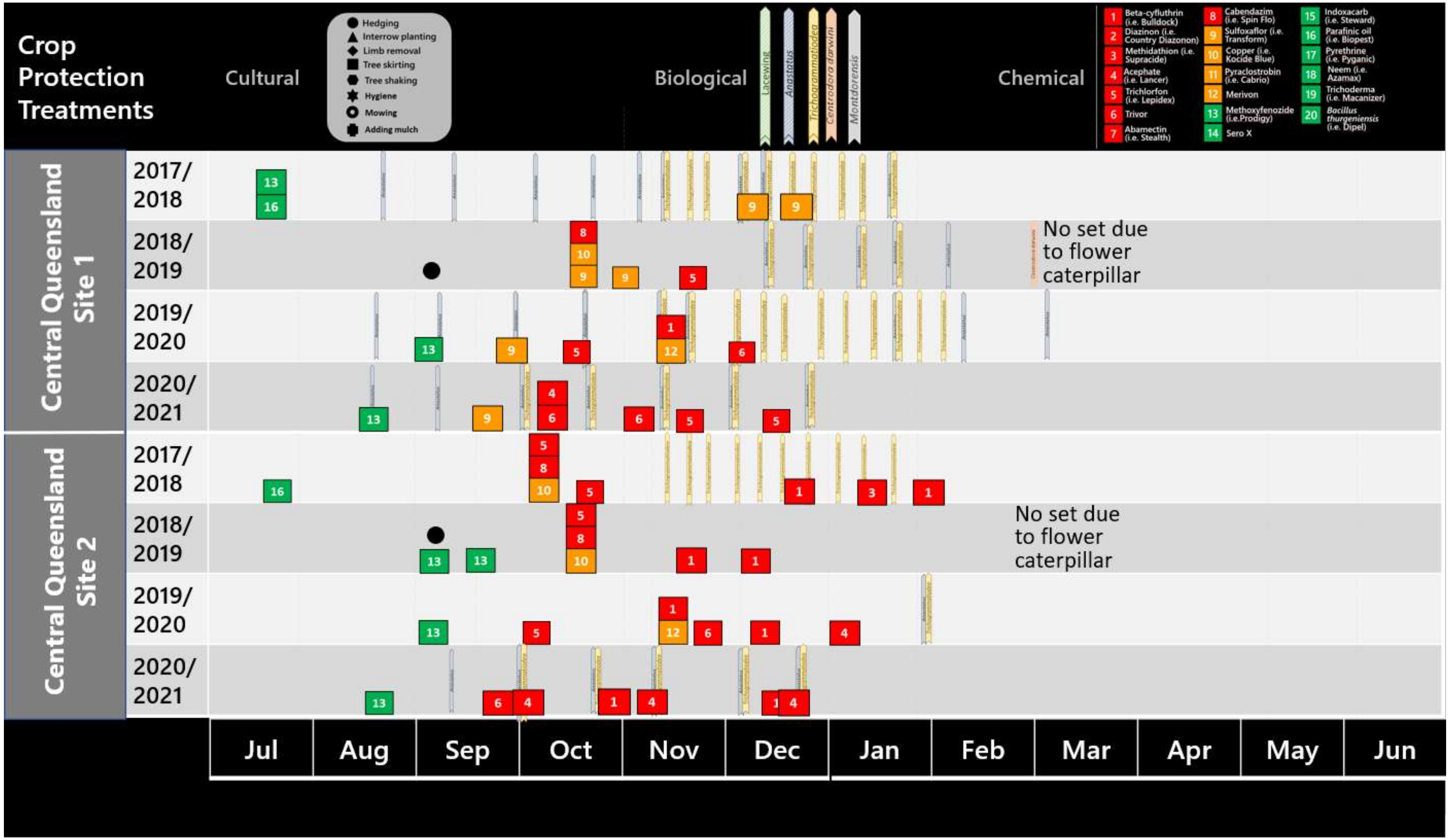

Figure 2: Treatments at sites in the Central Queensland region.

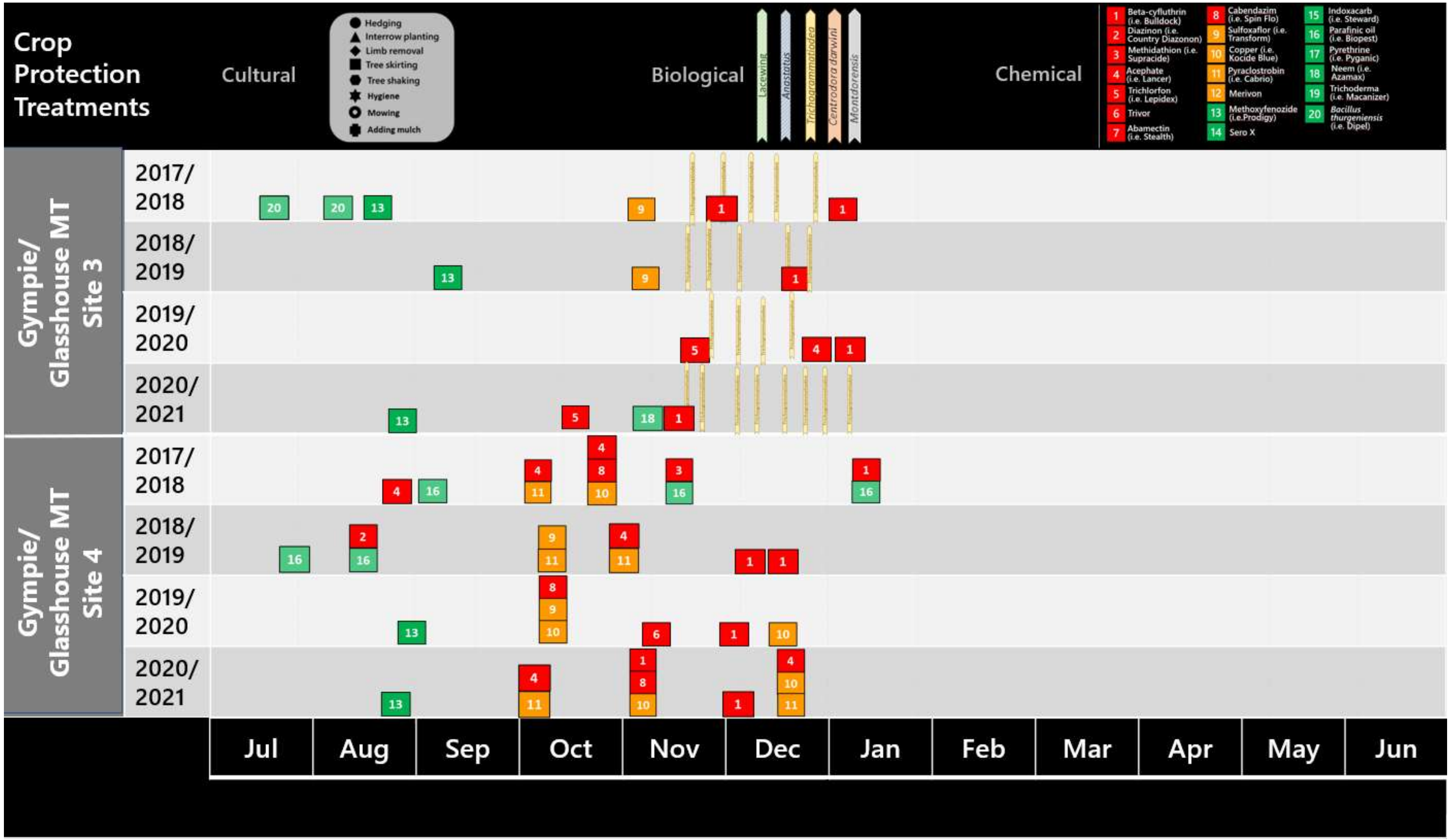

Figure 3: Treatments at sites in the Gympie - Glasshouse Mountain region.

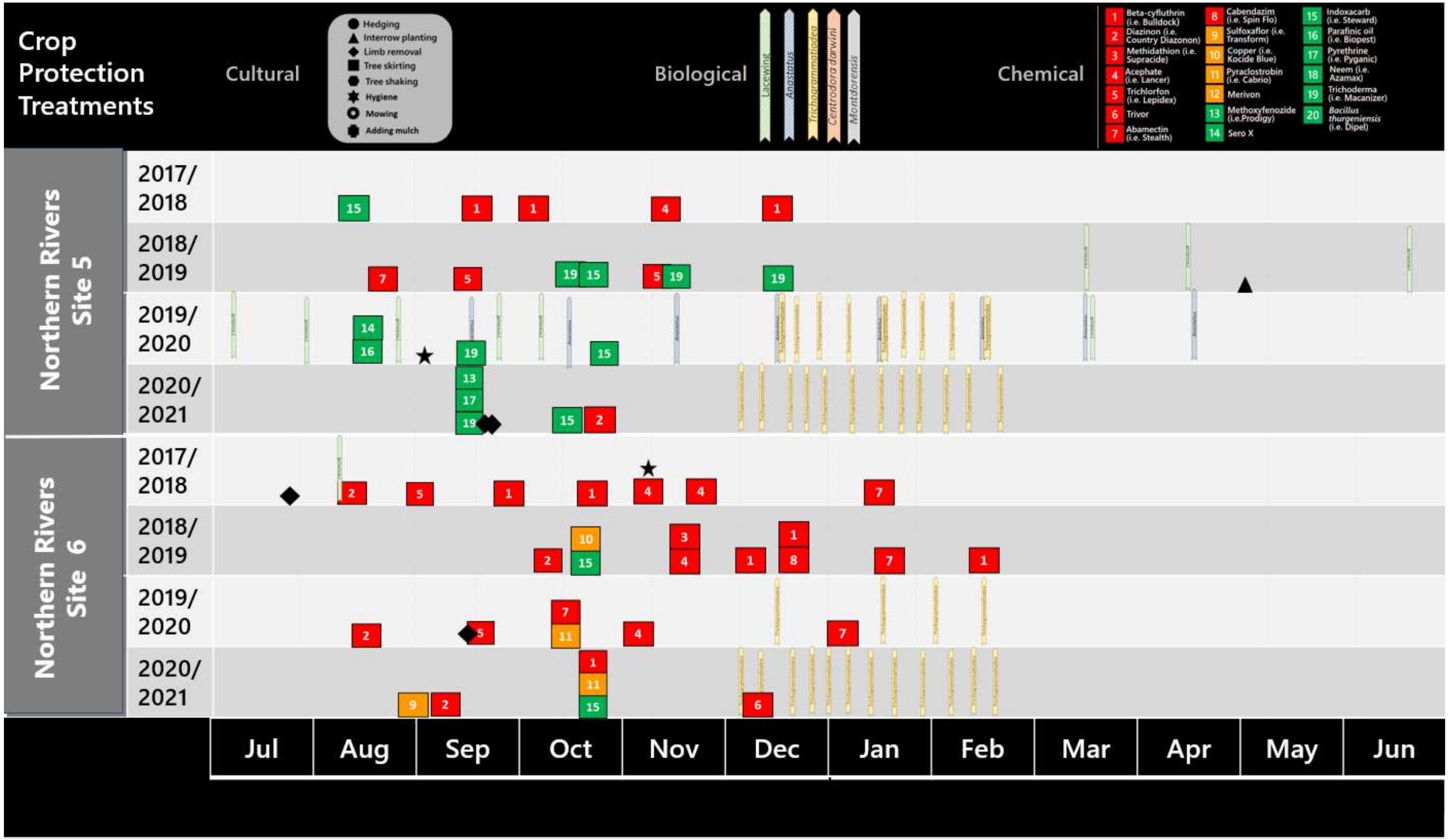

Figure 4: Treatments at sites in the Northern Rivers region.

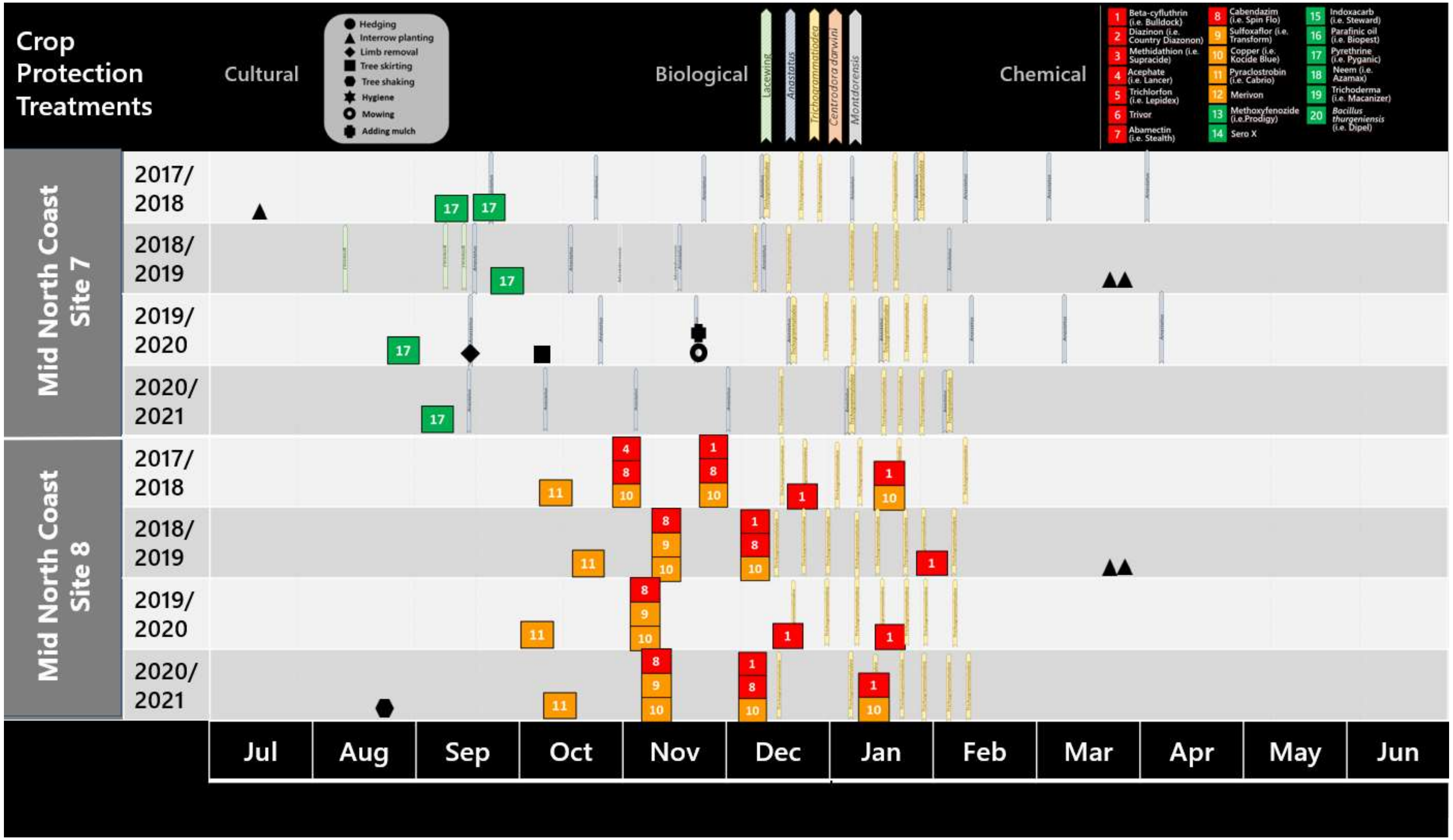

Figure 5: Treatments at sites in the Mid North Coast region.

Harvest and kernel assessment

Harvest yields and samples were taken from each trial site and sent to WPII where they were processed and assessed. Samples were visually assessed for insect damage to the husk (including thrips, felted coccid, MNB eggs, parasitism and tunnels, MSW feeding and oviposition marks and husk spot lesions) using Optivisor headband magnifiers. Husks were also cut to check for FSB damage.

After the husk assessment, nuts were de-husked in a small industrial de-husker and then dried in Thermoline dehydrating ovens for 6 days. After drying, nuts were cracked in a small industrial cracker and shells and kernels were separated, before industry standard kernel quality assessment (kernel recovery) was carried out.

During the kernel recovery process, the kernels were sorted into different categories, including different insect damage (i.e. MNB, FSB, *Leptocoris*, kernel grub), immaturity, discolouration, fungal infection and sound kernel. The proportion of defective kernels compared to total kernels was calculated.

Details of the methodology for harvest, nut in husk and kernel assessments are provided in Appendix 1.2.4.

IPM trial at CTH

In the main trial at CTH, different IPM options were compared side by side, including some of the new release chemicals. These trials combined cultural, biological and different chemical rotations for efficacy and IPM suitability. The trial design is shown in Appendix 1.3.1., Figure 1.3.1.1. and the detailed methodology for the field trial is described in Appendix 1.3.1. The list of treatments applied in different seasons is listed in Appendix 1.3.1. and Tables 1.3.1.1. to 1.3.1.4. For evaluation of the different treatments, pests and beneficials were monitored as described above and yield and damage to nut in husk and kernel were assessed as described above. For the latter, industry standard kernel quality assessment was used. Details of assessment methodologies are described in Appendix 1.3.1. The trial design is shown in Figure 1.3.2.1. The choice of chemistry to use was determined with input from the project steering committee.

The results from the different treatments were provided to the QDAF benchmarking project team and analysed for the cost-benefit of the treatments.

4. Biological control

A PhD study at the University of Southern Queensland was initiated to investigate options for using *Beauveria bassiana* and *Metarhizium anisopliae* for managing MSW. Details are described in Appendices 4.1. to 4.5.

The PhD study in collaboration with the University of Southern Queensland on entomopathogenic fungi

Research articles were reviewed for past use of entomopathogenic fungi for the control of selected beetle pests and their effectiveness. Details are described in Khun et al. (2020c) (Appendix 4.3.).

Characterising Beauveria and *Metarhizium anisopliae* strains

Molecular methods and screening in Petri dishes as described in Khun et al*.* (2020 a) (Appendix 4.1.).

Transmission of fungal conidia from cadavers

In laboratory trials, whether and how conidia can be transmitted from conidiated weevil cadavers to live weevils was investigated. Details are described in Khun et al*.* (2021a) (Appendix 4.4.).

Compatibility of entomopathogenic fungi with pesticides

Different pesticides registered for use when MSW are active were tested in Petri dishes in the laboratory for compatibility with *Beauveria bassiana* and *Metarhizium anisopliae*. Details are described in Khun et al*.* (2020b) (Appendix 4.2.).

Interaction of entomopathogenic fungi with pesticides

In laboratory and glasshouse trials, the compatibility of both pathogens with acephate and indoxacarb (the insecticides registered in Australia for MSW management) was demonstrated and synergistic interactions were explored. Details are described in Khun et al. (2021b) (Appendix 4.5.).

A small field trial tested the efficacy of *B. bassiana* using different application techniques: foliar, bare soil and grass or mulch bed. The ability to overwinter was also tested when the entomopathogen was applied in March. Details of the trials are described in Appendix 4.7.

Beauveria bassiana was evaluated as a foliar and ground application in the field at CTH Alstonville and a commercial farm at Tregeagle (Northern Rivers). Reduction in nut drop due to MSW was the key assessment criterion.

A PhD study at Southern Cross University that is investigating biological control options for MLB was commissioned and continues. As part of that PhD, 12 species of commercially available predators (purchased from Bugs for Bugs) were evaluated for their potential against MLB. The MLB were exposed to the different species separately in a Petri-dish experiment. Details are described in Appendix 4.6. The most successful of these is currently being evaluated in a field trial.

Apocephalus sp. (phorid fly) in fruit spotting bug colonies

A phorid fly species (*Apocephalus* sp.) has been noted as a naturally occurring parasite of FSB. Phorid fly pupae were regularly collected from dead bodies of the FSB colony, originating from individuals that were field collected. Flies were kept and numbers and dates recorded. Details are described in Appendix 4.8.2. and Table 4.8.2.1. and (Huwer et al. 2015b) This parasite was quite effective in the colony and should be further assessed in the laboratory and field.

<u>IPM Trials</u>

Biological control was integrated into the main trials at the case study sites and the IPM trial at CTH.

Case study trial

Biological control agents were purchased from BioResources (MacTrix and *Anastatus*) and Bugs for Bugs (green lacewings and *Montdorensis* mites). Releases were made as described in Appendix 1.2.2. (Tables 1.2.2.1 to 1.2.2.8). One season, small numbers of *Centrodora darwinii* were also provided to the Bundaberg case study sites (Table 1.2.2.1).

IPM trial at CTH

Biological control agents were purchased from Bugs for Bugs (green lacewings and *Montdorensis* mites) originating from colonies at Wollongbar Primary Industries Institute (MacTrix and *Centrodora darwinii*). Releases were made as described in Appendix 1.3.1. (Table 1.3.1.1).

5. Monitoring strategies

A monitoring protocol for the trials was developed in collaboration with the pest consultants managing the case-study trials. The monitoring protocols included visual observations, monitoring hedges for fruit spotting bugs (FSB and BSB) and pheromone traps for MNB. Details are described in Appendix 1.2.3.1. Monitoring included visual assessment, yellow sticky traps, a monitoring hedge with alternative hosts for FSB and pheromone traps for MNB, FSB and scolytid beetles as described above.

Yellow sticky traps

Commercial yellow sticky traps (i.e., from Bugs for Bugs) were deployed at trial sites and checked regularly for pests and beneficials. Details are described in Appendix 1.2.3.

Monitoring hedges for fruit spotting bugs (both Amblypelta spp.*)*

Monitoring hedges at or close to the trial sites were checked weekly (CTH) or fortnightly (case study sites) for nymphs and adults of FSB and BSB. Details are described in Huwer et al. (2016) (Appendix 7.6).

Pheromone trap for banana spotting bug

Commercial pheromone traps for BSB were provided by OCP for the Queensland case study sites. Details for monitoring traps are described in Huwer et al. (2016) (Appendix 7.6).

Pheromone traps for macadamia nut borer

Commercial delta traps with sticky plate inserts (i.e., ISCA Technologies, California) and pheromone lures (impregnated rubber septa) manufactured by Dr Vickers were used for monitoring MNB as described in Huwer et al. (2011). Lures (half a lure per trap) were changed fortnightly and moths on sticky plates were counted.

Pheromone traps for scolytid beetles

Commercial traps for coffee berry borer (Brocap®) and different commercial lures for different scolytid beetle species were used at the case study sites, at CTH and other selected orchards with damage and checked regularly. Details are described in Appendix 1.2.3.

Pheromone traps for cerambycid beetles

New lures for cerambycid beetles are in trials around the world, Alain Roques (INRAE France) and Myron Zalucki (UQ) provided NSW DPI with access to compounds for comparative work in summer and spring 2020. A macadamia farm at Caniaba, west of Lismore NSW, which was badly drought-affected in 2019–2020, and the CTH Alstonville sites were chosen. The new lures were compared to the Ambro lure and the methanol/ethanol trapping system (Appendix 1.2.3.).

Light traps for scarab beetles

A commercial macadamia farm was affected by scarab beetles. Light trapping was conducted to gain an understanding of scarab beetle populations on the farm (Appendix 1.2.3.).

6. Cultural control

Cultural control was integrated into the main trials at the case study sites and the IPM trial at CTH.

Inter-rows and biodiversity

The trial aimed to investigate if increased biodiversity and the subsequent increase in beneficial insects would be sufficient to manage some of the pests, particularly MLB. While there are papers discussing the influence of inter-row crops on pest populations, few of them include a link to yield. Measuring yields has to be considered an important factor for IPM adoption, as stated by Herz et al. (2019) “in terms of interest for the farmer, these data are necessary to evaluate the purpose of such measures for fruit growing and to convince growers about their adoption and implementation on a long term”.

An unsprayed block of macadamias was used for the biodiversity trial from 2020 to 2021. The trees were all cultivar 246. Originally the block was planted to investigate the effect of tree density on pests, particularly FSB. The block was planted in 2007 at 3 different densities as follows: 10 × 3.5 m x 10 × 7 m and 10 × 10 m. The block is close to houses and therefore, has not been sprayed with insecticides. Since 2015 the annual crop yield from this block has been less than a kilo of nuts per tree due to MLB and MSW damage. To determine the effect of MLB on crop yield and quality, the block was sprayed with indoxacarb (Steward®) at 50 mL/100 L and organosilicone surfactant fluid (Designer®) at 10 mL/100 L on 31 October 2019 and again in October 2020 to reduce MSW populations. The block design is shown in Figure 1.3.2.1.

Canopy management

Canopy management was included in trials to increase ventilation, light penetration and spray coverage.

Case study trial

Cultural control was integrated as part of the overall management at the case study sites (i.e. management of inter-rows and pruning were included). Skirting, limb and tree removal were undertaken and inter-rows were seeded with flowering plants. Details are described in Appendix 1.2.2.

IPM trial at CTH

Cultural control was integrated as part of the overall management of the CTH IPM trial (i.e. hygiene, MSW-infested nuts were removed, and tops were taken out to 6 m in centre rows in the entomology block). This included mulching MSW-infected nuts and using a hedger to lower tree height. Additionally, selective limb removal was applied. Details are described in Appendix 1.3.1. (Table 1.3.1.1).

7. Chemical screening

Many new chemicals were screened in bio-assays against key pests, with the number of new chemicals evaluated as follows:

- Macadamia lace bug 15
- Felted coccid 3
- Macadamia nut borer 3
- Macadamia seed weevil 9
- Fruit spotting bugs 16
- *Leptocoris* spp. 15

Note: As part of this research work, evaluation of potential chemistries for the control of a range of pests was undertaken. This work involved testing unregistered (in macadamia) products and utilised current registered/permitted products (in macadamia) as a baseline for comparison. The research also examined the efficacy of currently registered (in macadamias) products against new and emerging pest complexes for which the product is not registered. If a product showed efficacy within the research project, this is not an endorsement of that product and only registered products should be utilised.

Table 1.1 specifies the products evaluated and their registration for use within macadamias status at the time of publication of this report (September 2022). Only registered and/or permitted products should be used and as registrations can change, before using and pesticide, check for registration with the APVMA (www.apvma.gov.au).

Table 1.1. Chemicals evaluated and registration status in macadamia utilised within this research project.

Product Name	APVMA Registration
25 Naphalene Imtrade	At time of evaluation unregistered
25 xylene Imtrade	At time of evaluation unregistered
Actara	At time of evaluation unregistered for use in macadamia
Agral	Registered/permitted at time of evaluation (wetting agent)
Altacor	At time of evaluation unregistered for use in macadamia
Avatar	At time of evaluation unregistered, subsequently registered/permitted for use in macadamias
B27 Spore	At time of evaluation unregistered
B48 Spore	At time of evaluation unregistered
BAS 440	At time of evaluation unregistered
BAS 450	At time of evaluation unregistered
BAS 550	At time of evaluation unregistered
Bifenthrin 300	At time of evaluation unregistered for use in macadamia
Biopest oil	Registered/permitted at time of evaluation for use in macadamia
BNV1027	At time of evaluation unregistered
Bond	Registered/permitted at time of evaluation (adjuvant)
Bulldock	Registered/permitted at time of evaluation for use in macadamia
Cabrio	Registered/permitted at time of evaluation for use in macadamia
Carbaryl	Registered/permitted at time of evaluation for use in macadamia
Chess	At time of evaluation unregistered for use in macadamia
Copper Sulphate	At time of evaluation unregistered for use in macadamia
Cyborg Plus	At time of evaluation unregistered, subsequently registered/permitted for use in macadamia
Daniels xxtra BB spore	At time of evaluation unregistered
DC123	At time of evaluation unregistered
DC143	At time of evaluation unregistered
DC154	At time of evaluation unregistered
DC163	At time of evaluation unregistered
Designer	Registered/permitted at time of evaluation (adjuvant)
Diazinon	Registered/permitted at time of evaluation for use in macadamia
Du Wett	Registered/permitted at time of evaluation (adjuvant)
Endosulfan	Registered/permitted at time of evaluation. No longer registered/permitted for use
Ethrel	Registered/permitted at time of evaluation for use in macadamia
Exirel	At time of evaluation unregistered for use in macadamia
Grandivo	At time of evaluation unregistered for use in macadamia
Hasten	Registered/permitted at time of evaluation (adjuvant)
Imidan	At time of evaluation unregistered for use in macadamia
Imitrade Dictate Duo	At time of evaluation unregistered for use in macadamia
Lancer	Registered/permitted at time of evaluation for use in macadamia
Lannate	Registered/permitted at time of evaluation for use in macadamia (QLD only)
Lebaycid	At time of evaluation unregistered for use in macadamia. No longer registered/permitted for use

Table 1.1. Chemicals evaluated and registration status in macadamia utilised within this research project (cont.)

Product Name	APVMA Registration
Lepidex 500	Registered/permitted at time of evaluation for use in macadamia
Lorsban	Registered/permitted at time of evaluation
Mainman	At time of evaluation unregistered for use in macadamia
Malathion	Registered/permitted at time of evaluation for use in macadamia
Methidathion	Registered/permitted at time of evaluation. No longer registered/permitted for use in macadamia
Movento	At time of evaluation unregistered for use in macadamia
Nu3145	At time of evaluation unregistered for use in macadamia
Nufarm 3445	At time of evaluation unregistered
OCP Azamax	At time of evaluation unregistered for use in macadamia
OCP Oil	At time of evaluation unregistered for use in macadamia
P122 Spore	At time of evaluation unregistered
Propar	At time of evaluation unregistered
Pulse	Registered/permitted at time of evaluation(adjuvant)
Pyganic	Registered/permitted at time of evaluation. No longer registered/permitted for use in macadamia
Regent	At time of evaluation unregistered for use in macadamia
Sero X	At time of evaluation unregistered for use in macadamia
Spin-flo	Registered/permitted at time of evaluation for use in macadamia
Stealth	At time of evaluation unregistered, subsequently registered/permitted for use in macadamia
Steward	At time of evaluation unregistered, subsequently registered/permitted for use in macadamia
Success	Registered/permitted at time of evaluation for use in macadamia. No longer registered/permitted for use (replaced by Success Neo)
Success Neo	Registered/permitted at time of evaluation for use in macadamia
Summer Oil	Registered/permitted at time of evaluation
Synertrol	Registered/permitted at time of evaluation
Synfo121/Syn121	At time of evaluation unregistered
Tea Tree oil 18%	At time of evaluation unregistered
Tea Tree oil 23%	At time of evaluation unregistered
Tebufenozide	At time of evaluation registered for use in macadamia
Transform	At time of evaluation unregistered, subsequently registered/permitted for use in macadamia
Trivor	At time of evaluation unregistered, subsequently registered/permitted for use in macadamia
Vayego	At time of evaluation unregistered subsequently registered/permitted for use in macadamia
Velifer	At time of evaluation unregistered for use in macadamia
Venerate	At time of evaluation unregistered for use in macadamia
Wetcit	Registered/permitted at time of evaluation (wetting agent)
Wettable Sulfur	At time of evaluation unregistered for use in macadamia
Zeus	At time of evaluation unregistered for use in macadamia

Insect colonies

To enable laboratory screening, maintaining insect colonies was very important.

Macadamia nut borer

Macadamia nut borer larvae were reared on an artificial diet to the pupal stage. Pupae were transferred into a flight cage for adults to emerge. Adults were caught in the flight cage 3 times a week and put into cups lined with corrugated cardboard for oviposition. Adults were fed with a honey solution.

Cardboards with fresh MNB eggs were collected 3 times a week. Part of the cardboard cards (egg cards) was used to maintain the MNB colony and a portion of the egg cards were used to feed the egg parasitoid (*Trichogrammatoidea cryptophlebiae*).

Details of the rearing of macadamia nut borer are described in Appendix 4.8.1.

Even though numbers fluctuated over time, pupae numbers were always adequate for sustaining the MNB colony and larvae production for insecticide assays.

Trichogrammatoidea cryptophlebiae

The wasp colony was kept in several glass jars. Jars with parasitised egg cards that were between 7 and 14 days old were fed 3 times a week with fresh egg cards from the MNB colony. Jars with cards older than 14 days were emptied 3 times a week. New parasitised cards were recovered from the jars and one part of freshly parasitised cards was kept to maintain the wasp colony and excess cards were kept for releases in the orchards at CTH Alstonville. Details of the colony of the egg parasitoid *Trichogrammatoidea cryptophlebiae* are described in Appendix 4.8.1.

Spotting bugs

FSB and BSB adults were kept in insect cages and nymphs were kept separate (BSB nymphs in a cage, small FSB in plastic food containers with ventilated lids and larger FSB nymphs in a Styrofoam box with ventilated lid). Adults were fed once a week with fresh green beans, corn cobs and, depending on availability, *Murraya paniculata* berries, macadamia nuts, longans and guava.

Eggs were collected weekly from adult cages and put onto moist filter paper in Petri dishes. The Petri dish with the eggs was put into a plastic food container with some beans and corn. Small nymphs (1st and 2nd instar) were kept in the food container with the ventilated lid. Once nymphs reached about 3rd instar, they were transferred into the larger Styrofoam box (*A. nitida*) or cage (*A. lutescens*). Young adults were collected weekly from the Styrofoam box (*A. nitida*) or nymph cage (*A. lutescens*) and transferred to an adult cage or used in a pesticide assay.

Details of the FSB colonies are described in Huwer et al. (2015b).

Leptocoris bugs

Leptocoris spp. adults and nymphs were collected in the field and kept in insect cages (see spotting bug section). Insect cages were cleaned once a week and bugs were fed with green beans, corn cobs and macadamias. Adults were kept for maintaining the colony or used for bioassays.

Macadamia seed weevil

Adult MSW were collected in the field and put into insect cages (see bug colonies). Adults were fed with fresh macadamia nuts and cages were cleaned once a week. If suitable young nuts were available from the orchard, female weevils laid eggs and nuts with eggs and developing larvae were kept until new adults emerged.

Bioassays

Details of the bioassays are described in Appendix 1.4.1. In summary, 2 screening methods were used:

1. A drop test, where the chemical was dropped from a micro-syringe on the back of the insect to test the knock-

down effect

2. A feeding test, where the food source was dipped in the chemical solution to test the effect of the chemical through ingestion.

Those that showed efficacy through the laboratory screening process were then assessed in field trials. Those insecticides that would benefit the industry were advised to the Regulatory Affairs – Crop Protection Manager at Hort Innovation and/or the manufacturers so that registration could be pursued.

Macadamia lace bug

Macadamia lace bug assay work was conducted on trees with tagged racemes and 2 mL mist applications when infestations were present at significant levels and the population was expanding into new racemes. MLB need live florets to breed and survive and flowers collected from the field do not survive long enough in laboratory conditions for this assessment. After spray applications are performed with a hand mister, the populations by life stage and mortality at 7 days (post-application) are monitored by collecting them into labelled bags and examining them under a 12× microscope. Using 7 days is critical as it allows for eggs within florets to hatch and covers the potential for re-infestation to occur. A 3-day field assay of MLB is not sufficient as it does not cover the potential period for re-infestation or eggs within florets to hatch.

Felted coccid

New chemistries were evaluated in a field trial on a co-operating grower's property that had felted coccid present. After application, flower racemes were sampled and evaluated under a microscope for the presence of dead and live felted coccid.

Macadamia nut borer

Cryptophlebia ombrodelta assays involve standard 20 µL droplets on the artificial diets, measuring 1-day old larval survival over 3 days (could they enter a nut husk or not, used initially in MC99001, Maddox et al. 2002).

As part of the insecticide screening, the effect on MacTrix wasps (*Trichogrammatoidea cryptophlebiae*), which are a key biological control agent was undertaken for selected insecticides to determine their fit into the IPM program, especially late in the production season (MC99001, Maddox et al. 2002).

Fruit spotting bugs and Leptocoris

Feeding tests were used for FSB and *Leptocoris* bugs. For screening of FSB also see Huwer et al. (2015b).

After laboratory evaluation, field trials were conducted to assess the level of control achieved by the insecticides. The best performing chemicals from the laboratory screening were included in the field trials as treatments in the CTH trials between October and February (Appendices 1.3.1. and 1.4.2.). Bug populations were monitored between July and March. At harvest, nut samples were taken and visually assessed for bug damage (Appendices 1.3.1. and 1.4.2.).

8. Industry Adoption

Different channels of communication to foster industry adoption (see Outputs) were used, including:

- presentations to growers at MacGroups
- discussions at benchmarking groups
- presentations at AMS pest consultant meetings
- presentations at processor field days and articles for their newsletters
- industry magazine articles (i.e. AMS News Bulletin)
- updates in NSW DPI Macadamia Plant Protection Guides
- fact sheets – both NSW DPI and AMS produced. In addition, links were provided in AMS e-blasts
- sharing information via e-mail with grower and consultant networks.

9. Diagnostics and responses

On more than 65 occasions, insect samples were identified. These samples were from consultants and growers or collected by NSW DPI. For known pests or those that are easily identified, these were identified by project staff at Wollongbar Primary Industry Institute. If they were new pests or beneficials that could not be identified easily, they were forwarded to the taxonomists at the Agricultural Scientific Collection in Orange or resident taxonomic experts were contacted either locally or internationally for identification. The identification included confirmation of known pests and new pests. This service also provided the opportunity to undertake extension activities with the person on the pest and its control and in addition, it allowed pest incursions and/or expansion to be detected e.g. MSW found in the Clarence Valley.

10. Linkages

There were good collaborative discussions and information exchange with several macadamia industry projects in different areas. Figure 7 provides a graphical representation of the linkages between this and other projects to enhance adoption and ensure research is targeted at relevant key areas.

This collaboration gave a connection to all macadamia research, communication and adoption programs. It linked different macadamia production research aspects and their relevance to pest management. This provided the opportunity for discussions and input into other research areas and programs on pest management. The linkage to the communication adoption programs provided a good communication channel for consultants, growers and industry stakeholders in general. This also provided the opportunity for other industry stakeholders to have input into pest management research and ensured its relevance. The linkage to the communication and adoption programs was an important channel for the adoption of research outcomes and an essential part of the overall program.

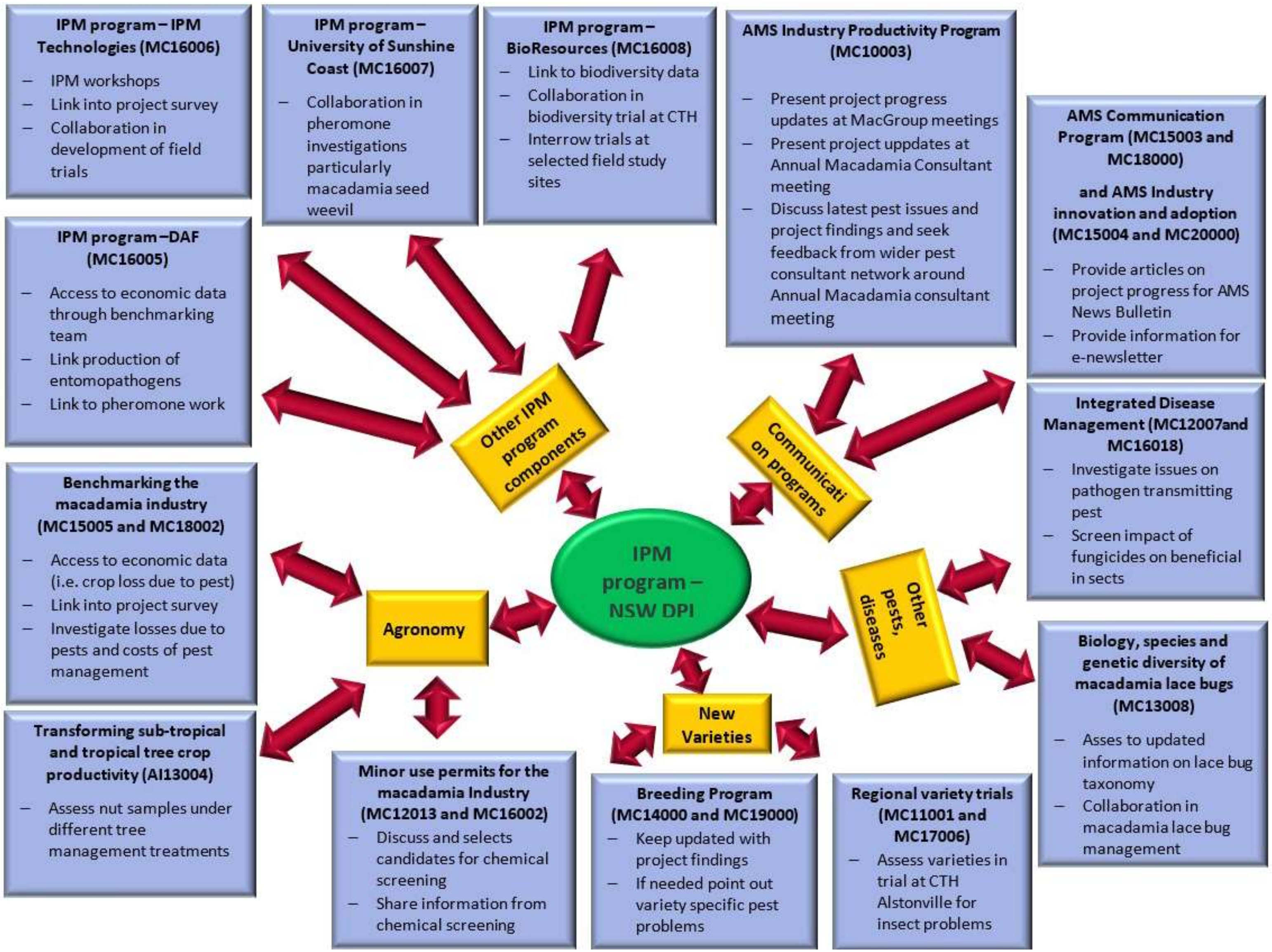

Figure 7: Project linkage.

Results and discussion

1. **Gap analysis**

An extensive literature review (Appendix 1.1.1.) of 84 papers provided a thorough view of IPM in horticulture in general, but also some specifically in tree nuts.

<u>Conclusion and relevant implication for an improved IPM system in macadamias:</u>

Research in the past developed biological control for MNB, which has been successfully adopted by the Australian macadamia industry.

Monitoring strategies for MNB and FSB are well developed and well adopted, but monitoring of other pests and beneficial insects is the key to an overall IPM strategy. More monitoring tools for some pests are needed for IPM in Australian macadamias to be fully integrated into the production system.

There is a lack of biological control options for some of the key pests including MLB and MSW. The effect of biological control on FSB is not fully understood.

The biology and ecology of MLB and MSW need to be better understood.

Cultural control and orchard habitat management are identified as essential components of an IPM program but are not well understood for Australian macadamia orchards.

The effect of inter-rows increasing biodiversity and the link to yield would be important, as a review showed that while there has been a lot of research on biodiversity, few have included the link to crop quality and yield (Herz et al*.* 2019). This is important for industry adoption and advancing IPM.

<u>Conclusion</u>

Several gaps have been identified that need to be reviewed and prioritised for future research (Appendix 2.1.) including:

- Developing and/or implementing cultural control, which includes:
    - enhancing biological control
- Developing and/or adopting monitoring tools including the following:
    - investigating IPM compatible chemicals and their adoption
    - IPM adoption
    - IPM ranking/scoring system to enable comparison of IPM strategies.

2. **Ecology and biology studies**

<u>PhD study in collaboration with the University of Southern Queensland on entomopathogenic fungi</u>

The PhD study at the University of Southern Queensland investigated options for using *Beauveria bassiana* and *Metarhizium anisopliae* for managing MSW. Detailed results are presented in Appendices 4.1. to 4.5.

A summary of the results is as follows:

Review of integration of entomopathogenic fungi into an IPM program in other horticultural crops

Various studies on *M. anisopliae* and *B. bassiana* on weevils affecting horticultural crops that share similar habitats to MSW were compiled and synthesised, and a model on how to integrate entomopathogenic fungi with other IPM programs was designed. Details are presented in Khun et al*.* (2020c) (Appendix 4.3.).

Characterising Beauveria and *Metarhizium anisopliae* strains

A key finding from this study is that all strains of *M. anisopliae* applied at ECS1 at 1×10^7 conidia/mL resulted in the highest mortality of MSW adults (97.5%). At the same concentration, *B. bassiana* strain B27 was the most effective, also inducing high mortality in adults (92.5%). The median lethal time (LT_{50}) for both strains was around 5 days. Detailed results are presented in Khun et al. (2020a) (Appendix 4.1.).

Transmission of fungal conidia from cadavers

A key finding from this study is that fungal entomopathogens could provide an additional means of sustainable control of adult MSW through horizontal transmission from fungal-infected adults to healthy adults and horizontal infection arising as a consequence of physical contact with conidiated cadavers. Details of the results are presented in Khun et al. (2021a) (Appendix 4.4.).

Compatibility of entomopathogenic fungi with pesticides

The key finding in this study is that at their full field concentrations (FFCs), the formulated insecticides trichlorfon, acephate and indoxacarb were compatible with *M. anisopliae* whereas *B. bassiana* showed compatibility with 5 formulated insecticides: trichlorfon, acephate, indoxacarb, sulfoxaflor and spinetoram. However, methidathion, diazinon and beta-cyfluthrin were toxic to both fungal species. Both fungicides, carbendazim and pyraclostrobin, were very toxic to both fungal species. Details of the results are presented in Khun et al. (2020b) (Appendix 4.2.).

Interaction of entomopathogenic fungi with pesticides

The key finding in this study suggests that acephate and indoxacarb have both synergistic and additive effects against MSW when deployed together with fungal entomopathogens, depending on the initial concentrations of mixture components. Details of the results are presented in Khun et al. (2021b) (Appendix 4.5.).

<u>PhD study in collaboration with the Southern Cross University on biology and ecology of macadamia lace bug and biological control options</u>

Ecology studies on MLB are still underway and results are not available at this stage.

NSW DPI monitoring of MLB in different managed blocks at CTH Alstonville

Monitoring in the main IPM trial in the entomology block showed that flupyradifurone (Sivanto® Prime) and the new experimental compound successfully controlled the pest (Appendix 2.5.2.). Flupyradifurone is safe to use near bees, but residues still need to be investigated. Bee toxicity and residues of the new experimental compound are still unknown.

When managed, even with a longer flowering period due to 2 early (246 and 741 cv.) and 2 late (849 and A4 cv.) cultivars, MLB can be easily controlled.

The monitoring in the density, sink and main IPM trials also showed that a long flowering window makes the orchard more susceptible to MLB, as the pest breeds during flowering and populations build up. The sink block has multiple flowering windows, continuous build-up of MLB and no nut set.

The density block has only one variety (246 cv.), a single wide flowering window and low numbers of MLB for a short time in widely spaced trees, which get normal production figures. However, in the tightly spaced blocks, MLB are far more prevalent and production is poor. Out of season flowering needs to be monitored and makes the orchard more susceptible to MLB.

Monitoring results and comparison between the three blocks are illustrated in Figure 8.

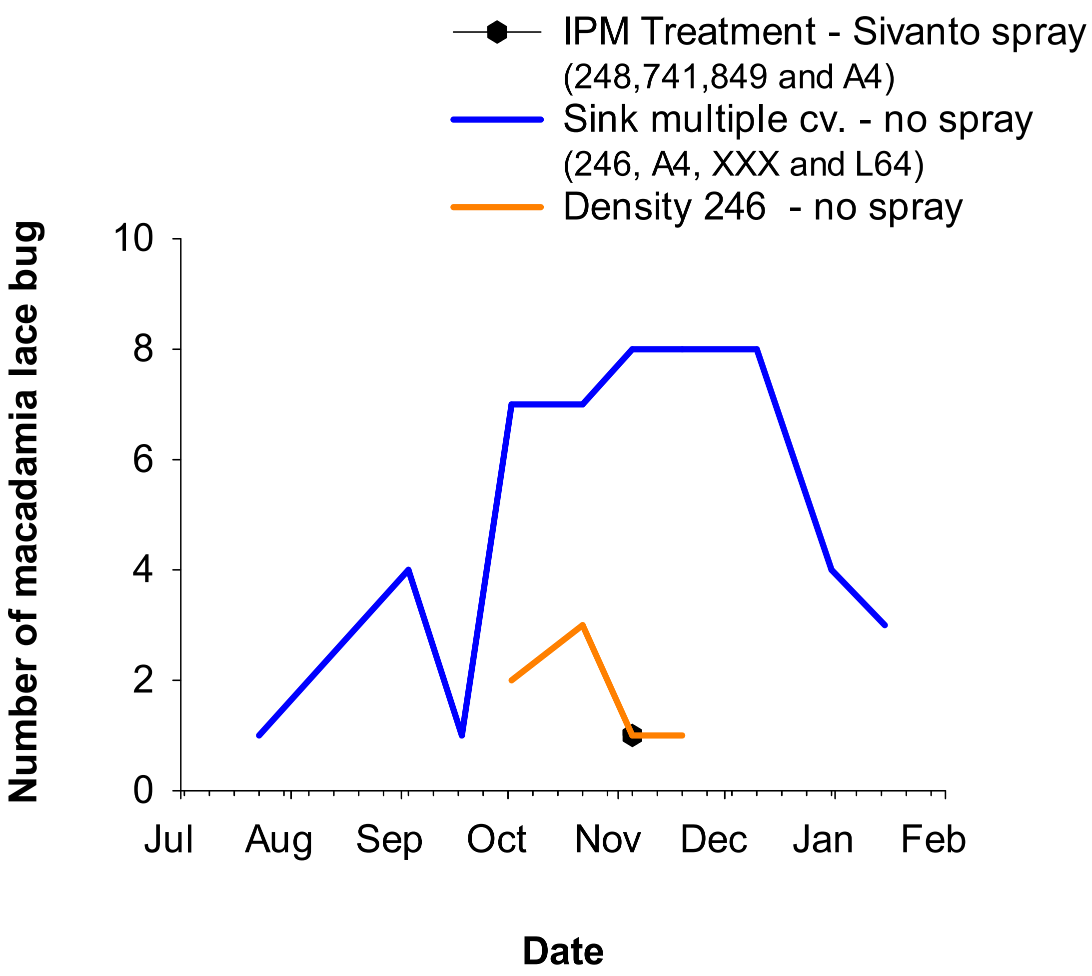

Figure 8: Comparison of macadamia lace bug numbers at CTH Alstonville during 2018 and 2019. The sink block with multiple flowering windows has macadamia lace bug present all year, while in the density block with only one variety, the pest is only present for a short time in low numbers, and in the main IPM trial in the entomology block, management controlled macadamia lace bug numbers.

Biodiversity trial at CTH

Monitoring with yellow sticky traps showed that thrips and planthoppers were the main pests. The main beneficials recorded were parasitic wasps, spiders and predatory flies. Detailed monitoring results are shown in Appendix 2.3.2. and Figures 2.3.2.1 to 2.3.2.3.

Husk assessment showed that MNB parasitism had increased from previous years. Felted coccid populations had also increased, while scale populations were reduced from previous years (Appendix 2.3.2. and Table: 2.3.2.1.).

Kernel assessment showed that FSB damage, particularly in the tighter planting densities, was reduced from previous years and generally the overall insect damage was also reduced.

The yield had increased from the previous year when there was no flowering inter-row in the one-year trial.

This trial was only run for the last year of the program and results are therefore to be taken with caution. However, it showed a positive trend was achieved by including inter-rows and increasing biodiversity. However, while yield increased, 1.5 t of DNIS/ha was still low compared to the industry average of 2.9 t/ha. This was possibly due to MLB reducing flowering and therefore creating low nut set opportunities.

It would be important to run trials looking at the effect of inter-row plantings on yield and nut quality at a commercial farm level over an extended period. One season for the trial was not long enough to draw a decisive conclusion.

Conclusions

Entomopathogens are very effective under controlled environmental conditions, but future work needs to focus on their stability under field conditions. This will require close collaboration with the manufacturing industry.

New options for biological control of MLB have been identified and need to be further explored.

The longer the flowering window, the more MLB populations can build up and out of season flowering needs to be avoided and monitored.

Increased biodiversity needs to be part of any IPM strategy. There is a lack of understanding of the relationship between increased biodiversity on yield and quality.

3. IPM strategies

To develop IPM strategies, we need to look at the different treatments applied and their effect on pests, beneficials, yield and nut quality. This started to evolve over the short period of the project but to get more reliable results, it needs to be evaluated over a longer period.

IPM options were developed for growers to be considered, adjusted and chosen, as there is no single strategy that fits all farm situations, locations or seasons. The options include monitoring as an essential part of any IPM strategy, along with cultural, biological and chemical controls. IPM options are presented in Appendix 10.

Case study sites

General monitoring results found:

- broad-spectrum insecticides had negative effects on the beneficial populations
- releases of MacTrix in particular, increased numbers of egg parasitoids
- the diversity of beneficials was generally higher on case study farms with inter-row plantings
- the complex of pests and beneficials on each farm generally stayed similar over time, however, the different climates in different seasons affected the populations.

Details of monitoring results from case study sites are shown in Appendix 2.2.1. (Figures 2.2.1.1. to 2.2.1.32. and Tables 2.2.1.1. to 2.2.1.16.).

Scolytid beetle monitoring

Detailed results for monitoring scolytid beetles are presented in Appendix 2.2.2. (Figures 2.2.2.1 to 2.2.16. Results are also summarised in Tables 2.2.2.1. to 2.2.2.4.)

Dominant species appeared to vary across regions rather than between seasons:

- the branch borer *Cnestus solidus* was dominant in the Central Queensland Region and the Northern Rivers Region
- the pinhole borers *Hypothenemus* spp. were dominant in the Gympie-Glasshouse Mountains Region and the Mid North Coast Region.

This monitoring gave us a better understanding of the complexity of scolytid beetles at the different sites. Beetle numbers were not affected by the management strategy. Case study sites with conventional management strategies did not necessarily have lower scolytid numbers or different species.

Husk, kernel and yield assessment

Detailed harvest results are provided in Appendix 2.2.3. (Figures 2.2.3.1.to 2.2.3.8. and Tables 2.2.3.1. and 2.2.3.2).

General trends were as follows:

- Yields in differently managed sites were comparable.

'IPM sites' (minimal pesticide approach – sites 1, 3, 5 and 7)

- Generally higher percentage of insect damage
- Generally higher reject kernel recovery

'Conventional sites' (several applications of broad-spectrum insecticides - sites 2, 4, 6 and 8)

- Generally lower percentage of insect damage
- Generally higher percentage of sound kernel

To identify further the cause of the losses and effects of different pests, the results from husk and kernel assessments were reviewed. Results are shown in Tables 2.2.3.1. and 2.2.3.2. and Figures 2.2.3.1. to 2.2.3.8.

Husk and kernel assessment:

'IPM sites' (minimal pesticide approach – sites 1, 3, 5 and 7)
- Levels of felted coccid were sometimes, but not always lower
- Higher number of nuts with MNB tunnels on the husk
- Mostly higher percentage of kernels with FSB damage
- Mostly higher percentage of kernels with MNB damage
- Mostly higher percentage of kernels with total insect damage

'Conventional sites' (several applications of broad-spectrum insecticides - sites 2, 4, 6 and 8)

- Generally higher percentage of husks with thrips present
- Mostly higher number of scales
- Levels of felted coccid were sometimes but not always higher
- Mostly higher yield.

Main IPM trial

Monitoring with yellow sticky traps

Details of monitoring results from the main IPM trial at CTH are shown in Appendix 2.3.1. (Figures 2.3.1.1. to 2.3.1.16. and Tables 2.3.1.1. to 2.3.1.4.).

Thrips were a major problem across the trial block.

MacTrix (*T. cryptophlebiae*) were released and the numbers of egg parasitoids were also high across the block, despite chemical applications.

Scolytid beetle monitoring

Details of monitoring results from the main IPM trial at CTH are shown in Appendix 2.3.1. (Figures 2.3.1.17 to 2.3.1.24).

Other than in the case study sites, a greater number of different species including branch borers (*Cnestus solidus*, *Xyleborus* sp. and *Xylosandrus* sp.) were dominant in the different treatment strips. Species differed with seasons but not so much with treatments. During the dry season (2019–2020), the number of scolytid beetles captured increased.

Husk, kernel and yield assessment

Detailed harvest results are provided in Appendix 2.2.3 (Figures 2.2.3.1.to 2.2.3.8. and Tables 2.3.1.1. to 2.3.1.8).

While the standard treatment (broad-spectrum insecticides) had the most effective control of FSB and achieved the highest yields, similar yields and sound kernel recovery were achieved with less broad-spectrum insecticide use, which also generally resulted in fewer problems from secondary pests scales and thrips.

Parasitism of MNB eggs was not always lower where broad-spectrum insecticides were used, therefore minimal strategic use of these pesticides appears to be compatible with MacTrix (*T. cryptophlebiae*).

As shown in previous studies (e.g. MC05005), FSB show a definite preference for certain varieties (late maturing and high kernel recovery) (Figures 2.3.1.1. to 2.3.1.4).

<u>Conclusions</u>

Over time, all case study sites reduced their broad-spectrum insecticide use and incorporated biological control (Figures 2 to 5). In general, the strategic use of pesticides is compatible with the biological control of MNB. In particular, the Mid North Coast case study site 7 showed that, without broad-spectrum insecticides, high yield can be achieved with no more reject from insect damage than the pesticide managed case study site in the region.

A measurement of IPM strategy i.e. ranking or scoring system would be useful for comparison of the farms and their results.

Each farm and season is different. There is no 'one size fits all' strategy. However, we have put together a chart of management options (Appendix 10). This looks at key pests at different phenological stages, with monitoring options as being key to their management strategy. It also includes cultural, biological and chemical control options as they are known and available at this time.

The IPM trial at CTH showed that using pesticides with a shorter residual time than diazinon for MLB meant that timing was essential. This timing is due to a better understanding of their life cycle and spray timing is important if an additional chemical application was needed for MSW control if acephate was relied on.

Variety selection has to be an important part of any IPM strategy.

An IPM strategy for the macadamia industry is evolving throughout the different regions and different management scenarios. IPM is not a destination but rather a journey. This project, although being over such a limited time frame, has delivered many useful outcomes to add to the IPM journey.

4. **Biological control**

<u>PhD study in collaboration with the University of Southern Queensland on entomopathogenic fungi</u>

See section 2. Ecology and biology studies for results. Detailed results are presented in Appendices 4.1. to 4.5.

<u>Small field trials testing the efficacy of *B. bassiana*</u>

Foliar *Beauveria* treatment

In the first trial, the foliar *Beauveria* treatment only marginally reduced the MSW oviposition compared to the unsprayed treatment. Detailed results are in Appendix 4.7.

Comparing foliar *Beauveria* treatment to ground treatments

Not more than a 30% reduction in nut drop was observed for treatments where *Beauveria* was applied to either bare ground or grass beneath trees. The foliar application in this trial only showed an 8% reduction in nut drop. Detailed results are in Appendix 4.7.

Testing the overwintering of *Beauveria* treatment

When applications were made in March and dropped nuts checked in September–October, foliar applications were showing 0–1% infection rates (Table 3.1.). When applied under trees to heavily infested MSW areas, trees were showing 3.4–4.3% infection rates of MSW larvae. Detailed results are in Appendix 4.7.

<u>PhD study in collaboration with the University on biology and ecology of MLB and biological control options</u>

Screening of commercial biological control agents

Out of the 12 commercial biological control agents tested (provided by Bugs for Bugs), the pirate/*Orius* bugs gave the best results in the pilot screening test. This was a very simple test exploring whether some commercially tested pests would prey on MLB under laboratory conditions in a Petri dish. The results need to be confirmed in further laboratory testing and the field.

Biological control agents tested include:

- green lacewing (*Mallada signatus)*
- different ladybird beetle species adults (C*hilocorus circumdatus*), larvae (*Harmonia conformis*), larvae and adults (*Cryptolaemus montrouzieri*)
- predatory mites (*Typhlodromips montdorensis* and *Neoseiulus californicus)*
- predatory bugs (*Orius tantillus*, pirate/*Orius* bug)

<u>*Apocephalus* sp. (phorid fly) in fruit spotting bug colonies</u>

This parasitic fly was quite effective in the colony and should be further assessed in the laboratory and field. A challenge for rearing the fly is that it currently has been pest-specific and rearing FSB in captivity has not been possible, thus reliance has been on field-collected FSB. For any future studies, it would be important to find another host that is easier to rear in large numbers for *Apocephalus* to feed on.

<u>Case study sites and IPM trial at CTH</u>

Inundated releases of additional commercial biological control agents (i.e. *Anastatus* wasps (*Anastatus* nr *pentatomidivorus*) and some small releases of *Centrodora darwinii* for managing FSB, green lacewings (*Mallada signatus*), MLB and Montdorensis mites (*Typhlodromips montdorensis,* for managing thrips) did not show a significant effect on quality and yield throughout the trial. Even though releases were reflected in the numbers of beneficials monitored to some extent (see above sections on monitoring), releases of MacTrix (*T. cryptophlebiae*) appeared to have the most effect on MNB. See results for monitoring and kernel and yield assessment for case study sites and IPM at CTH (Appendix 2.2.1., 2.2.3. and 2.3.1.).

Encouraging and preserving biological control using inter-rows is an important aspect of biological control that has been shown to assist in increasing populations of biological control agents (Appendix 2.2.1., 2.2.3. and 2.3.2.).

<u>*Conclusions*</u>

The research identified the importance of the integration of biological control.

Some specific biological control options for adult FSB and BSB that will have more effect on the pest populations still need to be identified. In previous work (AV06001), Drew (2007) suggested spiders are important predators of the bugs, reducing the FSB damage in avocados, and any strategy that preserves spiders would be beneficial.

Successful biological control for MSW was identified but more studies need to look at making the entomopathogenic fungi more stable and effective in the field.

The pirate bug (*Orius tantillus*) has been identified as a potentially useful biological control agent for MLB. Further testing will be required to confirm the results from the pilot study.

The phorid fly would be an effective parasite for FSB, but very challenging to mass rear unless an alternative host that is easier to rear can be found.

5. **Monitoring strategies**

For general monitoring, the strategy and protocol developed in collaboration with the consultants were successful (Appendix 1.2.3.1).

The monitoring hedges were a good tool for monitoring both FSB and BSB. Sharing the results proved this also can be the basis of area-wide management.

A new monitoring strategy was developed for scolytid beetles in macadamias (Appendix 1.2.3., Figure 1.2.3.1.). The commercially available BROCAP® coffee berry borer panel traps were a practical tool and commercially available lures captured a range of beetle species (Appendix 2.2.2. (Figures 2.2.2.1 to 2.2.16, Tables 2.2.2.1. to 2.2.2.4.) and Appendix 2.3.1. (Figures 2.3.1.17 to 2.3.1.24)).

For MSW in NSW, checking fallen nuts gave a good indication of the population dynamic of the weevil and the effectiveness of the management of the pest.

Conclusion

The program has developed monitoring strategies for key pests that have proven to be successful. All monitoring strategies and information have been made available to industry and growers through communication programs such as MacGroups and AMS News Bulletin.

Better adoption of monitoring and sharing of monitoring data in groups and a more coordinated monitoring regime in the regions is recommended to progress area-wide management as the next step.

6. **Cultural control**

Tree height has been important for pest management (Appendix 2.5.2.). Reduced ventilation in thicker canopies increases the susceptibility to pathogens by providing more opportunities for sheltering pests and better connections between tree canopies. As trees grow larger, chemical applications become more difficult and ineffective if spray machinery is not suitable for tree coverage.

The main IPM trial at CTH Alstonville showed the importance of selecting varieties for FSB management (Appendix 2.3.1., Figures 2.3.1.1. to 2.3.1.4). The spatial distribution of the FSB damage in the block showed the preference for the late maturity and high kernel recovery from varieties 849 and A4.

The small-scale biodiversity trial showed a few key points for cultural control:

- there were trends toward improved yields and pest control (it is hard to make a conclusive judgement from one season) (Appendix 2.3.2., Table: 2.3.2.1.).
- tree density can also be a tool for managing FSB, as in the widest planting (10 × 10 m), FSB damage was constantly lowest and higher density orchards needed more input for pest management (Appendix 2.3.2., Table: 2.3.2.1.).

Orchard hygiene needs to be part of an integrated orchard management system.

Hygiene measures such as farm biosecurity and awareness of its importance, as well as good communication to growers, helped prevent the spread of MSW in the Yamba region.

Removing wood infected by scolytid, bostrychids and longicorn beetles from the orchard is the best way of stopping the pest from spreading throughout the orchard.

Conclusions

The research showed that cultural control is an integral part of IPM to minimise insect damage and input of insecticides and is part of improving orchard resilience.

Factors that are driving the benefit of cultural control are:

- Making the environment less hospitable for the pests:
  - choosing more resistant or more tolerant varieties, e.g. for FSB, early varieties with smaller KR
  - increasing the opportunity for natural predators through increased biodiversity by providing refugia and food sources
  - removing shelters for the pest through canopy management and optimising chemical control coverage
  - increasing ventilation to reduce the risk of pathogens
- Removing infection sources of pests:
  - preventing 'out of season' flowering, which, if left, would provide a constant food source for key pests in the orchard
  - removing infected plant material out of the orchard
- Farm biosecurity
  - having in place an on-farm biosecurity plan that explains where visitors should go and the movement of traffic to prevent incursions
  - preventing infected material movement between orchards by humans, machinery and vehicles
  - using healthy plant material i.e. inspecting material before it leaves the nursery is advised.

7. **Chemical screening**

Insect colonies

Macadamia nut borer

Even though numbers fluctuated over time, pupae numbers were always adequate for sustaining the MNB colony and larvae production for insecticide assays.

Trichogrammatoidea cryptophlebiae

Wasp card production provided sufficient material to release egg parasitoids in all trials at CTH Alstonville and insecticide assays. Emergence rates of the wasps were variable (Table 4.8.1.2.). The egg parasitoid was a good example of a beneficial for insecticide screening.

Spotting bug colonies

The spotting bug colony numbers also fluctuated over time. Usually laboratory colonies decreased during winter. Maintaining good numbers in the colonies was dependent on field collection of new insects, which due to the pandemic (after March 2020), was limited, as travel to other regions was difficult or not possible. Despite fluctuating numbers, the colonies produced sufficient numbers of insects to enable laboratory screening of several pesticides.

Leptocoris bugs

Maintaining the *Leptocoris* bug colony was dependent on regular field collections. Getting sufficient numbers in the colony for laboratory screening was best during the dry season of 2019–2020. During the following wet seasons, insufficient insects were available from the field for bioassays.

Macadamia seed weevil

Maintaining the weevil colony was dependent on the supply of young macadamia nuts, suitable for oviposition. Once no young nut was available, females stopped egg-laying and switched to feeding only. Maintaining a colony was only possible between October and February. Even though there was a time window, enough weevils have been collected for bioassays.

Bioassays

Laboratory screening of selected chemicals was undertaken to determine efficacy and compatibility with selected biological control options and fungicides.

Macadamia lace bug: 16 products were assessed resulting in isoclast (Transform®), diazinon, flupyradifurone (Sivanto® Prime) and an experimental product giving the best results.

Felted coccid: 4 products were tested, and flupyradifurone (Sivanto® Prime) gave the best results.

Macadamia seed weevil: 9 different chemicals were assessed, and the new experimental chemical gave the best knockdown results, followed by acephate.

Fruit spotting bugs (both FSB and BSB): 20 products were tested, and the most successful chemicals were acephate (i.e. Lancer®), acetamiprid and pyriproxyfen (Trivor®), beta-cyfluthrin (i.e. Bulldock®), tetraniliprole (Vayego®), a new compound and trichlorfon (i.e. Lepidex®).

Leptocoris: 15 products were tested. A new compound looks most promising. It was just as successful as acephate and trichlorfon (i.e. Lepidex®). The population from the Gympie region showed resistance against several key pesticides including beta-cyfluthrin (i.e. Bulldock®) and isoclast (Transform®). The *Leptocoris* populations from the Northern Rivers were more variable with resistance.

Residual time for selected chemicals was also tested for FSB. Beta-cyfluthrin (i.e. Bulldock®) and a new compound had the longest residual time, with 14 days of activity in the field.

Insecticide screening

Chemical companies supplied experimental products to conduct assays with the cultures present in the Wollongbar laboratories and the field. The companies and products are listed in Appendices 2.5.1 and 2.5.2. The screening findings are summarised as follows:

1. Products that will give comparable control of MLB to diazinon are:
    a. isoclast (Transform® @ 40 mL/100 L registered)
    b. flupyradifurone (Sivanto® Prime @ 50 mL/100 L) will be registered pending residues from pre-flower application work
    c. SYNFO 121 (Syngenta) field assays in 2019 were effective
    d. OCP pyrethrum oil @ 160 mL/100 L was significantly better than the untreated controls in 2019 but not equivalent to diazinon in the 2019 assays

All sampling results are shown in Appendices 2.5.1. and 2.5.2.

2. Products that failed to deliver control of MLB at suggested rates are:
    a. *Clitoria ternatea* extract (Sero X® @ 1,000 mL/100 L *Clittoria* extract 2 L/ha, roughly 100 mL/100 L with 2,000 L/ha macadamia application rates). Between 2017–2018, there was no significant level of MLB control until dose rates approached 1,000 mL/100 L
    b. Wetcit® (orange oils) gave no control up to 800 mL/100 L application
    c. Wettable sulfur gave no control at the fungicide rates of 500 g/100 L

All sampling results are shown in Appendices 2.5.1. and 2.5.2.

Comparative field trials monitoring MLB incursions in the CTH entomology trials have shown the new product options to be equally effective as diazinon in seasons 2019, 2020 and 2021. Other areas monitored during the same periods are showing significant pest build-up (see Appendix 2.5.2).

3. Products that will give comparable control of macadamia felted coccid to diazinon and diazinon in oil are:
    a. isoclast (Transform® @ 40 mL/100 L registered)
    b. flupyradifurone (Sivanto® Prime @ 50mL/100 L will be registered pending residue analysis from pre-flower application work)

4. Products that failed to deliver control of macadamia felted coccid and MLB at suggested rates are
    a. spirotetramat (Movento® @ 40 mL/100 L) did not show a significant level of control

All sampling results are shown in Appendices 2.5.1. and 2.5.2.

5. Product compatibility with *Trichogrammatoidea cryptophlebiae* use for MNB parasitism showed:
    a. indoxacarb applications (Steward® or Avatar®) at registered rates were no worse than acephate use for parasitoid emergence from dipped Day 1, Day 4 and Day 7 wasp release cards
    b. Syngenta (SYNFO 121) is not affecting emergence rates of the parasitoids at the rates tested

All sampling results are shown in Appendices 2.5.1. and 2.5.2.

6. New products for MNB control tested using the 1-day old larva assay techniques:
    a. Syngenta (SYNFO 121) was showing efficacy at the tested rates when compared with beta-cyfluthrin
    b. DC 143 (Vayego®) dose rates were determined, efficacy above 10 mL/100 L shown
    c. neonicotinoid products (Trivor®, Transform®, Sivanto® Prime) all show less MNB efficacy at registered rates (laboratory assays and field comparative work)

All sampling results are shown in Appendices 2.5.1 and 2.5.2.

7. New products for MSW control tested using the dipped nut feeding assay techniques and topical application:
    a. topical applications showed very little efficacy for products tested. *Beauvaria bassiana* shows some effect in assays
    b. acephate is the most effective knockdown compound
    c. Syngenta (SYNFO 121) shows a strong knockdown effect
    d. indoxacarb does not have a strong knockdown effect (lab assay) but has a major effect on MSW oviposition rate as determined in field assays. Indoxacarb gave the most effective weevil control with 1 application as laying commences in the field, providing 12 weeks of oviposition disruption (3 seasons data)
    e. DC 143 (Vayego®) also showed some effect but was slower to work and did not act like indoxacarb

All sampling results are shown in Appendices 2.5.1 and 2.5.2.

8. New products for FSB and BSB using the dipped berry feeding assay techniques and topical application:
    a. all products tested work much better on nymphs than the adults in assays
    b. cypermethrin and bifenthrin are stronger than beta-cyfluthrin for knockdowns
    c. the naphthalene carrier rather than the xylene carrier is equally effective

All sampling results are shown in Appendices 2.5.1. and 2.5.2.

9. New products for *Leptocoris* spp. (soapberry bugs) using the dipped berry feeding assay techniques and topical application:
    a. acephate was the most effective compound on adults in assays (consistent in all regions sampled)
    b. acetamiprid + pyriproxyfen (Trivor®) also shows some effect (variable some populations less)
    c. Syngenta (SYNFO 121) was effective
    d. parasitic flies were emerging from the bugs as they were dying in the assays. At each site sampled, they were showing a level around the 1–10% maximum
    e. pyrethroids were not showing consistent efficacy in the laboratory as reported initially from Les Gain Amamoor QLD, pyrethroid resistance was also detected in populations at Wollongbar and CTH Alstonville

All sampling results are shown in Appendices 2.5.1. and 2.5.2.

10. Residual activity of registered and new products for FSB and *Leptocoris* spp. using the dipped berry feeding assay techniques and weathered field treated *Murraya* berries brought back at 1, 7, 14 and 21 day intervals and monitoring survivorship over the following 7 days:
    a. knockdown effects of most products are good (day 1)
    b. beta-cyfluthrin showed the longest residual activity; 14 days for FSB and susceptible *Leptocoris* spp. populations
    c. acetamiprid + pyriproxyfen (Trivor®) also shows some effect at day 7 but is variable on some *Leptocoris* spp. populations
    d. Syngenta (SYNFO 121) is effective on both species for at least 7 days
    e. tetraniliprole (Vayego®) is not as effective against *Leptocoris* spp.
    f. flupyradifurone (Sivanto® Prime) is not as effective against *Leptocoris* spp.
    g. isoclast (Transform®) is not as effective against *Leptocoris* spp.
    h. nymphs are also more susceptible than adults to most products

All sampling results are shown in Appendices 2.5.1. and 2.5.2.

11. Field assessment of the strategic agrichemical review process (SARP) (MT 19008, Anonymous) for the macadamia pesticide review for new products compared to current industry best practice. Weather conditions delivered high FSB, MSW and MNB pressure during the 2020–2021 season at CTH Alstonville on cv. 849 in the physiology block:

    a. three new options were suggested in MT19008: DC143 (Vayego®), SYNFO 121, and Nufarm 3445 for managing the key macadamia pest species (FSB, MSW and MNB)

b. MSW is better managed with a single indoxacarb than double applications of any of the 3 new products
c. FSB damage levels managed with DC143 and SYNFO 121 were equivalent to beta-cyfluthrin managed areas; we do not have yield data only kernel damage data at this stage
d. MNB is better managed with DC143 and SYNFO 121 than with beta-cyfluthrin
e. Nufarm 3445 was only showing activity against MNB
f. managing incursions of pyrethroid-resistant *Leptocoris* sp. during summer needs to be evaluated in the same way, given the lesser effect on MNB than the noenicitinoids (Trivor®, Transform® or Sivanto® Prime) have compared to either DC143 or SYNFO 121 especially.

All sampling results are shown in Appendices 2.5.2.

Conclusion

All insect colonies provided enough insects to enable bioassays. Chemical screening identified IPM compatible insecticides that are already available and proven in field trials but also identified new compounds that still need to be registered. A good fit for chemicals with the rotation of a chemical management strategy has been identified. With the new chemicals, it is important to be aware of the mostly shorter residual time. Therefore, a good understanding of pest biology and ecology to enable optimal timing and monitoring becomes even more important.

8. Industry adoption

This project had several different avenues to promote the adoption of outcomes, including the following:

- presentations at AMS pest consultant meetings allowed good discussions and consultant input into the progress of the project
- communication with a network of consultants and growers led to good connections with key consultants and growers in the industry and made them aware of upcoming pest issues
- MacGroups allowed presenting research updates to growers and having discussions with the end-users of the research, keeping the practicality of outcomes and recommendations in perspective
- benchmarking groups allowed discussions with leading growers and made them aware of the outcomes of the research
- regular publications in the AMS News Bulletin allowed all stakeholders to read about the outcomes of the project
- videos were particularly important during COVID restrictions, allowing all stakeholders to keep updated on research outcomes at their convenience
- annual updates in the NSW DPI Macadamia Plant Protection Guide gave the industry updates on the research outcomes and alerted them of upcoming pest issues
- with MSW, we saw that through good communication channels with a network of growers and consultants, the adoption rate was quick (within the season) and very high (> 95% only organic growers would adopt the new management strategy).

Conclusion

A lot of different extension avenues were taken to reach the maximum number of stakeholders in the industry. Pest consultant meetings and benchmarking meetings were the main and most important opportunities for feedback for researchers. With regards to publications, the NSW DPI Macadamia Plant Protection Guide has been extremely popular and supported by growers.

9. Diagnostics and response

Many insect samples were provided by growers, consultants and processors and also collected by NSW DPI. Insects that could not easily be identified were sent to taxonomists at the Agricultural Scientific Collection in Orange for identification. Identification by experts was provided for 59 samples.

Diagnostic services were provided, and a response strategy was developed in consultation with the program team and industry consultants about a new incursion of MSW in the Yamba region. An awareness workshop prevented further outbreaks in this area, preventing further spread of the weevil in this region. This is summarised in Appendix 2.6 and Table 2.6.1. explaining the identification of numerous samples that had been submitted.

Several new species were recorded (Appendix 2.6, Figure 2.6.1.) as pests and some have regional effect. *Leptocoris tagalica* appears to have moved from QLD into NSW; this was not a problem until 2019. *Mussidia* sp., a new pyralid moth, was found in a crop in 2019 in Bundaberg and Rockhampton, and in 2020, MSW appeared in the Clarence River area for the first time.

During the project, many different scolytid beetles were identified. Some of them caused tree death. In response, a monitoring system was developed.

Climate changes also bring new pests. By far the most insidious problem related to drought was the rise of the scolytid, bostrychid, scarab and cerambycid borers, similar to what Greaves witnessed in the 1960s drought. The coastal eucalypts suffered massive dieback then, which was monitored by NSW forestry. The rainforest heritage of macadamia makes them even more susceptible to prolonged drought; shallow-rooted trees being the most at risk. The range of beetles present during that period and the level of tree death were monitored and some trials were conducted at places where particular species were present.

The scolytid problem has always been linked with drought, a side effect of phytophthora infections, lightning strikes, and associated sudden dieback in macadamia have been related and listed problems in Hawaii, South Africa, Central America, Brazil and Australia since the middle 1980s. We have always had bark beetle (*Cryphalus subcompactus)* and *Dothriella* fungal disease associations in northern rivers NSW macadamia (NSW DPI identifications). Other scolytids are known to affect macadamia, the most common are *Cnestes solidus, Xyleborus bispinatus* and a range of *Hypothenemus* species, some in the nut in shell. The tree death and branch death associated with *Euwallacea* sp*. b*egan around Beerwah, Glasshouse Mountains area in 2009 (O'Hare – Sahara farms) and has been sporadically occurring since. Our original identification of those insects by Roger Beaver (Thailand) was *E. nr fornicates*. Helen Nahrung has suggested we have a new name; *E. prebrevis.* In NSW we have seen a few examples and there are reports of more *Euwallacea* in other states now, including North Queensland.

The link between ethephon use and *Cryphalus subcompactus* has long been known. Trees double-sprayed by mistake by growers to drop nuts in April–May will be carrying powder post beetle marks from crown to trunk within 48 hours. Other pest species might also be targeting the plant response to ethephon, but ethephon itself is not the attractant. Similar work in Peachester (2021) has shown that ethrel branch applications have enhanced tunnelling in the *Euwallacea* areas (Appendix 2.6. and Table 2.6.1.).

Differences in FSB and *Leptocoris* sp. damage were established.

The benefit of this work was that it enabled us to monitor new emerging pests and their importance for biosecurity.

<u>*Conclusion*</u>

We have identified new pest issues during the project. Diagnostics are an important part of pest management efforts, as they provide information about current pests recorded and their distribution. Correct identification of the pest enables the correct pest management strategy. Diagnostics and identification of new insects are part of biosecurity efforts.

10. Linkage

Results of the good linkages where input into other macadamia research projects from a pest management aspect:

- good collaboration with the other projects from the IPM program allowed access to their expertise and coordinated approach to IPM research
- opportunity to present at MacGroups and pest consultant meetings
- good collaboration with the disease management program, working on a scoring system for IPDM and looking at the transmission of pathogens by scolytid beetles
- input from 'champion' growers through discussions at benchmarking meetings
- good collaboration with the breeding and regional variety trial program and having the input of pest susceptibility issues in new varieties
- opportunity to assess new varieties
- publications in the AMS New Bulletin
- involvement in the SARP process.

Conclusion

Linkages and collaboration between different macadamia research projects enabled us to maximise the combined research efforts and outcomes for the Australian Macadamia Industry.

Outputs

Table 2. Output summary

Output	Description	Detail
Journal article	*Australian Macadamia – Society News Bulletin* Journal for Industry stakeholders	Bright, J. (2017) Are we dropping the ball on nut borer protection? *Australian Macadamia Society News Bulletin* **45**: 1, 23 (Appendix 5.2.).
Journal article	*Australian Macadamia – Society News Bulletin* Journal for Macadamia Industry stakeholders	Bright, J. (2019a) Incorporating indoxacarb into IPM programs paying dividends for Northern Rivers growers. *Australian Macadamia Society News Bulletin* **47**: 1, 42-43 (Appendix 5.8.).
Journal article	Australian Tree Crop magazine for stakeholders in the Australian tree crop industries	Bright, J., (2019b) Tailoring options for seed weevil control, *Australian Tree Crop magazine*, February–March 2019, p. 19.
Journal article	*Australian Macadamia – Society News Bulletin* Journal for Macadamia Industry stakeholders	Bright, J., Maddox, C. and Kojetin, L. (2019) Managing macadamia seed weevil. *Australian Macadamia Society News Bulletin* **47**: 2, 24-26 (Appendix 5.9.).

Journal article	*Australian Macadamia – Society News Bulletin* Journal for Industry stakeholders	Bright, J. (2020) *Leptocoris* in macadamia. *Australian Macadamia Society News Bulletin* **48**: 1, 78-79 (Appendix 5.12.).
Journal article	*Australian Macadamia – Society News Bulletin* Journal for Macadamia Industry stakeholders	Huwer, R., Maddox, C., Hickey, M. and Bright, J. (2017) IPM Project – a busy year establishing research and case study sites. *Australian Macadamia Society News Bulletin* **45**: 4, 52-55 (Appendix 5.3.).
Journal article	*Australian Macadamia – Society News Bulletin* Journal for Macadamia Industry stakeholders	Huwer, R. Maddox C. Bright, J. and Hickey, M. (2018) Numbers in for year 1 of CTH IPDM trial. *Australian Macadamia Society News Bulletin* **46:** 3, 68-69 (Appendix 5.6.).
Journal article	*Australian Macadamia – Society News Bulletin* Journal for Industry stakeholders	Huwer, R., Maddox, C., Bright, J. and Adkins, M. 2021 IPM in macadamias – not a strategy but different options (2021) *Australian Macadamia Society News Bulletin* **49:** 3, 21-23 (Appendix 5.16.).

Table 2. Output summary (cont.)

Output	Description	Detail
Journal article	Australian Tree Crop magazine for stakeholders in Australian tree crop industries	Huwer, R., Maddox, C., Bright, J. and Adkins, M. 2021 IPM in macadamia: not a single fix but options. *Australian Tree Crop*, October–November 2021, 52-54 (Appendix 5.17).
Journal article	*Australian Macadamia – Society News Bulletin* Journal for Industry stakeholders	Maddox C. and Huwer, R. (2018) Indoxacarb – a new option for macadamia seed weevil management. *Australian Macadamia Society News Bulletin* **46**: 4, 66-67 (Appendix 5.1.).
Journal article	*Australian Macadamia – Society News Bulletin* Journal for Industry stakeholders	Maddox, C. (2019). Boring beetles: depends on how you look at it! *Australian Macadamia Society News Bulletin* **47**: 2, 29-31 (Appendix 5.10.).
Journal article	*Australian Macadamia – Society News Bulletin* Journal for Industry stakeholders	Maddox, C., Huwer, R., Roberson, D., Janetzki, A. and Purdue, I. (2019) Assessing fresh Fruit spotting bug damage on mature green nut. *Australian Macadamia Society News Bulletin* **47**: 2, 34 (Appendix 5.11.).
Journal article	*Australian Macadamia – Society News Bulletin* Journal for Industry stakeholders	Maddox, C. (2020) To yield or not to yield? *Australian Macadamia Society News Bulletin* **48**: 2, 54-55 (Appendix 5.13.).
Journal article	*Australian Macadamia – Society News Bulletin* Journal for Industry stakeholders	Maddox, C., Cook, C. and Maier, B. (2021) Controlling Fruit spotting bug damage in macadamia: Timing is everything. *Australian Macadamia Society News Bulletin*-**48:**4, 67-69 (Appendix 5.14.).
Journal article	*Australian Macadamia – Society News Bulletin* Journal for Industry stakeholders	Maddox, C. and Huwer, R. (2021) Understanding the risk of crop loss to macadamia nut borer (*Cryptophlebia ombrodelta*) *Australian Macadamia Society News Bulletin* **49:** 3, 17-19 (Appendix 5.15.).
Conference presentation	Conference proceedings International macadamia industry stakeholders	Bright, J., 2018 Doing more with less. 8th International Macadamia Symposium, 14–19 October 2018, Lincang, China.
Conference presentation	Conference proceedings International macadamia researchers	Hickey, M., 2018 Macadamia IPM: Are we there yet? 2018 Australian Macadamia Conference, 13-15 November 2018, Royal Pines Resort, Gold Coast, Australia.
Conference presentation	Conference proceedings International macadamia researchers	Huwer, R.K., Maddox, C.D.A., Hickey, M. and Bright, J. (2017) Towards a fully integrated pest management strategy for Australian macadamias. International Macadamia Research Forum in Hilo Hawaii 12-15 September 2017 (Abstract shown in Appendix 6.1.).

Table 2. Output summary (cont.)

Output	**Description**	**Detail**
Conference presentation	Conference proceedings Australian macadamia industry stakeholders	Huwer, R.K. and Maddox, C., (2018) Taking a fully integrated approach to pest management in macadamias. 8th International Macadamia Symposium, 14–19 October 2018, Lincang, China (Abstract shown in Appendix 6.4.).
Conference presentation	Conference proceedings International macadamia researchers	Huwer, R.K. and Maddox, C., Purdue, I., Bright, J. and Hickey, M. (2019) Update on integrated pest management in Australian macadamias. 2nd International Macadamia Researcher Forum 5-6-November, Lingcang, China (Abstract shown in Appendix 6.5.).
Conference presentation	Conference Handbook Plant Protection researchers	Maddox, C.D.A., Simpson C., Newton, I., Stacey, P., Stacey, P., Huwer, R., Purdue, I., Robertson, D., Janetzki, A. and Maddox, C., (2017) *Amblypelta* spp. management for NSW and SE QLD avocado and macadamia orchards. Can we reduce the spray frequency with better timing? Science Protecting Plant Health, 26-28 September 2017 Brisbane Convention Centre, Conference Handbook**,** p**.** 167 (Abstract shown in Appendix 6.2.).
Conference presentation	Conference Handbook Plant Protection researchers	Maddox, C.D.A., Huwer, R., Purdue, I., Robertson, D., Janetzki, A., Pretorius, J., Newell, B., Ford, Quinlan, K., Griffiths, M., Seago, A., Gopurenko, D. and Mitchel, A. (2017) The rise of scolytid beetle activity ....is it just the hot weather? Science Protecting Plant Health, 26-28 September 2017 Brisbane Convention Centre, Conference Handbook**,** p**.** 167 (Abstract shown in Appendix 6.3.).
Meeting Presentation	Presentation for Australian macadamia pest consultants	AMS Pest consultant meeting July 2017 A presentation introducing the project was given to introduce the project, published on the AMS website.
Meeting Presentation	Presentation to Australian macadamia growers	MacGroups in July 2017 A presentation on the IPM program was given at 15 MacGroup meetings (18 July Glasshouse Mt., 19 July Gympie (x2), 20 and 21 July Bundaberg (x3), 25-28 July Northern Rivers (x7), 31 July Northern Rivers, 6 October, Mackay) – published on the AMS website.
Meeting Presentation	Presentation for Australian macadamia pest consultants	AMS Consultants Meeting 6-7 June 2018 in Caloundra: Ruth Huwer gave a presentation giving an update on the NSW DPI component of the IPM program for the Australian Macadamia Industry – published on the AMS website.

Table 2. Output summary (cont.)

Output	**Description**	**Detail**
Display and discussion	Display and discussion of macadamia pests for Australian macadamia growers	MacGroups in July 2018: Jeremy Bright gave a presentation on the Macadamia Plant Protection Guide 2018–2019 and Ruth Huwer showed and explained a display of different macadamia pests at the July (3 July Mid North Coast; 4 and 5 July Northern Rivers, 10 July Glasshouse, 11 July Gympie, 12 July Bundaberg). Growers were very interested in the new publication and pests display.
Meeting Presentation	Presentation to Australian macadamia growers	MacGroup in February March 2020: A presentation was given at 7 MacGroup meetings. (Glasshouse Mountains 25 February; Gympie 26 February; Bundaberg 27 February; Mid North Coast 10 March; Northern Rivers (coastal) 11 March; Northern Rivers (plateau) 12 March × 2) Huwer, R., Maddox, C., Bright, J. 2020: Pests prevalent in dry conditions – published on the AMS website https://www.australianmacadamias.org/industry/resources/pests-prevalent-in-dry-conditions-febmarch-2020-macgroup
Workshop	Presentation to Australian macadamia growers	Clarence Valley – Macadamia seed weevil workshops October 2020: Two (Covid 19 safe) workshops on awareness and information on macadamia seed weevil were held on 22 October 2020, at Harwood in the Clarence Valley, where macadamia seed weevil had recently been detected for the first time. The two workshops were limited to 20 participants each, due to COVID-19 regulations. Information on pest biology, ecology, management and farm biosecurity measures was presented by NSW DPI (Jeremy Bright and Dr Ruth Huwer).
Meeting Presentation	Presentation for Australian macadamia pest consultants	Pest consultant meetings November 2021: A presentation was given on the final summary of the project at the NSW meeting on 11 November by Ruth Huwer and the QLD meeting on 19 November by Kevin Quinlan - published on the AMS website.
Meeting Presentation	Presentation to Australian macadamia growers	AMS MacGroups November/December 2021: A presentation - published on the AMS website, was given on the final summary of the project at 8 MacGroup meetings by Kevin Quinlan (22 November Bundaberg x2, 23 November Gympie x1; 24 November Glass House Mountains x1; 30 November Mid North Coast x1; 1 and 2 December Northern Rivers x3.
Interview	Radio presentation	J. Bright 2020: ABC radio interview Bundaberg MacGroup on 27 March on bark beetles and *Leptocoris* bugs and dry weather pests in general.
Interview	Radio presentation	R. Huwer 2021: ABC radio interview aired on 2 September 2021 on a summary of the IPM project.

Table 2. Output summary (cont.)

Output	Description	Detail
Plant protection guide	Plant protection guidelines and updates for stakeholders in the macadamia industry	Bright, J. (2016) Macadamia Plant protection guide 2016-17 (Appendix 7.1.) – published on NSW DPI website
Plant protection guide	Plant protection guidelines and updates for stakeholders in the macadamia industry	Bright, J. (2018) Macadamia Plant protection guide 2018-19 (Appendix 7.2.) – published on NSW DPI website
Plant protection guide	Plant protection guidelines and updates for stakeholders in the macadamia industry	Bright, J. (2019) Macadamia Plant protection guide 2019-20 (Appendix 7.3.) – published on NSW DPI website
Plant protection guide	Plant protection guidelines and updates for stakeholders in the macadamia industry	Bright, J. (2020) Macadamia Plant protection guide 2020-21 (Appendix 7.4.) – published on NSW DPI website https://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/529161/Macadamia-plant-protection-guide-2020.pdf
Plant protection guide	Plant protection guidelines and updates for stakeholders in the macadamia industry	Bright, J. (2020) Macadamia Plant protection guide 2021-22 (Appendix 7.5.) – published on NSW DPI website https://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/529161/Macadamia-plant-protection-guide-2021-22.pdf
Prime Facts	Information material for growers	Bright, J. (2017) Macadamia seed weevil, life cycle and monitoring Primefact 1586 First Edition, August 2017 (Appendix 8.1.) – published on NSW DPI website https://www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/731982/Macadamia-seed-weevil-update-lifecycle_2.pdf
Prime Facts	Information material for growers	Bright, J. (2018) Macadamia seed weevil orchard management (Revised) Primefact 1585 First Edition August 2017 (Appendix 8.2) – published on NSW DPI website https://www.dpi.nsw.gov.au/__data/assets/pdf_file/0008/731987/Macadamia-seed-weevil-update-orchard-management_2.pdf
Prime Facts	Information material for growers	Bright, J. (2020) *Leptocoris* in macadamia (Primefact 1716-First Edition, January 2020) (Appendix 8.3.) – published on NSW DPI website https://www.dpi.nsw.gov.au/__data/assets/pdf_file/0004/1195591/Leptocoris-in-macadamia.pdf

Table 2. Output summary (cont.)

Output	**Description**	**Detail**
Prime Facts	Information material for growers	Bright, J. (2020) Macadamia lace bug management and control (Primefact 1661 Third edition, July 2020) (Appendix 8.4.) – published on NSW DPI website https://www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/836463/Macadamia-lace-bug-management-and-control-V3.pdf
Prime Facts	Information material for growers	Bright, J. (2020) Fruit spotting bug in macadamia (Primefact 1777-First Edition, September 2020) (Appendix 8.5.) – published on NSW DPI website https://www.dpi.nsw.gov.au/__data/assets/pdf_file/0004/1258933/Fruit-spotting-bug-in-macadamia.pdf
Prime Facts	Information material for growers	Bright, J. (2020) Green vegetable bug in macadamia (Primefact 1781-First Edition, September 2020) (Appendix 8.6.) – published on NSW DPI website https://www.dpi.nsw.gov.au/__data/assets/pdf_file/0009/1258821/Green-vegetable-bug-in-macadamia.pdf
Prime Facts	Information material for growers	Bright, J. (2020) Macadamia nut borer (Primefact 20/778-First Edition, September 2020) (Appendix 8.7.) – published on NSW DPI website https://www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/1258824/Macadamia-nut-borer.pdf
Video	Information for macadamia growers	Bright, J. (2018) Macadamia seed weevil (Primefact 20/782 First Edition, September 2020 (Appendix 8.8)) – published on NSW DPI website https://www.dpi.nsw.gov.au/__data/assets/pdf_file/0007/1259044/Macadamia-seed-weevil.pdf
Video	Information for macadamia growers	A video on Sigastus weevil management has been released in October 2018. (scripted by NSW DPI, filmed and edited by QDAF) – published on the AMS website https://www.youtube.com/watch?v=4QcO8oLh9hw
Video	Information for macadamia growers	Video on macadamia seed weevil (formerly Sigastus weevil) life cycle (by Kim Khuy Khun, USQ) – published on the AMS website https://www.youtube.com/watch?v=2LeFc55vvAw
Video	Information for macadamia growers	The AMS arranged a video production about the changing landscape of pest and disease management in macadamia (AMS production) – published on the AMS website https://www.youtube.com/watch?v=C9pXjszRZbI

Outcomes

Table 3. Outcome summary

Outcome	**Alignment to fund outcome, strategy and KPI**	**Description**	**Evidence**
Practice change	Outcomes Supply, productivity and sustainability Strategies 6. Support an IPDM program that addresses key economic, social and environmental outcomes for the macadamia industry KPI Increased adoption of IPDM strategies. Reduction in crop loss from FSB, Botryosphaeria and other major pests and diseases	Tool for managing MSW that provides effective control and does not negatively affect IOM or IPM	Observation of a high adoption rate by growers
Practice change		Options for managing MLB that are less disruptive to pollinators (i.e. bees)	Observation of a high adoption rate by growers
Knowledge		Monitor for different beetle pests (scolytids, scarab beetles) and understand that tree health is critical to prevention	Adoption of removal and destroying dead branches by industry. Enhancing soil health and tree health adoption by growers
Knowledge		Pesticide options that prevent secondary pests such as felted coccid and thrips	Transitioning through industry
Knowledge		Options for IPM strategies that can be chosen to fit individual pest and farm situation and season, which includes options currently available for monitoring, biological control, cultural control and chemical control	Adoption in progress
Knowledge		Prototype of IPDM ranking system to determine the level of IPDM strategy – note produced internally through NSW DPI resources but linked to this project	A pilot study is being undertaken through linkages with the Benchmarking project (MC18002)

Monitoring and evaluation

A copy of the original monitoring and evaluation plan (M&E plan) for the IPM Program for the Macadamia Industry MC16003-8 is attached in Appendix 9. Note that as the original M&E plan was completed for the suite of IPM projects, the following have been completed for activities undertaken in this project to meet those objectives. This may mean that while we have evaluated the performance of this project against that key evaluation questions, other projects undertaken would provide the basis for achieving those objectives.

Table 4. Key evaluation questions.

BROADER GOALS		
Key evaluation question	**Project performance**	**Continuous improvement opportunities**
• Strategic investment areas • ID opportunities to improve productivity in existing orchard base (or, in this case, maintain productivity even though less use of broad-spectrum pesticides)	• We reduced the need for broad-spectrum insecticides • All study sites showed a reduction of broad-spectrum insecticides • We replaced broad-spectrum insecticides with more IPM compatible products • We achieved higher productivity by reducing the nut loss and rejection due to insect damage promoting a more profitable industry	• Opportunities for more selective chemistries in conjunction with cultural and biological control need further investigation of inter-row crops and their effect on yield and quality • Development of an IPDM scorecard to get a better understanding of cultural and biological influences on productivity
IMMEDIATE PROGRAM OUTCOMES		
Key evaluation question	**Project performance**	**Continuous improvement opportunities**
• Increased understanding of biology and ecology of insects by consultants, researchers and growers – underpinning interest in IPM and willingness to progress and adopt • 80+% of scouts are using new/improved tools • 40+% of consultants/scouts and producers (by ha) have adopted or refined their use of two or more of the key IPM components (tools, chemicals, beneficials, lures, management approaches – e.g. monitoring thresholds) • 50% of consultants are using best management (BM) reports as a tool for increasing the uptake of IPM • Coordinated chemical management as part of AWM • Reduction of use of broad-spectrum insecticides by 20+%	• We provided a better understanding of the biology and ecology of MSW • We achieved a wider awareness use of the monitoring hedge as a tool for monitoring FSB • A new management strategy for MSW was adopted by almost 100% of growers in one season • Monitoring hedge data from NSW DPI is being used as a decision tool by consultants across 4 major growing regions along the east coast, which is a pilot program for area-wide management	• Development of a region-specific area-wide management system across multiple pests • Further investigation into inter-row crops for their effects on yield and quality • Identification of tolerance or resistance of varieties to different pests, investigating the new varieties in the regional variety • More collaboration with universities to focus the research more on student projects

Table 4 Key Evaluation Questions (cont.)

<table>
<tr><th colspan="3">IMMEDIATE PROGRAM OUTCOMES (cont.)</th></tr>
<tr><th>Key evaluation question</th><th>Project performance</th><th>Continuous improvement opportunities</th></tr>
<tr><td>Increased professional/scientific capacity within the industry – graduates and existing researchers</td><td>The industry has adapted the reduction of older broad-spectrum chemicals, which were replaced by more pest-specific chemicals and cultural control. For example, using indoxacarb across the entire Northern Rivers region for MSW control compared with 2 organophosphates before its registration
Two PhD students have been involved in the program</td><td></td></tr>
<tr><th colspan="3">INFLUENCING ACTIVITIES</th></tr>
<tr><th>Key Evaluation Question</th><th>Project performance</th><th>Continuous improvement opportunities</th></tr>
<tr><td>Communication
On-going liaison with and materials provided to Macadamia Communications Project, MacBulletin
Extension activities
Overall – across the program
Ongoing liaison and joint activities with Macadamia Innovation and Adoption program
Attend and engage with MacGroups
Presentations at conferences
Publication of scientific papers
Distribution, promotion and use of IPM Guide
Biology and Ecology
Engagement with other researchers
Grower and crop consultant training – improved understanding
Biosecurity awareness activities
Monitoring and Attractants
Field days</td><td>Several different extension activities were delivered during the program, which included the following:
5 Scientific publications
17 Journal articles
7 Conference presentations
36 MacGroup presentations
6 Consultant meeting presentations
5 Presentations at Benchmarking groups
5 Macadamia Plant Protection Guides
8 PrimeFacts
2 Videos
2 Radio and 2 TV interviews
Awareness activities of the MSW in all growing areas
We have been consulting with different chemical companies and assisting with the generation of data for selecting new chemistry progressing registration</td><td>Further biosecurity awareness for growers
Continuation of collaboration with chemical industries for more IPM compatible products
More investigation of biopesticides</td></tr>
</table>

Table 4 Key Evaluation Questions (cont.)

INFLUENCING ACTIVITIES (cont.)		
Chemical Control • On-going liaison with industry re recommended chemical management strategy using different platforms ***Extension development*** Field days on demonstration sites	• See above	• See above
OUTPUTS and PRODUCTS		
Key Evaluation Question	**Project performance**	**Continuous improvement opportunities**

Biology and Ecology
• Information packages for researchers, consultants and growers
• Workshop materials and presentations
 	
Monitoring and Attractants
• Lures/attractants based on thresholds
 	
Insect Pathology
• Isolates of fungi identified for commercialisation
• A best-bet formulation for testing
• Report/paper on best fungi
• Workshop materials
 	
Chemical Control
• Recommendations on chemical strategy as part of an IPM guide
• Regionally customised and relevant case studies as part of an IPM Program
• Permits for IPM compatible chemicals
• Review of IPM compatible chemicals
 	
Extension development
• Summaries of demonstrations
• Fact sheets
• Manuals
• Videos
 	
Cross-program
• Conference articles
• Media and communication articles
• Website content
• Scientific publications
	• Gap analysis is provided in this report
	• Updates of the program were features of the DPI Macadamia Plant Protection Guides
	• Information for lures and traps for scolytid beetles and longicorn beetles have been made public and information provided to the industry
	• Entomopathogen research has been conducted as part of a PhD. Successful strains of *Beauveria bassiana* and *Metarhizium anisopliae* have been identified and tested, but field efficacy needs to be further investigated
	• New chemicals, including Avatar®, Trivor® and Transform® were registered and are now available to the industry; Sivanto® Prime will become available next season
	• Workshops on MSW biology (including life cycle) and management were held in Yamba, Lismore and Alstonville
	• Several different extension activities were delivered during the program, which included the following:
	  • 5 Scientific publications
	  • 17 Journal articles
	  • 7 Conference presentations
	  • 36 MacGroup presentations
		• Commercial traps and lures for scolytid beetles are available overseas and need to be made more accessible to the Australian market
		• Entomopathogens need to be tested in more stable formulations

Table 4 Key Evaluation Questions (cont.)

OUTPUTS and PRODUCTS (cont.)		
Key evaluation question	**Project performance**	**Continuous improvement opportunities**
• See above	• 6 Consultant meeting presentations • 5 Presentations at Benchmarking groups • 5 Macadamia Plant Protection Guides • 8 PrimeFacts • 2 Videos • 2 Radio and 2 TV interviews	• See above
RESEARCH and DEVELOPMENT		
Key evaluation question	**Project performance**	**Continuous improvement opportunities**
Biology and Ecology • Insect survey (DPI and Scouts) • Identification of knowledge gaps in insect biology and ecology • Studies on population dynamics • Literature review ***Monitoring and Attractants*** • Development and testing of lures to aggregate pests and optimised timing of pesticide application • Development of *Sigastus* lure • Trials to maximise beneficials ***Insect Pathology*** • Researching insect colony management • Isolation of cultures and characteristics • Production of spores for trials • Testing of existing best-bet fungi bioassays • Literature review on Macadamia pests and control ***Chemical Control*** • Laboratory screening of chemicals on selected pests and beneficials	• Scouts monitored and reported on insects found • A literature review and gap analysis are presented in this report • Population dynamics were studied on MSW and generally on pests and beneficials monitored • Attempts were made to develop a lure for MSW, but this needs further investigation • A biodiversity trial with inter-row planting was done to investigate the effect of inter-rows on beneficial populations, but also on yield and quality • A methodology for maintaining colonies of *Leptocoris* spp. has been developed • As part of a PhD study on entomopathogens for managing MSW, different strains of *Beauveria bassiana* and *Metarhizium* were described • Spores of *Beauveria bassiana* were produced by QDAF to be tested in laboratory screening against MSW • A large number of insecticides were screened for different pests	• Thresholds for scolytid beetles still need to be developed • A producer or importer for scolytid traps and lures in Australia needs to be identified • More detailed research on the lure for MSW is required, possibly with commercial input • Testing new products as they become available • Testing different approaches on the same farm to make a comparison more robust • More input from industry representatives, consultants and researchers into the SARP process, as it used to be in the past • Formal AWM groups should be established in each region and be supported by industry, consultants and researchers • Trials on commercial farm blocks in different regions need to be established to identify the effect of inter-rows on biodiversity, yield and quality

• Selection and recommendation of chemicals for field efficacy trials • Testing chemical management strategy and evaluating against selected beneficials	and MNB egg parasitoids	

Table 4 Key Evaluation Questions (cont.)

RESEARCH and DEVELOPMENT (cont.)		
Key Evaluation Question	**Project performance**	**Continuous improvement opportunities**
Chemical Control • Recommend and test management strategy and evaluate against beneficials on farm and case study sites ***Extension development*** • Undertake IPM baseline – in year 1 • The pilot of ARGA wide forecasting • Establishment of demonstrations on farms	• 15 products were tested for MLB • 3 products were screened to reduce flare-up of felted coccid • 3 products were screened against MNB • 9 products were tested for managing MSW • 16 chemicals were screened against FSB • 15 products were tested for management of *Leptocoris* bugs • New products were tested against the egg parasitoid *Trichogrammatoidea cryptophlebiae* • A new permit for indoxacarb for managing MSW was granted by the APVMA • The program investigated 8 case study sites in the 4 main production regions, comparing conventional vs. IPM treatment and change to a more sustainable approach over time • Baseline data was collected in the first year at all case study sites and CTH and is presented in this report • An e-mail group was established by NSW DPI including selected consultants, processors and growers as a pilot for AWM groups. Monitoring results were shared weekly	• See above

Recommendations

This project made many advances in integrated pest management for macadamias. To ensure the successful adoption of IPM, a one size fits all approach cannot be taken. It is recommended that the results of this project need to be placed into the context of each grower's circumstances, location and farming system. Factors that need to be considered include location, varieties, spacings, tree height, adjoining vegetation and threshold tolerance.

To achieve this objective, it is recommended that the concept of an IPDM scorecard that relates pest and disease management activities to farm performance (yield and quality) is pursued. This system will allow comparisons to be made by a grower across seasons and allow the industry to highlight its continuous improvement in IPM.

Diligent monitoring is paramount to any successful IPM strategy. It is recommended that the industry produce a series of case studies to highlight how monitoring has improved the performance of macadamia growers (using a triple bottom line approach) to promote the further adoption of monitoring and only intervening when thresholds have been exceeded.

Area-wide management is important for coordinated monitoring and better management across a region. The email sharing of monitoring results was a successful start but needs to be progressed to formalised groups. Area-wide management would also be a good platform for extension and benefit adoption, directly working with growers and consultants.

It is recommended that further evaluations of new and emerging insecticides that are IPM compatible are undertaken. Due to the long lead time between showing efficacy and registration, continual evaluation needs to be conducted. Further, it is recommended that the evaluations be handled independently and undertaken by service providers with a history of independence within the macadamia industry. This is to ensure grower confidence in using any new products released. As part of these evaluations, the effect of the chemistries upon biological control agents such as MacTrix should be performed.

Entomopathogens need further investigation regarding field stability. Research should include other coleopteran pests as well. Incorporating entomopathogens into trapping systems to keep them more protected, particularly from UV, should be explored.

The effect of cultural control, especially reducing host susceptibility and/or resistance should be considered. This would involve establishing an orchard with traits making it less prone to pest attack and therefore not needing as much chemical intervention. A key aspect of this would be varietal selection. Part of this work should include the integration of orchard management practices such as pruning, light distribution and hygiene.

The link between tree health and the susceptibility of macadamias to beetle attack should be further investigated. Determining key thresholds for sap flow levels and duration should be better understood.

It is recommended that new macadamia cultivars be bred with pest susceptibility to decrease the reliance upon the need for intervention. Within the context of breeding, consideration of drought tolerance as protection for beetle ingress and the effects of climate change should also be incorporated.

The full value of increasing biodiversity in orchards should be considered. This would include not only considering the improvement in biodiversity gained from planting inter-row crops, but also the effect on pest populations within the crop, the level of control achieved within the crop and the yield and quality of production. This study should also look at the inter-row system in its entirety, for example, the potential to use inter-row biodiversity to increase pollination (and ultimately crop yield) should be considered.

Refereed scientific publications

Khun, K.K., Ash, G.J., Stevens, M.M., Huwer R. and Wilson, B.A.L. (2020) Response of the macadamia seed weevil Kuschelorhynchus macadamiae (Coleoptera: Curculionidae) to *Metarhizium anisopliae* and *Beauveria bassiana* in laboratory bioassays. *Journal of Invertebrate Pathology*, 174 (2020) 107437, 7pp. (Appendix 4.1.) https://www.sciencedirect.com/science/article/abs/pii/S0022201120301439?via%3Dihub

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Intellectual property

No project IP or commercialisation to report

Intellectual property, commercialisation and confidentiality

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Appendix 1: Detailed methodology

1.1. Gap analysis

Gaps in IPM for the Australian Macadamia Industry were identified by conducting an extensive literature review on IPM in general, area-wide management, IPM in other horticultural tree crops including apples, pears, pecan and macadamia nuts.

The current situation of IPM in Australian macadamias was reviewed and examined in the light of the literature review to establish where pest management for the Australian macadamia industry fits and where the opportunities are to improve on IPM and link different components. Comments and input from consultants (Appendix 2.5.3.) were also an important part of the considerations.

1.2. Literature review

A total of 84 references were reviewed on different aspects of IPM. This included general aspects (definition, different levels of IPM, different steps of IPM), IPM in other horticultural tree crops, IPM in other nuts and macadamias in other countries.

A comparison was made to current IPM efforts in Australian Macadamias.

The detailed literature review is presented in Appendix 2.1.1.

Conclusions drawn from the review and gaps identified for Australian macadamias are presented in Appendix 2.1.

1.3. Regional case study sites

Two case study sites were set up in each of the four major macadamia growing areas by collaborating consultants as follows:

- Central Queensland, Bundaberg Region: Eddy Dunn
- Glasshouse Mountain/ Gympie Region: Chris Fuller
- Northern Rivers Region: Jarrah Coates
- NSW Mid North Coast Region: Bob Maier

In each area, a site with different pest management; one site with a higher level of IPM management and one site with more reliance on broad-spectrum insecticides were chosen. An overview of some details of the case study farm sites in the four different regions is shown in Table 1.2.1.

Table 1.2.1.: Overview of the case study sites

Region	Sites	Treatment	Tree number	Spacing in meters	Size in Ha	Planting year	Varieties
Central Queensland	1	High IPM	6513/ 3347 trees respectively	7x4 (7.9ha) and 14 x 4 (19ha) since June 2017	27.21	1993	741 and 344
Central Queensland	2	Low IPM	2794	7x4	9.8	1993	741 and 344
Gympie- Glasshouse Mountains	3	High IPM	1000	9X4.5	6	1997	817, 741 and Daddow
Gympie- Glasshouse Mountains	4	Low IPM	1000	8X4	21.01	1992-1994 2001-2002	Daddow, 741, 344, 842 and 849
Northern Rivers	5	High IPM	1200	10x5	6	2004	816, 246 and 849
Northern Rivers	6	Low IPM	3,626	9X5	16.4	1998	741, 344 and A16
Mid North Coast	7	High IPM	1,177	9x4 - for A16 9x5 - for all other varieties	5.1	1997-2001	A29, 842, 268, 849, Daddow, A4, A16, A38 and A203
Mid North Coast	8	Low IPM	1,417	10x5	7.01	1998-2000	Daddow, A38 and A16

A description of the site by the collaborating consultant for each of their site is presented in Appendix 1.2.1.

Treatments, including cultural, biological and chemical control were common practices for each case study site using the consultant's recommendations. Each site used some level of IPM. An overview of treatments applied at each site is shown in Appendix 1.2.2.

Case study sites were monitored fortnightly for pests and beneficials between July and March each year.

A monitoring protocol was developed at the beginning of the project in collaboration with the participating consultants. An example of a monitoring sheet and general information on monitoring and thresholds is shown in Appendix 1.2.3.

Monitoring techniques were the following:

- Visual observations: pests and beneficials in general
- Yellow sticky traps pests and beneficials in general
- Pheromone traps: macadamia nut borer, scolytid beetles, banana spotting bug (*Amblypelta l. lutescens*)

<u>Harvesting</u>

Early (around March) and later (July) in the season 300 nuts were randomly picked up by the consultants at each site and submitted to NSW DPI at Wollongbar for processing and assessment. Sometimes an additional sample from the middle of the harvest season was provided.

<u>Nut processing and kernel assessment</u>

To assess the effect on quality, 2-3 nut samples per site were taken by the consultants and green husk for insect damage, nuts were processed, and kernel was assessed using industry guidelines (AMS, 2019).

Nut samples were de-husked and the number of nuts passing through the de-husker for each sample was recorded, along with the weight of wet nut in shell. Nut in shell samples were then put into plastic nets and placed in a dehydrator for drying: 48 hours at 38°C, followed by 48 hours at 45°C and a further 48 hours at 60°C to achieve 1.5% moisture content (AMS, 2019).

Once dried samples were counted, weighed and dry nut in shell weights were recorded. Nuts were then cracked, poured through a sieve and any parts > 2 mm were sorted into the following categories:

- FSB damage
- *Leptocoris* damage
- MNB damage
- Kernel grub damage
- Fungus
- Discolouration
- Germination
- Immature kernel
- Sound kernel

After sorting, the sound kernel weight was determined, and the sound kernel then floated in a bowl of water to separate mature kernels with a higher oil content that floated from immature kernels with lower oil content that sank. The immature kernel was discarded, and the mature kernels were placed into plastic bags and returned to the dehydrator for 24 hours at 60 °C. The nut samples were then re-weighed and the A-grade kernel fraction of the nut sample was calculated (Huwer et al. 2006).

The average nut yield per tree was expressed as dry nut in shell (DNIS) at 10% moisture content.

1.2.1. Descriptions of regional case study sites

Central Queensland - Bundaberg Region

Site Descriptions – Eddy Dunn

Both orchards are older variety 344 /741 located at Winfield farm, approximately 70km north of Bundaberg.

Bundaberg is a fairly diverse area with a reliance on pesticides for many crops in the region. Questions about possible FSB resistance to synthetic pyrethroids, poor spray coverage and poor spray timing may all contribute to the grower's problem in this area and these trials will allow us to focus on some alternate control strategies which might address the control issues experienced better.

Case Study Site 1

This orchard block was chosen as the IPM orchard as it has always had spray issues with residential housing that prevents spraying unless the wind is blowing from the correct direction. The block is notoriously heavy for Fruit spotting bug damage and does get pressure from Banana fruit caterpillar and Macadamia flower caterpillar which virtually wiped out the 2017 crop (1 t/ha).

The monitoring for this season has already shown the need to treat for flower caterpillar with prodigy being applied 18/7/17. The use of *Anastatus* sp. to reduce FSB damage is thought to be a better bet in a more isolated area away from the main farm which is sprayed heavily.

Case Study Site 2

This orchard block was chosen as it has similar spacing, size and varieties to the available IPM block. There is also heavy FSB pressure in the area, as well as banana fruit caterpillar and flower caterpillar, but these can be sprayed at the correct time. The current production level has ranged between 2-3T/ha, poor nut quality is evident with an improvement in FSB management the biggest issue facing the farm. Both areas do have neighbouring pockets of scrub and some houses have fruiting *Murraya paniculata* hedges which will assist with the local FSB monitoring.

Gympie – Glasshouse Mountain Region

Site Descriptions – Chris Fuller

Case Study Site 3**:**

This orchard was chosen as the IPM orchard as it is the only orchard I consult where the grower has a strong commitment to furthering IPM principles. It is a 10-year-old orchard of 817, 741 and Daddows. The trial block includes around 1000 trees of a 1500 tree planting which is the older section of the orchard. There are another 1000 odd younger trees in a second block a short distance away on the property. Matthew and Nicola have a zero-herbicide policy within the orchard with grass being grown and mown right up to the trunk line. Mathew uses Bt sprays whenever it is just the Lepidoptera pests he is targeting. He will always use the softest option when it comes to chemical application. The orchard did have MLB at a level that was acted on about three years ago but it has caused no significant problems since. Mathew has in the past tried to establish Weaver ant colonies in tubes within the tree to act as general predators but found they were knocked back severely during the spotting bug spray season. There are still some present within the orchard. He has a belief that strong, healthy trees will help combat some pest and disease attacks. He does accept however that some sprays are required in our current pest system but wanted to be involved in the trial to be at the forefront of any information that may lead to a further reduction in chemical usage. Interestingly FSB pressure seems generally lighter on this orchard and this may well be because of Mathew's softer approach to earlier pests.

Case Study Site 4

This orchard was chosen as it has a block that was the best fit for matching the available IPM block. There is a block of trees around the same size, which is comprised of Daddows, 741, 344, 842 and 849. The orchardists have a fairly standard approach to pest control. They rely on a scout, myself, for advice but will spray as soon as advised thresholds have been neared or met. There have been moderate levels of MLB detected and we have put on a pre flower spray two out of the last three seasons. Spotting bug is the biggest pest and is targeted with spray numerous times throughout the season. Nut borer is also monitored and a broader spectrum product is often used as it will also take out any late spotting bug. These growers have a strong focus on pest control and also are very particular about spray coverage and effectiveness. We have often done one more FSB spray on this orchard compared to other orchards nearby. Phosphoric acid is used to treat any *Phytophthora* affected trees and Ethrel is often used in harvesting management.

Northern Rivers Region

Site Descriptions – Jarah Coates

Case Study Site 5

This site was chosen as the IPM site for the trial for the following reasons:

Willingness to experiment with novel potential cultural and biological control practices, recent change from organics, desirable tree age on good spacings, already established inter-row with desirable plant species to support beneficials, some tolerance for loss, reluctance to spray will consider other options before a spray decision is made.

The IPM site will be managed with more flexibility than a typical conventional situation. The intent will be to apply less insecticide and no fungicide applications through the course of the season.

The major insect pest on this site is MSW. Efforts will be made to explore potential alternate control strategies. Attention to try to minimise disruption of non-target minor pests and beneficials.

Case Study Site 6

This site was selected as the conventional site for the following reasons:

Good production/yield, manageable tree height and favourable orchard age, very thorough historical record-keeping i.e. tonnage per Ha per variety, Responsive to advice/recommendations, Own spray equipment and other machinery (no contractors required), long term clients/familiarity with the site over many years, focus on productivity and returns.

The conventional site will be managed with a focus on adhering to more conventional practices and standard control measures. Although some proven biological control agents such as MacTrix (*Trichogrammatoidea cryptophlebiae*) for MNB will continue to be used the main form of control will be through pesticide treatments.

As always, the monitoring data collected from each inspection will form the basis for any recommendations that are made. The key differences between the sites would be the owners contrasting farming ideologies.

Different goals and measures of success. The IPM site is high risk for macadamia seed weevil but relatively low risk for MLB and FSB. The conventional site is higher risk for MLB, high risk for FSB, and moderate risk for macadamia seed weevil.

The farms have similar orchard tree age, soil type, nutrition programs, location and size.

Nambucca - Mid North Coast NSW Region

Site Descriptions – Bob Maier

Case Study Site 7

This block consists of 1,184 trees planted on 5.4ha, with trees ranging from 16 to 20 years of age. Spacing is a mix averaging 9m x 4m with some rows at 9.5m. Varieties are A29, 842, 268, 849, Daddow, A4, A16, A38 and A203. The orchard is in very good health, with average NIS/ha at 2.5 tonnes. This organic block relies heavily on cultural control options, very restrictive chemical usage, and has 10 varieties. Given bush boundaries around the block FSB pressure is typically high and *Anastatus* wasp releases to date not as effective in high pressure seasons. There is sufficient row space for mohawks, the orchard is at stage 2, has good ground cover and there are no low light issues. Hedges on the nearby Maier block will provide the FSB count data for the site.

Case Study Site 8

The trees on this block are between 17 and 19 years of age. There are a total of 1,417 trees on 7.01 ha. Row spacings are 10 x 5 m and are regarded as low density. The varieties are Daddow, A38and A16. Trees are in general good health with some dieback in the A16s. The average NIS yield is 3t/ha.

This conventional block only has 3 varieties to manage. Bark beetle has been an issue in recent years in sections. Adjacent mangroves tend to make this a higher MNB pressure farm in some seasons. There is sufficient row space for mohawks, the orchard is at stage 2, has good ground cover and there are no low light issues. Hedges on the nearby Maier block will provide the FSB count data for the site.

The management choices for each block will be driven by the pest pressure thresholds we have agreed on balanced against use of cost- effective control options that are available in each case, while trying to protect natural enemies. Treatments at regional case study sites

1.2.2. Details of treatments at case study sites

A detailed description and date for treatments at different case study sites are listed in Tables 1.2.2.1 to 1.2.2.8.

Table 1.2.2.1.: Treatments for Central Queensland case study site 1

Season	Region	Site Number	Date	Treatment application
Season 1: 2017-2018	Central Queensland	1	18/07/2017	Prodigy® and Biopest®
			21/08/2017	*Anastatus*
			11/09/2017	*Anastatus*
			05/10/2017	*Anastatus*
			23/10/2017	*Anastatus*
			03/11/2017	*Anastatus*
			13/11/2017	*Anastatus, T. cryptophlebiae*
			20/11/2017	*T. cryptophlebiae*
			27/11/2017	*T. cryptophlebiae*
			04/12/2017	*Anastatus/ T. cryptophlebiae*
			08/12/2017	Transform®
			14/12/2017	*Anastatus, T. cryptophlebiae*
			18/12/2017	*T. cryptophlebiae*
			20/12/2017	Transform®
			26/12/2017	*T. cryptophlebiae*
			02/01/2018	*T. cryptophlebiae*
			09/01/2018	*T. cryptophlebiae*
			17/01/2018	*Anastatus, T. cryptophlebiae*
Season 2: 2018–2019	Central Queensland	1	06/09/2018	Hedging
			18/10/2018	Transform®, Spin Flo®, Kocide®
			01/11/2018	Transform®
			20/11/2018	Lepidex®
			13/12/2018	*Anastatus, T. cryptophlebiae*
			27/12/2018	*Anastatus, T. cryptophlebiae*
			10/01/2019	*Anastatus, T. cryptophlebiae*
			24/01/2019	*Anastatus, T. cryptophlebiae*
			07/02/2019	*Anastatus*
			28/02/2019	*Centrodora darwinii*

Table 1.2.2.1.: Treatments for Central Queensland case study site 1 (cont.)

Season	Region	Site Number	Date	Treatment application
Season 3: 2019–2020	Central Queensland	1	19/08/2019	*Anastatus* release (4000)
			6/09/2019	Prodigy® @ 25 mL/100 L
			9/09/2019	*Anastatus* release (4000)
			30/09/2019	Transform® @ 40 mL/100 L and *Anastatus* release (4000)
			17/10/2019	Lepidex® @ 200 mL/100 L
			21/10/2019	*Anastatus* release (4000)
			11/11/2019	*T. cryptophlebiae* (4000) and *Anastatus* (4000) releases
			12/11/2019	Bulldock® @ 50 mL/100 L and Merivon® @ 40 mL/100 L; fertiliser spreading
			18/11/2019	*T. cryptophlebiae* (4000) and *Anastatus* (4000) releases
			25/11/2019	*T. cryptophlebiae* (4000) and *Anastatus* (4000) releases
			2/12/2019	*T. cryptophlebiae* release (4000)
			4/12/2019	Trivor® @ 20 mL/100 L
			9/12/2019	*T. cryptophlebiae* release (4000)
			16/12/2019	*T. cryptophlebiae* release (4000)
			30/12/2019	*T. cryptophlebiae* release (4000)
			6/01/2020	*T. cryptophlebiae* release (4000)
			13/01/2020	*T. cryptophlebiae* release (4000)
			20/01/2020	*T. cryptophlebiae* (4000) and *Anastatus* (4000) releases
			27/01/2020	*T. cryptophlebiae* release (4000)
			3/02/2020	*T. cryptophlebiae* release (4000)
			10/02/2020	*Anastatus* release (4000)
			2/03/2020	*Anastatus* release (4000)
Season 4: 2020–2021	Central Queensland	1	17/08/2020	*Anastatus*
			19/08/2020	Prodigy®
			07/09/2020	*Anastatus*
			21/09/2020	Transform®
			01/10/2020	*Anastatus, T. cryptophlebiae*
			11/10/2020	Trivor®, Orthene®
			22/10/2020	*Anastatus, T. cryptophlebiae*
			04/11/2020	Trivor®
			12/11/2020	*Anastatus, T. cryptophlebiae*
			22/11/2020	Tyranex®
			03/12/2020	*Anastatus, T. cryptophlebiae*
			15/12/2020	Tyranex®
			24/12/2020	*Anastatus, T. cryptophlebiae*

Table 1.2.2.2.: Treatments for Central Queensland case study site 2

Season number	Region	Site Number	Date	Treatment application
Season 1: 2017-2018	**Central Queensland**	**2**	18/07/2017	Biopest®
			06/10/2017	Lepidex®, SpinFlo®, Copper
			24/10/2017	Lepidex®
			13/11/2017	*T. cryptophlebiae*
			20/11/2017	*T. cryptophlebiae*
			27/11/2017	*T. cryptophlebiae*
			04/12/2017	*T. cryptophlebiae*
			11/12/2017	*T. cryptophlebiae*
			18/12/2017	*T. cryptophlebiae*
			20/12/2017	Bulldock®
			26/12/2017	*T. cryptophlebiae*
			02/01/2018	*T. cryptophlebiae*
			09/01/2018	*T. cryptophlebiae*
			12/01/2018	Suprathion®
			17/01/2018	*T. cryptophlebiae*
			31/01/2018	Bulldock®
			18/07/2017	Biopest ®
			06/10/2017	Lepidex®, SpinFlo®, Copper
Season 2: 2018–2019	**Central Queensland**	**2**	06/09/2018	Prodigy®, Heding
			20/09/2018	Prodigy®
			18/10/2018	Lepidex®, Spin® Flo, Kocide
			20/11/2018	Bulldock®
			13/12/2018	Bulldock®
Season 3: 2019–2020	**Central Queensland**	**2**	06/09/2019	Prodigy® @ 25 mL/100 L
			03/10/2019	Lepidex® @ 200 mL/100 L
			14/11/2019	Bulldock® @ 50 mL/100 L and Merivon® @ 40 mL/100 L
			28/11/2019	Trivor® @ 20 mL/100 L
			12/12/2019	Bulldock® @ 50 mL/100 L
			04/01/2020	Acephate @ 80 g/100 L
			30/01/2020	*Anastatus, T. cryptophlebiae*
Season 4: 2020–2021	**Central Queensland**	**2**	20/08/2020	Prodigy® (Methoxyfenozide)
			10/09/2020	*Anastatus*
			25/09/2020	Trivor® (Acetamiprid + pyriproxyfen)
			01/10/2020	*Anastatus, T. cryptophlebiae*
			02/10/2020	Orthene®
			22/10/2020	*Anastatus, T. cryptophlebiae*
			29/10/2020	Bulldock®
			11/11/2021	Orthene®
			12/11/2020	*Anastatus, T. cryptophlebiae*
			03/12/2020	*Anastatus, T. cryptophlebiae*
			14/12/2020	Bulldock®
			17/12/2020	Acephate
			24/12/2020	*Anastatus, T. cryptophlebiae*

Table 1.2.2.3.: Treatments for Gympie-Glasshouse Mt. case study site 3

Season number	Region	Site Number	Date	Treatment application
Season 1: 2017-2018	Gympie-Glasshouse Mt.	3	17/07/2017	Dipel®
			07/08/2017	Dipel® (816-only)
			20/08/2017	Prodigy®
			05/11/2017	Transform®
			23/11/2017	*T. cryptophlebiae*
			30/11/2017	*T. cryptophlebiae*, Bulldock
			07/12/2017	*T. cryptophlebiae*
			14/12/2017	*T. cryptophlebiae*
			28/12/2017	*T. cryptophlebiae*
			05/01/2018	Bulldock®
Season 2: 2018–2019	Gympie-Glasshouse Mt.	3	09/09/2018	Prodigy®
			09/11/2018	Transform®
			19/11/2018	*T. cryptophlebiae*
			26/11/2018	*T. cryptophlebiae*
			03/12/2018	*T. cryptophlebiae*
			17/12/2018	*T. cryptophlebiae*
			19/12/2019	Bulldock®
			24/12/2018	*T. cryptophlebiae*
Season 3: 2019–2020	Gympie-Glasshouse Mt.	3	21/11/2019	Lepidex® @ 200 mL/100 L
			28/11/2019	*T. cryptophlebiae* release (3000 wasps)
			04/12/2019	*T. cryptophlebiae* release (3000 wasps)
			11/12/2019	*T. cryptophlebiae* release (3000 wasps)
			18/12/2019	*T. cryptophlebiae* release (3000 wasps)
			29/12/2019	Lancer @ 80 g/100 L (Leptocoris hotspot only)
			09/01/2020	Bulldock @ 50 mL/100 L (hotspot spray)
Season 4: 2020–2021	Gympie-Glasshouse Mt.	3	28/08/2020	Prodigy® (Methoxyfenozide)
			15/10/2020	Lepidex®
			10/11/2020	Neem
			16/11/2020	Bulldock®
			19/11/2020	*T. cryptophlebiae*
			26/11/2020	*T. cryptophlebiae*
			03/12/2020	*T. cryptophlebiae*
			10/12/2020	*T. cryptophlebiae*
			17/12/2020	*T. cryptophlebiae*
			24/12/2020	*T. cryptophlebiae*
			31/12/2020	*T. cryptophlebiae*
			07/01/2021	*T. cryptophlebiae*

Table 1.2.2.4.: Treatments for Gympie-Glasshouse Mt. case study site 4

Season number	Region	Site Number	Date	Treatment application
Season 1: 2017-2018	Gympie-Glasshouse Mt.	4	25/08/2017	Lancer®
			03/10/2017	Lancer®/ Cabrio®
			24/10/2017	Lancer®/ SpinFlo®/ Copper
			15/11/2017	Supracide®, Biopest® oil
			10/01/2018	Bulldock® and Biopest®
Season 2: 2018–2019	Gympie-Glasshouse Mt.	4	25/07/2018	1% Biopest® oil
			13/08/2018	Diazinon + Biopest® oil
			10/10/2018	Transform®, Cabrio®
			01/11/2018	Lancer®, Cabrio®
			07/12/2018	Bulldock®
			16/01/2019	Bulldock®
Season 3: 2019–2020	Gympie-Glasshouse Mt.	4	30/08/2019	Prodigy® @ 25 mL/100 L
			09/10/2019	Transform® @ 40 mL/100 L; Spinflo® @ 50 mL/100 L; copper
			09/11/2019	Trivor® @ 40 mL/100 L
			02/12/2019	Bulldock® @ 50 mL/100 L
			14/12/2019	Champ @ 80 g/100 L
Season 4: 2020–2021	Gympie-Glasshouse Mt.	4	25/08/2020	Prodigy®
			07/10/2020	Lancer®, Cabrio®
			03/11/2020	Bulldock®, Howzat® (Cabendazim), Champ® Dry Pill
			03/12/2020	Bulldock®
			18/12/2020	Lancer®, Cabrio®, Champ®

Table 1.2.2.5.: Treatments for Northern Rivers case study site 5

Season number	Region	Site Number	Date	Treatment application
Season 1: 2017-2018	Northern Rivers	5	14/08/2017	Avatar®
			18/09/2017	Bulldock®
			05/10/2017	Bulldock®
			13/11/2017	Acephate spot spray
			14/12/2017	Bulldock® spot spray
Season 2: 2018–2019	Northern Rivers	5	21/08/2018	Stealth®
			14/09/2018	Tyranex®
			15/10/2018	Macanizer®
			20/10/2018	Steward®
			09/11/2018	Tyranex®
			15/11/2018	Macanizer®
			15/12/2018	Macanizer®
Season 3: 2019–2020	Northern Rivers	5	25/03/2019	Lacewing release (400 adults)
			15/04/2019	Lacewing release (400 adults)
			01/05/2019	Inter-row planting
			17/06/2019	Lacewing release (400 adults)
			08/07/2019	Lacewing release (400 adults)
			29/07/2019	Lacewing release (400 adults)
			15/08/2019	SeroX® @ 600 mL/100 L (Spot spray); Biopest® @ 500 mL/100 L
			26/08/2019	Lacewing release (400 adults)
			01/09/2019	Removal of racemes affected by macadamia lace bug
			15/09/2019	Trichoderma application at peak flowering, *Anastatus* release
			23/09/2019	Lacewing release (400 adults)
			07/10/2019	Lacewing release (400 adults)
			15/10/2019	*Anastatus* release
			27/10/2019	Steward® @ 50 mL/100 L; Designer @ 10 mL/100 L
			15/11/2019	*Anastatus* release
			15/12/2019	*Anastatus, T. cryptophlebiae*
			22/12/2019	*T. cryptophlebiae*
			29/12/2019	*T. cryptophlebiae*
			07/01/2020	*T. cryptophlebiae*
			15/01/2020	*Anastatus, T. cryptophlebiae*
			22/01/2020	*T. cryptophlebiae*
			30/01/2020	*T. cryptophlebiae*
			07/02/2020	*T. cryptophlebiae*
			15/02/2020	*Anastatus, T. cryptophlebiae*
			15/03/2020	*Anastatus* release
			16/03/2019	Lacewing release (400 adults)
			15/04/2020	*Anastatus* release

Table 1.2.2.5.: Treatments for Northern Rivers case study site 5 (cont.)

Season number	Region	Site Number	Date	Treatment application
Season 4: 2020–2021	Northern Rivers	5	13/09/2020	Macanizer® *(Trichoderma),* SeroX® (Butterfly pea extract), Azamax® (Azadirachtin-neem*)*
			14/09/2020	Selective limb removal
			15/09/2020	Selective limb removal
			15/10/2020	Steward® (Indoxacarb)
			04/12/2020	*T. cryptophlebiae*
			11/12/2020	*T. cryptophlebiae*
			18/12/2020	*T. cryptophlebiae*
			24/12/2020	*T. cryptophlebiae*
			31/12/2020	*T. cryptophlebiae*
			07/01/2021	*T. cryptophlebiae*
			14/01/2021	*T. cryptophlebiae*
			21/01/2021	*T. cryptophlebiae*
			28/01/2021	*T. cryptophlebiae*
			04/02/2021	*T. cryptophlebiae*
			11/02/2021	*T. cryptophlebiae*
			18/02/2021	*T. cryptophlebiae*

Table 1.2.2.6.: Treatments for Northern Rivers case study site 6

Season number	Region	Site Number	Date	Treatment application
Season 1: 2017-2018	Northern Rivers	6	26/07/2017	Limb removal
			09/08/2017	Lacewing release
			12/08/2017	Diazinon
			01/09/2017	Lepidex®
			29/09/2017	Bulldock®
			25/10/2017	Bulldock®
			08/11/2017	Acephate, Hygiene pick up, phosphoric acid to storm damaged trees
			24/11/2017	Acephate
			15/01/2018	Abamectin®
Season 2: 2018–2019	Northern Rivers	6	10/08/2018	Diazinon
			23/10/2018	Steward®, SureFire® Symbio
			20/11/2018	Acephate and Tyranex® in different sections
			06/12/2018	Bulldock®
			19/12/2018	Bulldock®, Spin Flo®
			18/01/2019	Stealth®
			14/02/2019	Bulldock®
Season 3: 2019–2020	Northern Rivers	6	16/08/2019	Diazinon @ 125 mL/100 L
			15/09/2019	Limb removal
			18/09/2019	Tyranex® @ 200 mL/100 L; Designer® @ 10 mL/100 L
			14/10/2019	Steward® @ 50 mL/100 L, SureFire® Symbio @ 40 mL/100L and Designer® @ 10 mL/100 L
			04/11/2019	Acephate @ 80 g/100 L (spot spray)
			15/12/2019	*T. cryptophlebiae*
			27/12/2019	Bulldock® @ 50 mL/100 L (East Block); Designer® @ 10 mL/100 L
			02/01/2020	*T. cryptophlebiae*
			05/01/2020	*T. cryptophlebiae*
			15/01/2020	*T. cryptophlebiae*
			01/02/2020	*T. cryptophlebiae*
			15/02/2020	*T. cryptophlebiae*

Table 1.2.2.6.: Treatments for Northern Rivers case study site 6

Season number	Region	Site Number	Date	Treatment application
Season 4: 2020–2021	Northern Rivers	6	31/08/2020	Transform®
			07/09/2020	Diazinon
			23/10/2020	Steward® (Indoxacarb), Bulldock®, Cabrio® (Pyraclostrobin)
			04/12/2020	*T. cryptophlebiae*
			10/12/2020	Trivor® (Acetamiprid + pyriproxyfen)
			11/12/2020	*T. cryptophlebiae*
			18/12/2020	*T. cryptophlebiae*
			24/12/2020	*T. cryptophlebiae*
			31/12/2020	*T. cryptophlebiae*
			07/01/2021	*T. cryptophlebiae*
			14/01/2021	*T. cryptophlebiae*
			21/01/2021	*T. cryptophlebiae*
			28/01/2021	*T. cryptophlebiae*
			04/02/2021	*T. cryptophlebiae*
			11/02/2021	*T. cryptophlebiae*
			18/02/2021	*T. cryptophlebiae*

Table 1.2.2.7.: Treatments for Mid North Coast case study site 7

Season number	Region	Site Number	Date	Treatment application
Season 1: 2017-2018	Mid North Coast	7	13/07/2017	Mohawk inter-rows
			09/09/2017	Pyganic®
			22/09/2017	Pyganic®, *Anastatus*
			20/10/2017	*Anastatus*
			24/11/2017	*Anastatus*
			12/12/2017	*Anastatus, T. cryptophlebiae*
			22/12/2017	*T. cryptophlebiae*
			29/12/2017	*T. cryptophlebiae*
			10/01/2018	*Anastatus*
			19/01/2018	*T. cryptophlebiae*
			26/01/2018	*Anastatus, T. cryptophlebiae*
			09/02/2018	*Anastatus*
			05/03/2018	*Anastatus*
			02/04/2018	*Anastatus*
Season 2: 2018–2019	Mid North Coast	7	09/08/2018	Lacewings
			09/09/2018	Lacewings
			14/09/2018	Lacewings
			17/09/2018	*Anastatus*
			29/09/2018	Pyganic®
			15/10/2018	*Anastatus*
			31/10/2018	*Montdorensis*
			16/11/2018	*Montdorensis, Anastatus*
			10/12/2018	*Trichogrammatoidea cryptophlebiae*
			12/12/2018	*Anastatus*
			17/12/2018	*Trichogrammatoidea cryptophlebiae*
			07/01/2019	*Trichogrammatoidea cryptophlebiae, Anastatus*
			14/01/2019	*Trichogrammatoidea cryptophlebiae*
			21/01/2019	*Trichogrammatoidea cryptophlebiae*
			04/02/2019	*Anastatus*

Table 1.2.2.7.: Treatments for Mid North Coast case study site 7 (cont.)

Season number	Region	Site Number	Date	Treatment application
Season 3: 2019–2020	Mid North Coast	7	20/03/2019	6 inter-rows power harrowed to reduce setaria grass dominance and prepare the seed bed
			25/03/2019	Seed mixture of buckwheat, Green Harvest 'Good Bug Mix', lucerne 'Hunter River', red clover and Wynns Cassia broadcasted into inter-row
			29/08/2019	Pyganic® @ 200 mL/100 L
			15/09/2019	Reduction of canopy density – limb removal
			16/09/2019	*Anastatus* release (1000/ha)
			09/10/2019	Skirting of trees
			23/10/2019	*Anastatus* release (1000/ha)
			20/11/2019	*Anastatus* release (1000/ha); mowing and adding grass mulch
			18/12/2019	*Trichogrammatoidea* and *Anastatus* releases (1000/ha)
			31/12/2019	*Trichogrammatoidea* release
			07/01/2020	*Trichogrammatoidea* release
			15/01/2019	*Trichogrammatoidea* and *Anastatus* releases (1000/ha)
			22/01/2020	*Trichogrammatoidea* release
			29/01/2020	*Trichogrammatoidea* release
			12/02/2020	*Anastatus* releases (1000/ha)
			11/03/2020	*Anastatus* releases (1000/ha)
			06/04/2020	*Anastatus* releases (1000/ha)
Season 4: 2020–2021	Mid North Coast	7	07/09/2020	Pyganic® (Pyrethrins)
			15/09/2020	*Anastatus* sp.
			07/10/2020	*Anastatus* sp.
			04/11/2020	*Anastatus* sp.
			01/12/2020	*Anastatus* sp.
			16/12/2020	*Trichogrammatoidea cryptophlebiae*
			06/01/2021	*Anastatus, Trichogrammatoidea cryptophlebiae*
			16/01/2021	*Trichogrammatoidea cryptophlebiae*
			20/01/2021	*Trichogrammatoidea cryptophlebiae*
			28/01/2021	*Trichogrammatoidea cryptophlebiae*
			03/02/2021	*Anastatus, Trichogrammatoidea cryptophlebiae*

Table 1.2.2.8.: Treatments for Mid North Coast case study site 8

Season number	Region	Site Number	Date	Treatment application
Season 1: 2017-2018	Mid North Coast	8	12/10/2017	Cabrio®
			01/11/2018	Spin Flo®, Copper, Lancer®
			27/11/2017	Spin Flo®, Copper, Bulldock®
			15/12/2017	*T. cryptophlebiae*
			22/12/2017	Bulldock®, *T. cryptophlebiae*
			05/01/2018	*T. cryptophlebiae*
			11/01/2018	*T. cryptophlebiae*
			18/01/2018	Copper, Bulldock®
			19/01/2018	*T. cryptophlebiae*
			09/02/2018	*T. cryptophlebiae*
Season 2: 2018–2019	Mid North Coast	8	22/10/2018	SureFire® Symbio (Pyraclostrobin)
			12/11/2018	Transform®, Spin Flo®, Copper
			07/12/2018	Bulldock®, Spin Flo®, Copper
			14/12/2018	*Trichogrammatoidea cryptophlebiae*
			21/12/2018	*Trichogrammatoidea cryptophlebiae*
			31/12/2018	*Trichogrammatoidea cryptophlebiae*
			07/01/2019	*Trichogrammatoidea cryptophlebiae*
			14/01/2019	*Trichogrammatoidea cryptophlebiae*
			21/01/2019	*Trichogrammatoidea cryptophlebiae*
			28/01/2019	*Trichogrammatoidea cryptophlebiae*
			30/01/2019	Bulldock®
			04/02/2019	*Trichogrammatoidea cryptophlebiae*
Season 3: 2019–2020	Mid North Coast	8	20/03/2019	6 inter-rows power harrowed to reduce setaria grass dominance and prepare the seed bed
			25/03/2019	Seed mixture of buckwheat, Green Harvest 'Good Bug Mix', lucerne 'Hunter River', red clover and Wynns Cassia broadcasted into inter-row
			16/10/2019	Cabrio® @ 50 mL/100 L
			06/11/2019	Transform® @ 40 mL/100 L; Kocide Blue® @ 150 g/100 L; Spin Flo® @ 50 mL/100 L and Designer® @ 15 mL/100 L
			17/12/2019	Bulldock® @ 50 mL/100 L; Designer® @ 15 mL/100 L
			18/12/2019	*Trichogrammatoidea* release
			31/12/2019	*Trichogrammatoidea* release
			07/01/2020	*Trichogrammatoidea* release
			15/01/2020	*Trichogrammatoidea* release
			17/01/2020	Bulldock® @ 50 mL/100 L; Designer® @ 15 mL/100 L
			22/01/2020	*Trichogrammatoidea* release
			29/01/2020	*Trichogrammatoidea* release
			05/02/2020	*Trichogrammatoidea* release

Table 1.2.2.8.: Treatments for Mid North Coast case study site 8 (cont.)

Season number	Region	Site Number	Date	Treatment application
Season 4: 2020–2021	Mid North Coast	8	19/08/2020	Tree shaking
			12/10/2020	Cabrio® (Pyraclostrobin)
			11/11/2020	Transform® (Sulfoxaflor), Spin Flo® (Carbendazim), Champ® Dry Pill (Copper Cupric Hydroxide)
			07/12/2020	Bulldock®, Spin Flo® (Carbendazim), Champ® Dry Pill (Copper Cupric Hydroxide)
			16/12/2020	*Trichogrammatoidea cryptophlebiae*
			06/01/2021	*Trichogrammatoidea cryptophlebiae*
			13/01/2021	*Trichogrammatoidea cryptophlebiae, Bulldock, Champ* Dry Pill (Copper Cupric Hydroxide)
			20/01/2021	*Trichogrammatoidea cryptophlebiae*
			28/01/2021	*Trichogrammatoidea cryptophlebiae*
			03/02/2021	*Trichogrammatoidea cryptophlebiae*
			10/02/2021	*Trichogrammatoidea cryptophlebiae*

1.2.3. Monitoring

Visual assessment

Thirty trees were visually assessed using a protocol that was developed by NSW DPI entomologists and consultants that were taking care of the case study sites. A copy of the monitoring protocol is shown in Appendix 1.2.3.1.

Yellow sticky traps

Pests and beneficial populations were monitored using commercial yellow sticky traps (e.g. Bugs for Bugs, Toowoomba) (1 per treatment strip of 3 rows), which was changed usually once a fortnight. When yellow sticky traps were changed, the old ones were taken back to Wollongbar Primary Industries institute and checked under a stereo microscope in the laboratory. Insects were counted and classified into groups of pest and beneficial species.

Scolytid beetle traps

Scolytid beetles, bark beetles, trunk and branch borers and also pinhole borers had been noted as potential issues for the industry in recent times. To get an understanding of the species involved, we investigated pheromone traps that would be useful. In preliminary trials, we tested different traps and lures specific to scolytid beetles.

BROCAP® coffee berry borer panel traps (developed by CIRAD (Centre de coopération Internationale en recherche, Montpellier, France) proved to be the cheapest of the traps and the easiest and most practical ones to service and the "Ambro" lure, developed for *Xyleborus* spp., proved to be the one that caught the widest range of scolytid beetle species.

BROCAP® coffee berry borer panel traps (purchased from Ecom Group, JI. P. Tirtayasa Kp. Galih LK II RT 02 Bandar Lampung 35122, Indonesia) (Figure1.2.3.1.) were fitted with ambrosia beetle lures ("Ambro" lures from Alpha Scents, Inc., 360 S. Sequoia Parkway, Canby, OR 97013, USA). Lures were suspended under the roof of the trap. The liquid container of the panel trap was half filled with a mixture of propylene glycol and water (1:1) with a few drops of unscented detergent (i.e. Tween 20) to break the surface tension.

Traps were emptied usually once a month. The liquid in the capture container was poured through a tea strainer to collect the beetles. Beetles from each trap were put into 50 ml specimen jars (Sarstedt Australia) that was taken back to Wollongbar Primary Industries Institute and checked under a stereo microscope in the laboratory. Insects were counted and identified when possible to species level under a stereo microscope. Results are presented in Appendix 2.2.2.

Longicorn beetle (Cerambycidae) trapping

Extreme dry conditions during 2019 (Appendix 2.4.5.) has exacerbated the effect longicorn beetles have on macadamia trees. On a commercial farm at Caniaba (west of Lismore, NSW) and at CTH Alstonville, pheromone lures for longicorn beetles were tested. Commercial Lindgren funnel traps were provided as well as lures from Alain Roques (INRAE France) and Myron Zalucki (UQ).

Traps were hung into a tree and lures were changed once every three weeks. The content of the trap was collected also every three weeks and taken back to Wollongbar WPII for examination and identification, using Ślipiński and Escalona (2013 and 2016) as a reference. Results are presented in Appendix 2.2.2.

Light trapping for scarab beetles

On a commercial farm at Caniaba (west of Lismore, NSW) and at CTH Alstonville light trapping was undertaken to get an understanding of scarab beetle populations, particularly during dry seasons. Bed sheets were pegged on a line tightened between posts. A mercury vapour light, a flood light and UV light were run, powered by a generator. Scarab beetles attracted by the light, that had flown onto the sheets or on the ground in front of the sheets were collected, in a plastic container and taken back to Wollongbar WPII for counting, examination and identification. Results are presented in Appendix 2.2.2.

Figure 1.2.3.1.: BROCAP® trap (left) and “Ambro” lure (right)

1.2.3.1. Monitoring protocol

IPM MONITORING SHEET (1)

Location	**Farm**	**Block**
GPS	**Monitoring Date**	Last monitoring/recommendation date
Biological control Release date	Biocontrol agent(s) and rate	
Chemical control Application date	Chemical(s) and rate	
Cultural control Application date	Measure(s)	
Weather at monitoring (i.e. hot, dry, raining)	**Leaf flush**	

Tree number		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Tree site (i.e. row)																					
Variety																					
General tree health	Excellent (E), Good (G), Poor (P)																				
Flowering (%)	Bud (B), open (O), post anthesis (PA)																				
Nut development	Nut filling (NF), whits soft Shell (WS), tan hard shell (TS), brown hard shell (BS)																				

Tree number		**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**	**34**	**35**	**36**	**37**	**38**	**39**	**40**
Tree site (i.e. row)																					
Variety																					
General tree health	Excellent (E), Good (G), Poor (P)																				
Flowering (%)	Bud (B), open (O), post anthesis (PA)																				
Nut development	Nut filling (NF), whits soft Shell (WS), tan hard shell (TS), brown hard shell (BS)																				

Pest	**Monitoring Unit**	**Tree number** (10 hotspot trees and 20 others)																				
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**T#**
Macadamia lace bug	**2 racemes per tree**																					
(%racemes affected)																						
# of adults																						
# of nymphs																						
Evidence of skins																						
Flower caterpillar	**2 racemes per tree**																					
# of eggs																						
# of larvae																						
Felted coccid	**5 samples**																					
Scales	(from leaves, shoots branches																					
Thrips	racemes)																					
Mites																						

1

IPM MONITORING SHEET (2)

Pest	**Monitoring Unit**	**Tree number** (10 hotspot trees and 20 others)																				
		21	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**	**34**	**35**	**36**	**37**	**38**	**39**	**40**	**T#**
Macadamia lace bug	**2 racemes per tree**																					
(%racemes affected)																						
# of adults																						
# of nymphs																						
Evidence of skins																						
Flower caterpillar	**2 racemes per tree**																					
# of eggs																						
# of larvae																						
Felted coccid	**5 samples**																					
Scales	(from leaves, shoots branches																					
Thrips	racemes)																					
Mites																						

Pest	**Monitoring Unit**	**Tree number** (10 hotspot trees and 20 others)																				
Macadamia nutborer																						
Adults	**Trap**																					
	Tree	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**T#**
# of live eggs	10 nuts on tree																					
# of live larvae																						
# of parasitised eggs																						
	Tree	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**	**34**	**35**	**36**	**37**	**38**	**39**	**40**	**T#**
# of live eggs	10 nuts on tree																					
# of live larvae																						
# of parasitised eggs																						
Macadamia seed weevil																						
	Tree	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**T#**
# of Adults	Tree																					
Presence of feeding	10 nuts on ground																					
Presence of live eggs																						
Presence of live larva																						
	Tree	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**	**34**	**35**	**36**	**37**	**38**	**39**	**40**	**T#**
# of Adults	Tree																					
Presence of feeding	10 nuts on ground																					
Presence of live eggs																						
Presence of live larva																						

2

IPM MONITORING SHEET (3)

Fruitspotting bugs / Green vegetable bugs – orchard

	Tree	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	T#
# of FSB																						
FSB damage	Numbers of nuts with damage																					
GVB damage	30 nuts per tree / Total 300 nuts on ground																					

	Tree	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	T#
# of FSB																						
FSB damage	Numbers of nuts with damage																					
GVB damage	30 nuts per tree / Total 300 nuts on ground																					

Trap		**1**	**2**	**3**	**4**	**5**	**6**	**Total**
# of FSB	**Trap**							

Hedge		**Plant 1**	**Plant 2**	**Plant 3**	**Plant 4**	**Plant 5**	**Plant 6**	**Total**
Adults	**Tree** Numbers of bugs per tree							
1-4th instar nymphs								
5th instar nymphs								

Other pest insects

	Tree	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	T#
Species	1																					
	2																					
	3																					
	4																					
	5																					
	6																					
	7																					
	8																					
	9																					
	10																					

	Tree	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	T#
Species	1																					
	2																					
	3																					
	4																					
	5																					
	6																					
	7																					
	8																					
	9																					
	10																					

3

IPM MONITORING SHEET (4)

BENEFICIAL INSECTS (i.e. lace wings, lady birds, assassin bugs etc.) Section Break (Next Page)

	Tree	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	T#
Species	1																					
	2																					
	3																					
	4																					
	5																					
	6																					
	7																					
	8																					
	Tree	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**	**34**	**35**	**36**	**37**	**38**	**39**	**40**	**T#**
Species	1																					
	2																					
	3																					
	4																					
	5																					
	6																					
	7																					
	8																					

DISEASES

Disease	Monitoring Unit	Tree number (10 hotspot trees and 20 others)																				
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	T#
Botrytis	Tree																					
Blights																						
Husk spot																						
Husk rot																						
Phytophthora																						
		21	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**	**34**	**35**	**36**	**37**	**38**	**39**	**40**	**T#**
Botrytis	Tree																					
Blights																						
Husk spot																						
Husk rot																						
Phytophthora																						

	GENERAL COMMENTS
Rainfall	
Weather notes	
Out of season nuts	
OTHER	

4

General Information

General tree health: excellent-(E), good – (G), poor – (P)

Flowering: bud –(B), open – (O), post-anthesis – (PA)

Nut development: nut filling – (NF), white soft shell - (WS), tan hard shell - (TS), brown hard shell – (BS)

Crop status: nut growth – (NG), oil accumulation – (OA), maturity – (M)

Felted coccid rating: clean=0; low =1, moderate =2, high= 4, very high = 8

Scale, thrips and mites pressure rating: clean=0; low =1, moderate =2, high= 4, very high = 8

Fruit spotting bug ground sample: 30 trees-maximum sample ground sample 300 nuts. Sample from 10 hotspot sites, 20 others

Beneficials: Monitor unit: assuming we are recording numbers, e.g.2 lacewing larvae, 1 assassin bug egg mass. Need some agreement on limits of which part of tree to assess. Generally quickly scan all tree parts within a quadrant zone (quarter radius of outside canopy, from skirt to a height that can be viewed easily of tree)

Diseases rating: clean=0, low =1, moderate =2, high= 4, very high = 8

Suggested thresholds and decision levels (DL):

Macadamia lace bug:	**suggestion:** > 5% affected racemes
Macadamia flower caterpillar:	**suggestion:** >40% flowers affected
Felted coccid:	**suggestion:** generally, if rating score exceeds 2.5 in the absence of any parasite emergence holes and beneficials like lacewing a control measure may be considered-depends on stage of crop development and 'crawler activity
Thrips and mites	**suggestion:** consider if present conditions are hot/dry and long term forecast is more of the same- means higher risk. If autumn flush gets affected then need to look more closely at protecting spring flush.
Macadamia nut borer	**suggestion:** general rule of thumb-once 40% black eggs, a high % of 'not black' eggs collected on day will be parasitised. If light moth counts, and light MNB tunneled nuts from ground sample still evident late January then light pressure
Fruit spotting bug	**suggestion: 1. Hedge:** spray within 10-14 days if 30% of bugs from trap hedge reach the 5th instar stage; **2. Trap:** 0.4 bugs/trap/fortnight.
Fruit spotting bug and Green vegetable bug	**suggestion: Ground nut sample:** 3% damaged nuts

Monitoring Protocol

Designate 30 trees for monitoring in a trial block. Choose trees to representatively cover the block. An example is given in Figure 1

Border

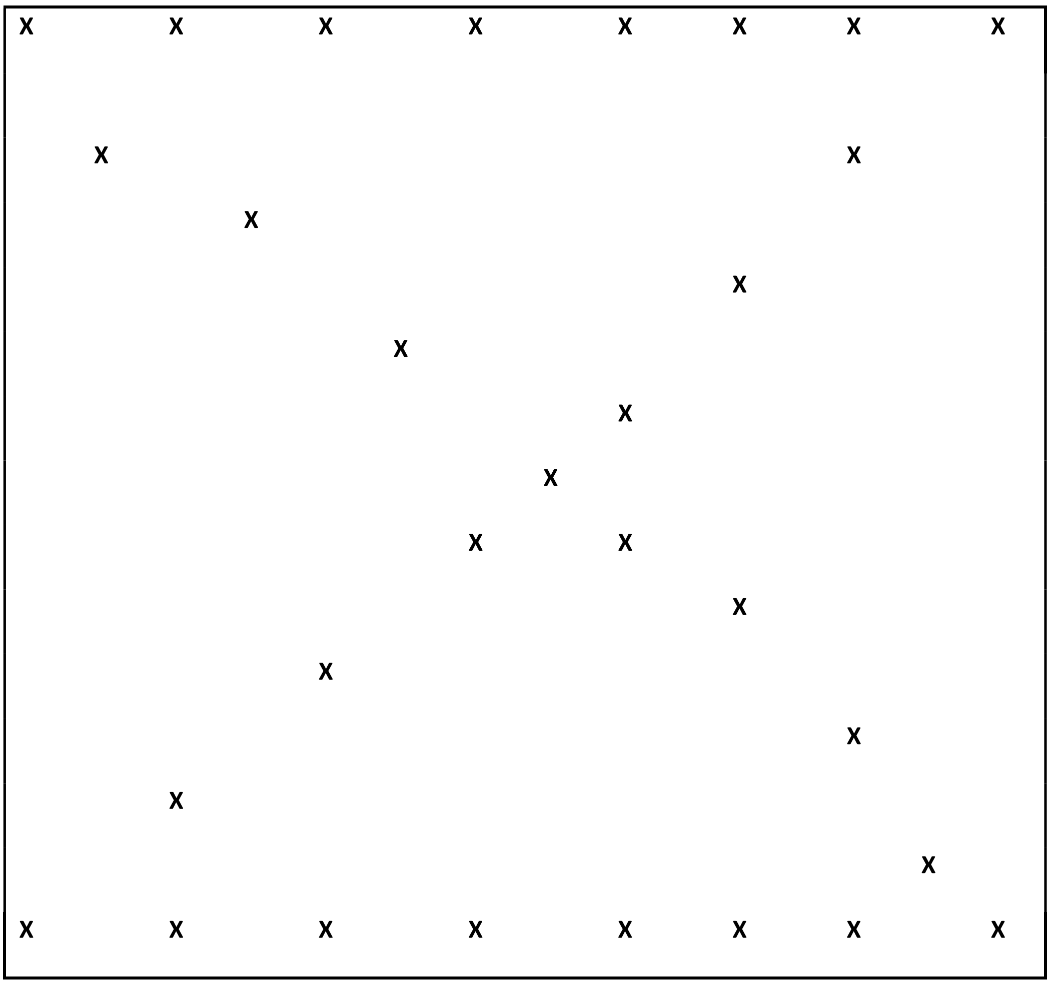

Figure 1: Distribution of monitoring trees (**X**= selected monitoring trees across the block)

PESTS

Macadamia lace bug

<u>Damage</u> (% racemes with MLB): Scan 4 quadrants of tree and estimate percentage of racemes with MLB

<u>Adults, nymphs skins</u>: Scan 4 quadrants of tree for activity and check 2 damaged racemes for presence of nymphs, skins and adults

Flower caterpillar

<u>Eggs and larvae</u>: Scan 4 quadrants of tree for activity and check 2 affected racemes for presence. Record number of eggs and larva

Macadamia seed weevil

Adults: Scan 4 quadrants of tree for macadamia seed weevil adults and record numbers

Feeding damage, live eggs, live larvae: Collect 10 nut from the ground and check for presence of feeding damage, live eggs, live larvae

Macadamia nut borer

Adults: Use one pheromone trap per block. Check trap once a fortnight, record numbers of MNB males every 2 weeks.

Macadamia nut borer larvae and eggs (live and live parasitised): Check 10 nuts on tree for presence of larvae and record numbers of live and live parasitised eggs

Fruit spotting bug s/green vegetable bugs (orchard)

Damage: Collect 10 from ground and tree, per tree (300 total), cut nuts and record percentage of nuts with FSB/GVB damage

Fruit spotting bugs (orchard)

FSB adults and nymphs: Scan 4 quadrants of tree canopy for FSB adults and nymphs and record numbers

Fruit spotting bugs (pheromone trap – *A. l. lutescens* only)

FSB adults and nymphs: Use one pheromone trap per block in hotspot. Check once a fortnight and record numbers of adults and nymphs. Replace pheromone lure every 6 weeks.

Fruit spotting bug trap hedge (both *Amblypelta* spp.)

FSB adults and nymphs: Check monitoring hedge once a fortnight (for about 15 minutes), record numbers of FSB adults and nymphs, identify 5^{th} instar nymph and calculate percentage of those in the population observed. - >30% 5^{th} instar nymphs = spray decision

Felted coccid

Adults, immature: Scan tree for activity, take 5 samples (from leaves, leave shoot, branches, racemes) and check for presence of felted coccid

Scales

Adults, immature: Scan tree for activity, take 5 samples (from leaves, leave shoot, branches, racemes) and check for presence of scales

Thrips

Adults, immature: Scan tree for activity, take 5 samples (from leaves, leave shoot, branches, racemes) and check for presence of thrips

Mites

Adults, immature: Scan tree for activity, take 5 samples (from leaves, leave shoot, branches, racemes) and check for presence of mites

BENEFICIALS

Orchard: *Trichogrammatoidea chryptophelbiae* (see protocol for MNB) generally assassin bugs, Ladybirds, lacewings, hoverflies, Tachinid flies, spiders, honeybees, native bees:

> Conduct a quick scan of all tree parts within a quadrant zone (quarter radius of outside canopy, from skirt to a height that can be viewed easily of tree and record presence) – record presence of any of the listed beneficials and score 1 =low, 2=medium; 3= high numbers.

Hedge: When checking hedge for FSB, note presence of assassin bugs, ladybirds, lacewings, hoverflies, Tachinid flies, spiders, honey bees, native bees and record presence of any of the listed beneficials and score 1 =low, 2=medium; 3= high numbers.

DISEASES

Blights

When scanning trees, record presence of any of blights and score 1 =low, 2=moderate, 3= high pressure.

Botrytis

When scanning trees, record presence of any of *Botrytis* and score 1 =low, 2=moderate, 3= high pressure.

Husk spot

When scanning trees, record presence of any of husk spot and score 1 =low, 2=moderate, 3= high pressure.

Phytophthora

When scanning trees, record presence of any of *Phytophthora*.

Abbreviations used:

- MU = monitoring unit
- race. = racemes
- samp. = samples
- MLB = macadamia lace bug
- % racemes = % racemes damaged
- Flower c.= flower caterpillar
- Felted c. = felted coccid
- T#= Total number
- # = number
- L-larvae = live larvae
- P-eggs = parasitised eggs
- dam. = damage
- n. = nymphs
- Phytoph. = Phytophthora

1.2.4. Methodologies for harvest, nut in husk and kernel assessment

Harvest

Early and mid-season (around March/April and June/July), samples of 300 nuts were collected randomly of each block by consultants and sent to Wollongbar Primary Industries institute for assessment. Nut samples were then de-husked and processed as described in (Huwer et al. 2006; Huwer et al. 2011).

Nut in husk

Nuts in green husk were visually assessed with an "Optivisor" headband magnifier with a 7 times magnification.

Nut samples were checked for the following:

- Macadamia nut borer tunnels (presence)
- Live macadamia nut borer eggs (counts)
- Hatched macadamia nut borer eggs (counts)
- Live parasitised macadamia nut borer eggs (counts)
- Hatched parasitised macadamia nut borer eggs (counts)
- Presence of thrip and mite damage (presence if more than 25% of husk affected)
- Presence of felted coccid (presence if more than 10 individuals)
- Presence of scales (presence if more than 10 individuals)
- Presence of macadamia seed weevil feeding (presence)
- Presence of macadamia seed weevil egg marks (presence)
- Presence of pinhole borer (presence)
- Presence of FSB marks in husk (presence)
- Presence of FSB marks on shell (presence)
- Presence of husk spot lesions (presence)

Kernel assessment

Nut samples were de-husked, the number of nuts passing through the de-husker for each sample was recorded, along with the weight of wet nut in shell. Nut in shell samples were then put into plastic nets and placed in a dehydrator for drying: 48 hours at 38°C, followed by 48 hours at 45°C and a further 48 hours at 60°C to achieve 1.5% moisture content (AMS, 2001).

Once dried samples were counted, weighed and dry nut in shell weights recorded. Nuts were then cracked, poured on a sieve and any parts >2mm were sorted into the following categories:

- MNB damage
- FSB damage
- *Leptocoris* damage
- Kernel grub damage
- Mould
- Discolouration
- Germination
- Immature kernel
- Sound kernel

After sorting, the sound kernel weight was determined, and the sound kernel then floated in a bowl of water to separate mature kernel with a higher oil content that floated from immature kernel with lower oil content that sank. The immature kernel was discarded, and the mature kernels placed into plastic bags and returned to the dehydrator for 24 hours at 50°C. The nut samples were then re-weighed again, and the A-grade kernel fraction of the nut sample calculated (Huwer et al. 2006).

At the end of the season, yield data from trial blocks was provided by consultants. The average yield was expressed as ton of dry nut in shell (DNIS) at 10% moisture content per hectare.

1.3. Trials at the Centre for Tropical Horticulture (CTH) at Alstonville (Northern Rivers)

Smaller field trials were conducted at the Centre for Tropical Horticulture (CTH) at Alstonville to investigate specific research questions and they included more detailed monitoring and data collection. Details of the methodology of the trials are included in Appendices 2.4., 2.5.2, 2.5.5 and 2.5.6. Rain data for a drought and a wet season is presented in Appendix 2.5.4.

1.3.1. Main IPM trial

The small-scale field trial at CTH Alstonville which was planted in 1998, used macadamia trees of the varieties 246, 741, 849 and A4. Trees were spaced at 5 meters within rows and 7 meters between rows (equivalent to 285 trees per hectare). The varieties were allocated to blocks (three rows of three trees) in a Latin square array and the blocks were separated by a buffer row of the variety 246 (Figure 1.3.1.1.). Variety 246 was chosen for cross pollination (McConchie et al. 1997).

Treatments

During spring and summer, the entomology block was sprayed with different chemicals. Up to 3 different treatments minimising the input of broad spectrum insecticides were compared to a standard treatment based on broad spectrum insecticides. There were four different treatment strips of 3 rows. Each treatment strip had four blocks of nine trees.

Treatments combinations changed yearly. Treatments applied in different treatment strips and different years are listed in Tables 1.3.1.1. to 1.3.1.4. The trial plan for each year was developed in consultation with the project reference group.

Six to 8 litres (depending on tree height) of spray solution were applied to each treatment strip of 3 rows. A “Tornado” air blast sprayer was used in 2016 and 2017 and a “Tuffass” air blast sprayer from 2018 to 2021.

As the tall trees imposed coverage problems, in 2016 the middle row of each block (trees 4-6) were cut down to 6 meters. With the purchase of the new air-blast sprayer previous coverage problems were solved.

Entomology Block

																NE					
	105	**98**	**91**	**84**	**77**	**70**	**63**	**56**	**49**	**42**	**35**	**28**	**21**	**14**	**7**	**0**					
A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A		A	A	A	A
A	16	B	16	A	12	D	12	A	8	A	8	A	4	C	4	A		A	A	A	A
A	16	B	16	A	12	D	12	A	8	A	8	A	4	C	4	A		A	Block 19	A	A
A	16	B	16	A	12	D	12	A	8	A	8	A	4	C	4	A		A	A	A	A
A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A		A	A	A	A
A	15	A	15	A	11	C	11	A	7	D	7	A	3	B	3	A		A	A	A	A
A	15	A	15	A	11	C	11	A	7	D	7	A	3	B	3	A		A	A	A	A
A	15	A	15	A	11	C	11	A	7	D	7	A	3	B	3	A	WIND BREAK	A	A	A	A
A	A	A-Trap	A	A	A	A-Trap	A	Met	A	A-Trap	A	A	A	A-Trap	A	A		A	A	A	A
A	14	D	14	A	10	B	10	A	6	C	6	A	2	A	2	A		A	A	A	A
A	14	D	14	A	10	B	10	A	6	C	6	A	2	A	2	A		A	A	A	A
A	14	D	14	A	10	B	10	A	6	C	6	A	2	A	2	A		A	A	A	A
A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A		A	A	A	A
A	13	C	13	A	9	A	9	A	5	B	5	A	1	D	1	A		A	A	A	A
A	13	C	13	A	9	A	9	A	5	B	5	A	1	D	1	A		A	Block 20	A	A
A	13	C	13	A	9	A	9	A	5	B	5	A	1	D	1	A		A	A	A	A
A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A		A	A	A	A

Treatment strip 4: Rows 13-15 Standard | **Treatment strip 3: Rows 9-11** | **Treatment stip 2: Rows 5-7** | **Treatment strip 1: Rows 1-3**

Block 20	Standard treatment; cv. 246
Block 19	Untreated; cv. 246

Monitoring trees (shaded)

CODE	VARIETY
A	246
B	849
C	A4
D	741

BLOCK TREE POSITION CODE

9	6	3
8	5	2
7	4	1

A-Trap	MNB pheromone trap
Met	Weather station

Figure 1.3.1.1.: Layout of Entomology block at the Centre for Tropical Horticulture (CTH) at Alstonville

Table: 1.3.1.1.: Treatments applied at IPM trial at the Centre for Tropical Horticulture (CTH) at Alstonville during 2017/2018

SEASON 2017/2018						
Date	**Row**	**Treatment**	**Category**	**Treatment**	**Chemical Active**	**Rate**
18/08/2017	13 to 15	Standard	**Chemical**	Diazinon® 800	Diazinon	125mL/100L
19/10/2017	13 to 15	Standard	**Chemical**	Supracide® 400	Methidathion	125mL/100L
19/10/2017	13 to 15	Standard	**Chemical**	Spin Flo®	Carbendazim	50mL/ 100L
	13 to 15	Standard	Cultural	Hygiene: Removing of MSW infested nuts		
13/11/2017	13 to 15	Standard	**Chemical**	Lancer® 970	Acephate	80g/ 100L
18/12/2017	13 to 15	Standard	**Chemical**	Bulldock® 25	Beta-cyfluthrin	50mL/ 100L
17/01/2018	13 to 15	Standard	**Chemical**	Bulldock® 25	Beta-cyfluthrin	50mL/ 100L
18/08/2017	9 to 11	Strip-3	**Chemical**	Diazinon® 800	Diazinon	125mL/100L
	9 to 11	Strip-3	Biological	Lacewing		
19/10/2017	9 to 11	Strip-3	**Chemical**	Lancer® 970	Acephate	80g/ 100L
	9 to 11	Strip-3	Cultural	Hygiene: Removing of MSW infested nuts		
	9 to 11	Strip-3	Biological	*Montdorensis*		
	9 to 11	Strip-3	Biological	*Centrodora*		
	9 to 11	Strip-3	Biological	MacTrix		
13/11/2017	9 to 11	Strip-3	**Chemical**	Lepidex® 500	Trichlorfon	200mL/ 100L
	9 to 11	Strip-3	Cultural	Hygiene: Removing of MSW infested nuts		
	9 to 11	Strip-3	Biological	*Montdorensis*		
	9 to 11	Strip-3	Biological	*Centrodora*		
	9 to 11	Strip-3	Biological	MacTrix		
18/12/2017	9 to 11	Strip-3	**Chemical**	Transform®	Sulfoxaflor	40mL/100L
	9 to 11	Strip-3	Biological	*Centrodora*		
	9 to 11	Strip-3	Biological	MacTrix		
17/01/2018	9 to 11	Strip-3	**Chemical**	Trivor® 125	Acetamiprid + pyriproxyfen	80mL/100L
	9 to 11	Strip-3	Biological	*Centrodora*		
	9 to 11	Strip-3	Biological	MacTrix		
	9 to 11	Strip-3	Biological	*Montdorensis*		

Table: 1.3.1.1.: Treatments applied at IPM trial at the Centre for Tropical Horticulture (CTH) at Alstonville during 2017/2018 (cont.)

SEASON 2017/2018						
Date	**Row**	**Treatment**	**Category**	**Treatment**	**Chemical Active**	**Rate**
18/08/2017	5 to 7	Strip-2	**Chemical**	SeroX®	Butterfly pea extract	100mL/100L
	5 to 7	Strip-2	Biological	Lacewing		
19/10/2017	5 to 7	Strip-2	**Chemical**	Avatar® 300	Indoxacarb	30mL/ 100L
	5 to 7	Strip-2	Cultural	Hygiene: Removing of MSW infested nuts		
	5 to 7	Strip-2	Biological	*Montdorensis*		
	5 to 7	Strip-2	Biological	*Centrodora*		
	5 to 7	Strip-2	Biological	MacTrix		
13/11/2017	5 to 7	Strip-2	**Chemical**	Exirel® 100	Cyantraniliprole	100mL/ 100L
	5 to 7	Strip-2	**Chemical**	Cabrio®	Pyraclostrobin	40mL/100L
	5 to 7	Strip-2	Cultural	Hygiene: Removing of MSW infested nuts		
	5 to 7	Strip-2	Biological	*Montdorensis*		
	5 to 7	Strip-2	Biological	*Centrodora*		
	5 to 7	Strip-2	Biological	MacTrix		
18/12/2017	5 to 7	Strip-2	**Chemical**	Mainman®	Flonicamid	20g/ 100L
	5 to 7	Strip-2	Biological	*Centrodora*		
	5 to 7	Strip-2	Biological	MacTrix		
17/01/2018	5 to 7	Strip-2	**Chemical**	SeroX®	Butterfly pea extract	100mL/100L
	5 to 7	Strip-2	Biological	*Centrodora*		
	5 to 7	Strip-2	Biological	MacTrix		
	5 to 7	Strip-2	Biological	*Montdorensis*		

Table: 1.3.1.1.: Treatments applied at IPM trial at the Centre for Tropical Horticulture (CTH) at Alstonville during 2017/2018 (cont.)

SEASON 2017/2018						
Date	**Row**	**Treatment**	**Category**	**Treatment**	**Chemical Active**	**Rate**
18/08/2017	1 to 3	Strip-1	**Chemical**	Pyganic®	Pyrethrin	200mL/100L
	1 to 3	Strip-1	Biological	Lacewing		
19/10/2017	1 to 3	Strip-1	Biological	*Beauveria*	Beauveria	50 g in Synetrol 10mL/L
	1 to 3	Strip-1	Cultural	Hygiene: Removing of MSW infested nuts		
	1 to 3	Strip-1	Biological	*Montdorensis*		
	1 to 3	Strip-1	Biological	*Centrodora*		
	1 to 3	Strip-1	Biological	MacTrix		
13/11/2017	1 to 3	Strip-1	**Chemical**	SeroX®	Butterfly pea extract	150mL/ 100L
	1 to 3	Strip-1	Cultural	Hygiene: Removing of MSW infested nuts		
	1 to 3	Strip-1	Biological	*Montdorensis*		
	1 to 3	Strip-1	Biological	*Centrodora*		
	1 to 3	Strip-1	Biological	MacTrix		
18/12/2017	1 to 3	Strip-1	**Chemical**	Exirel® 100	Cyantraniliprole	100mL/ 100L
	1 to 3	Strip-1	Biological	*Centrodora*		
	1 to 3	Strip-1	Biological	MacTrix		
17/01/2018	1 to 3	Strip-1	**Chemical**	Mainman®	Flonicamid	20g/ 100L
	1 to 3	Strip-1	Biological	*Centrodora*		
	1 to 3	Strip-1	Biological	MacTrix		
	1 to 3	Strip-1	Biological	*Montdorensis*		

Table: 1.3.1.2.: Treatments applied at IPM trial at the Centre for Tropical Horticulture (CTH) at Alstonville during 2018/2019

SEASON 2018/2019						
Date	**Row**	**Treatment**	**Category**	**Treatment**	**Chemical Active**	**Rate**
30/08/2018	13 to 15	Standard	**Chemical**	Diazinon® 800	Diazinon	125mL/100L
23/10/2018	13 to 15	Standard	**Chemical**	Lancer® 970	Acephate	80g/ 100L
23/10/2018	13 to 15	Standard	**Chemical**	Spin Flo®	Carbendazim	50mL/ 100L
	13 to 15	Standard	Cultural	Hygiene: Removing of MSW infested nuts		
23/11/2018	13 to 15	Standard	**Chemical**	Lancer® 970	Acephate	80g/ 100L
23/11/2018	13 to 15	Standard	**Chemical**	Cabrio®	Pyraclostrobin	40mL/100L
	13 to 15	Standard	Cultural	Hygiene: Removing of MSW infested nuts		
24/12/2018	13 to 15	Standard	**Chemical**	Bulldock® 25	Beta-cyfluthrin	50mL/ 100L
13/02/2019	13 to 15	Standard	**Chemical**	Bulldock® 25	Beta-cyfluthrin	50mL/ 100L
30/08/2018	9 to 11	Strip-3	**Chemical**	Transform®	Sulfoxaflor	40mL/100L
	9 to 11	Strip-3	Biological	Lacewing		
23/10/2018	9 to 11	Strip-3	**Chemical**	Lancer ®970	Acephate	80g/ 100L
23/10/2018	9 to 11	Strip-3	**Chemical**	Spin Flo®	Carbendazim	50mL/ 100L
	9 to 11	Strip-3	Cultural	Hygiene: Removing of MSW infested nuts		
	9 to 11	Strip-3	Biological	*Montdorensis*		
	9 to 11	Strip-3	Biological	*Centrodora*		
	9 to 11	Strip-3	Biological	MacTrix		
23/11/2018	9 to 11	Strip-3	**Chemical**	Lepidex® 500	Trichlorfon	200mL/ 100L
23/11/2018	9 to 11	Strip-3	**Chemical**	Cabrio®	Pyraclostrobin	40mL/100L
	9 to 11	Strip-3	Cultural	Hygiene: Removing of MSW infested nuts		
	9 to 11	Strip-3	Biological	*Centrodora*		
	9 to 11	Strip-3	Biological	MacTrix		
24/12/2018	9 to 11	Strip-3	**Chemical**	Bulldock® 25	Beta-cyfluthrin	50mL/ 100L
	9 to 11	Strip-3	Biological	*Centrodora*		
	9 to 11	Strip-3	Biological	MacTrix		
13/02/2019	9 to 11	Strip-3	**Chemical**	Bulldock® 25	Beta-cyfluthrin	50mL/ 100L
	9 to 11	Strip-3	Biological	MacTrix		
	9 to 11	Strip-3	Biological	*Montdorensis*		

Table: 1.3.1.2.: Treatments applied at IPM trial at the Centre for Tropical Horticulture (CTH) at Alstonville during 2018/2019 (cont.)

SEASON 2018/2019						
Date	**Row**	**Treatment**	**Category**	**Treatment**	**Chemical Active**	**Rate**
30/08/2018	5 to 7	Strip-2	**Chemical**	SeroX®	Butterfly pea extract	
	5 to 7	Strip-2	Biological	Lacewing		
23/10/2018	5 to 7	Strip-2	**Chemical**	SeroX®	Butterfly pea extract	
23/10/2018	5 to 7	Strip-2	**Chemical**	Spin Flo®	Carbendazim	50mL/ 100L
	5 to 7	Strip-2	Cultural	Hygiene: Removing of MSW infested nuts		
	5 to 7	Strip-2	Biological	*Montdorensis*		
	5 to 7	Strip-2	Biological	*Centrodora*		
	5 to 7	Strip-2	Biological	MacTrix		
23/11/2018	5 to 7	Strip-2	**Chemical**	Success Neo®	Spinetoram	20mL/100L
23/11/2018	5 to 7	Strip-2	**Chemical**	Cabrio®	Pyraclostrobin	40mL/100L
	5 to 7	Strip-2	Cultural	Hygiene: Removing of MSW infested nuts		
	5 to 7	Strip-2	Biological	*Centrodora*		
	5 to 7	Strip-2	Biological	MacTrix		
24/12/2018	5 to 7	Strip-2	**Chemical**	Transform®	Sulfoxaflor	40mL/100L
	5 to 7	Strip-2	Biological	*Centrodora*		
	5 to 7	Strip-2	Biological	MacTrix		
13/02/2019	5 to 7	Strip-2	**Chemical**	Trivor® 125	Acetamiprid + pyriproxyfen	40mL/100L

Table: 1.3.1.2.: Treatments applied at IPM trial at the Centre for Tropical Horticulture (CTH) at Alstonville during 2018/2019 (cont.)

SEASON 2018/2019						
Date	**Row**	**Treatment**	**Category**	**Treatment**	**Chemical Active**	**Rate**
30/08/2018	1 to 3	Strip-1	**Chemical**	Sivanto Prime®	Flupyradifurone	100mL/ 100L
	1 to 3	Strip-1	Biological	Lacewing		
23/10/2018	1 to 3	Strip-1	**Chemical**	Vayego® (DC0143)	Tetraniliprole	12.5ml/100L
23/10/2018	1 to 3	Strip-1	**Chemical**	Spin Flo®	Carbendazim	50mL/ 100L
	1 to 3	Strip-1	Cultural	Hygiene: Removing of MSW infested nuts		
	1 to 3	Strip-1	Biological	*Montdorensis*		
	1 to 3	Strip-1	Biological	*Centrodora*		
	1 to 3	Strip-1	Biological	MacTrix		
23/11/2018	1 to 3	Strip-1	**Chemical**	Steward®	Indoxacarb	50mL/ 100L
23/11/2018	1 to 3	Strip-1	**Chemical**	Cabrio®	Pyraclostrobin	40mL/100L
	1 to 3	Strip-1	Cultural	Hygiene: Removing of MSW infested nuts		
	1 to 3	Strip-1	Biological	*Centrodora*		
	1 to 3	Strip-1	Biological	MacTrix		
24/12/2018	1 to 3	Strip-1	**Chemical**	DC0163	DC0163	
	1 to 3	Strip-1	Biological	*Centrodora*		
	1 to 3	Strip-1	Biological	MacTrix		
13/02/2019	1 to 3	Strip-1	**Chemical**	DC0163	DC0163	
	1 to 3	Strip-1	Biological	MacTrix		
	1 to 3	Strip-1	Biological	*Montdorensis*		
19/03/2019	1 to 3	Strip-1	Biological	*Beauveria*	B27	

Table: 1.3.1.3.: Treatments applied at IPM trial at the Centre for Tropical Horticulture (CTH) at Alstonville during 2019/2020

SEASON 2019/2020						
Date	**Row**	**Treatment**	**Category**	**Treatment**	**Chemical Active**	**Rate**
18/07/2019	13 to 15	Standard	Cultural	Hedging		
13/08/2019	13 to 15	Standard	Cultural	Smother grass planting		
21/08/2019	13 to 15	Standard	**Chemical**	Diazinon 800®	Diazinon	125mL/100L
16/10/2019	13 to 15	Standard	Cultural	Mulching		
23/10/2019	13 to 15	Standard	Cultural	Hygiene: Removing of MSW infested nuts		
31/10/2019	13 to 15	Standard	**Chemical**	Lancer® 970	Acephate	80g/ 100L
31/10/2019	13 to 15	Standard	**Chemical**	Spin Flo®	Carbendazim	50mL/ 100L
06/11/2019	13 to 15	Standard	Cultural	Hygiene: Removing of MSW infested nuts		
20/11/2019	13 to 15	Standard	Cultural	Hygiene: Removing of MSW infested nuts		
26/11/2019	13 to 15	Standard	**Chemical**	Lancer® 970	Acephate	80g/ 100L
04/12/2019	13 to 15	Standard	Cultural	Hygiene: Removing of MSW infested nuts		
18/12/2019	13 to 15	Standard	Cultural	Hygiene: Removing of MSW infested nuts		
29/12/2019	13 to 15	Standard	**Chemical**	Bulldock® 25	Beta-cyfluthrin	50mL/ 100L
30/01/2020	13 to 15	Standard	**Chemical**	Bulldock® 25	Beta-cyfluthrin	50mL/ 100L

Table: 1.3.1.3.: Treatments applied at IPM trial at the Centre for Tropical Horticulture (CTH) at Alstonville during 2019/2020 (cont.)

SEASON 2019/2020						
Date	**Row**	**Treatment**	**Category**	**Treatment**	**Chemical Active**	**Rate**
18/07/2019	9 to 11	Strip-3	Cultural	Hedging		
13/08/2019	9 to 11	Strip-3	Cultural	Smother grass planting		
21/08/2019	9 to 11	Strip-3	**Chemical**	Transform®	Sulfoxaflor	40mL/100L
16/10/2019	9 to 11	Strip-3	Cultural	Mulching		
23/10/2019	9 to 11	Strip-3	Cultural	Hygiene: Removing of MSW infested nuts		
31/10/2019	9 to 11	Strip-3	**Chemical**	Steward®	Indoxacarb	50mL/ 100L
06/11/2019	9 to 11	Strip-3	Cultural	Hygiene: Removing of MSW infested nuts		
20/11/2019	9 to 11	Strip-3	Cultural	Hygiene: Removing of MSW infested nuts		
26/11/2019	9 to 11	Strip-3	**Chemical**	Transform®	Sulfoxaflor	40mL/100L
02/12/2019	9 to 11	Strip-3	Biological	MacTrix		
04/12/2019	9 to 11	Strip-3	Cultural	Hygiene: Removing of MSW infested nuts		
09/12/2019	9 to 11	Strip-3	Biological	MacTrix release		
18/12/2019	9 to 11	Strip-3	Cultural	Hygiene: Removing of MSW infested nuts		
29/12/2019	9 to 11	Strip-3	**Chemical**	Lepidex® 500	Trichlorfon	200mL/ 100L
13/01/2020	9 to 11	Strip-3	Biological	MacTrix		
20/01/2020	9 to 11	Strip-3	Biological	MacTrix		
30/01/2020	9 to 11	Strip-3	**Chemical**	Lepidex® 500	Trichlorfon	200mL/ 100L
03/02/2020	9 to 11	Strip-3	Biological	MacTrix		

Table: 1.3.1.3.: Treatments applied at IPM trial at the Centre for Tropical Horticulture (CTH) at Alstonville during 2019/2020 (cont.)

SEASON 2019/2020						
Date	**Row**	**Treatment**	**Category**	**Treatment**	**Chemical Active**	**Rate**
18/07/2019	5 to 7	Strip-2	Cultural	Hedging		
13/08/2019	5 to 7	Strip-2	Cultural	Smother grass planting		
21/08/2019	5 to 7	Strip-2	**Chemical**	Lepidex® 500	Trichlorfon	200mL/ 100L
16/10/2019	5 to 7	Strip-2	Cultural	Mulching		
23/10/2019	5 to 7	Strip-2	Cultural	Hygiene: Removing of MSW infested nuts		
31/10/2019	5 to 7	Strip-2	**Chemical**	Steward®	Indoxacarb	50mL/ 100L
06/11/2019	5 to 7	Strip-2	Cultural	Hygiene: Removing of MSW infested nuts		
20/11/2019	5 to 7	Strip-2	Cultural	Hygiene: Removing of MSW infested nuts		
26/11/2019	5 to 7	Strip-2	**Chemical**	Transform®	Sulfoxaflor	40mL/100L
02/12/2019	5 to 7	Strip-2	Biological	MacTrix		
04/12/2019	5 to 7	Strip-2	Cultural	Hygiene: Removing of MSW infested nuts		
09/12/2019	5 to 7	Strip-2	Biological	MacTrix release		
18/12/2019	5 to 7	Strip-2	Cultural	Hygiene: Removing of MSW infested nuts		
29/12/2019	5 to 7	Strip-2	**Chemical**	Lepidex® 500	Trichlorfon	200mL/ 100L
13/01/2020	5 to 7	Strip-2	Biological	MacTrix		
20/01/2020	5 to 7	Strip-2	Biological	MacTrix		
30/01/2020	5 to 7	Strip-2	**Chemical**	Lepidex® 500	Trichlorfon	200mL/ 100L
03/02/2020	5 to 7	Strip-2	Biological	MacTrix		

Table: 1.3.1.3.: Treatments applied at IPM trial at the Centre for Tropical Horticulture (CTH) at Alstonville during 2019/2020 (cont.)

SEASON 2019/2020						
Date	**Row**	**Treatment**	**Category**	**Treatment**	**Chemical Active**	**Rate**
18/07/2019	1 to 3	Strip-1	Cultural	Hedging		
13/08/2019	1 to 3	Strip-1	Cultural	Smother grass planting		
21/08/2019	1 to 3	Strip-1	**Chemical**	Sivanto® Prime	Flupyradifurone	50mL/ 100L
16/10/2019	1 to 3	Strip-1	Cultural	Mulching		
23/10/2019	1 to 3	Strip-1	Cultural	Hygiene: Removing of MSW infested nuts		
31/10/2019	1 to 3	Strip-1	**Chemical**	Steward®	Indoxacarb	50mL/ 100L
06/11/2019	1 to 3	Strip-1	Cultural	Hygiene: Removing of MSW infested nuts		
20/11/2019	1 to 3	Strip-1	Cultural	Hygiene: Removing of MSW infested nuts		
26/11/2019	1 to 3	Strip-1	**Chemical**	Transform®	Sulfoxaflor	40mL/100L
02/12/2019	1 to 3	Strip-1	Biological	MacTrix		
04/12/2019	1 to 3	Strip-1	Cultural	Hygiene: Removing of MSW infested nuts		
09/12/2019	1 to 3	Strip-1	Biological	MacTrix		
18/12/2019	1 to 3	Strip-1	Cultural	Hygiene: Removing of MSW infested nuts		
29/12/2019	1 to 3	Strip-1	**Chemical**	Lepidex® 500	Trichlorfon	200mL/ 100L
13/01/2020	1 to 3	Strip-1	Biological	MacTrix		
20/01/2020	1 to 3	Strip-1	Biological	MacTrix		
30/01/2020	1 to 3	Strip-1	**Chemical**	Lepidex® 500	Trichlorfon	M
03/02/2020	1 to 3	Strip-1	Biological	MacTrix		

Table: 1.3.1.4.: Treatments applied at IPM trial at the Centre for Tropical Horticulture (CTH) at Alstonville during 2020/2021

SEASON 2020/2021						
Date	**Row**	**Treatment**	**Category**	**Treatment**	**Chemical Active**	**Rate**
27/08/2020	13 to 15	Standard	**Chemical**	Diazinon 800®	Diazinon	125 mL/100 L
13/10/2020	13 to 15	Standard	**Chemical**	Lancer® 970	Acephate	80 g/100 L
06/11/2020	13 to 15	Standard	**Chemical**	Lancer® 970	Acephate	80 g/100 L
13/11/2020	13 to 15	Standard	Biological	MacTrix		
23/11/2020	13 to 15	Standard	Biological	MacTrix		
05/12/2020	13 to 15	Standard	**Chemical**	Bulldock® 25	Beta-cyfluthrin	50 mL/ 100L
14/12/2021	13 to 15	Standard	Biological	MacTrix		
21/12/2021	13 to 15	Standard	Biological	MacTrix		
01/01/2021	13 to 15	Standard	Biological	MacTrix		
05/01/2021	13 to 15	Standard	Biological	MacTrix		
18/01/2021	13 to 15	Standard	Biological	MacTrix		
22/01/2021	13 to 15	Standard	**Chemical**	Bulldock® 25	Beta-cyfluthrin	50 mL/ 100L
25/01/2021	13 to 15	Standard	Biological	MacTrix		
01/02/2021	13 to 15	Standard	Biological	MacTrix		
08/02/2021	13 to 15	Standard	Biological	MacTrix		
22/02/2021	13 to 15	Standard	Biological	MacTrix		

Table: 1.3.1.4.: Treatments applied at IPM trial at the Centre for Tropical Horticulture (CTH) at Alstonville during 2020/2021 (cont.)

SEASON 2020/2021						
Date	**Row**	**Treatment**	**Category**	**Treatment**	**Chemical Active**	**Rate**
27/08/2020	9 to 11	Strip-3	**Chemical**	Diazinon 800® (early)	Diazinon	125 mL/100 L
17/09/2020	9 to 11	Strip-3	**Chemical**	Diazinon 800® (late)	Diazinon	125 mL/100 L
13/10/2020	9 to 11	Strip-3	**Chemical**	Lancer® 970	Acephate	80 g/100 L
06/11/2020	9 to 11	Strip-3	**Chemical**	Lancer® 970	Acephate	80 g/100 L
13/11/2020	9 to 11	Strip-3	Biological	MacTrix		
23/11/2020	9 to 11	Strip-3	Biological	MacTrix		
05/12/2020	9 to 11	Strip-3	**Chemical**	Bulldock® 25	Beta-cyfluthrin	50 mL/ 100L
14/12/2021	9 to 11	Strip-3	Biological	MacTrix		
21/12/2021	9 to 11	Strip-3	Biological	MacTrix		
01/01/2021	9 to 11	Strip-3	Biological	MacTrix		
05/01/2021	9 to 11	Strip-3	Biological	MacTrix		
18/01/2021	9 to 11	Strip-3	Biological	MacTrix		
22/01/2021	9 to 11	Strip-3	**Chemical**	Bulldock® 25	Beta-cyfluthrin	50 mL/ 100L
25/01/2021	9 to 11	Strip-3	Biological	MacTrix		
01/02/2021	9 to 11	Strip-3	Biological	MacTrix		
08/02/2021	9 to 11	Strip-3	Biological	MacTrix		

Table: 1.3.1.4.: Treatments applied at IPM trial at the Centre for Tropical Horticulture (CTH) at Alstonville during 2020/2021 (cont.)

SEASON 2020/2021						
Date	**Row**	**Treatment**	**Category**	**Treatment**	**Chemical Active**	**Rate**
27/08/2020	5 to 7	Strip-2	**Chemical**	Sivanto® Prime (early)	Flupyradifurone	50 mL/100 L
17/09/2020	5 to 7	Strip-2	**Chemical**	Sivanto® Prime (late)	Flupyradifurone	50 mL/100 L
13/10/2020	5 to 7	Strip-2	**Chemical**	Steward®	Indoxacarb	50 mL/100 L
06/11/2020	5 to 7	Strip-2	**Chemical**	Trivor®	186g/L Acetamiprid + 124g/L Pyriproxyfen	20mL/100L
13/11/2020	5 to 7	Strip-2	Biological	MacTrix		
23/11/2020	5 to 7	Strip-2	Biological	MacTrix		
05/12/2020	5 to 7	Strip-2	**Chemical**	Lepidex 500	Trichlorfon	200 mL/100 L
14/12/2021	5 to 7	Strip-2	Biological	MacTrix		
21/12/2021	5 to 7	Strip-2	Biological	MacTrix		
01/01/2021	5 to 7	Strip-2	Biological	MacTrix		
05/01/2021	5 to 7	Strip-2	Biological	MacTrix		
18/01/2021	5 to 7	Strip-2	Biological	MacTrix		
22/01/2021	5 to 7	Strip-2	**Chemical**	Trivor®	186g/L Acetamiprid + 124g/L Pyriproxyfen	20mL/100L
25/01/2021	5 to 7	Strip-2	Biological	MacTrix		
01/02/2021	5 to 7	Strip-2	Biological	MacTrix		
08/02/2021	5 to 7	Strip-2	Biological	MacTrix		
22/02/2021	5 to 7	Strip-2	Biological	MacTrix		

Table: 1.3.1.4.: Treatments applied at IPM trial at the Centre for Tropical Horticulture (CTH) at Alstonville during 2020/2021 (cont.)

SEASON 2020/2021						
Date	**Row**	**Treatment**	**Category**	**Treatment**	**Chemical Active**	**Rate**
27/08/2020	1 to 3	Strip-1	**Chemical**	Sivanto® Prime	Flupyradifurone	50 mL/100 L
13/10/2019	1 to 3	Strip-1	**Chemical**	Steward®	Indoxacarb	50 mL/100 L
06/11/2020	1 to 3	Strip-1	**Chemical**	Trivor®	186g/L Acetamiprid + 124g/L Pyriproxyfen	20mL/100L
13/11/2020	1 to 3	Strip-1	Biological	MacTrix		
23/11/2020	1 to 3	Strip-1	Biological	MacTrix		
05/12/2020	1 to 3	Strip-1	**Chemical**	Lepidex® 500	Trichlorfon	200 mL/100 L
14/12/2021	1 to 3	Strip-1	Biological	MacTrix		
21/12/2021	1 to 3	Strip-1	Biological	MacTrix		
01/01/2021	1 to 3	Strip-1	Biological	MacTrix		
05/01/2021	1 to 3	Strip-1	Biological	MacTrix		
18/01/2021	1 to 3	Strip-1	Biological	MacTrix		
22/01/2021	1 to 3	Strip-1	**Chemical**	Trivor®	186g/L Acetamiprid + 124g/L Pyriproxyfen	20mL/100L
25/01/2021	1 to 3	Strip-1	Biological	MacTrix		
01/02/2021	1 to 3	Strip-1	Biological	MacTrix		
08/02/2021	1 to 3	Strip-1	Biological	MacTrix		
22/02/2021	1 to 3	Strip-1	Biological	MacTrix		

Monitoring

Yellow sticky traps

Pests and beneficial populations were monitored using yellow sticky traps as described in Appendix 1.2.3.

Scolytid beetle traps

Commercial traps and lures were tested for monitoring a range of scolytid beetles. A detailed description can be found in Appendix 1.2.3.

Harvest

Nuts were harvested during the first week of each month between March and August each year. Nuts under each treatment tree were collected by hand and weighted using a clock face scale (max. 25kg with a min. reading accuracy of 50g) mounted on a steel tripod. A standard 4kg weight was used for scale calibration. A random sub-sample of up to 30 nuts with green husk (if possible) was taken out of the harvest for each individual tree. The sample was put into a plastic net and the weight and number of nuts recorded. For March and April harvests the samples of nuts in husk were examined for macadamia nut borer (MNB) damage and eggs. Nut samples were then de-husked and processed as described in (Huwer et al. 2006; Huwer et al. 2011).

Nut in husk

As described in Appendix 1.2.4.

Kernel assessment

As described in Appendix 1.2.4.

1.3.2. Biodiversity trial

An unsprayed block of macadamias was used for the biodiversity trial 2020 to 2021. The trees were all of the cultivar 246. Originally the block was planted to investigate the effect of tree density on pests, particularly on Fruit spotting bugs. The block was planted in 2007 at 3 different densities as follows: 10 x 3.5m x 10m x 7m and 10 x 10m. The block is close to houses and therefore, it has not been sprayed with insecticides. Since 2015 the annual crop yield from this block has been less than a kilo of nuts per tree due to macadamia lace bug (MLB) and macadamia seed weevil (MSW) damage. So that the effect of MLB on crop yield and quality could be examined, the block was sprayed with Steward (50 mL/100 L) and Designer (10 mL/100 L) on 31 October 2019 and again in October 2020 to reduce MSW populations. The block design is shown in Figure 1.3.2.1.

Aim of the trial was to investigate if an increased biodiversity and following increase in beneficial insects would be sufficient to manage some of the pest, particularly MLB. A review paper on effect of inter-row crops on pest populations pointed out that a lack of a lot of studies was the missing link to yield. The measurement of yields have to be considered as an important adoption tool. With regards to yield data, “in terms of interest for the farmer, these data are necessary to evaluate the purpose of such measures for fruit growing and to convince growers about their adoption and implementation on a long term” (Herz et al. 2019).

Density Block

	TREE	Row 1	Row 2	Row 3	Row 4	Row 5	
Buffer	1	X	X	O	O	P	
	2	M	X	O	M	P	10 X 3.5m
	3	X	M	O	M	P	
Buffer	4	X	M	O	O	P	
	5	O	O	X	X	P	
	6	O	O	X	X	P	10 X 7m
Buffer	7	M	O	X	X	P	
	8	M	X	M	O	P	
	9	M	X	M	M	P	10 X 10m
Buffer	10	X	X	O	O	P	
	11	O	O	X	X	P	
	12	O	O	X	X	P	10 X 10m
Buffer	13	O	M	X	M	P	
	14	X	X	M	O	P	
	15	X	X	O	M	P	10 X 7m
Buffer	16	X	X	O	O	P	
	17	O	M	X	X	P	
	18	O	O	X	M	P	10 X 3.5m
Buffer	19	M	O	X	M	P	

Monitoring trees (highlighted)

X= Tetraphylla rootstock and 246 scion

O= H2 Rootstock and 246 scion

P = 741 Pollinator

M= missing trees

Figure 1.3.2.1.: Biodiversity trial block design

Options for inter-row crops were discussed with Dr. Abigail Makim from BioResources and Tony Hodges from Williams Seeds of the Williams group at Murwillumbah. Inter-rows were seeded on 10 February 2020 with the following mixture:

- Callide (Rhodes grass) 40%
- White clover (legume) 10%
- Red clover (legume) 10%
- Mustard (brassica) 25%
- Chicory (Asteraceae) 5%
- Lucerne (legume) 10%

In addition to the inter-row plantings, adjacent to the orchard, along the fence line 6 groups of native flowering shrubs were planted to provide continuous flowering. Native shrubs planted including *Grevillia* sp., *Banksia* sp., *Leptospermum* sp., *Westringia* sp. and *Lomandra* sp. (Figure 1.3.2.2.).

Figure 1.3.2.2.: One of six groups of native shrubs planted next to macadamia orchard (Density block).

1.4. Insecticide screening

Specific chemicals were screened for targeted pests in laboratory and small scale field trials.

1.4.1. Laboratory insecticides screening

Insecticides were screened in the laboratory. For most insects the following tests were used:

- Drop tests, investigating contact toxicity
- Feeding test, investigating the ingestion toxicity
- Feeding test for MNB larvae in treated artificial diet
- Screening chemicals for macadamia lace bug on treated racemes in the orchard
- Residual trials, investigating for how long different chemicals are active after application
- Screening macadamia nut borer eggs parasitised with *Trichogrammatoidea cryptophlebiae*

Drop test

In a drop test, 1µl of insecticide solution was put on the back of on each insect (nymphs and adults) with a micro syringe. Insects were checked after 1, 2, 3 and 7 days for mortality. Data was analysed with Genstat 21 using analysis of variance (ANOVA). Where a significant difference was found, this was followed by a pairwise comparison using the 95% least significant difference (LSD) after data was checked for homogeneity.

Details of the methodology are described in Appendix 2.5.1.

Feeding test

Over time, a number of chemicals have been screened in the laboratory and compared with a water treated control. A small raceme with macadamia nuts, or a bunch of twigs with *Murraya paniculata* berries that were dipped in insecticide solution or water (control) was put in a glass vial and placed in a glass jar (800ml). Five individuals were placed into the jar with the treated macadamia nuts or *M. paniculata* berries and the jar was covered with gauze to allow for ventilation in the jars. Mortality was checked after 24 hours, 48 hours, 3 or 5 days and 7 or 8 days. A series of different screening experiments were conducted as insects were available over time. Individual screening trials tested different chemicals. Treatments were repeated across the whole screening 2 or 3 times depending on the availability of insects.

Data was analysed with Genstat 21 using analysis of variance (ANOVA). Where a significant difference was found, this was followed by a pairwise comparison using the 95% least significant difference (LSD) after data was checked for homogeneity.

Details of the methodology are described in Appendix 2.5.1.

Residual trials

Residual times of chemicals were investigated for FSB and *Leptocoris* sp. At CTH branches of fruiting *Murraya paniculata* were treated with different chemicals. Treated branches were taken 1,7,14 and 21 days after application and presented to insects as described in feeding test and resulting mortality checked after further 7 days.

Details of the methodology are described in Appendix 2.5.1. and Appendix 2.5.2.

Screening chemicals for macadamia lace bug

Flower racemes were tagged and treated in the orchard at CTH. Racemes were taken back to the laboratory after 7 days and racemes were checked for mortality of lace bug adults and nymphs.

Details of the methodology are described in Appendix 2.5.1. and Appendix 2.5.2.

Feeding test for MNB larvae

Artificial diet was poured into cell trays. Individual cells were treated with chemicals to be tested (20µl aliquot) and individual 1st instar MNB larvae were put into each cell. Cells with diet were monitored for feeding evidence and mortality of larvae after 3 days.

Details of the methodology are described in Appendix 2.5.1.

Screening macadamia nut borer eggs parasitised with *Trichogrammatoidea cryptophlebiae*

Strips of cardboard cards with freshly parasitised MNB eggs were dipped into pesticide solution and checked for egg parasitoid emergence and capacity to parasitise fresh eggs for 2 generations. Survivorship and fecundity were assessed.

Details of the trial are described in Maddox et al. 2002a and Appendix 2.5.1.

Different numbers of chemicals that were investigated in main investigations are listed in Table 1.4.1.

Details of the methodology are described in Appendix 2.5.1. and 2.5.2.

Table 1.4.1.: Numbers of chemicals screened in laboratory tests against specific pests

Insect	Number of chemicals screened	Type of test
Macadamia lace bug	15	Raceme test
Macadamia nut borer	3	Treated test in treated artificial diet
Macadamia seed weevil	9	Feeding trial
Trichogrammatoidea cryptophlebiae	4	Screening parasitised macadamia nut borer eggs
Fruit spotting bugs and banana spotting bug	16	Feeding trial, residue trial
Leptocoris	15	Feeding trial and residue trial

1.4.1.2. Insecticide screening in field trials

Some specific trials were undertaken to screen some chemicals that gave promising results in laboratory screening for selected pests (including felted coccid and macadamia seed weevil) in the field.

<u>Felted coccid screening trials</u>

A small scale field trial was undertaken on a commercial farm in the at Rous in the Northern Rivers to investigate chemicals that did not flare felted coccid as a secondary pest. Trees in the orchard were sprayed with commercial sprayer. Flower racemes were taken back to the laboratories at Wollongbar WPII and examined for presence of live crawlers and adults of felted coccid. Details of the trial are described in Appendix 2.5.1.

<u>Assessing entomopathogenic fungi for macadamia seed weevil in the field</u>

Beauveria bassiana was evaluated as foliar and ground application in the field, at CTH Alstonville and a commercial farm at Tregeagle (Northern Rivers). Reduction in nut drop due to macadamia seed weevil was the key assessment point.

The original *Beauveria bassiana* possibly came from infected pyrgo beetles from tea tree and therefore some trials were undertaken to compare the spore viability of cultured and natural spore material from pyrgo beetles.

Details of the trial are described in Appendix 2.4.

<u>Evaluation of SARP (2020) recommendations</u>

Small scale field trials were conducted at CTH Alstonville to assess chemicals recommended in SARP report 2020 under high pressure of macadamia nut borer, macadamia seed weevil and FSB. Selected chemicals were applied with an air-blast sprayer and monitoring and assessment were undertaken fortnightly and evaluated as described in main IPM trial at CTH (Appendix 1.3.1.). Trial details are described in Appendices 2.5.2, 2.5.5. and 2.5.6.

1.5. Diagnostics

Macadamia samples that were received from consultants, factories and what has been collected in the various trial samplings over the period. Most have been diagnosed, some are not known to science as we have frequently found in macadamia, and many name changes are occurring with the push to DNA code most of the Australian insect fauna this will slowly become less frequent.

Universities are part of the international effort to "barcode" the entire entomological fauna globally, the renaming of at least 5 pest species has happened during that past 5 years (e.g. macadamia lace bugs, seed weevil and felted coccid have been well known since the 1980's), and quite a few potential new ones have been detected (e.g. Schofner and Cassis UNSW). The ones that defy or change management options are the real threats and have to be examined closer.

Samples were usually provided directly to office where possible for diagnostic work or if likely unknown to send to Orange. More commonly now a photo will be sent to my phone with the identification. Where possible we handle the workload of at least 3-5 per week from August to the end of January each monitoring season (75-125 per season). During the last 5 years needing to send 62 to higher authorities for genetic work (David Gopourenko) and Ainsley Segao (scolytids), Marianne Horak, Andrew Mitchell (moths), Danuta Knihinicki (mites), Peter Gillespie for main general unknowns. Scolytids were the bulk of the problem ones with some new moth pests and a few likely bug issues from north Queensland as well.

Details are described in Appendix 2.6.

Appendix 2: Detailed results

2.1. Gap analysis

Gaps identified from the literature review and evaluation of current industry practices were the following:

Development and/or implementation of cultural control, which include:

- Reduction of tree height
- Effect of previously recommended inter-row crops on beneficials (smother-grass, Pinto-peanut) (in consultation with Bioresources)
- Orchard hygiene for macadamia seed weevil management

Enhancing biological control

- Survey of general beneficials
- Investigate options for use of commercially available biological control agents
- Identify options for orchard habitat manipulation

Development and/or adoption of monitoring tools including the following:

- Development of pheromones for macadamia seed weevil
- Testing of already commercially available pheromones for different scolytid species and Carpophilus beetle
- Development for pheromone lure for *Amblypelta nitida*
- Adoption of pheromone traps for *Amblypelta l. lutescens* and the monitoring hedge for both Fruit spotting bug species
- Monitoring technique for late season Fruit spotting bug damage
- Monitoring tool for kernel grub

Investigation of IPM compatible chemicals and their adoption

- Screening of new chemicals against pests and beneficials
- Screening of biopesticides including *Beauveria* sp. against macadamia seed weevil
- Identification of IPM system compatible chemical options for industry

IPM adoption

- Developing Area-wide Management in main growing areas
- Development of an IPM guide with more information (i.e. monitoring protocols, IPM and organic treatment options) for different pests would be useful. University of California (UC) IPM guides are good examples.
- Workshops for growers and farm managers on IPM
- Education and marketing strategy that will give an incentive for growers/industry to shift to IPM. The biggest hurdle for adoption of IPM is that chemicals are still considered the quick, easy and cheap solution to pest management

2.1.1. Literature review

Background

A number of pest insects cause losses of quality and yield (Ironside, 1981), reducing the productivity of the macadamia industry in Australia. Major pests include flower and foliage pests (i.e. macadamia lace bug (*Ulonemia* spp. Drake and Poor); kernel and post-harvest pests (i.e. Fruit spotting bugs (*Amblypelta* spp. Stål); and pests that attack the branches and trunk including bark beetles (i.e. *Cryphalus subcompactus* Lea).

Pest management in macadamias mainly relies on broad spectrum insecticides. The general reliance on broad spectrum insecticides poses a problem for the industry. A large proportion of the Australian macadamias (approximately 80%) are exported (Australian Macadamia Society, 2021), and therefore an improved pest management strategy is desirable to maintain market access and to comply with strict regulations for pesticide use, to manage chemical resistance and to reduce secondary pest problems caused by the use of broad spectrum insecticides, such as synthetic pyrethroids (Stern, 1959; Treverrow, 1987; Kogan, 1998).

In the past, pest management strategies for macadamia in Australia, have been developed to manage single pest species (Huwer et al. 2007, 2011; Maddox et al. 2002a, b). These strategies have covered a number of approaches, including monitoring tools, chemical and biological control, cultural control and area-wide management (Huwer et al. 2011). However, to date, no integrated strategy has been developed for more than one or two key-pests

In Australian macadamias, there a lack of understanding of the ecology of key pests and beneficial insects, a lack of monitoring tools and strategies and limited knowledge of the role that orchard habitat management plats as part of an IPM program for Australian macadamias.

Past studies provided some basic information of the effect of canopy management, row spacing and ground cover in the orchard on specific pests, like Fruit spotting bugs (*Amblypelta* spp). However, chemical control options compatible with IPM need to be further investigated, and more reliable monitoring strategies need to be developed.

Cultural control options need to be explored and a better linkage with management strategies of other pests and diseases, needs to be developed.

The Australian Macadamia industry now desires an ecologically focussed IPM approach to pest management and is looking for a more holistic and sustainable approach.

Integrated Pest Management (IPM) is considered to be a long-term and sustainable strategy but is also very complex because it requires a good understanding of ecological processes in the crop environment.

To get a better understanding of IPM in general and what has been developed for other horticultural tree crops, in particular other nuts, an extensive literature review needed to be undertaken.

A thorough review of IPM in general, including the principle, definition, history, and past research of IPM in selected tree selected crops (including apples, almonds, pecan and macadamias in Hawaii) revealed a lack of understanding of ecology in Australian macadamia orchards and consequent opportunities to improve pest management.

Preventative management strategies, such as orchard management and enhancement of natural control or cultural control, are currently not included. In other crops, IPM rests on a superior understanding of the whole complex of pest and beneficial insects and improved monitoring.

Any new Integrated Pest Management (IPM) strategy should reduce chemical input and focus on the ecology of the macadamia orchard, with a view to enhancing natural control and fostering more integration of biological and cultural control.

To develop a useful IPM approach for the Australian macadamia industry, successes and pitfalls from the past need to be identified. Thus, literature was reviewed to investigate the definition, the concept, and the history of IPM and IPM strategies in other horticultural crops and countries (including apples, other nut crops like almonds and pecans, and macadamias in Hawaii). The aim of this review is to identify gaps and opportunities to develop an improved pest management strategy for Australian macadamia orchards.

Integrated Pest Management (IPM)

The concept of IPM was first established more than 50 years ago (Stern et al. 1959). Extensive research exists on IPM in general (Castle and Bentley, 2009; Castle and Naranjo, 2009; Castle et al. 2009; Hill et al. 1999; Prokopy 1993, 1994; Way and van Emden, 2000) , as well as for individual fruit and crops (Jones et al. 2009) including apples (MacHardy, 2000; Pekár, 1999; Prokopy 1996; Prokopy, 2003) other nut crops like pecans (Harris et al. 1998; McVay and Hall, 1998; Heerema et al. 2015; Reid, W., 1999, 2002), hazelnut (Olsen, 2000; Progar et al. 2000; Wiman et al. 2016) and almonds (Bentley et al. 2016; Sonke et al.2016), and a review of previous research in macadamias (Armstrong et al. 2006; Huwer et al. 2007; Jones, 2000, 2002).

Concerns about the negative effect of broad spectrum insecticides in agriculture in the late 1950's led to the development of an integrated pest management concept (Stern et al, 1959; Kogan, 1998; Castle and Bentley, 2009; Castle and Naranjo, 2009; Castle et al. 2009; Horowitz et al. 2009; Jones et al. 2009; Naranjo and Ellsworth, 2009; Way and van Emden, 2000; Weddle et al. 2009). This concept identified that natural biological control has to be part of a long-term pest management and chemical control is only an immediate and short term control measure (Stern et al. 1959). In the early 60's, the problematic of reliance on pesticide use to a wider public (Carson, 1962). Pesticide use was perceived as being caught up in an endless spiral (Carson, 1962), alluding to a constant need for stronger and new chemicals to manage resistant surviving pests. In the late 60's the failure and problems of synthetic insecticides including resistance, resurgence of primary pests, rise of secondary pests and the negative effect on the environment were recognised (Kogan, 1998). To overcome these issues, it was suggested that biological and chemical control should be integrated as certain insecticides can reduce chemical resistance and secondary pests outbreaks by preserving beneficial insects (Stern et al. 1959).

Definition and concept of IPM

There have been numerous interpretations and definitions for IPM (Bajwa and Kogan, 2002; Ehler, 2006; FAO, 2017; Horowitz et al. 2009; NSW EPA, 2013; United States EPA, 2016; University of California; 2016a) with 67 different definitions collated and listed (Bajwa and Kogan, 2002). One definition of IPM is "the careful consideration of all available pest control techniques and subsequent integration of appropriate measures that discourage the development of pest populations and keep pesticides and other interventions to levels that are economically justified and reduce or minimise risks to human health and the environment. IPM emphasises the growth of a healthy crop with the least possible disruption to agro-ecosystems and encourages natural pest control mechanisms "(FAO, 2017).

Commonalities in the numerous IPM definitions include natural or ecological principles, a proactive control approach keeping pests below the economic damage levels and using a number of different methods, including cultural, biological and chemical management strategies (Bajwa and Kogan, 2002) and therefore a combination of management tools is deemed essential (Dover, 1984). Pesticides are generally considered a last resort and preferably pest specific chemicals are only used after monitoring indicates they are needed (University of California, 2016a). It is considered a better strategy to prevent pest problems rather than manage them once they occur (Bajwa and Kogan, 2002; NSW EPA, 2013).

The four basic elements of integrated pest management include a) monitoring of pests and beneficial insects, b) development of treatment thresholds, c) the use of biological control (natural control and/or augmentation of beneficial insects) when possible and d) the use of selective pesticides (Naranjo and Ellsworth, 2009).

Tactics used in IPM are either a) remedial (i.e. releases of biological control agents, physical control and chemical control) or b) preventative (i.e. enhancement of natural control, cultural control, resistant varieties and behavioural control) (Kogan, 1998).

Different levels of IPM and implementations

There are recognised difficulties implementing an IPM program and the progress towards implantation has been compared to "climbing up a stepladder" (Prokopy, 1990, 1991, 1993). The first step or first level includes "ecologically sound multiple management tactics for a single class of pests" (i.e. arthropods) (Prokopy, 1993). The first 'half-step' is the use of selective pesticides. This step is called 'chemically-dependent IPM' (Frisbie and Smith, 1991; Prokopy, 1993). The second half-step includes all non-chemical control methods (Prokopy, 1993) and is called 'bio-intensive IPM' (Frisbie and Smith, 1991, Prokopy, 1993). The second level IPM includes the integration of multiple pest management tools across all pest classes (Prokopy, 1993). The third level IPM includes integration of all pest management strategies across all crop production on a farm level (Prokopy, 1993). The fourth level of IPM involves integration of interests of different stakeholders right across industry (Prokopy, 1993). An adapted illustration is shown in Figure 2.1.1.1.

One of the greatest hurdles to the implementation of IPM is the illusion that IPM can provide a simple quick fix, which is what most growers and pest consultants desire (Ehler, 2006). IPM is complex and challenging and requires a very good understanding ecology (Ehler, 2006). The key to successful and sustainable management relies on knowledgeable, well informed pest managers who can most effectively use different pest management tools with the least effect on the environment (Castle and Benley, 2009).

A successful IPM program needs to emphasise the understanding of the ecology of the environment and their interactions and use strategies that maximise natural control, including selective use of pesticides (Kogan, 1998). Often the success of IPM is measured via the reduction in pesticide use, but this is not always the case (Kogan, 1998). An area-wide management approach provides new prospects for IPM on an ecosystem level (Kogan, 1998).

Key steps important in any IPM strategy are described by Alston et al. 2000 and adapted.

Step 1: Identification of the pest species and its biology and ecology

Step 2: Monitoring for the pest

Step 3: Developing of action thresholds, which can even be individual for each grower

Step 4: Identify management options

Step 5: Identify "Window of opportunity" for action

As schematic IPM concept adapted from Alston et al. 2000 is shown in Figure 2.1.1.2.

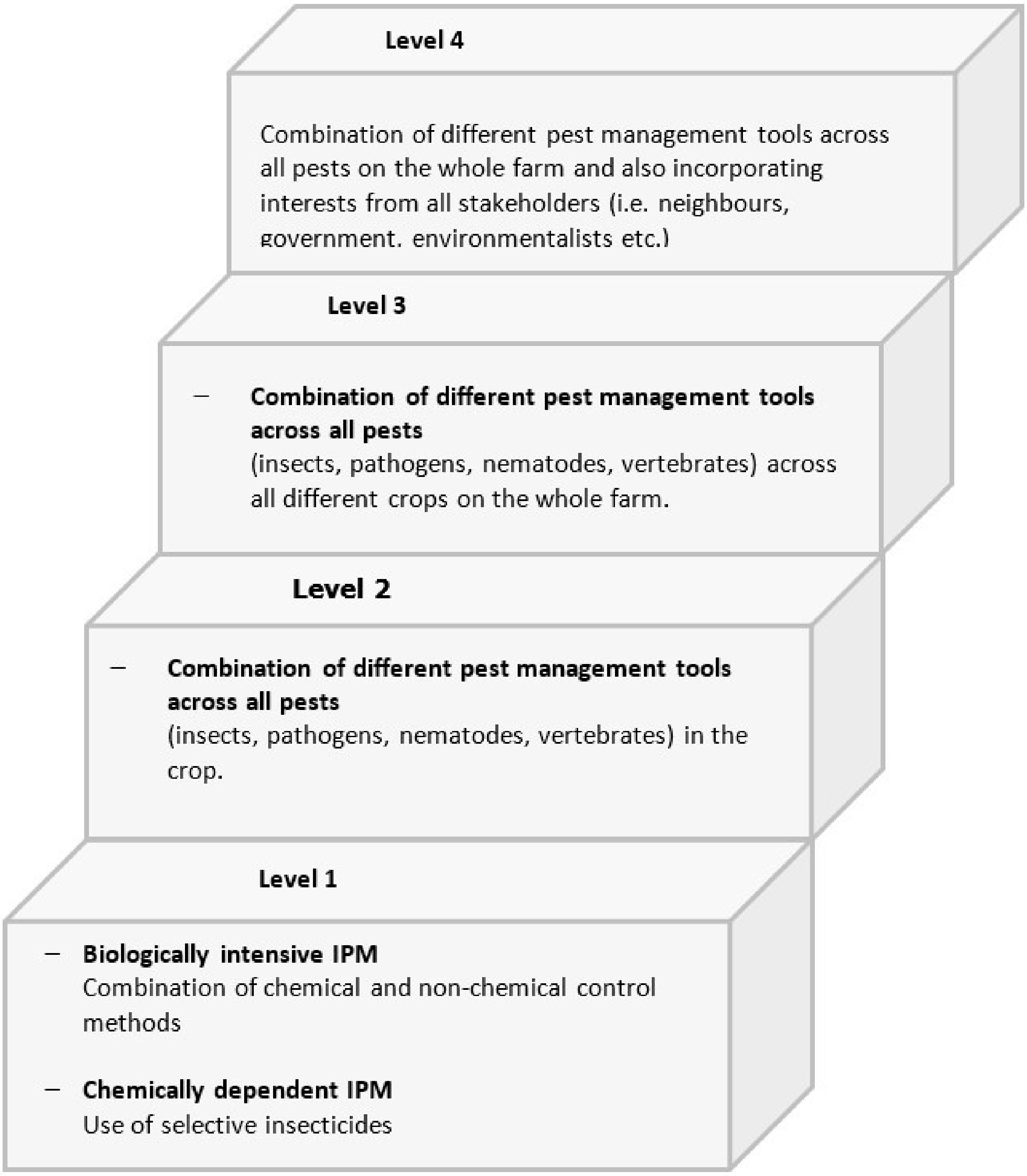

Figure 2.1.1.1.: Different levels of Integrated Pest Management, adapted from Prokopy (1993) and Kogan (1998)

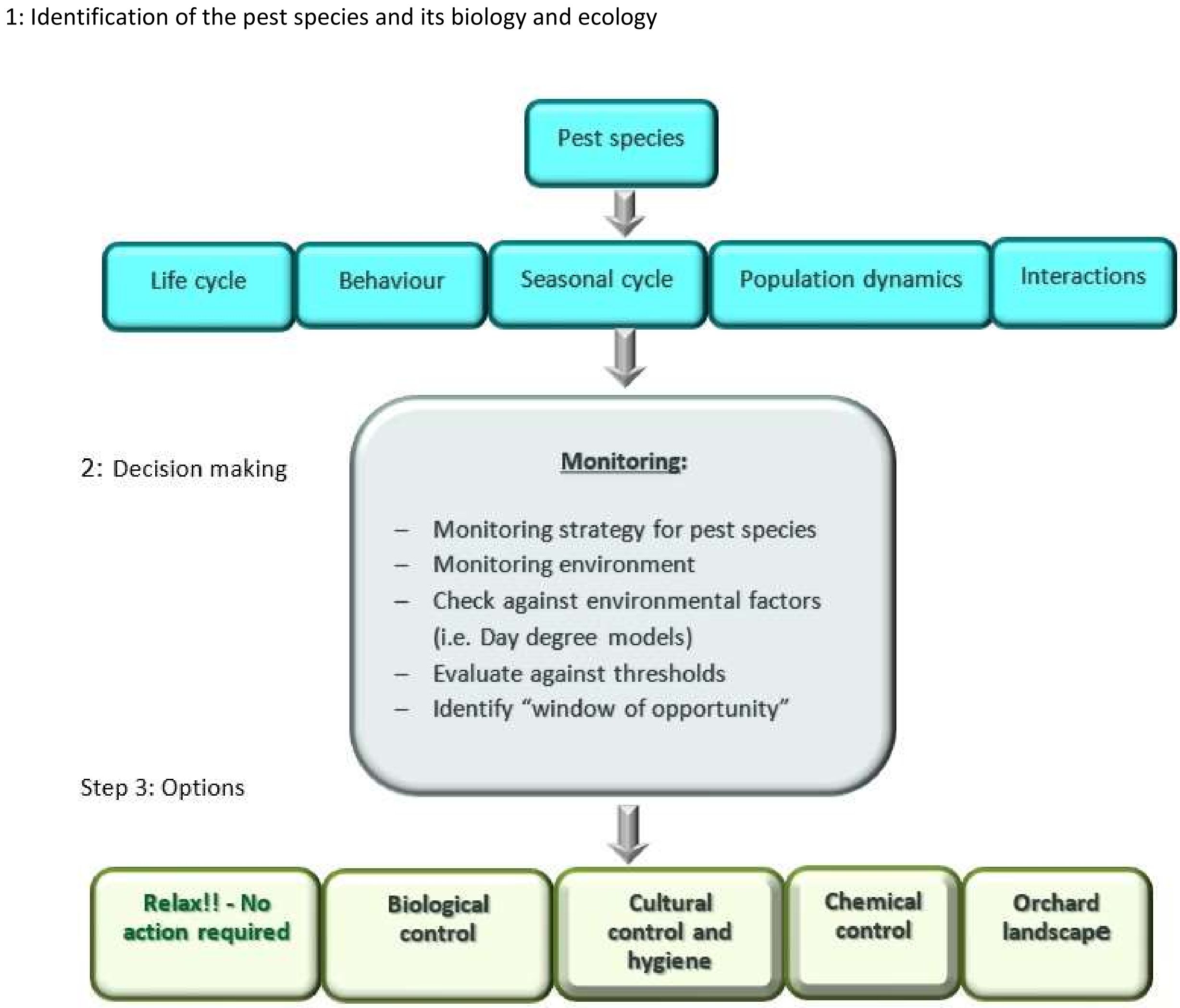

Figure 2.1.1.2: IPM concept and building blocks adapted from Alston et al. 2000

<u>Integrated Pest Management in other horticultural tree crops</u>

The main aim of the review was to examine the literature for successful examples of IPM in other horticultural tree crops and elements that could be adapted for macadamias in Australia.

Orchard habitat management

Ground cover has proven to be important to enhance populations of beneficial insects in US apple orchards, but the species of understory plants have to be carefully selected (Prokopy, 1994). A mixed ground cover, including grasses and weeds can successfully manipulate the arthropod community in the orchard canopy in pears (Rieux et al. 1999, De Pedro et al.2020).

Rhodes grass (*Chloris gayana*) is used in citrus orchards in Queensland to encourage and increase the populations of predatory phytoseiid mites (Smith et al. 1997).

Species selected for hedgerows need to have a similar suit of pests and beneficial insects to have an influence on the orchard (Rieux et al. 1999). However, strong similarity of arthropod fauna does not necessarily imply a high exchange between hedgerow and orchard (Rieux et al. 1999). In a study investigating ground dwelling arthropods in pear orchards in Spain, De Pedro et *al*. (2020), that he influences of cover crops on pest control is unclear. There need to be further investigations on the interaction of cover crops, beneficial insects in the cover crop and pest insects in the canopy of the tree crop (De Pedro et al. 2020).

Ground cover management and hedge rows can be used together to enhance the influence on populations of beneficial insects (Rieux et al. 1999). *Arachis pintoi* was considered a suitable ground cover for macadamia orchards in northern New South Wales with appropriate management during summer and autumn required (Firth and Wilson, 1995; Firth et al. 2003). Inter-row ground cover increased the number of beneficial insects and reduced Fruit spotting bug damage in macadamia orchards in northern New South Wales (Govender, 2015). Selected cover crops are used in pecans in the US to help maintain natural enemies of aphids (Reid, 1999, 2002).

For the management of inter-rows in citrus orchards, a combination of strip herbicide use and sod culture (cultivation of selected grasses and/ or legumes) is suggested to reduce the risk of frost damage, but it also results in a favourable environment for natural enemies and provides them with food (pollen and nectar) (Smith et al. 1997).

The facts that agro-ecosystems are composed of several interacting species forming complicated food webs and the structure of agricultural communities can vary over time needs be considered in pest management (Gonzáles et al. 2009). The addition of the non-herbivore food source (pollen) for the omnivore led to an increased number of predators and reduced populations of the herbivore and improve natural pest control in the avocado orchard ecosystem (Gonzáles et al. 2009).

Regular monitoring of pest and beneficial insects

Regular monitoring (i.e. weekly during the production season) in pecans was important to develop an understanding of arthropod (pests and insects) populations and allows for strategic timing of pest management (McVay and Hall, 1998). Populations of insects enable natural control of pest insects, in the background (McVay and Hall, 1998). A similar system was developed for avocados, including an Avocado year-round IPM program and checklist (Dreistadt, 2008; University of California, 2016b, 2016c,), as well as guidelines for timing of monitoring pests and their natural enemies (Dreistadt, 2008; University of California, 2016d, 2016e, 2016f).

Monitoring protocols and treatment thresholds

Detailed monitoring protocols have been developed and published for key pests in pecans and almonds (University of California, 2015, 2016a). The methodology for monitoring and sampling is explained in detail in the IPM guides for these nut crops. The almond guide also includes biological control and notes for organically acceptable methods (University of California, 2015, 2016a). The suggested monitoring tool for tropical nut borer *Hypothenemus obscurus* in macadamias in Hawaii are funnel traps baited with ethanol or sentinel bags of nuts (Armstrong et al. 2006, Jones, 2002). Commercially available pheromones are used to monitor Koa seed worm moth *Cryptophlebia illepida* and macadamia nut borer *Cryptophlebia ombrodelta* in Hawaii (Armstrong et al. 2006, Jones, 2002). Other monitoring tools in Hawaiian macadamia orchards are yellow sticky traps (for flies, aphids and thrips), beating sheets (for small insects in general) and a sweep net (for insects in ground cover and canopy in general) (Jones, 2002). Practical monitoring tools need to be developed for Australian macadamias.

Limited and selected use of insecticides, biological control and natural control

An IPM program in hazelnuts in the US is based on monitoring and releases of the parasite for the filbert aphid *Trioxys pallidus* and economic thresholds for the main pests, resulted in a 50% reduction in insecticide application (Progar, et al. 2000; Olsen, 2002).

Native pecan groves in the US are rich with natural predators, parasitoids, entomopathogenic fungi and nematodes and spiders (Reid, 1999). Growers have switched from using broad spectrum insecticides, to *Bacillus thuringiensis* (Berliner) and lepidopteran specific growth regulators to control lepidopteran pests like pecan casebearer *Acrobasis nuxvorella* Neunzig and hickory shuckworm, *Cydia carayana* (Fitch)) (Reid, 1999). Other than the use of these IPM compatible pesticides, pests in native pecan stands are managed by natural biological organisms and tree thinning (Reid, 1999).

In planted pecan orchards, monitoring of key pests and selective pesticides, including insect growth regulator (i.e. Tebufenozide) against lepidopteran pests and imidacloprid or potassium nitrate against yellow aphids are used (McVay and Hall, 1998; Reid, 2002). A comparison of different control strategies showed that treatments using targeted pesticides had minimal effect on the population of beneficials and enabled natural control in conjunction with chemical control (McVay and Hall, 1998).

Information on the relative toxicity of insecticides and miticides to 119 apitate 119 l insects and honey bees has been published for pecans and almonds (University of California, 2015, 2016a). This publication provides information on the selectivity of the chemical (broad or narrow), the level of effect on predatory mites, general predators and parasites (high, medium, low, unknown), instructions with relations to bees and information on the duration of effect on natural enemies (short, moderate, long or unknown) (University of California, 2015, 2016a). In addition, an almond management guide gives information on fungicides and resistance management (University of California, 2016a). The effect of selected pesticides (insecticides, fungicides, nematicides and herbicides), EPA exempt chemicals (garlic oil), but also cultural/non-chemical control measures on beneficial insects in macadamias in Hawaii has been investigated and categorised (Armstrong, et al. 2006).

In avocados in Israel outbreaks of the long-tailed mealybug *Pseudococcus longispinus* (Targioni-Tozzetti) (Hompotera: Pseidococcidae), were managed with releases of the two parasites *Aropheoideus pregrinus* (Compere) and *Agnagyrus fusciventris* (Girault) (Hymenoptera: Encyrtidae) (Ausher, 1997). *Batcillus thiringiensis* var. *kurstaki* is used to support natural enemies in the management of the giant looper *Boarmia selenaria* (Denis and Schiffermùller) (Lepidoptera: Geometridae) (Ausher, 1997). In California, the commercially available GHA strain of *Beauveria bassiana* (Balsamo) Vuillemin, was successfully tested against citrus thrips *Scirtothrips citri* (Moulton) and avocado thrips *Scirtothrips perseae* Nakahara (Thysanoptera: Thripidae) (Zahn and Morse, 2013).

Cultural control

Cultural control methods have been identified for pests in macadamia orchards in Hawaii (Armstrong et al. 2006). For the tropical nut borer *Hypothenemus obscurus* cultural control options included frequent harvesting, shaker harvesting, grinding or composting husks, mulching, reduction of sticktights (nuts that are not readily dropped at maturity so that the whole nut or husk and remain in the tree) and removal or avoidance of cultivars with a high proportion of sticktights (Armstrong et al. 2006, Jones, 2002). For red-banded thrips *Selenothrips rubrocinctus*, the control of weeds and alternative hosts is recommended (Armstrong, et al. 2006). Avoidance of compacted soil and maintenance of soil fertility are listed as cultural control options for management of the ambrosia beetle *Xyloborus affinis* in macadamia orchards in Hawaii (Armstrong, et al. 2006). Another example of cultural control in Hawaiian macadamias is the use of mowing to reduce the reproduction of the green vegetable bug *Nezara viridula* is by preventing seeding of alternate hosts (Jones, 2002). For avocados in California, guidelines were developed for manipulating cultural practices and growing conditions (Dreistadt, 2008; University of California, 2016g). Cultural control includes border vegetation management for management of caterpillars and glassy winged sharpshooter, dust control and also fertilisation for management of mites and thrips, pruning and harvest method and timing for management of caterpillars and greenhouse thrips, sanitation for a number of diseases. (Dreistadt, 2008; University of California, 2016g).

Area-wide management (AWM)

The Randall Island Area-Wide project on codling moth management (*Cydia pomonella*) in apples in the Sacramento delta is considered a successful example of an area-wide management and includes an area of 760 acres of adjoining orchards (Weddle, et al. 2009). In this program codling moth mating disruption and insecticides were used (Weddle, et al. 2009). Codling moth damage was kept below 0.2% with one application of azinphos-methyl or parathion-methyl at the second peak of the first flight. The use of organophosphates was reduced by 70-80%; moths captures in the program were reduced by over 90% (Weddle, et al. 2009).

In Californian pear orchards the use of insecticides, for codling moth and secondary pest like spider mites and pear psylla was reduced by 96% over a 10-year period (Varela and Elkins, 2008; Weddle et al. 2009). After three years, savings of $247-$511/ha were achieved (Varela and Elkins, 2008).

In Trentino –South Tyrol area in Italy, mating disruption was used in an area-wide approach to manage Tortricid moths (*Cydia pomonella* and *Lobesia* botrana) in apple orchards and vineyards (Ioriatti and Lucchi, 2016). In 1980's the use of mating disruption was limited to an area of about 400ha (300ha apples and 100ha grapes). This area has since expanded to 32,550ha (22,100ha in apples and 10,450ha grapes) in 2015 (Ioriatti and Lucchi, 2016). This approach significantly reduced the use of insecticides and provided better control of the Tortricid moths (Ioriatti and Lucchi, 2016).

An area-wide management program of the Mediterranean fruit fly *Ceratis capitata*, and the Oriental fruit fly, *Bactrocera dorsalis* was initiated in 2000 by the US Department of Agriculture in Kamuela in Hawaii (Vargas et al. 2010). The management strategy included sanitation, Naturalyte™ fruit fly bait sprays, male annihilation, Biolure® traps, parasitoids and the release of small numbers of sterile males against *B. dorsalis* across a 40km^2 area of urban, rural and agricultural land (Vargas, et al. 2010). Over the 6-year duration of the program, *C. capitata* was reduced by 90.7% and *B. dorsalis* by 60.7% (Vargas et al. 2010).

Area-wide management has also been successfully contributed to fruit fly management in Queensland, Australia (Kruger, 2016; Lloyd et al. 2010). In the Central Burnett region, male annihilation technology (MAT) including the use of a lure (cue-lure) and malathion in orchard and town areas, reduced the male trap catches by 95% between 2003 and 2007 (Lloyd et al. 2010). The overall fruit fly infestation of untreated backyards was reduced from 60.8 to 21.8% (Lloyd et al. 2010). The success of the project convinced the growers in the Central Burnett and the industry to continue and fund the AWM program (Lloyd et al. 2010). Adaptive co-management thinking, including social learning, communication, adaptive capacity, shared decision-making and shared authority, contributed to the success of the AWM program of fruit fly management in Queensland (Kruger, 2016).

At a community-level or whole orchard perspective, all major groups of pests (insects, diseases, weeds and vertebrates) and their natural enemies should be included (Prokopy, 1994). Social, psychological, cultural and political factors could have significant effect on biological factors (Prokopy, 1994).

Customising strategies for different regions

Pecans in the US are grown in different climatic regions and production systems and therefore IPM strategies have been developed to cater for the different agroecosystems (Reid, 2002). In South-eastern pecan orchards, pecan scab (*Fusicladium effusum*) control drives the IPM strategy (Reid, 2002). A breakthrough was achieved when insecticide and fungicide treatments were separated, as insecticides were mainly used as an insurance policy (Reid, 2002). Insect pests are now monitored, and insecticides are only applied when needed (Reid, 2002). In South-Central pecan orchards, IPM focusses on fruit eating insect pests, zinc deficiency and prevention of aphid population build-up (Reid, 2002). A combination of pheromone traps, field scouting and real time population models are used to manage pecan casebearer. In western pecan orchards the IPM strategy focusses on zinc deficiency, water and aphid control (Reid, 2002). Biological control of aphids is successfully used in some areas (Reid, 2002). In native pecan orchards the incorporation of grazing and wood production has been successful (Reid, 2002). Cultural control, including the removal trees with pathogens like phylloxera, is the most important part of IPM in native pecan orchards (Reid, 2002). Pecan weevils are monitored with traps and an insecticide is applied when needed (Reid, 2002).

<u>Adoption of IPM</u>

Check list for pest management for the industry

A checklist on practices for preventing pests (insects, diseases, nematodes, weeds) and pest management, in orchards and processing plants, provides targeted questions regarding orchard and management to be considered, assisting with different aspects of orchard management including monitoring, pest prevention and management of pest problems along the whole supply chain, for a sustainable production of almonds (Sonke et al. 2016).

For environmentally sustainable wine grape production in Australia 5 steps for adopting the strategy have been suggested (Bernard et al. 2007) (Figure 2.1.1.3.). All five steps build on each other, adding further components to completion of an IPM strategy.

Due to its complexity and time-consuming processes, there is resistance for the adoption of a IPM strategies by farmers (Ehler, 2006). Professional pest consultants are often pressed for time and the pesticide option is a quick and easy solution and often also considered a form of insurance (Ehler, 2006).

In an earlier review of IPM and its adoption it was suggested that the majority of IPM programs are using chemically based IPM (Prokopy, 1994) and therefore not progressing beyond step one towards IPM.

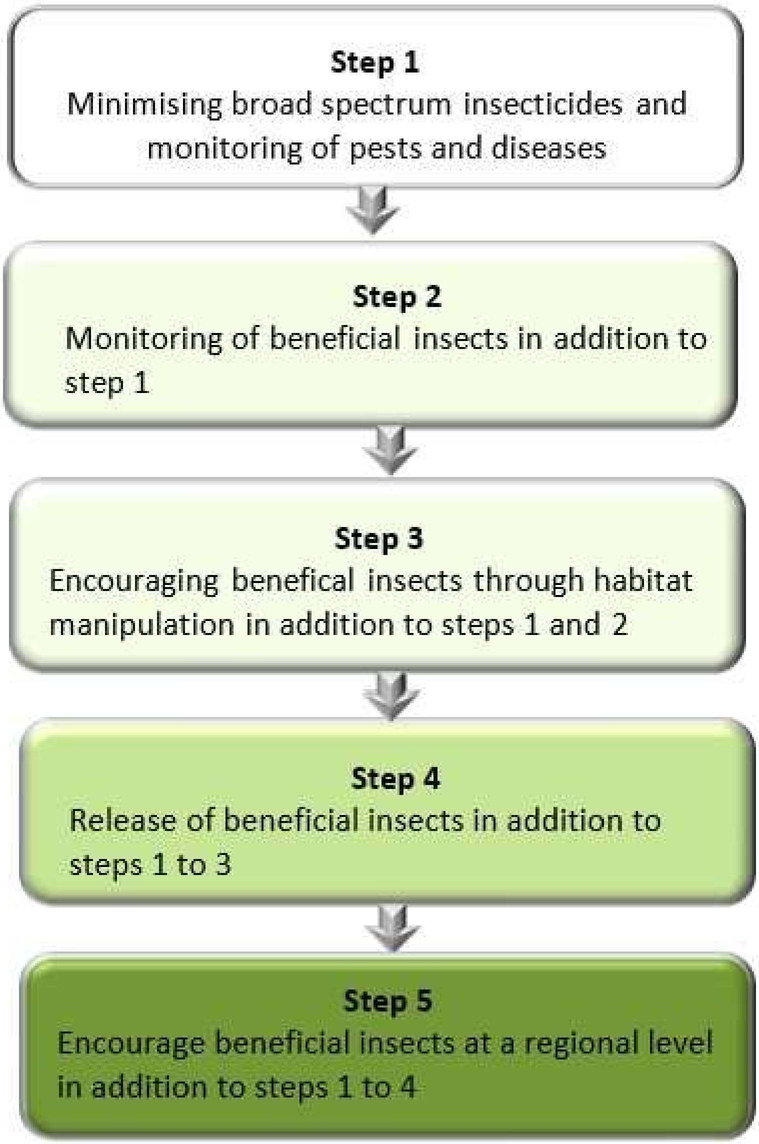

Figure 2.1.1.3.: Stepwise adoption of IPM

Economics

In the past there has been the perception that IPM is costly, a study on the citrus industry in Queensland however showed that IPM resulted in up to 53% cost reduction compared to chemical control (George et al. 2015). An economic study on celery production in California in the 1990's, comparing IPM versus chemical control resulted in a net profit of more than $US 410/ha (Trumble et al. 1997). A further study compared the costs of a reduced insecticide program in celery production in the US, relying on environmentally safe, biorational insecticides (*Bacillus thurginiensis*, spinosad, tebufenozide) used at threshold levels versus conventional prophylactic chemical management. The costs of the reduced insecticide program reduced costs by $US 250/ha with not significant difference in yield or net profits (Reitz et al. 1999).

Pitfalls

IPM is very complex and control measure for one pest, might cause problems or interfere with the control of other pests. Summer oils are a good option for management of mites in apples and don't harm beneficial insects. However, if diseases are a problem at the same time and the fungicide Captan® needs to be used, the use of oil becomes a problem, as in combination they can cause serious leaf burn (Prokopy, 1990). New resistant varieties of apples are generally difficult to market, as they are not yet accepted by a wide consumer base (Prokopy, 1990).

A particular chemical can be selective and suitable in one environment, but detrimental in another and this is hard to establish in laboratory screening and bioassays (Naranjo and Elthworth, 2009).

Pest management in macadamias

Pest management strategies in macadamias have been developed in the different countries where macadamias are grown. We looked at examples from Hawaii (Jones, 2002, Armstrong et al, 2006), South Africa (Schoeman, 2007, 2008, 2011, 2012, 2014) and past pest management of macadamias in Australia (Ironside, 1983; Campbell et al. 1999; Maddox et al*.* 2002a; Commens, 2012; Huwer. et al*.* 2006, 2011; 2015a,b).

Pest management in macadamias in Hawaii

In Hawaii, Jones (2002) pointed discusses different components of IPM, including biological control, monitoring options and He lists a hole complex of Hawaiian pests in macadamias (Jones, 2002). He also discusses economic threshold, economic injury and defines a "Gain Threshold".

The latter is important for getting better adoption of new pest management strategies. Jones (2002) defines the gain threshold (**GT**) as a way of defining the point where economic damage begins.

$$\textbf{GT}=\frac{Management\ costs\ (\frac{\$}{Ha})}{Total\ value=(\frac{kg\ nuts}{ha}\ x\frac{\$}{kg\ nuts})}x\ 100 = Y\%$$

(Adapted from Jones, 2002)

The costs of a management strategy need to reduce the loss by the **GT** percentage to break even and ideally the management costs will be less.

In a workshop in 2004 Armstrong et al*.* (2006) listed complex of macadamia pests in Hawaii and all management options, but no overall strategy.

Pest management in macadamias in South Africa

A study in Malawi (Schoeman, 2008) compared different spraying regimes (unsprayed, IPM and calendar sprays) with regards to stink bug damage, emphasising on the monitoring. It resulted in a 12% increase of saleable kernel over a 9-year period after IPM and improved agronomic practices.

Schoeman describes a detailed methodology for monitoring mainly the stink bug complex in South Africa (Schoeman, 2012), which the South African pest management in macadamias is based on. Further Schoeman also describes biological control, role of trap crops and tree density and height particularly with regards to stink bugs (Schoeman, 2014). Even though the parasitic fly *Trichopoda pennipes* was successfully established in South Africa, the effect of this biological control was not significantly (Schoeman, 2014). A combination of the entomopathogen *Beauveria bassiana* and low level of beta-cyfluthrin (125g/L SC at 1 ml/100L was very successful in controlling stink bugs. Preliminary studies on trap crops were not greatly successful. None of the hosts plants tested attracted the stink bugs in sufficient numbers to use them as trap crops (Schoeman, 2014). It was found that stink bugs were more prominent and damage higher denser tree canopy and was positively correlated with tree density in the orchard (Schoeman, 2014). Some level of host plant resistance was established, as it was found that in a mixture of cultivars the cultivar Beaumont (HAES 695) had considerably less damage than other cultivars (Schoeman, 2014).

Overall, the South African IPM research concentrates on the main pest complex, stink bugs, but does not take the whole pest complex into account.

Pest management in macadamias in Australia

Working towards IPM in macadamias Australia started in 1983. A concept for IPM in macadamias is described by Ironside (1983). He emphasises on monitoring and action levels at an economic threshold and appropriate use of insecticides (Ironside, 1983). The main pest complex in Australian macadamias, brief monitoring methods and thresholds were described, as well as known biological control options for different pests (Ironside, 1983). The lack of knowledge on biological phenological data of many key pests and importance of economic viability of an IPM strategy were pointed out (Ironside, 1983). For different pests Ironside developed a system, where he classifies the pest status, states the plant parts affected, notes were a monitoring, selective chemicals and information on natural enemies are available (Ironside, 1983).

The first step towards an IPM program was the introduction of biological control for macadamia nut borer (Maddox, C.D.A. et al*.* 2002; Huwer, R.K. et al*.* 2006, 2011). The egg parasitoid *Trichogrammatoidea cryptophlebiae* had been identified as suitable biological control agent. A rearing methodology was developed for laboratory rearing of macadamia nut borer and for the egg parasitoid and basic biology and ecology studies (Campbell et al*.* 1999; Maddox et al. 2002). Ways of integrating the egg parasitoid into a pest management system were refined in further research (Huwer et al*.* 2006). This led to commercialisation by BioResources and gradual adoption and refinement of pest management of macadamia nut borer (Huwer et al*.* 2011). This study also established the importance of susceptibility of different macadamia cultivars to Fruit spotting bugs (Huwer et al*.* 2011). Macadamia lace bug started to become a significant problem for the industry (Commens, 2015). A chemical management strategy was developed to manage the pest (Commens, 2012). Macadamia seed weevil (formerly Sigastus weevil) imposed a threat to the industry in NSW, specifically in the Northern Rivers (Huwer et al. 2015a). In order to manage the pest, a review was undertaken to get a better understanding of the pest and potential control options including entomopathogens and cultural control, specifically removing of infected nuts (Huwer et al. 2015a).

An extensive multi-industry research project was undertaken between 2011 and 2015, investigating a multi-targeted approach for Fruit spotting bug management. This was the first program that took a more holistic approach, developing monitoring options for this key pest in macadamia, developing biological control, investigating IPM compatible chemical control and also look into effect of tree density and confirmed the importance of susceptibility of different cultivars to Fruit spotting bugs (Huwer et al. 2015b).

Conclusion and relevant implication for an improved IPM system in macadamias

Research in the past developed biological control for macadamia nut borer, which has been successfully adopted by the Australian macadamia industry.

Monitoring strategies for macadamia nut borer and Fruit spotting bugs are well developed and well adopted but monitoring of other pest and beneficial insects is the key for and overall IPM and more monitoring tools for some pests are needed for IPM in Australian macadamias.

There is a lack of biological control option for some of the key pests like macadamia lace bug and macadamia seed weevil. The effect of biological control for Fruit spotting bugs is not fully understood.

The biology and ecology of macadamia lace bug and macadamia seed weevil need to be better understood.

Cultural control, orchard habitat management are identified as essential components of a IPM program but are not well understood with regards to Australian macadamia orchards.

The effect of inter-rows with regards to increased biodiversity and the link to yield would be important, as a review showed that there has been done a lot of research into inter-rows and improvement on biodiversity, but there has been only a few with a link to crop quality and yield (Herz et al*.* 2019), which would be important for industry adoption and advancement of IPM.

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2.2. Regional case study sites

2.2.1. General monitoring results

Monitoring data from visual observations (monitoring) and yellow sticky traps have been combined for each site and season. Monitoring results of key pests and beneficials are shown in Figures 2.2.1.1-2.2.1.32.

General trends were the following:

- "IPM sites" (Minimal pesticide approach – sites 1, 3, 5 and 7)

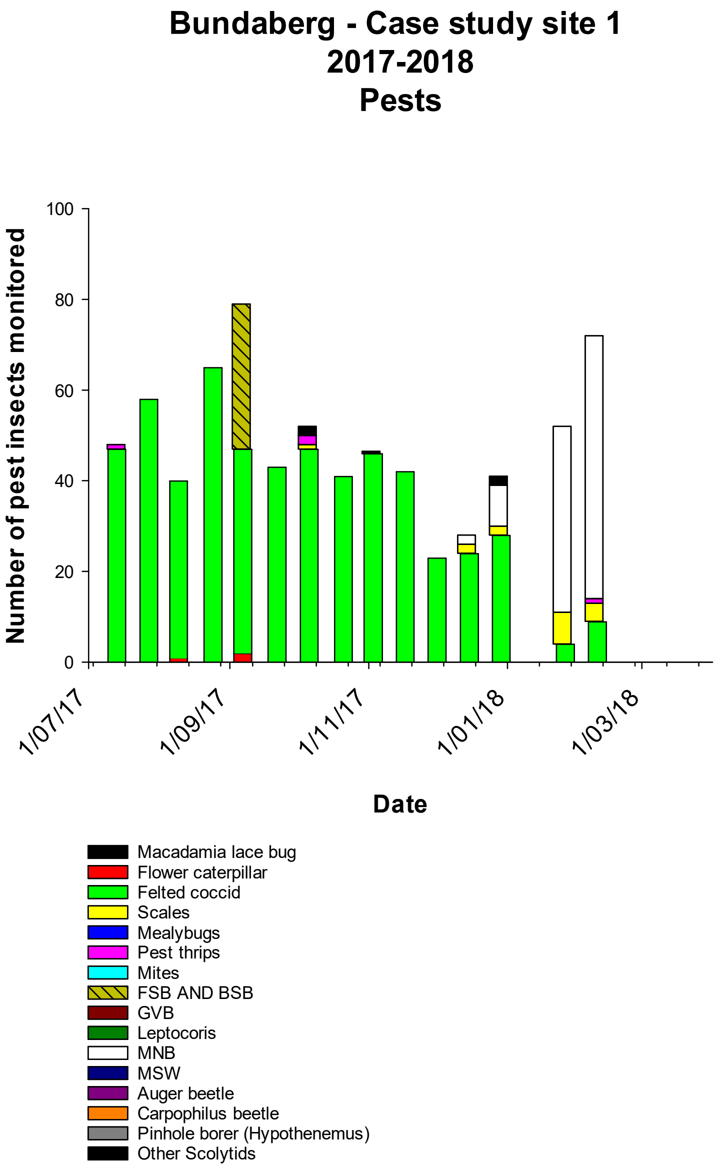
  Higher diversity of pests and beneficials

  Higher numbers of robber flies and parasitic flies, lady bird beetles, parasitic wasps, spiders, assassin bugs, predatory thrips and lacewings.

"Conventional sites" (Several applications of broad spectrum insecticides - sites 2, 4, 6 and 8)

  Higher numbers of felted coccid, scales, mealybugs thrips and mites – secondary pests due to effect on their natural enemies

The above are general trends only. To make a more detailed assessment of responses to treatments that have been applied on individual farms and seasons, individual years and farm results need to be assessed.



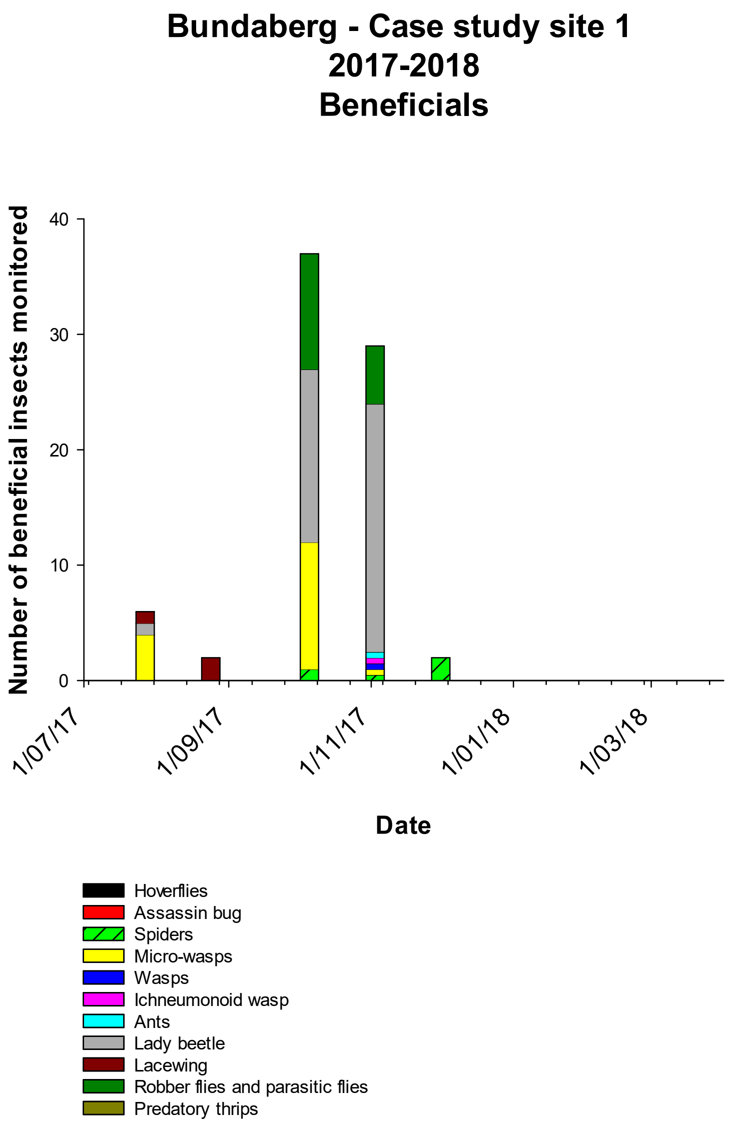
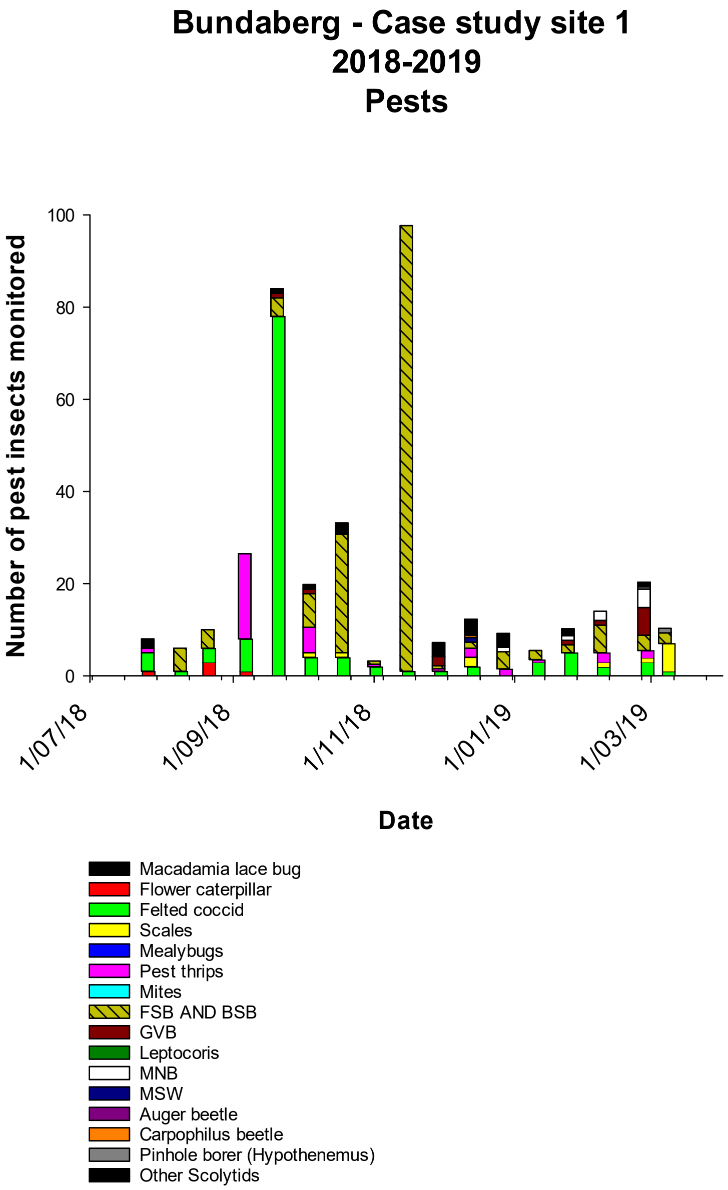


Figure 2.2.1.1.: Pest and beneficials in Central Queensland region at case study site 1 during the 2017-2018 season



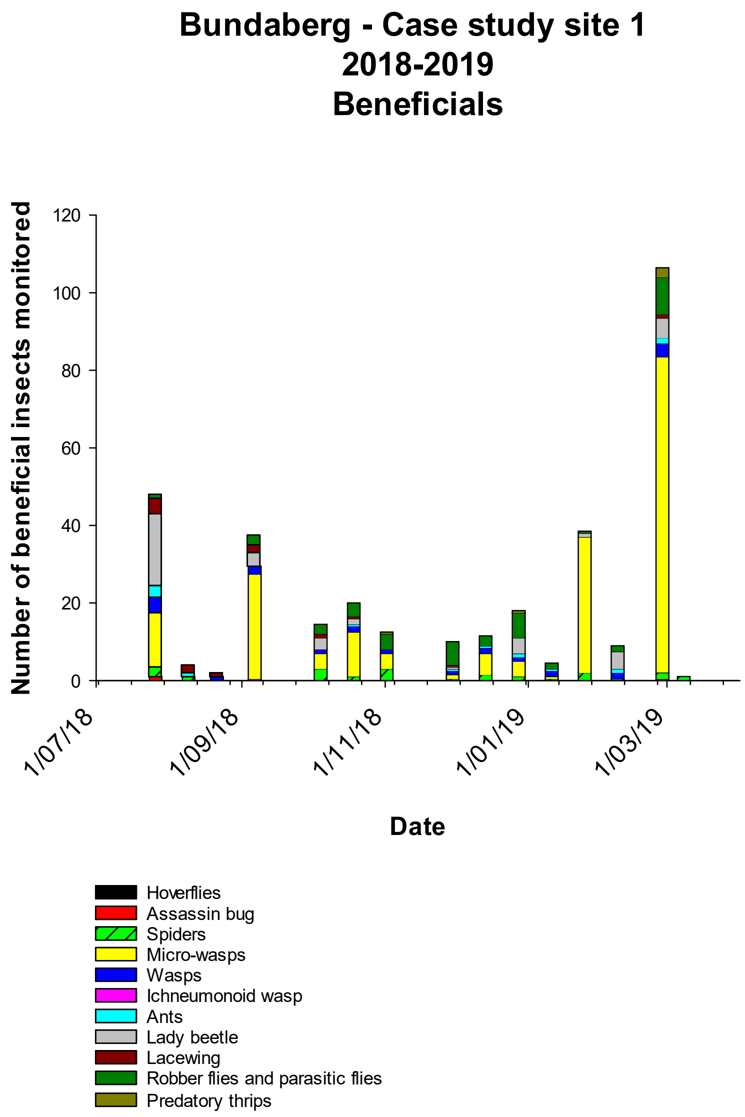
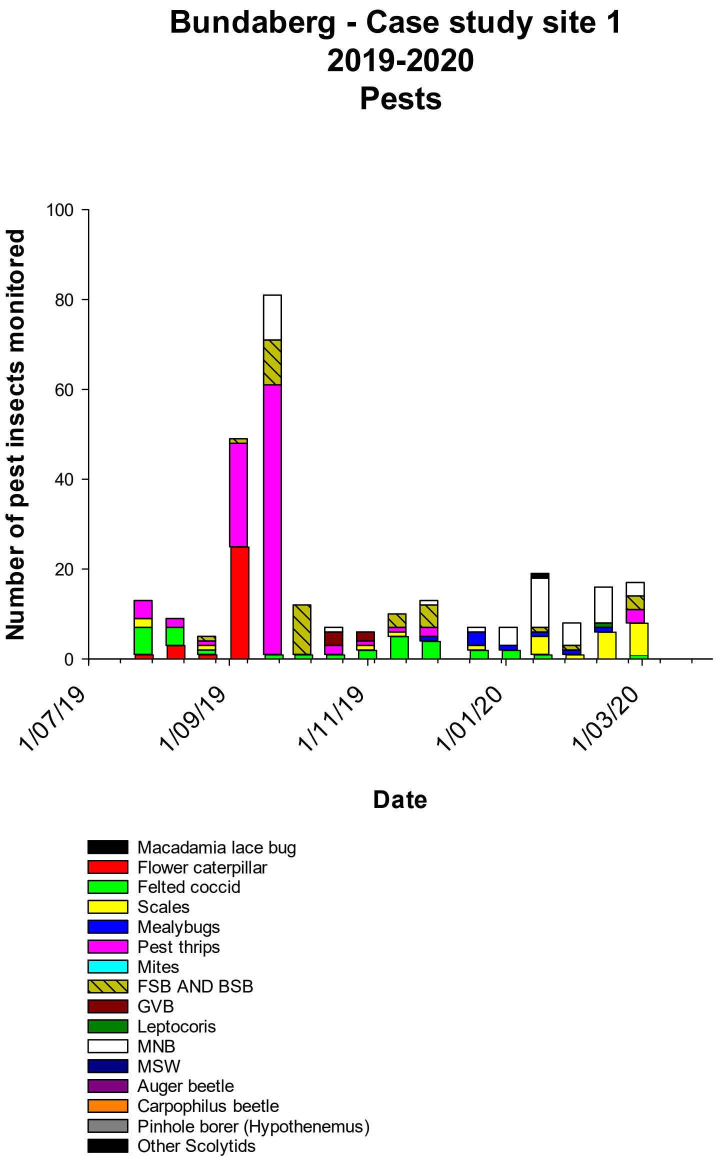


Figure 2.2.1.2.: Pest and beneficials in Central Queensland region at case study site 1 during the 2018–2019 season



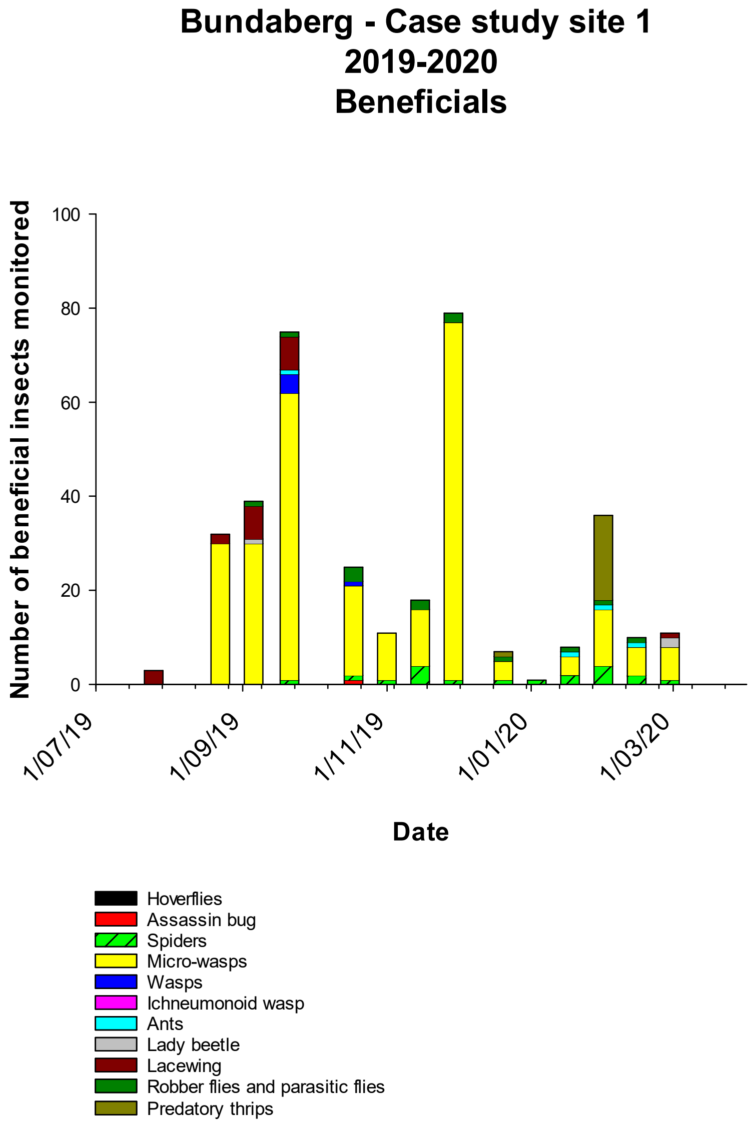
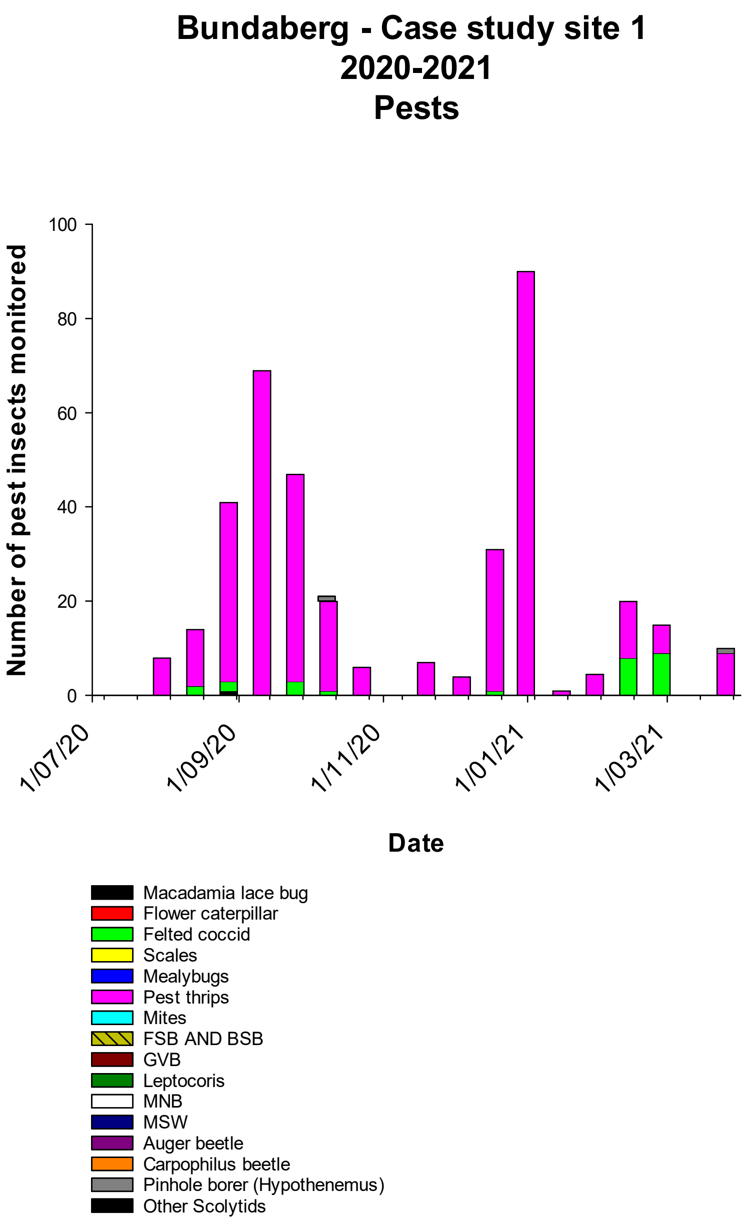


Figure 2.2.1.3.: Pest and beneficials in Central Queensland region at case study site 1 during the 2019–2020 season



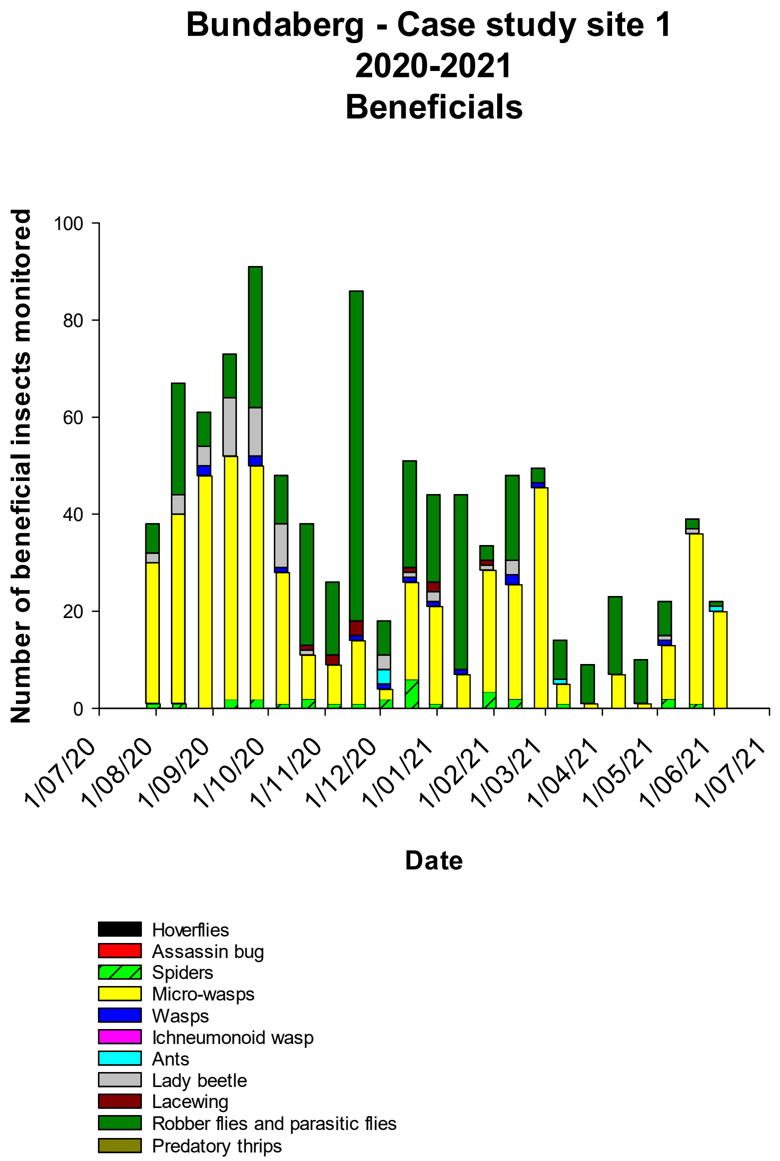
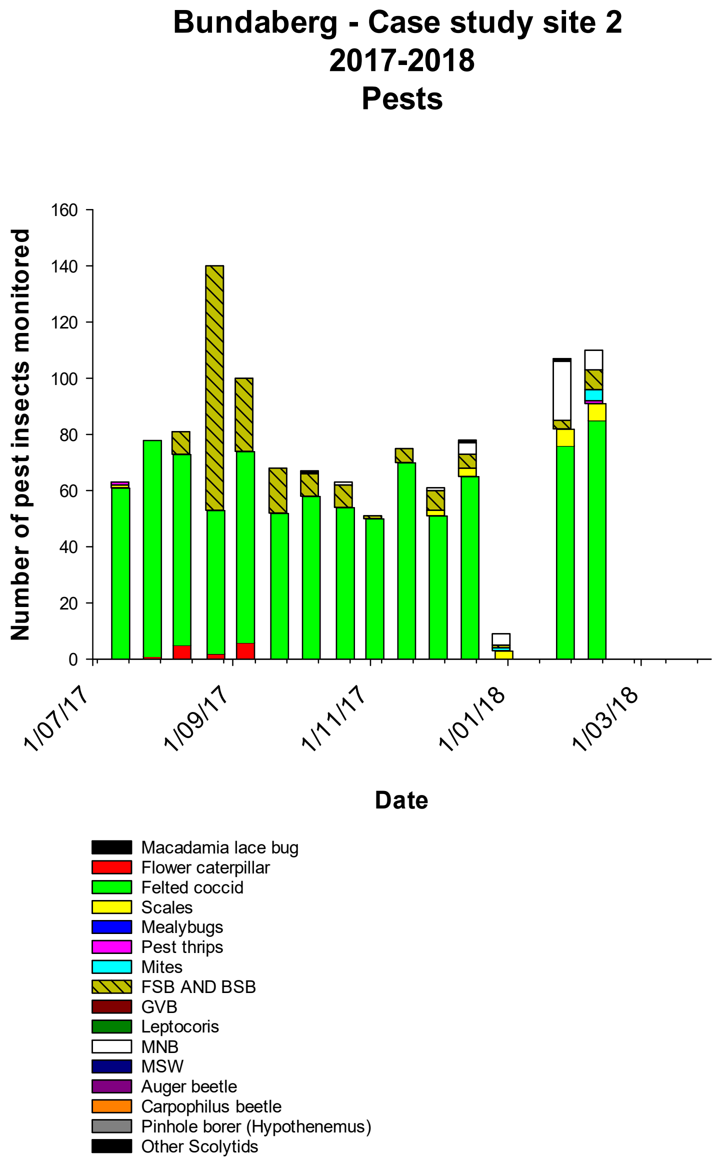


Figure 2.2.1.4.: Pest and beneficials in Central Queensland region at case study site 1 during the 2020–2021 season



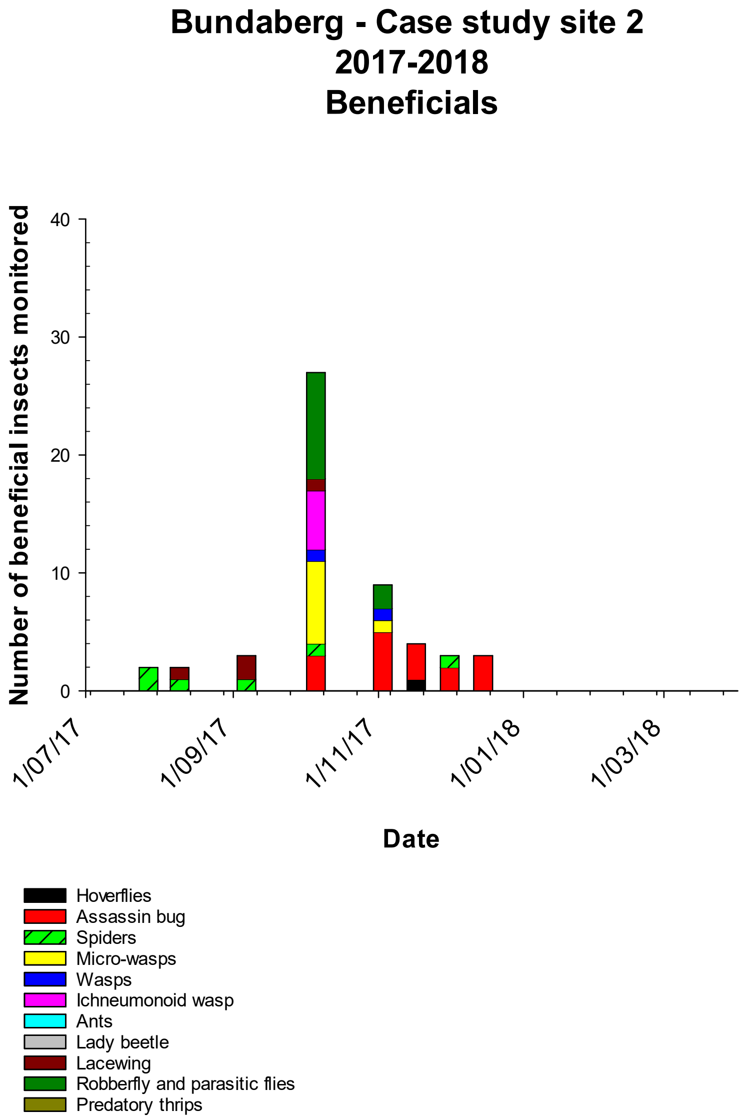
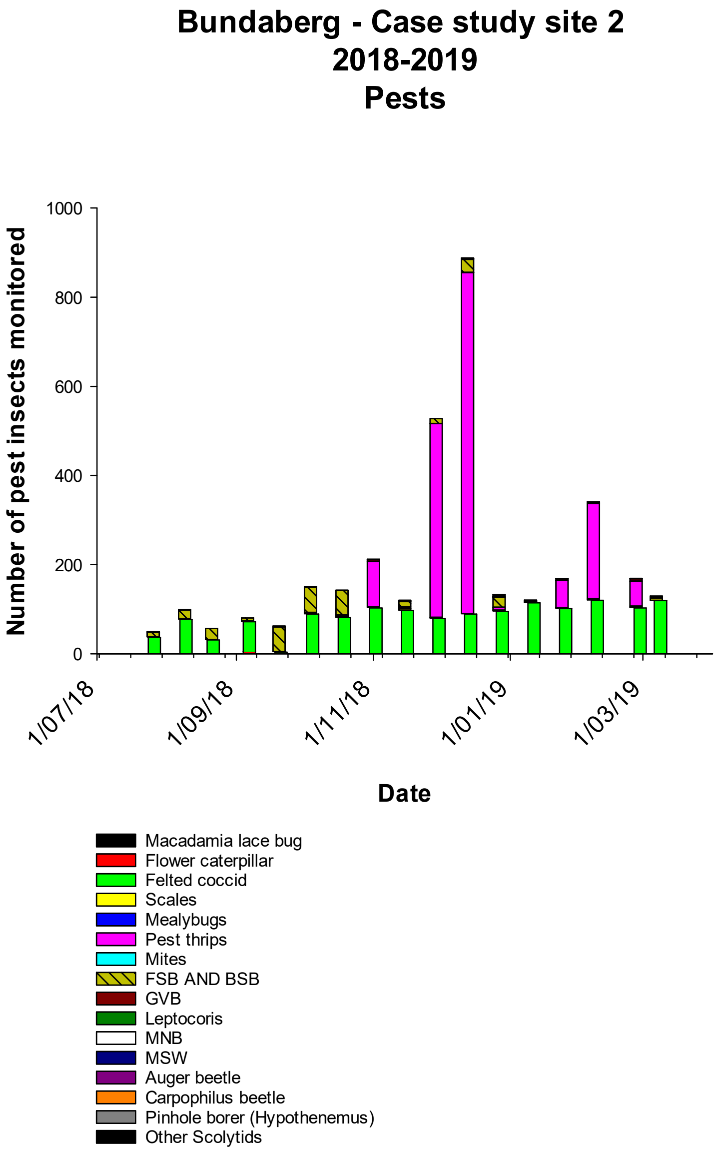


Figure 2.2.1.5.: Pest and beneficials in Central Queensland region at case study site 2 during the 2017-2018 season



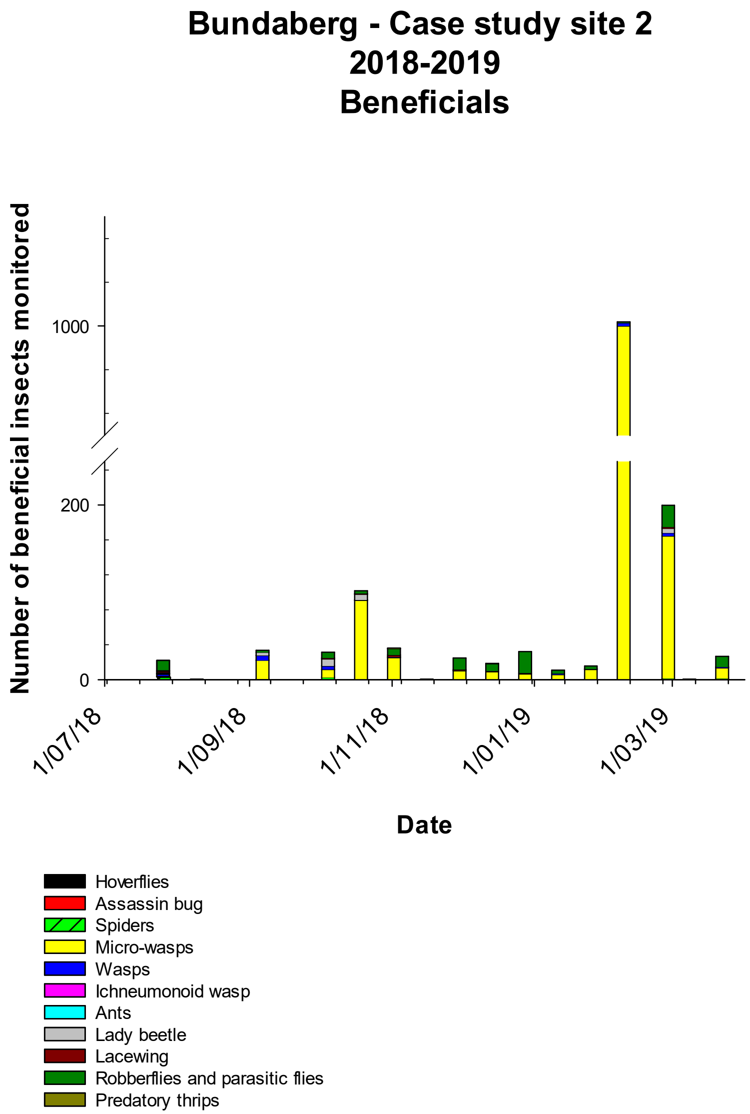
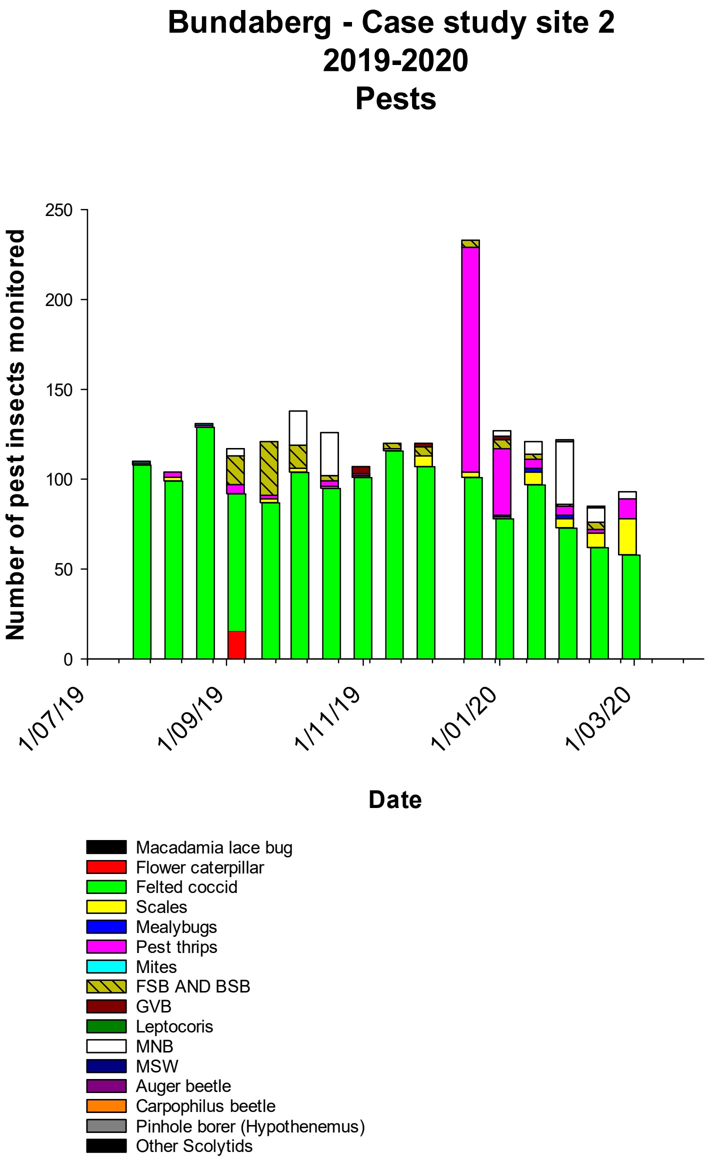


Figure 2.2.1.6.: Pest and beneficials in Central Queensland region at case study site 2 during the 2018–2019 season



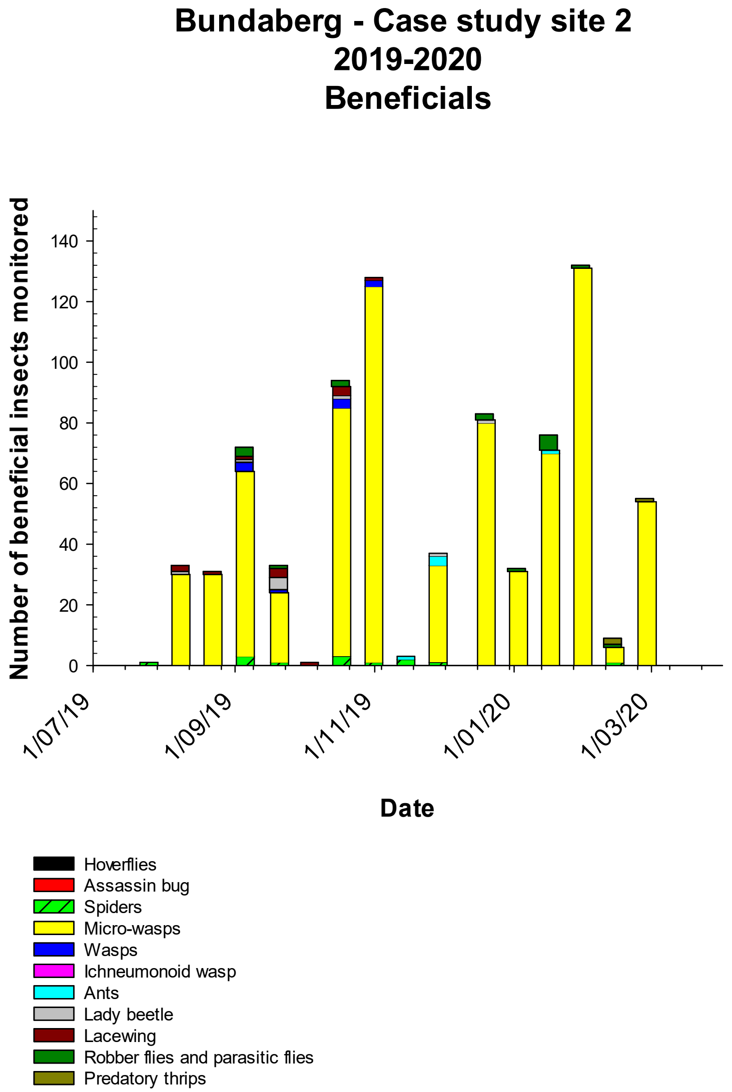
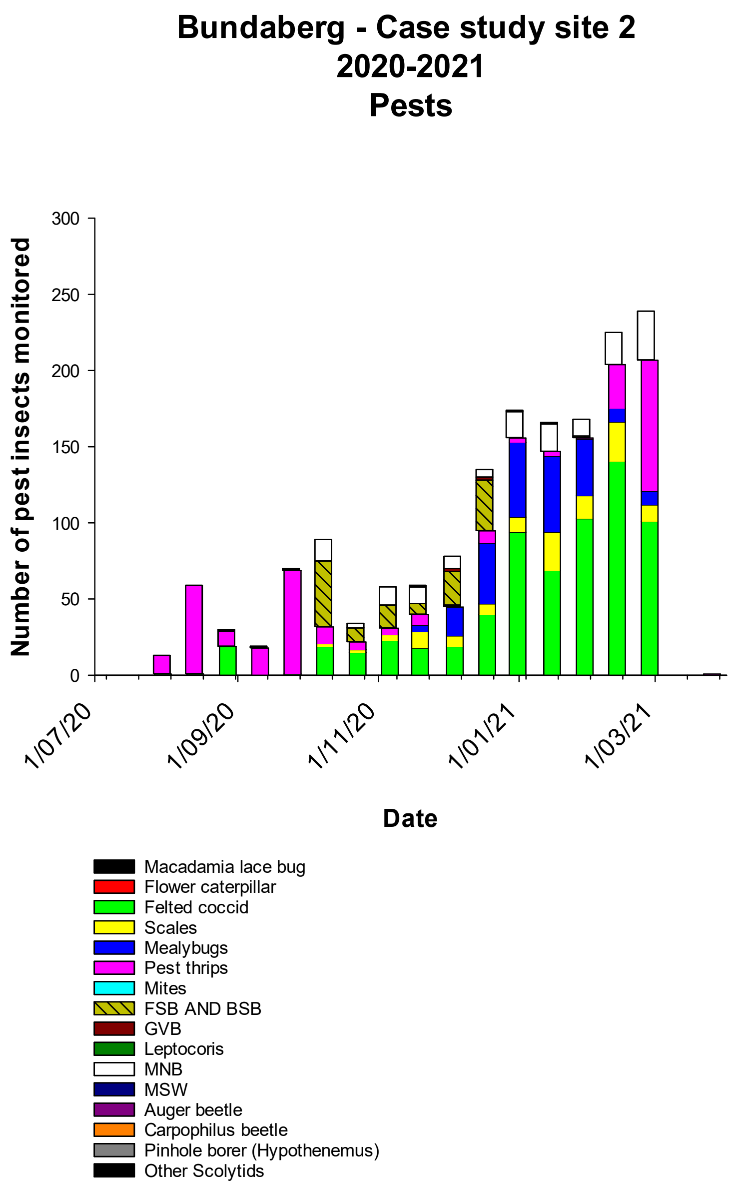


Figure 2.2.1.7.: Pest and beneficials in Central Queensland region at case study site 2 during the 2019–2020 season



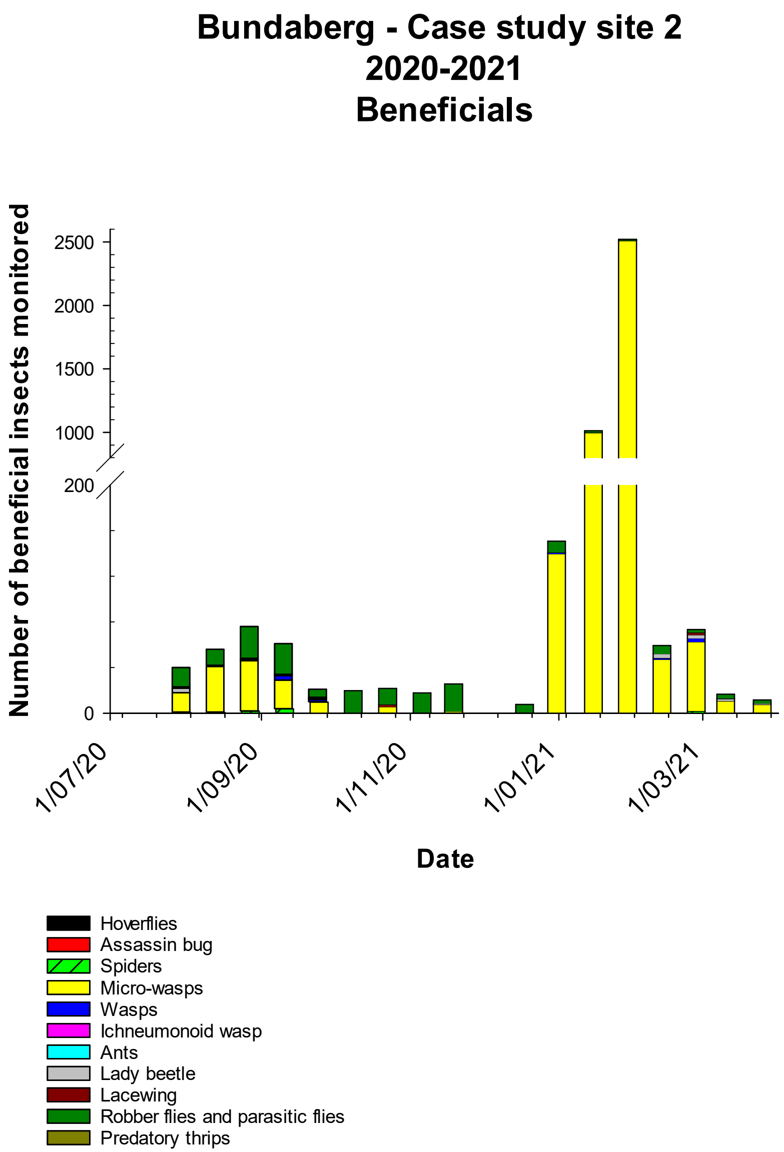


Figure 2.2.1.8.: Pest and beneficials in Central Queensland region at case study site 2 during the 2020–2021 season

Table 2.2.1.1.: Key points from Pest and beneficials in the Central Queensland region during the 2017-2018 season

	Pest and beneficial populations and treatments in the Central Queensland region - Key points	
	Pests (Table 2.2.1.1.)	**Beneficials (Table 2.2.1.1.)**
Case study site 1 2017-2018	– Felted coccid caused a problem during this season. Early in the season paraffinic oil was applied in the season to manage felted coccid and methoxyfenocide was applied for macadamia flower caterpillar (Figure 1 and Table 1.2.2.1.). – Flower caterpillar was successfully managed, but paraffinic oil was not enough to manage felted coccid. – Sulfoxaflor spray in November December gave control for felted coccid, but this had no effect on the MNB population (Figure 1 and Table 1.2.2.1.) – MNB was kept mostly under control with releases of MacTrix (Figure 1 and Table 1.2.2.1.).	– Beneficial numbers monitored visually and on yellow sticky traps were generally low. – Despite regular releases of MacTrix, MNB (Figure 1 and Table 1.2.2.1.) got away late in the season, suggesting the conditions for MacTrix were unfavourable (maybe hot temperatures > 35°C). At this point in time MNB had no significant effect on kernel quality any more – Lady bird beetles and robber and parasitic flies were the dominant groups of beneficials that were not effected by the two sulfoxaflor applications (Figure 1 and Table 1.2.2.1.).
	Pests (Table 2.2.1.5).	**Beneficials (Table 2.2.1.5)**
Case study site 2 2017-2018	– Felted coccid caused a problem during this season. Early in the season paraffinic oil was applied in the season to manage felted coccid (Figure 1 and Table 1.2.2.2.). – FSB became more active in August September, which was managed by 2 applications of trichlorfon (Figure 1 and Table 1.2.2.2.). – Regular releases of MacTrix managed MNB by an application of beta-cyfluthrin (Figure 1 and Table 1.2.2.1.). – A methidathion application and a second beta-cyfluthrin application in January significantly reduced all pest (Figure 1 and Table 1.2.2.2.).	– Small populations of a number of beneficials were present until the first application of beta-cyfluthrin (Figure 1 and Table 1.2.2.2.). – The application of methidathion eliminated any beneficials that were present and populations of beneficials did not re-establish for the rest of the monitoring season (Figure 1 and Table 1.2.2.2.).
Harvest summary	– In comparison, the percentage of nuts with thrips on husk was much higher on case study site 1 (Table 2.2.1.). – Insect damage was higher in case study site 1 (Table 2.2.1. and Figure 2.2.2.1.) – Yield was higher in case study site 1 (Table 2.2.1. and Figure 2.2.2.1.).	

Table 2.2.1.2.: Key points from Pest and beneficials in the Central Queensland region during the 2018–2019 season

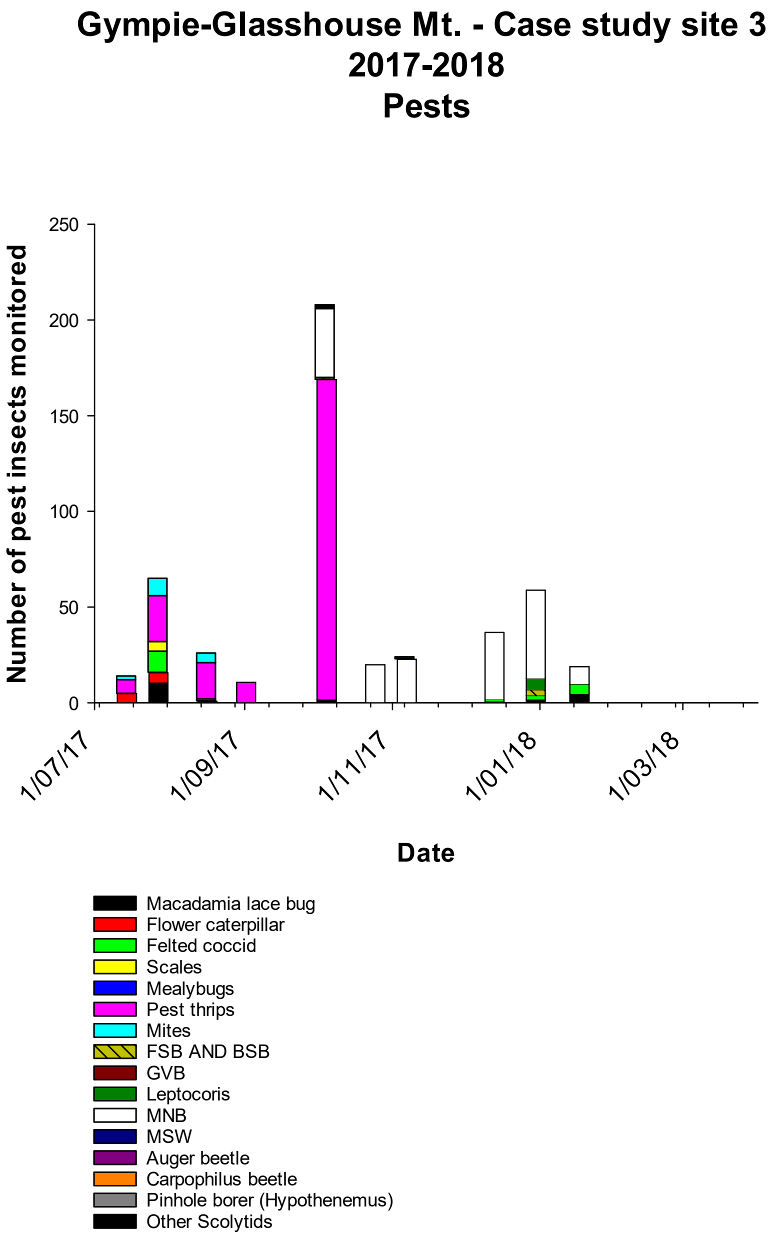
	Pest and beneficial populations and treatments in the Central Queensland region - Key points	
	Pests (Table 2.2.1.2.)	**Beneficials (Table 2.2.1.2.)**
Case study site 1 2018–2019	– Thrips numbers started to increase in September. – Felted coccid increased in late September/October which was managed with two applications of sulfoxaflor (Figure 1 and Table 1.2.2.1.). – FSB/BSB populations increased in October/November. This was not controlled by the 2 sulfoxaflor applications, but by a trichlorfon application (Figure 1 and Table 1.2.2.1.).	– Very small populations of beneficials, including wasps and lady beetles were present throughout the season. – Only after MacTrix and *Anastatus* releases between December and January, numbers of micro wasps increased (Figure 1 and Table 1.2.2.1.).
	Pests (Table 2.2.1.6.)	**Beneficials (Table 2.2.1.6.)**
Case study site 2 2018–2019	– There were low numbers of pests until November. There was a small population of felted coccid and FSB/BSB. – FSB/BSB were managed with on trichlorfon application in October and 2 applications of beta-cyfluthrin in December and late January (Figure 1 and Table 1.2.2.2.). – Thrips numbers increased in December possibly a secondary effect of beta-cyfluthrin applications (Figure 1 and Table 1.2.2.2.).	– There were very small populations of beneficials, particularly micro-wasps – There was no release of beneficials, but number of micro-wasps did not increase until after the last beta-cyfluthrin application and got to a very high level in February (Figure 1 and Table 1.2.2.2.).
Harvest summary	– In comparison, the percentage of nuts with thrips and scales on husk was much higher on case study site 2 (Table 2.2.1.), possibly induced by beta-cyflurin applications. – FS B/BSB and general insect damage was higher in case study site 1 (Table 2.2.1. and Figure 2.2.2.1.). – Yield was very low at both case study sites due to low set caused by macadamia flower caterpillar (Table 2.2.1. and Figure 2.2.2.1.).	

Table 2.2.1.3.: Key points from Pest and beneficials in the Central Queensland region during the 2019–2020 season

	Pest and beneficial populations and treatments in the Central Queensland region - Key points	
	Pests (Table 2.2.1.3.)	**Beneficials (Table 2.2.1.3.)**
Case study site 1 2019–2020	– Early in the season (September/ October) macadamia flower caterpillar and thrip numbers increased. – FSB/BSB numbers were kept down by a trichlorfon application in October, a beta-cyfluthrin application in November and a Trivor® application in December (Figure 1 and Table 1.2.2.1.). – Small MNB numbers at the end of the season were managed by MacTrix releases (Figure 1 and Table 1.2.2.1.).	– Beneficial numbers monitored visually and on yellow sticky traps were generally low. – Numbers increased after and *Anastatus* and MacTrix releases, but beta-cyfluthrin and Trivor® applications reduced the numbers of micro wasps (Figure 1 and Table 1.2.2.1.). .
	Pests (Table 2.2.1.7.)	**Beneficials (Table 2.2.1.7.)**
Case study site 2 2019–2020	– There were constant higher populations of felted coccid. – Flower caterpillar was kept under control with an application of methoxyfenozide in September (Figure 1 and Table 1.2.2.2.). – A trichlorfon application in October, a beta-cyfluthrin application in November and a Trivor® application in December managed FSB/BSB populations – Thrip populations increased in January but decreased fairly quickly.	– Micro-wasps were present throughout the season. Populations were reduced by applications of beta-cyfluthrin but increased again particularly with the release of MacTrix and *Anastatus* (Figure 1 and Table 1.2.2.2.).
Harvest summary	– In comparison, the percentage of nuts with clean husk was higher at case study site 1 (Table 2.2.2.). – Total insect damage and MNB damage were higher at case study site 2 (Table 2.2.2. and Figure 2.2.2.2.). – Yield was fairly low at both case study sites but slightly higher at case study site 2 (Table 2.2.2. and Figure 2.2.2.2.).	

Table 2.2.1.4.: Key points from Pest and beneficials in the Central Queensland region during the 2019–2020 season

	Pest and beneficial populations and treatments in the Central Queensland region - Key points	
	Pests (Table 2.2.1.4.)	**Beneficials (Table 2.2.1.4.)**
Case study site 1 2020–2021	– Thrips dominated the pests monitored over this season and a minor amount of felted coccid. – Thrip numbers were reduced by a Trivor® application in November (Figure 1 and Table 1.2.2.1.). – Thrip numbers later increased and crashed again, possibly due to environmental conditions.	– Populations of micro-wasps were generally low, but numbers of robber and parasitic flies were generally higher this season at case study site 1. – It appears that Trivor® applications in November reduced number of beneficials (Figure 1 and Table 1.2.2.1.).
	Pests (Table 2.2.1.8.)	**Beneficials (Table 2.2.1.8.)**
Case study site 2 2020–2021	– On case study site 2 pest populations increased over the season. – Early and late season thrips dominated the pest complex and felted coccid dominated from January to March 2021. The thrips population was reduced by a – FSB/BSB populations were highest between October and January, which were managed by beta-cyfluthrin applications at the end of October and December and an acephate application in November (Figure 1 and Table 1.2.2.2.). – Mealybugs increased between January and February, possibly due to the previous application of broad spectrum insecticides (Figure 1 and Table 1.2.2.2.).	– Numbers of beneficials were very low during most of the season – Numbers of beneficials were reduced during the period broad spectrum insecticide (beta-cyfluthrin and acephate) were applied (Figure 1 and Table 1.2.2.2.). – Micro-wasp increased significantly after the pesticide applications were completed in January.
Harvest summary	– Percentage with MNB numbers on husk was much higher at the case study site 1 and also the percentage of nuts with thrips on husk (Table 2.2.2.). – The percentage of nuts with felted coccid and scales on husk was higher on case study site 2, possibly due to broad spectrum insecticides (Table 2.2.2.). – FSB damage was higher at case study site 2 (Table 2.2.2. and Figure 2.2.2.2.). – Yield slightly higher at case study site 1 (Table 2.2.2. and Figure 2.2.2.2.).	



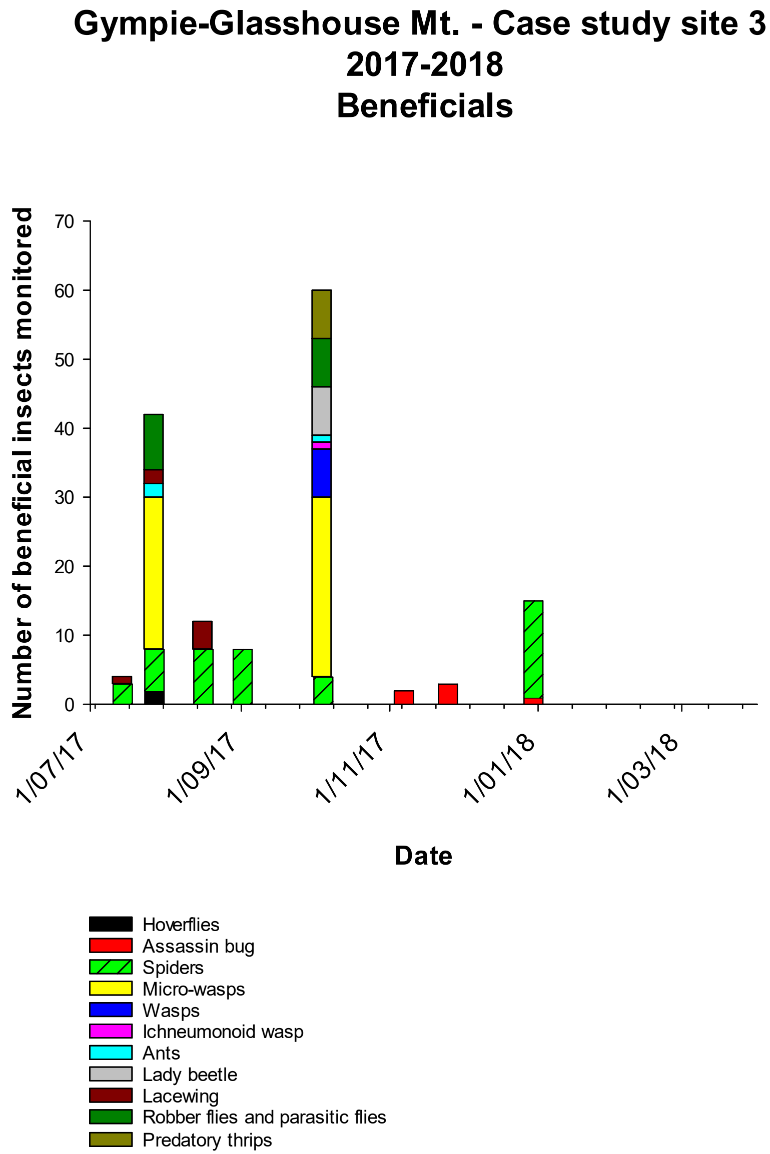
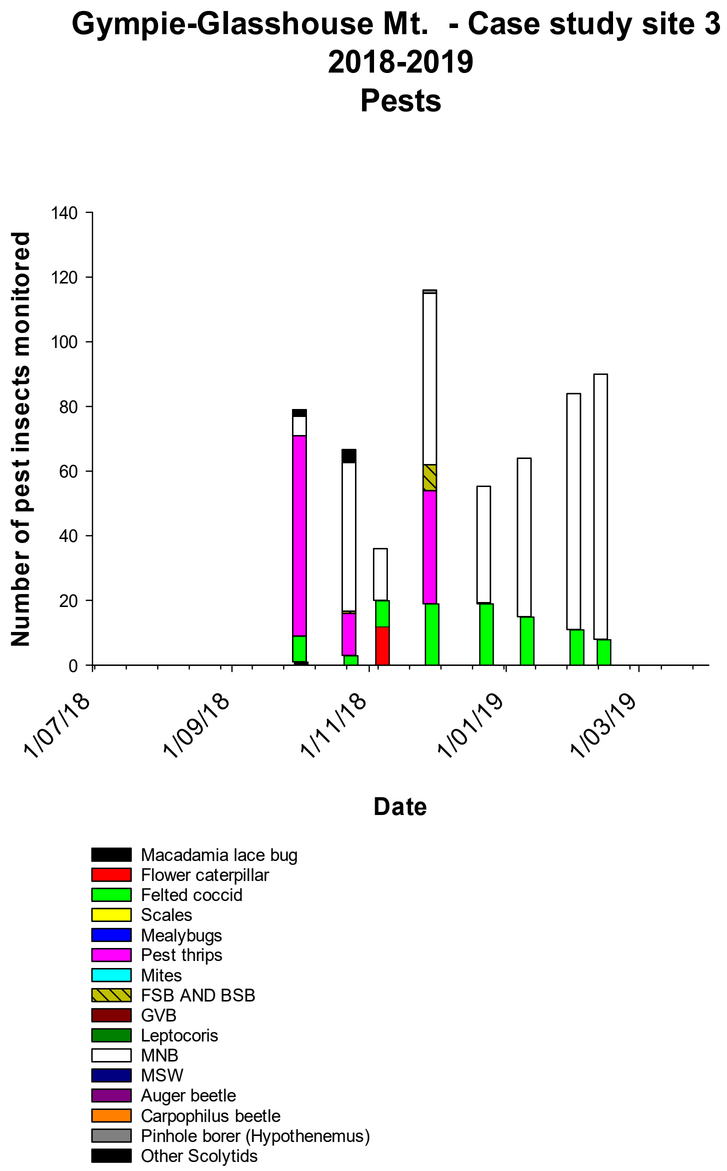


Figure 2.2.1.9.: Pest and beneficials in the Gympie – Glasshouse Mt. region at case study site 3 during the 2017-2018 season



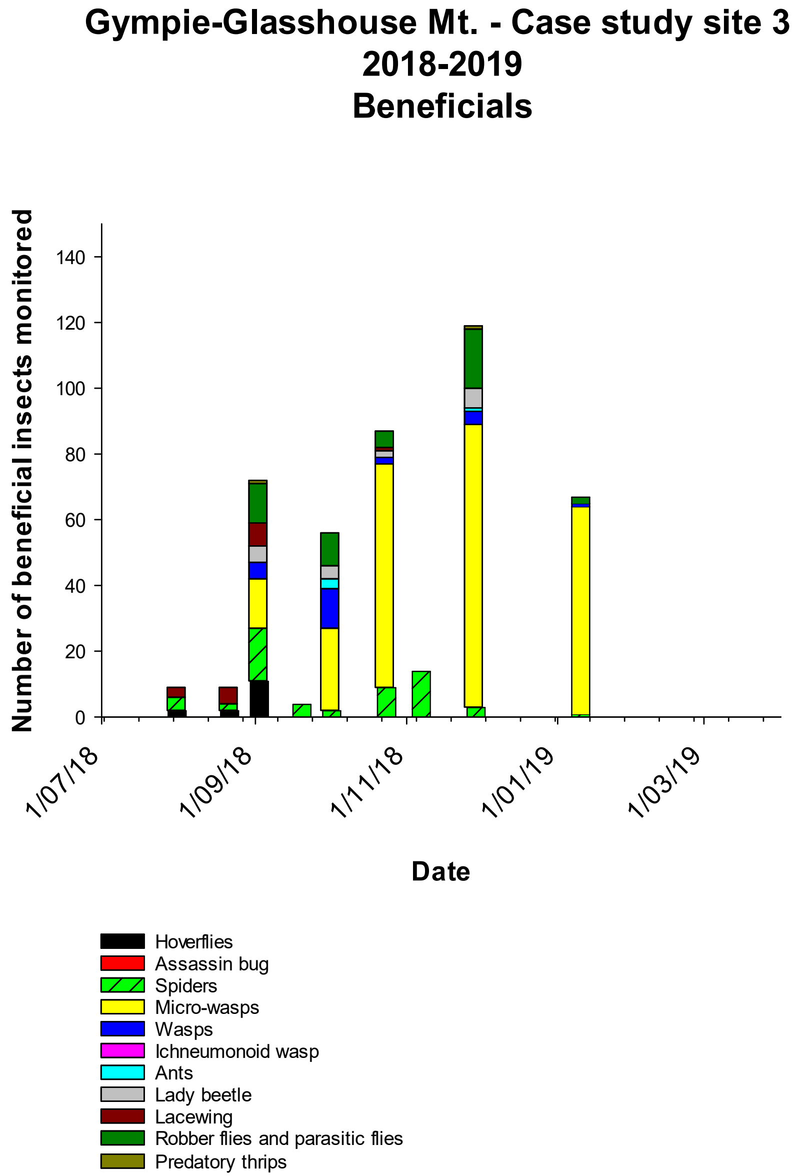
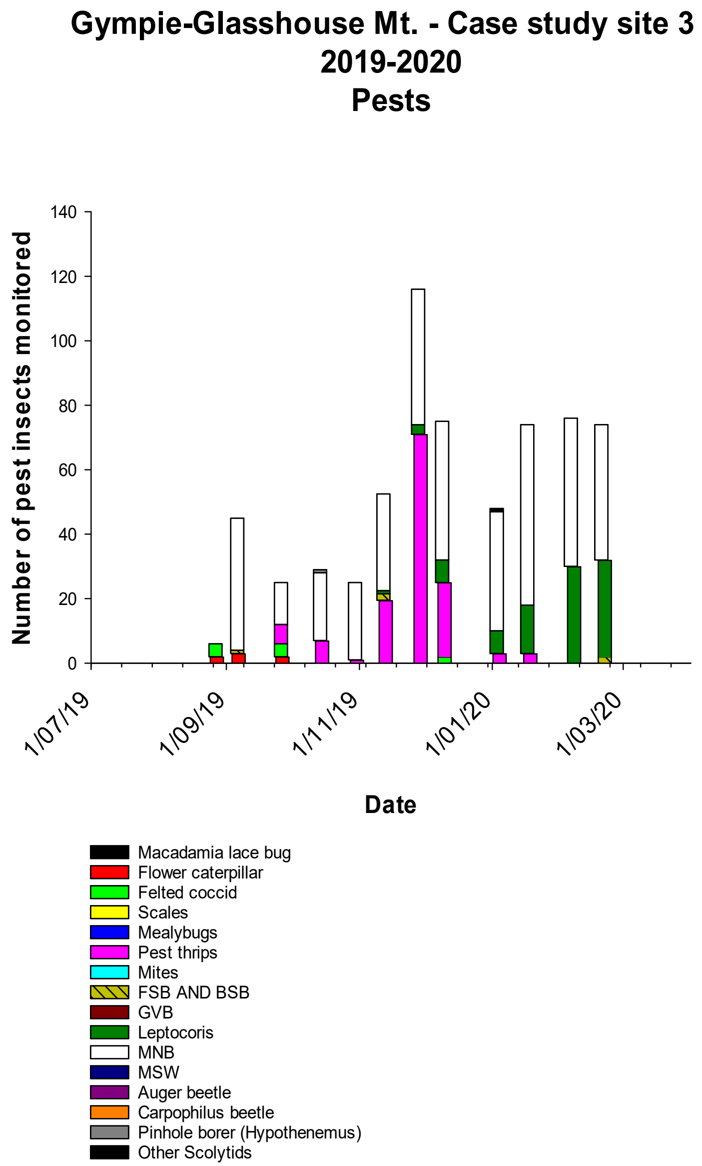


Figure 2.2.1.10.: Pest and beneficials in the Gympie – Glasshouse Mt. region at case study site 3 during the 2018–2019 season



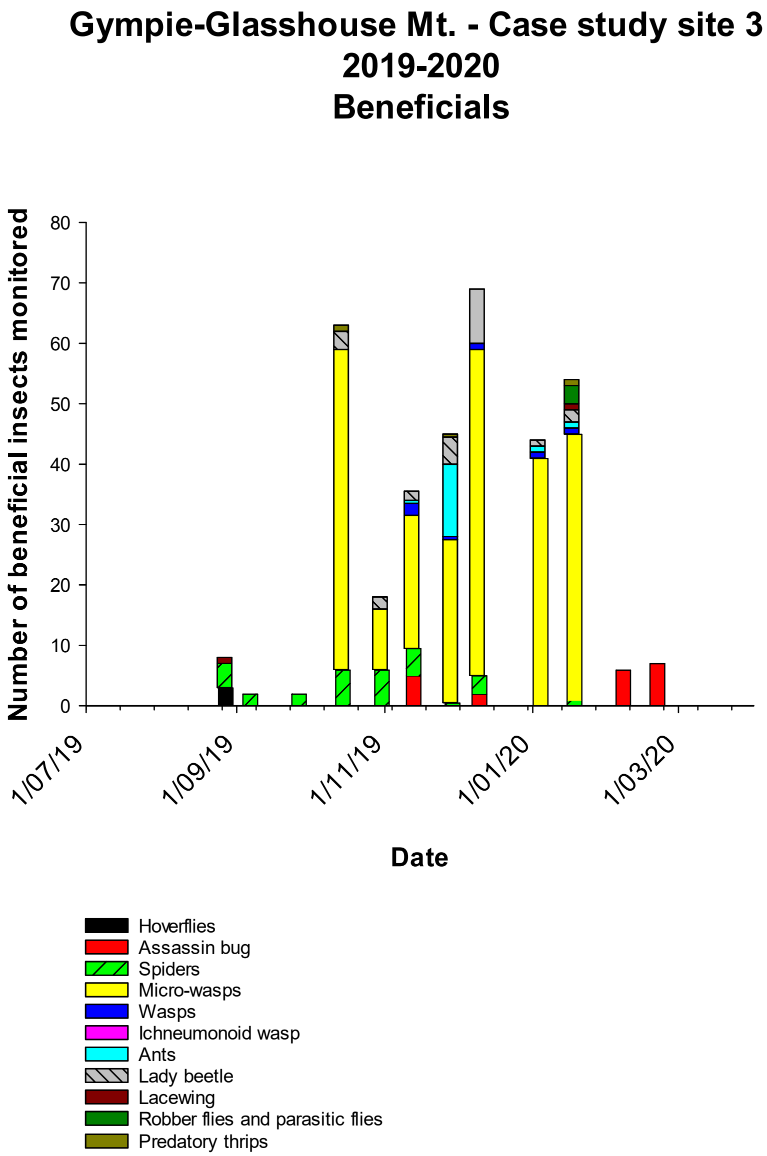
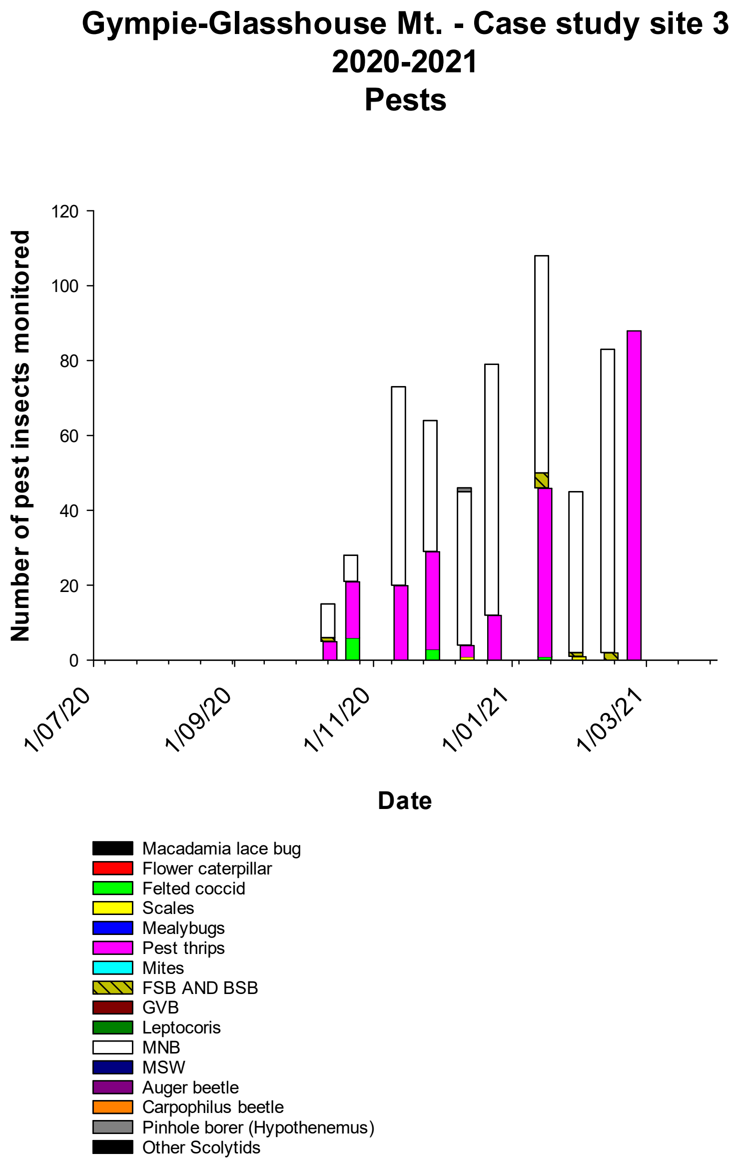


Figure 2.2.1.11.: Pest and beneficials in the Gympie – Glasshouse Mt. region at case study site 3 during the 2019–2020 season



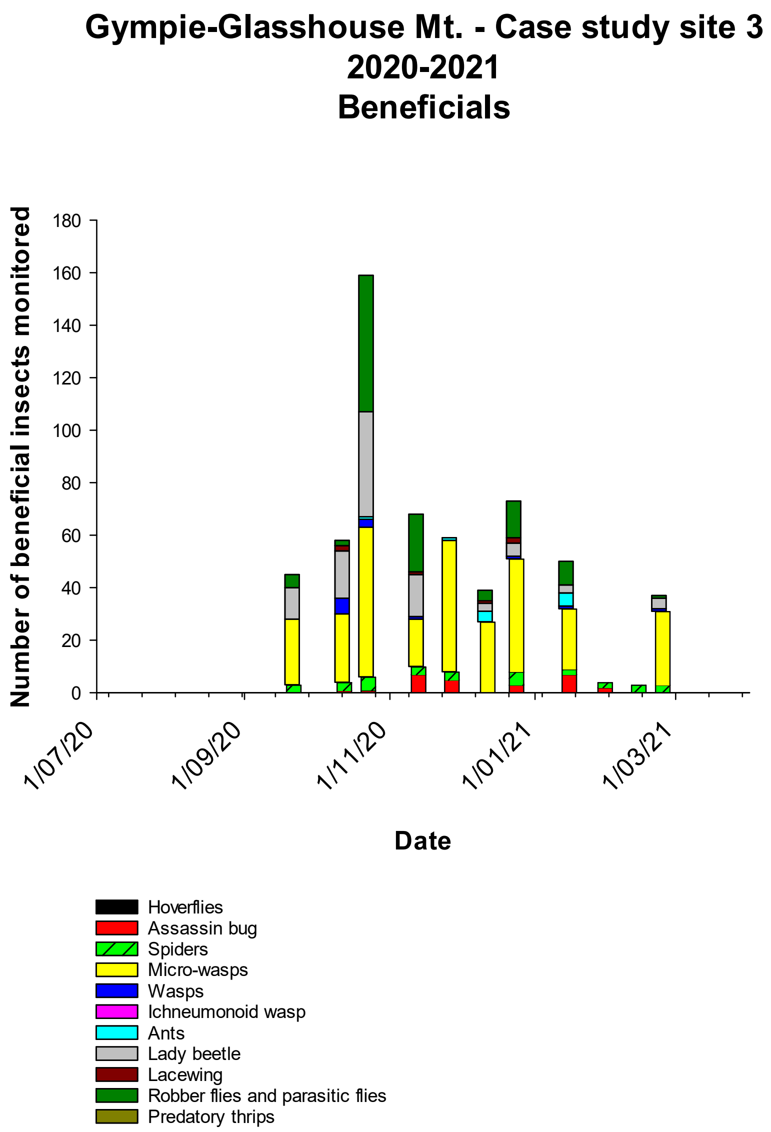
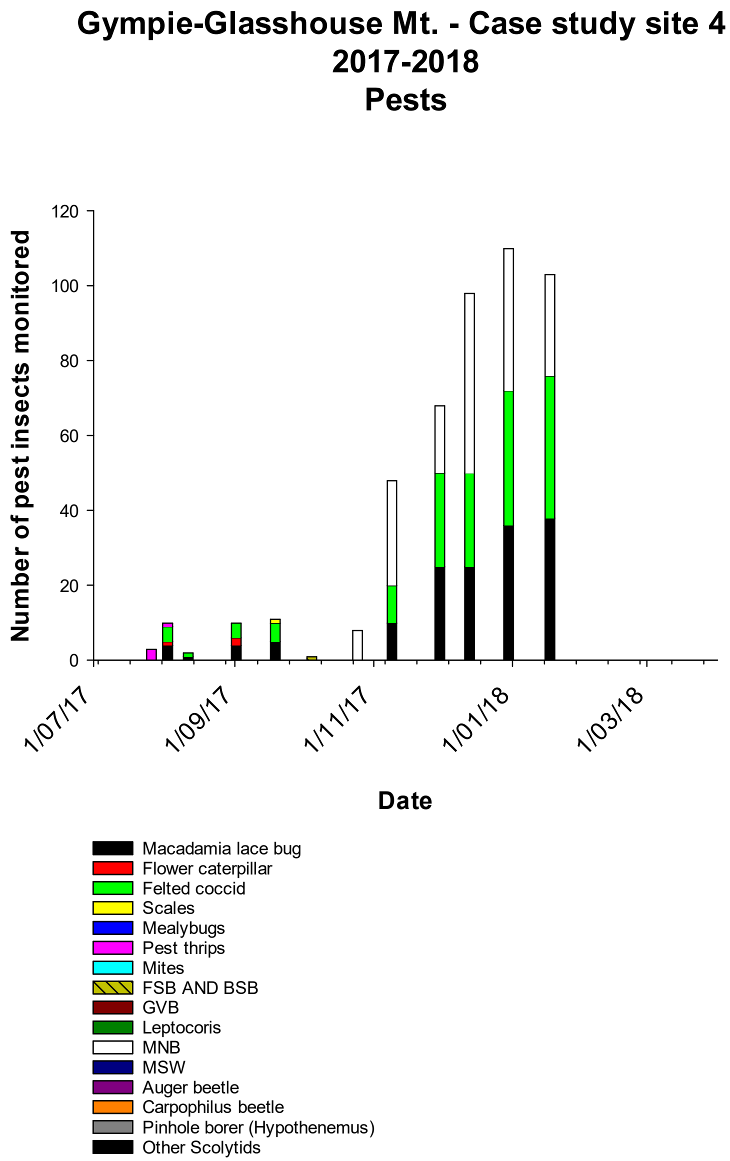


Figure 2.2.1.12.: Pest and beneficials in the Gympie – Glasshouse Mt. region at case study site 3 during the 2020–2021 season



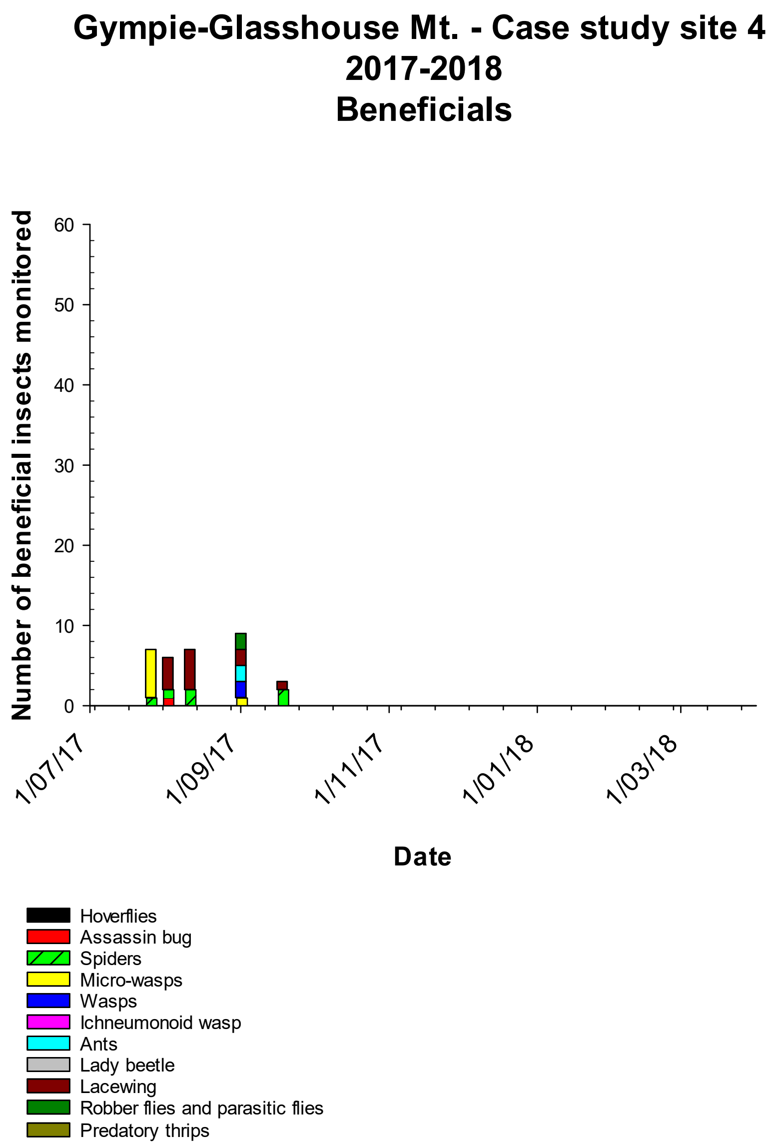
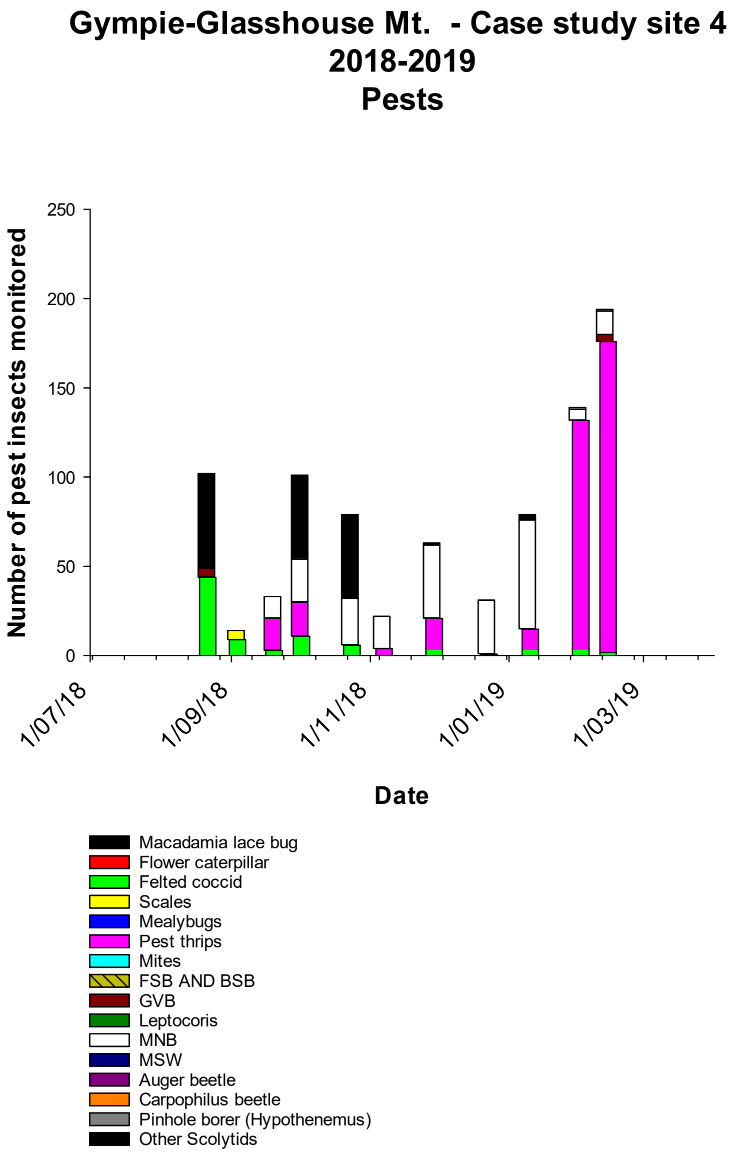


Figure 2.2.1.13.: Pest and beneficials in the Gympie – Glasshouse Mt. region at case study site 4 during the 2017-2018 season



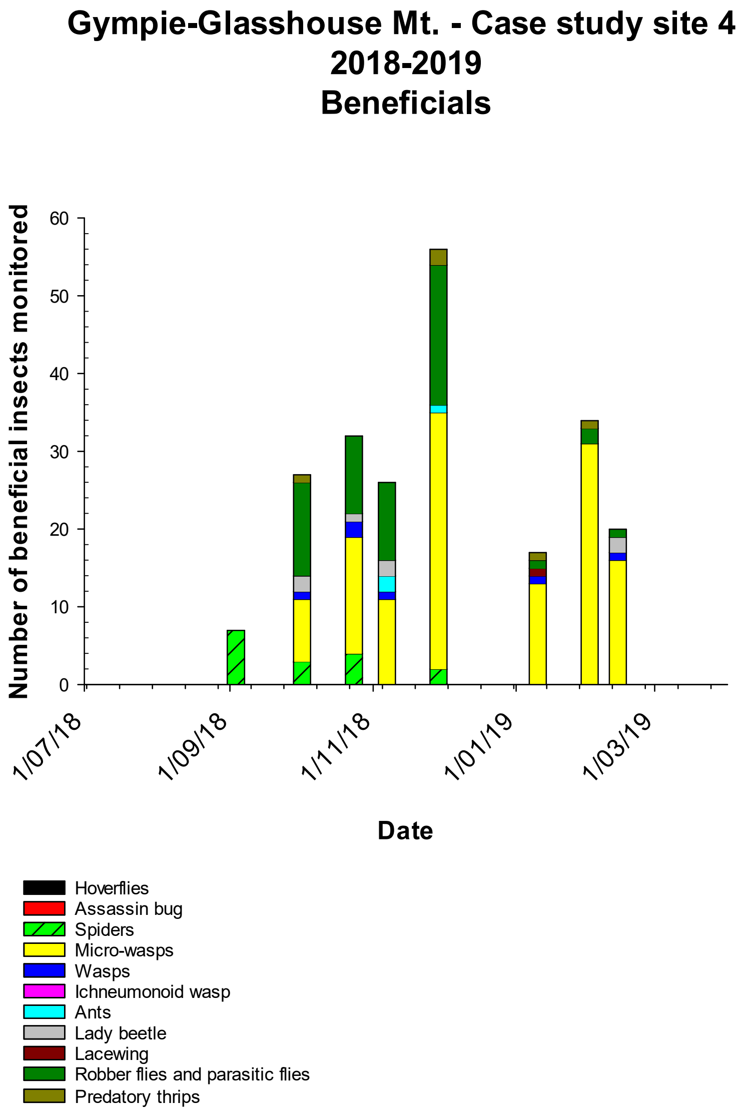
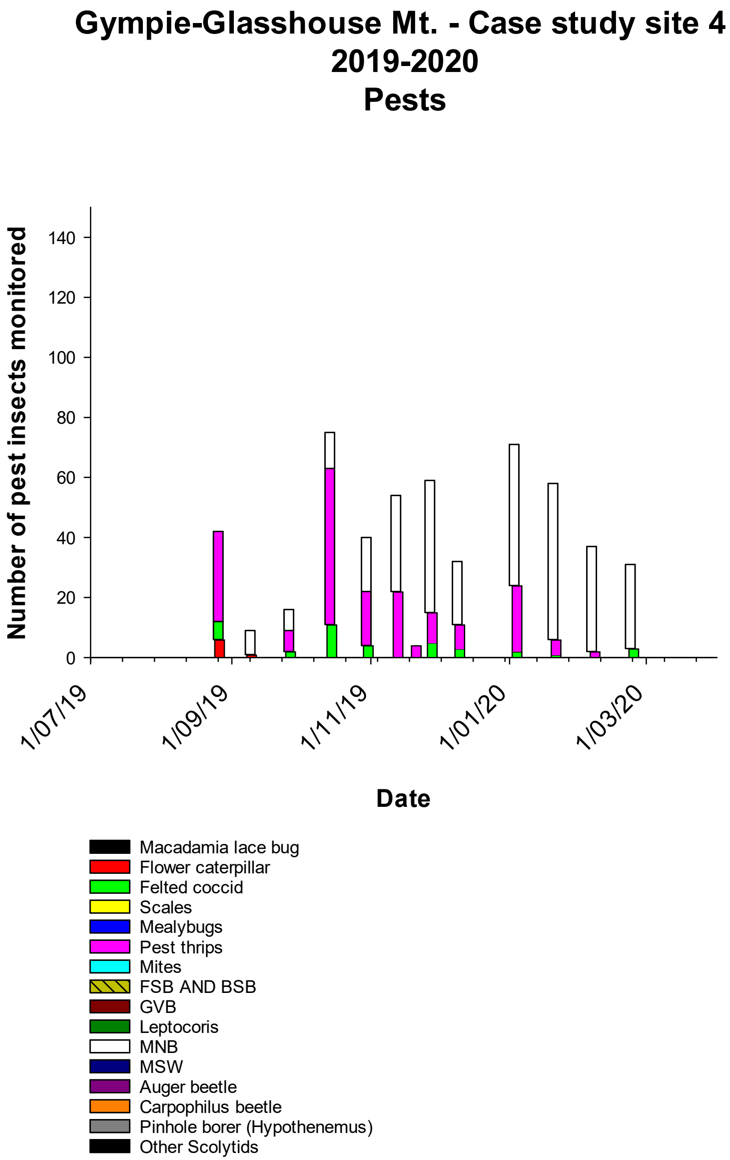


Figure 2.2.1.14.: Pest and beneficials in the Gympie – Glasshouse Mt. region at case study site 4 during the 2018–2019 season



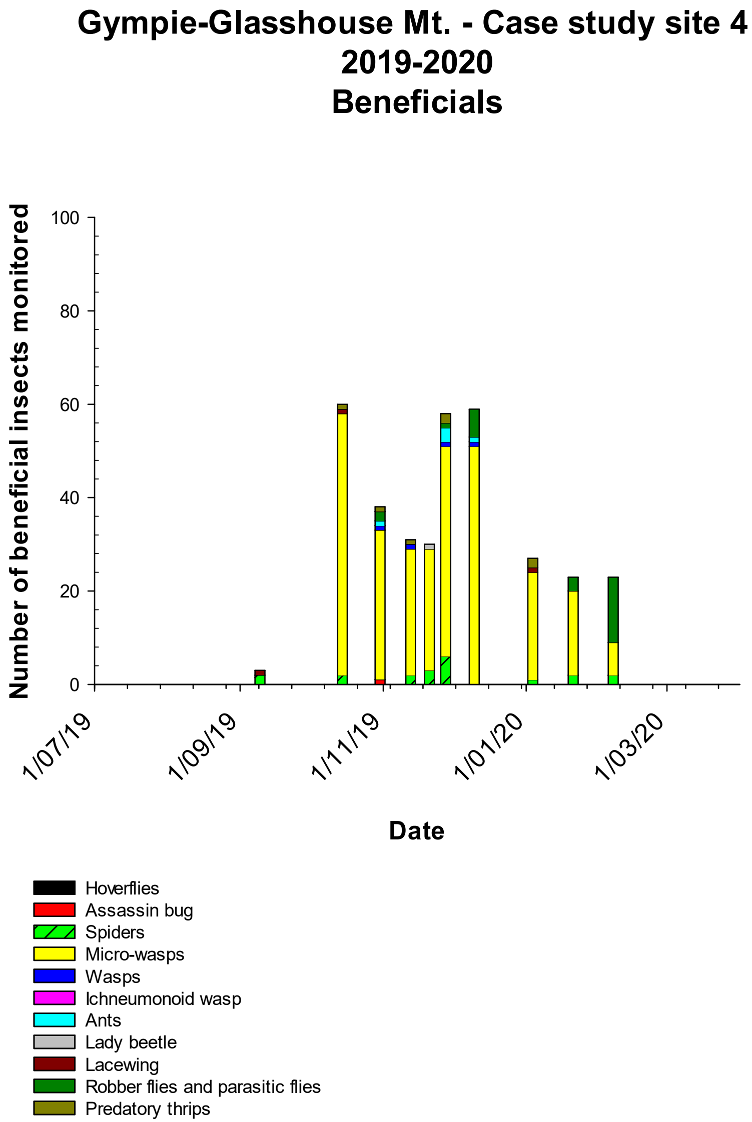
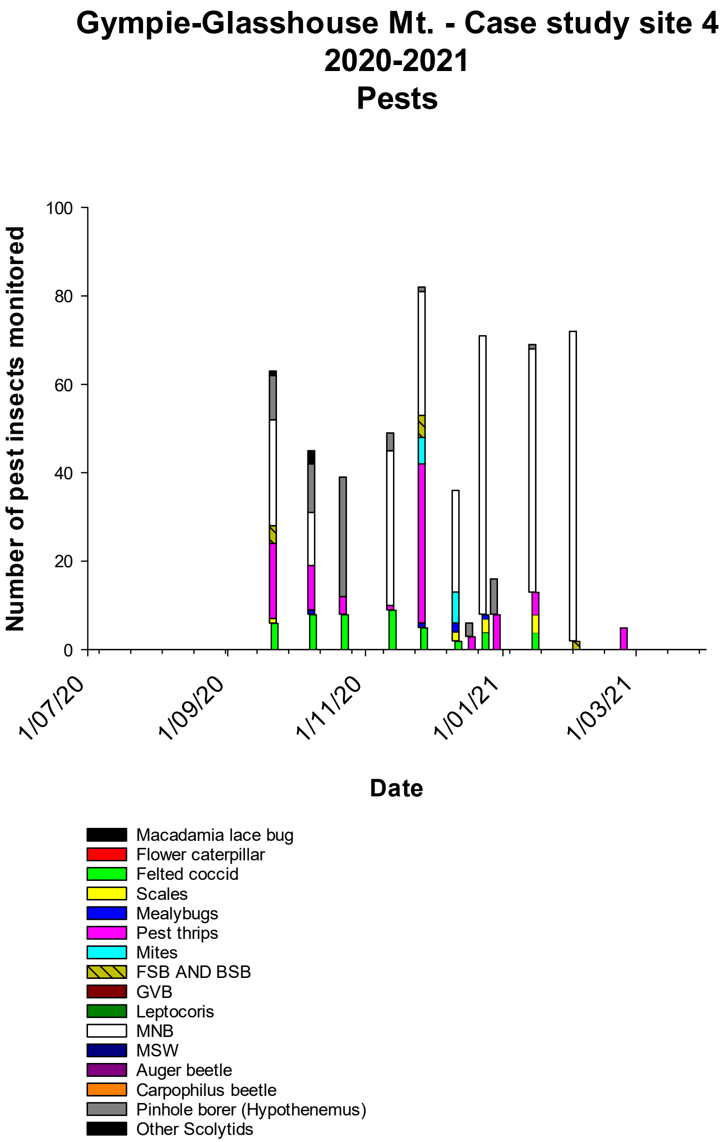


Figure 2.2.1.15.: Pest and beneficials in the Gympie – Glasshouse Mt. region at case study site 3 during the 2019–2020 season



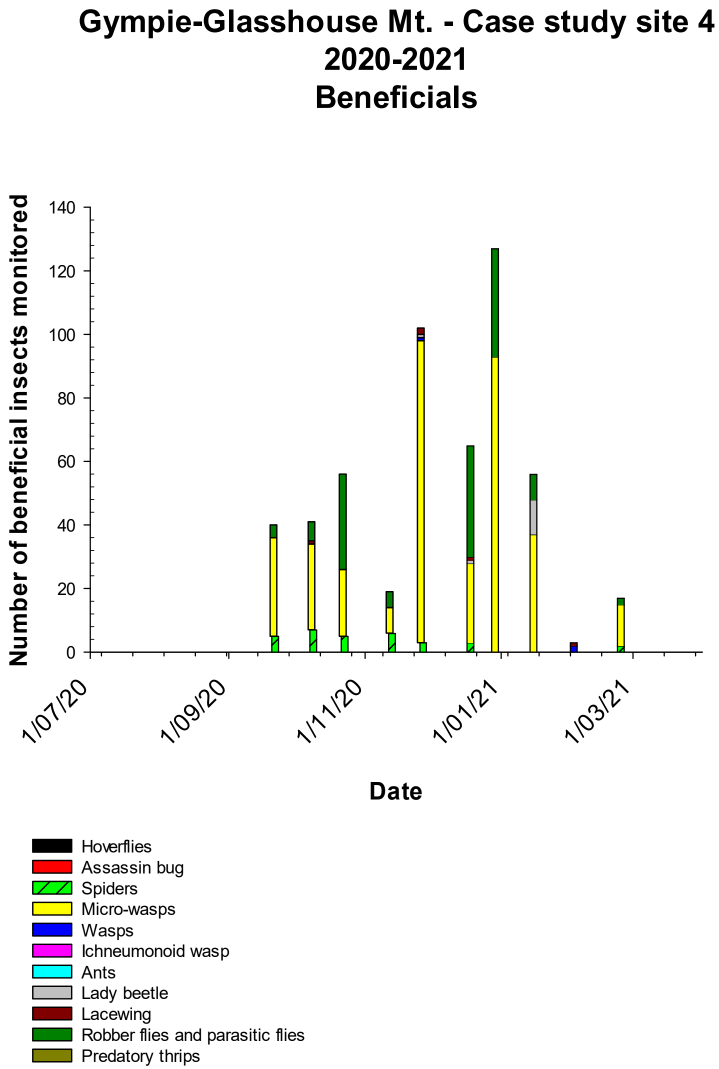


Figure 2.2.1.16: Pest and beneficials in the Gympie – Glasshouse Mt. region at case study site 4 during the 2020–2021 season

Table 2.2.1.5.: Key points from Pest and beneficials in the Gympie-Glasshouse Mt. region during the 2017-2018 season

	Pest and beneficial populations and treatments in the Gympie-Glasshouse Mt. region - Key points	
	Pests (Table 2.2.1.9.)	**Beneficials (Table 2.2.1.9.)**
Case study site 3 2017-2018	– There was a low number of different pests recorded early in the season including macadamia flower caterpillar, thrips and low levels of mites. – *Bacillus thuringiensis* (Bt) was applied in July and in cv. 816 also in August as well as a methoxyfenocide application in August to manage macadamia flower caterpillar (Figure 2 and Table 1.2.2.3.). – Thrips populations increased to high numbers in October. – From October to February MNB was significant. Regular MacTrix releases were made. A beta-cyfluthrin application brought the population right down, MNB picket up again shortly after until the second beta-cyfluthrin application in January (Figure 2 and Table 1.2.2.3.).	– Small numbers of different beneficial insects were recorded over the season, including spiders, micro-wasps and assassin bugs. – In November and December numbers of beneficials were highly reduced. Even though sulfoxaflor and beta-cyfluthrin were applied during this time, probably other environmental conditions also contributed to the crash of the populations (Figure 2 and Table 1.2.2.3.).
	Pests (Table 2.2.1.13).	**Beneficials (Table 2.2.1.13)**
Case study site 4 2017-2018	– Case study site 4 had very low pest populations until about the middle of November. – Three applications of acephate (1 in August and 2 in October) kept numbers down (Figure 2 and Table 1.2.2.4.).	– The populations of beneficials were negligible (Figure 2 and Table 1.2.2.4.). – Beneficials could not establish due to repeated applications of broad spectrum insecticides (4 organophosphates applications: 3x acephate and 1x methidathion) and 1 synthetic pyrethroids (beta-cyfluthrin) application (Figure 2 and Table 1.2.2.4.).
Harvest summary	– The percentage of nuts with scales on husk is higher at case study site 4 due to repeated broad spectrum insecticide applications (Table 2.2.1.). – Insect damage was very low in both case study sites (Table 2.2.1. and Figure 2.2.2.3.). – Yield was a little higher in case study site 4 (Table 2.2.1. and Figure 2.2.2.3.).	

Table 2.2.1.6.: Key points from Pest and beneficials in the Gympie-Glasshouse Mt. region during the 2018–2019 season

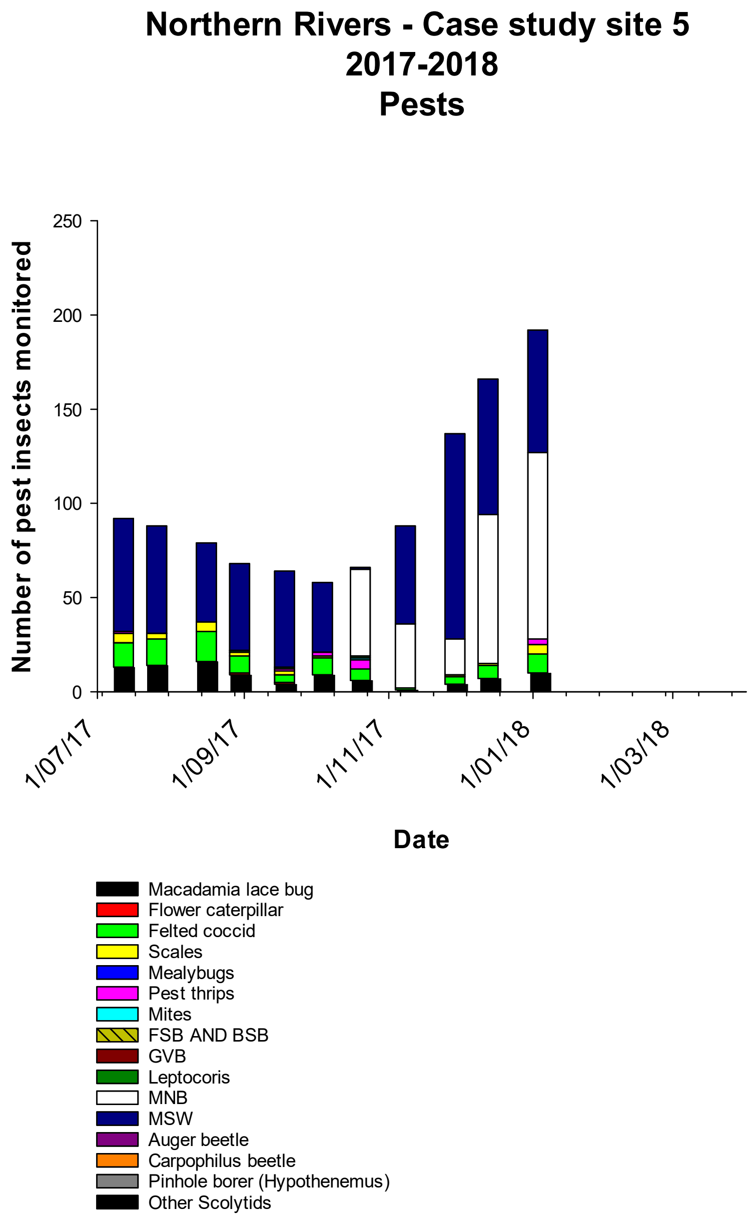
<table>
<tr><th></th><th colspan="2">Pest and beneficial populations and treatments in the Gympie-Glasshouse Mt. region - Key points</th></tr>
<tr><td></td><td>Pests (Table 2.2.1.10.)</td><td>Beneficials (Table 2.2.1.10.)</td></tr>
<tr><td>Case study site 3 2018–2019</td><td>– Thrips were the main issue in the first half of the season (Figure 2 and Table 1.2.2.3.).
– Despite regular releases of MacTrix, MNB were fairly high (Figure 2 and Table 1.2.2.3.). Possibly environmental issues were an impediment to the activity of MacTrix.
– FSB was detected at low levels and were managed with a beta-cyfluthrin spray in December (Figure 2 and Table 1.2.2.3.).
– Felted coccid was present throughout the season.</td><td>– Spiders, lacewings, small numbers of lady beetles and robber flies were present for most of the season.
– Micro-wasps were present for most of the season at various levels. Only after the sulfoxaflor application in early November (Figure 2 and Table 1.2.2.3.) numbers of beneficials were reduced.
– After the MacTrix releases started, micro-wasp numbers picked up. Releases of MacTrix possibly started to late (early December) (Figure 2 and Table 1.2.2.3.) to reduce the MNB populations, .</td></tr>
<tr><td></td><td>Pests (Table 2.2.1.14).</td><td>Beneficials (Table 2.2.1.14)</td></tr>
<tr><td>Case study site 4 2018–2019</td><td>– Macadamia lace bug was detected in higher numbers during and past the flowering season. A Diazinon application in mid-August temporarily reduced numbers (Figure 2 and Table 1.2.2.4.). Possibly a late flowering in late September caused an increase in macadamia lace bug population in October.
– Macadamia nut borer was managed with 2 applications of beta-cyfluthrin in early December and mid-January (Figure 2 and Table 1.2.2.4.).
– Beta-cyfluthrin applications possibly caused a flare up in the thrip population (Figure 2 and Table 1.2.2.4.).</td><td>– Spiders, micro-wasps, robber and parasitic flies were the main groups of beneficials.
– Spiders were reduced by applications of acephate in November and beta-cyfluthrin applications in early December and mid-January (Figure 2 and Table 1.2.2.4.).
– Robber and parasitic flies almost disappeared after the beta-cyfluthrin applications (Figure 2 and Table 1.2.2.4.).
– Broad spectrum pesticides also reduced the population of micro-wasps, but these picked up again after the last pesticide application (Figure 2 and Table 1.2.2.4.).</td></tr>
<tr><td>Harvest summary</td><td colspan="2">– Percentage of nuts with MNB tunnels on husk were higher on case study site 3 (Table 2.2.1. and Figure 2.2.2.3.).
– Percentage of nuts with scales on husk was higher on cased study site 4 (Table 2.2.1.), possibly caused by broad spectrum insecticide applications, particularly beta-cyfluthrin.
– MNB and FSB damage were higher on case study site 3 possibly due to late damage after the end of December. There was no more pest management after Christmas.
– Yield was a little higher in case study site 4 (Table 2.2.1. and Figure 2.2.2.3.).</td></tr>
</table>

Table 2.2.1.7.: Key points from Pest and beneficials in the Gympie-Glasshouse Mt. region during the 2019–2020 season

<table>
<tr><td></td><td colspan="2">Pest and beneficial populations and treatments in the Gympie-Glasshouse Mt. region - Key points</td></tr>
<tr><td></td><td>Pests (Table 2.2.1.11.)</td><td>Beneficials (Table 2.2.1.11.)</td></tr>
<tr><td>Case study site 3
2019–2020</td><td>– During the 2019–2020 season, main pest issues were MNB, thrips and Leptocoris bugs at the end of the season.
– The trichlorfon application in November did not reduce pest populations and the beta-cyfluthrin application in December reduced the pests a little (Figure 2 and Table 1.2.2.3.).
– The 4 MacTrix releases were not sufficient to manage MNB adequately.</td><td>– Case study site 3 had a variety of beneficials, including low levels of spiders, lady beetles and assassin bugs at the end of the season.
– Micro-wasp populations were not much effected by the acephate application in December and beta-cyfluthrin application in January (Figure 2 and Table 1.2.2.3.).</td></tr>
<tr><td></td><td>Pests (Table 2.2.1.15.)</td><td>Beneficials (Table 2.2.1.15.)</td></tr>
<tr><td>Case study site 4
2019–2020</td><td>– Pest numbers at case study site were low. Main issues were thrips and MNB
– A methoxyfenozide application in August kept macadamia flower caterpillar numbers low (Figure 2 and Table 1.2.2.4.).</td><td>– Beneficials were present at low levels.
– The main group of beneficials present were micro-wasps.
– Micro-wasp populations were not effected by chemical applications. (Figure 2 and Table 1.2.2.4.).
– It seems that the small spider population disappeared temporarily after the beta-cyfluthrin application in December (Figure 2 and Table 1.2.2.4.).</td></tr>
<tr><td>Harvest summary</td><td colspan="2">– The percentage of FSB and general Leptocoris damage was slightly higher on case study site 3 (Table 2.2.2. and Figure 2.2.2.4.).
– Other causes for reject kernel were higher on case study site 4 (Table 2.2.2. and Figure 2.2.2.4.),
– Yields were a higher on case study site 4 (Table 2.2.2. and Figure 2.2.2.4.).</td></tr>
</table>

Table 2.2.1.8.: Key points from Pest and beneficials in the Gympie-Glasshouse Mt. region during the 2020–2021 season

	Pest and beneficial populations and treatments in the Gympie-Glasshouse Mt. region - Key points	
	Pests (Table 2.2.1.12.)	**Beneficials (Table 2.2.1.12.)**
Case study site 3 2020–2021	– From October onwards, thrips and MNB were the main issues. – An application of trichlorfon in October, an application of beta-cyfluthrin in November and repeated releases of MacTrix did not change the MNB populations (Figure 2 and Table 1.2.2.3.).	– Different groups of beneficials were recorded through the season. The most important groups were lady beetles, micro-wasps and robber and parasitic flies. – The beta-cyfluthrin application in November reduced the numbers of beneficials (Figure 2 and Table 1.2.2.3.) –
	Pests (Table 2.2.1.16.)	**Beneficials (Table 2.2.1.16.)**
Case study site 4 2020–2021	– Pests recorded during this season were low level felted coccid, some thrips, some pinhole borer and MNB, – Despite several releases of MacTrix, MNB populations did not decline (Figure 2 and Table 1.2.2.4.).	– The main group of beneficials were micro-wasps. – The populations of micro-wasps got declined after beta-cyfluthrin application in November (Figure 2 and Table 1.2.2.4.). – Micro-wasp populations increased again with MacTrix releases between December and January (Figure 2 and Table 1.2.2.4.)
Harvest summary	– Case study site 3 had a higher percentage of nuts with clean husk (Table 2.2.1.). – The percentage of nuts with thrips on husk was twice as high on case study site 3 (Table 2.2.1.). – Yields were very similar on both case study sites (Table 2.2.1. and Figure 2.2.2.4.).	



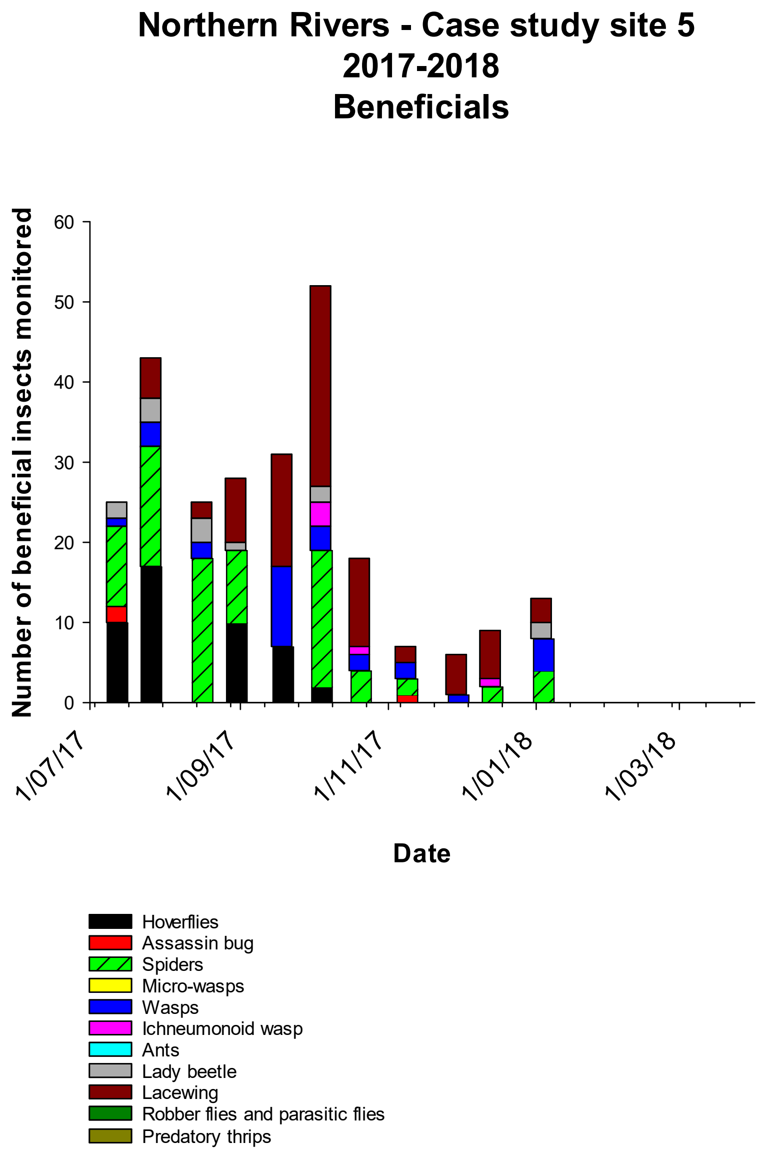
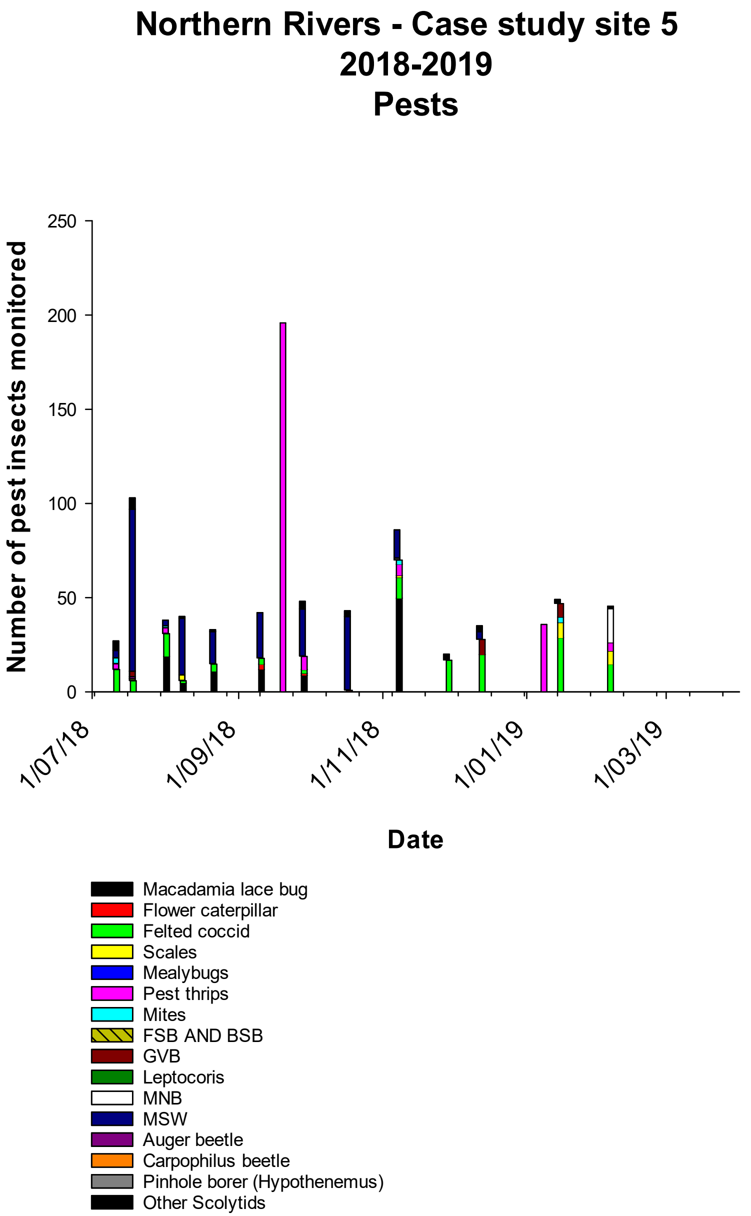


Figure 2.2.1.17: Pest and beneficials in the Northern Rivers region at case study site 5 during the 2017-2018 season



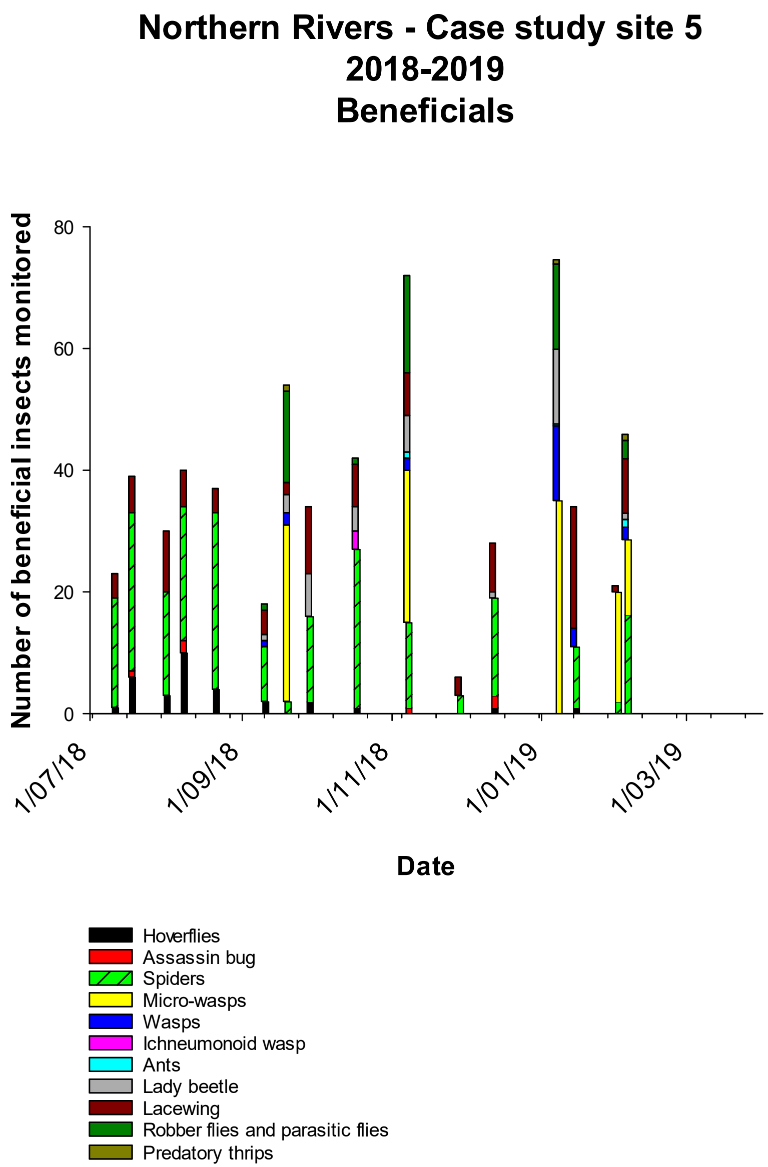
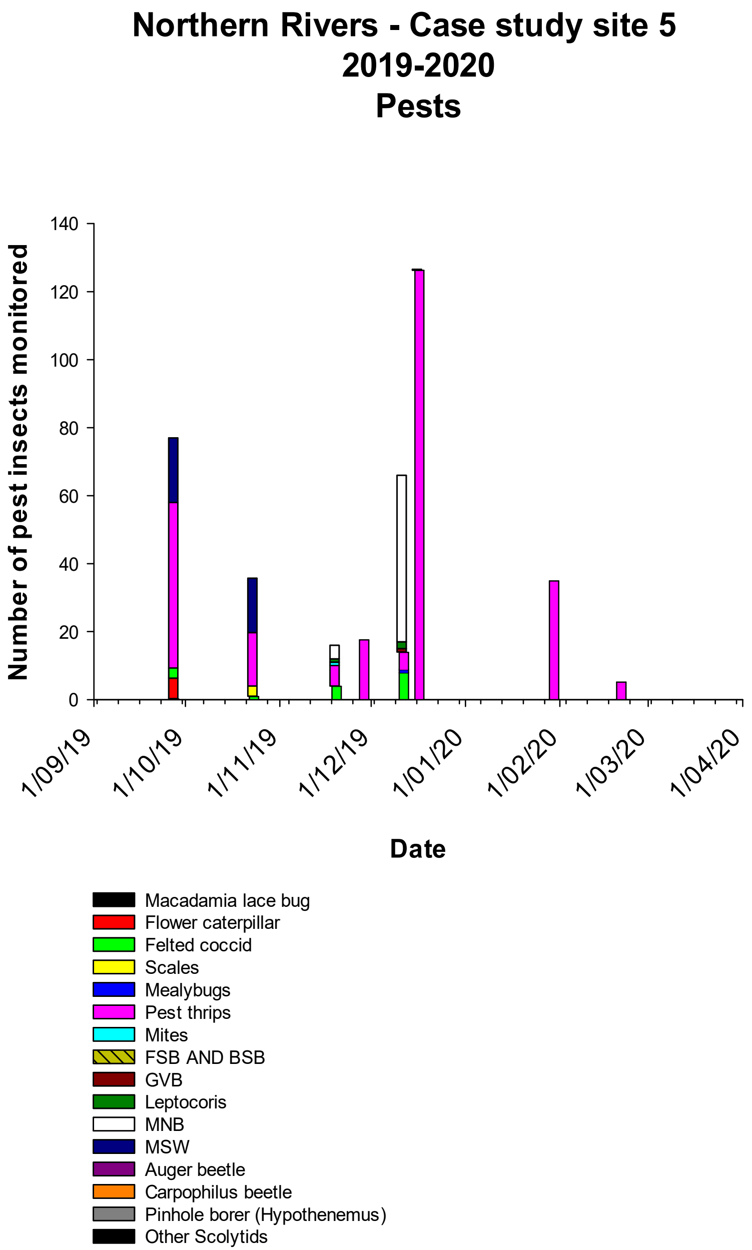


Figure 2.2.1.18.: Pest and beneficials in the Northern Rivers region at case study site 5 during the 2018–2019 season



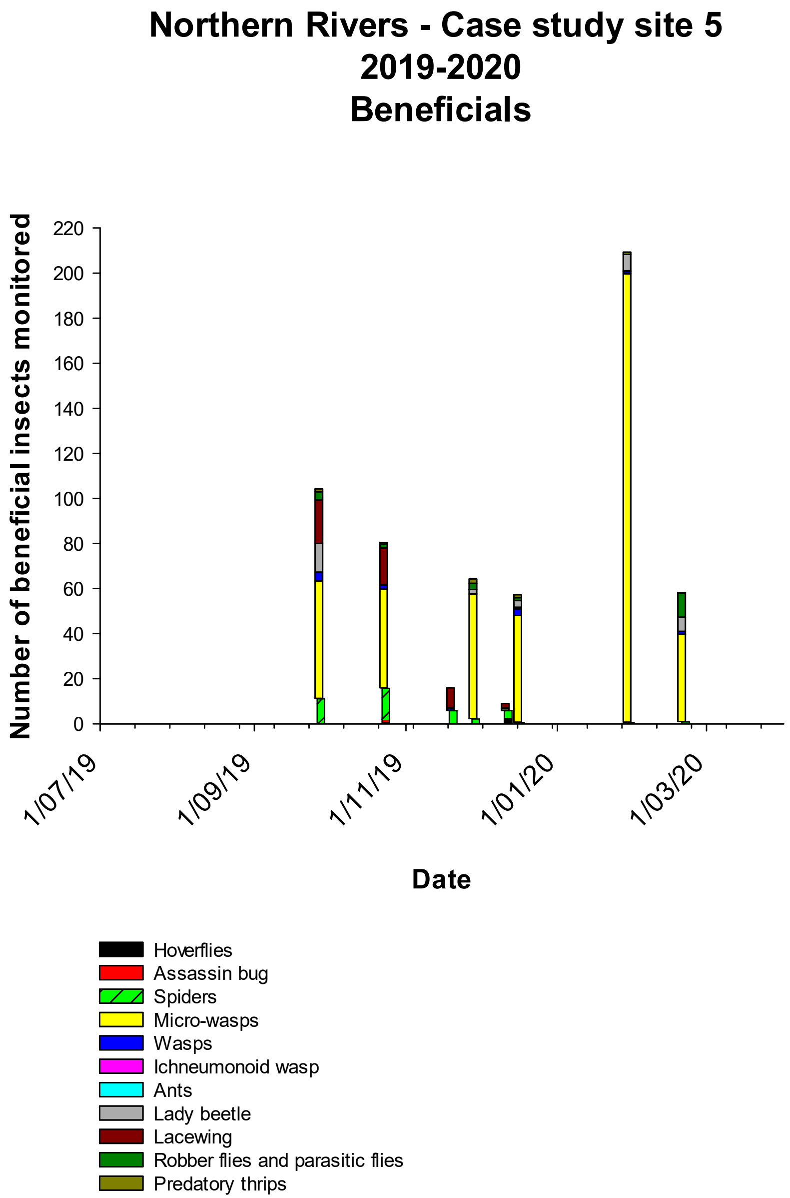
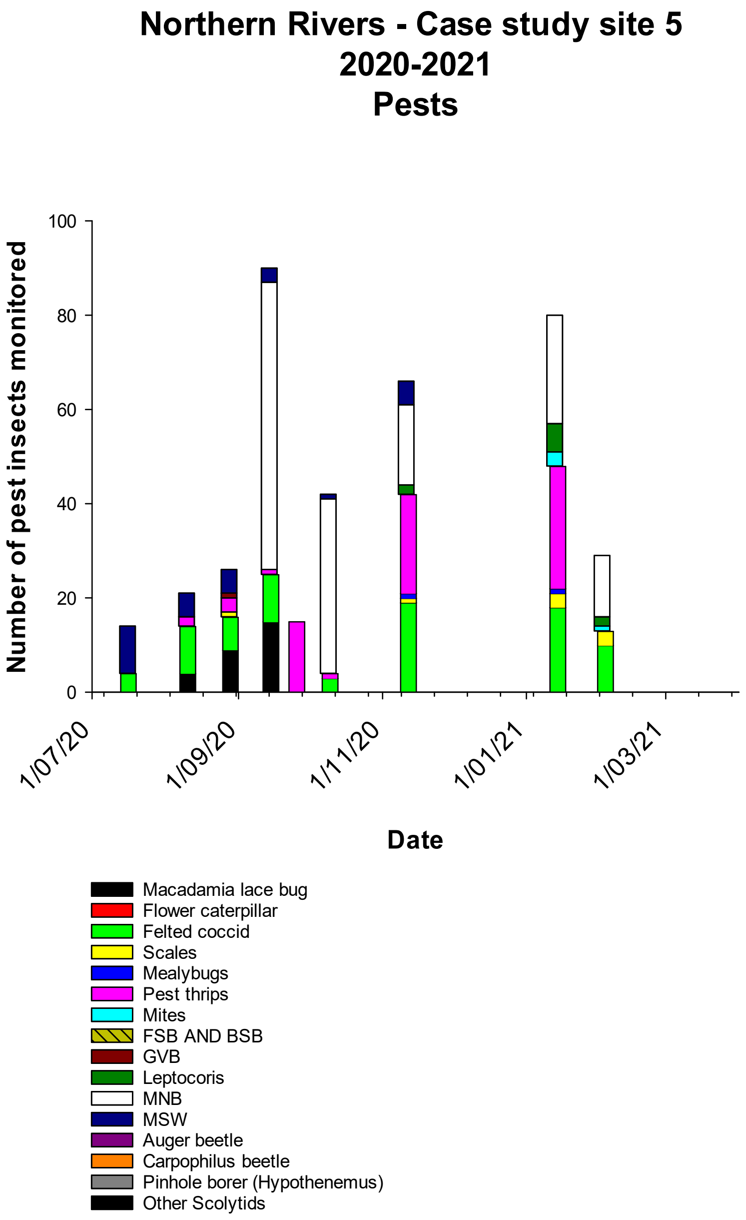


Figure 2.2.1.19.: Pest and beneficials in the Northern Rivers region at case study site 5 during the 2019–2020 season



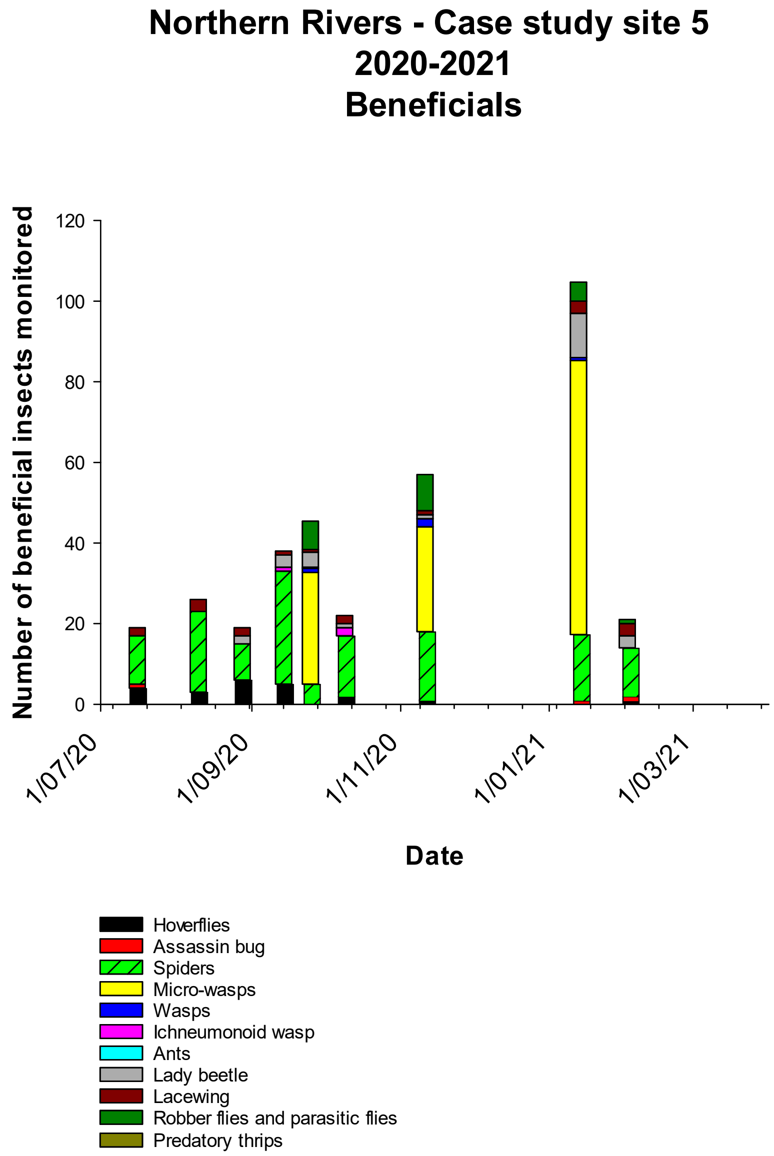
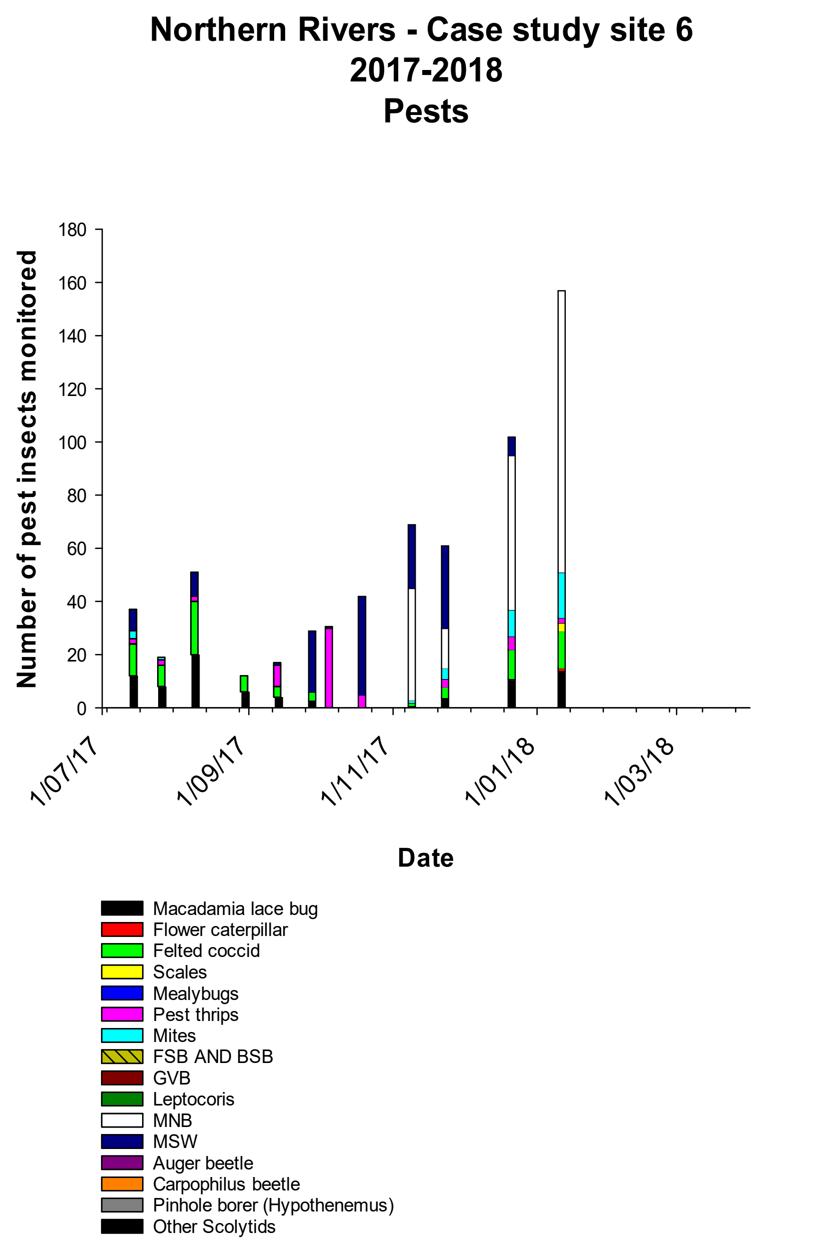


Figure 2.2.1.20.: Pest and beneficials in the Northern Rivers region at case study site 5 during the 2020–2021 season



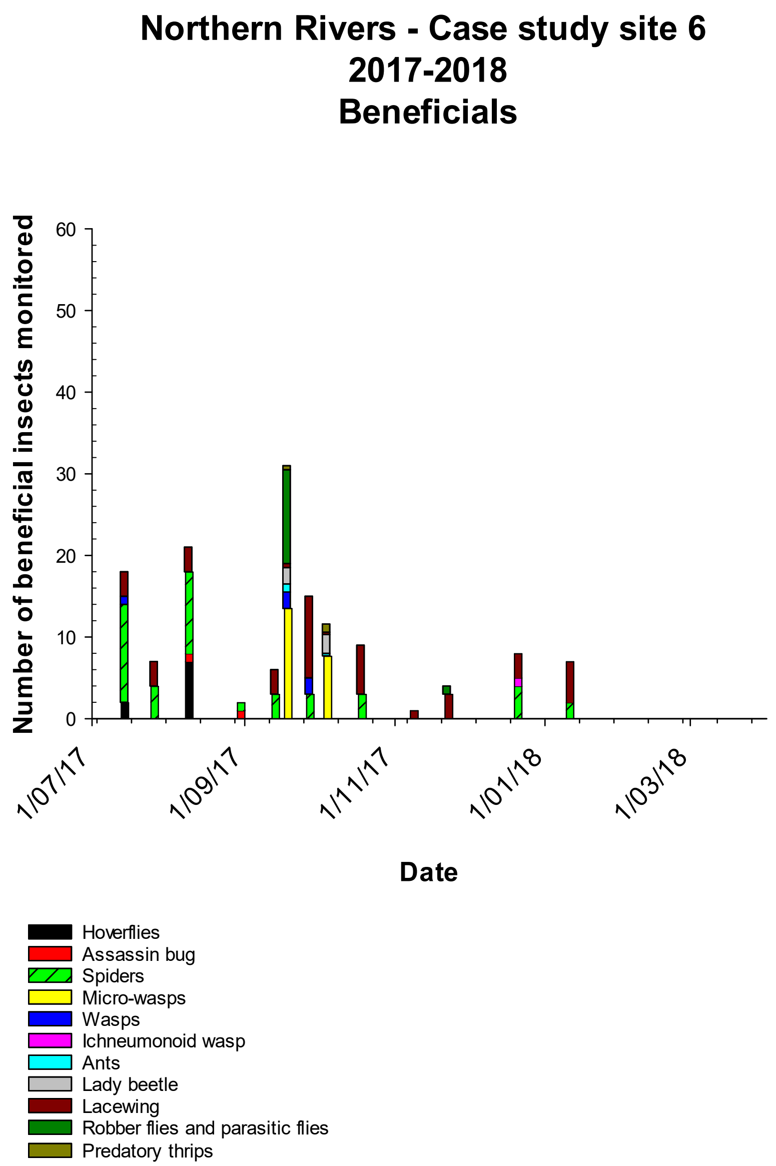
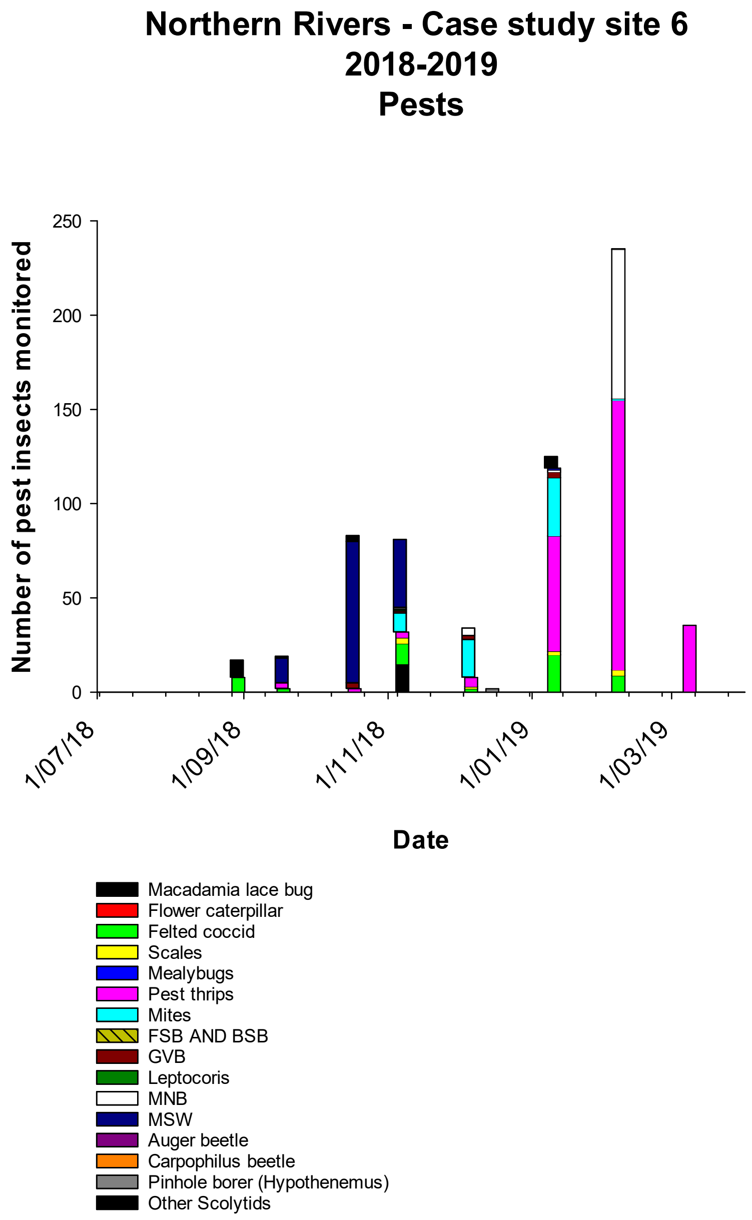


Figure 2.2.1.21.: Pest and beneficials in the Northern Rivers region at case study site 6 during the 2017-2018 season



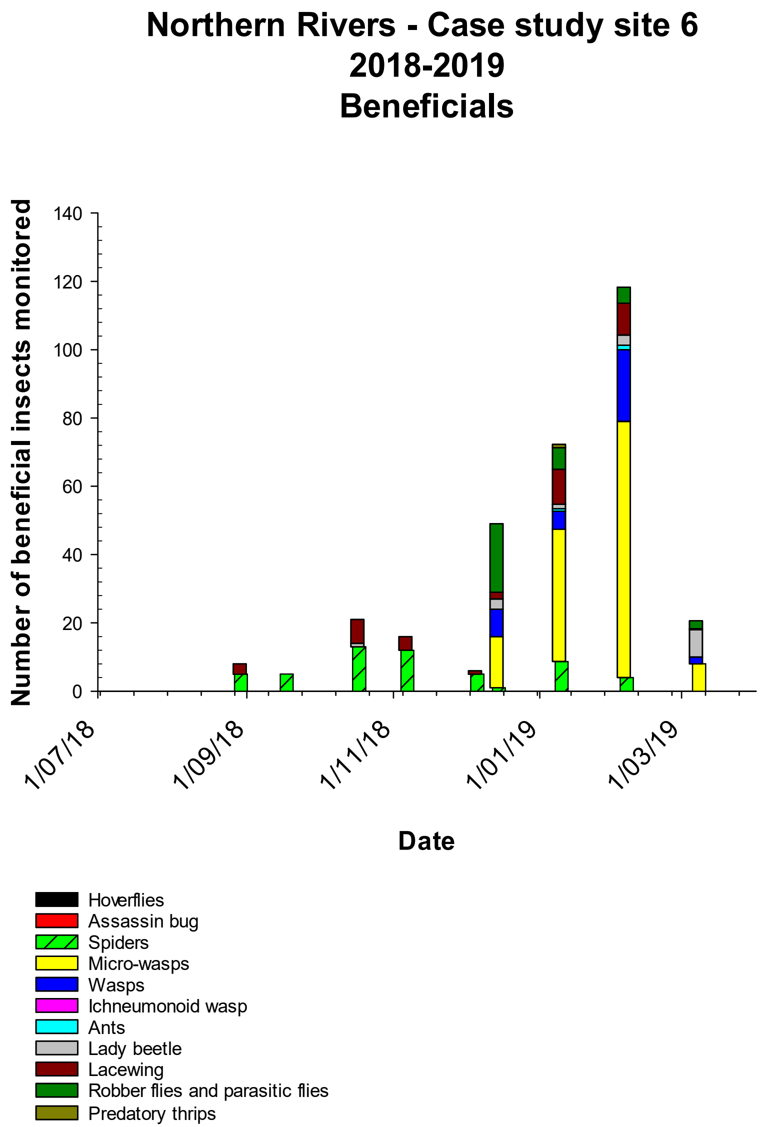
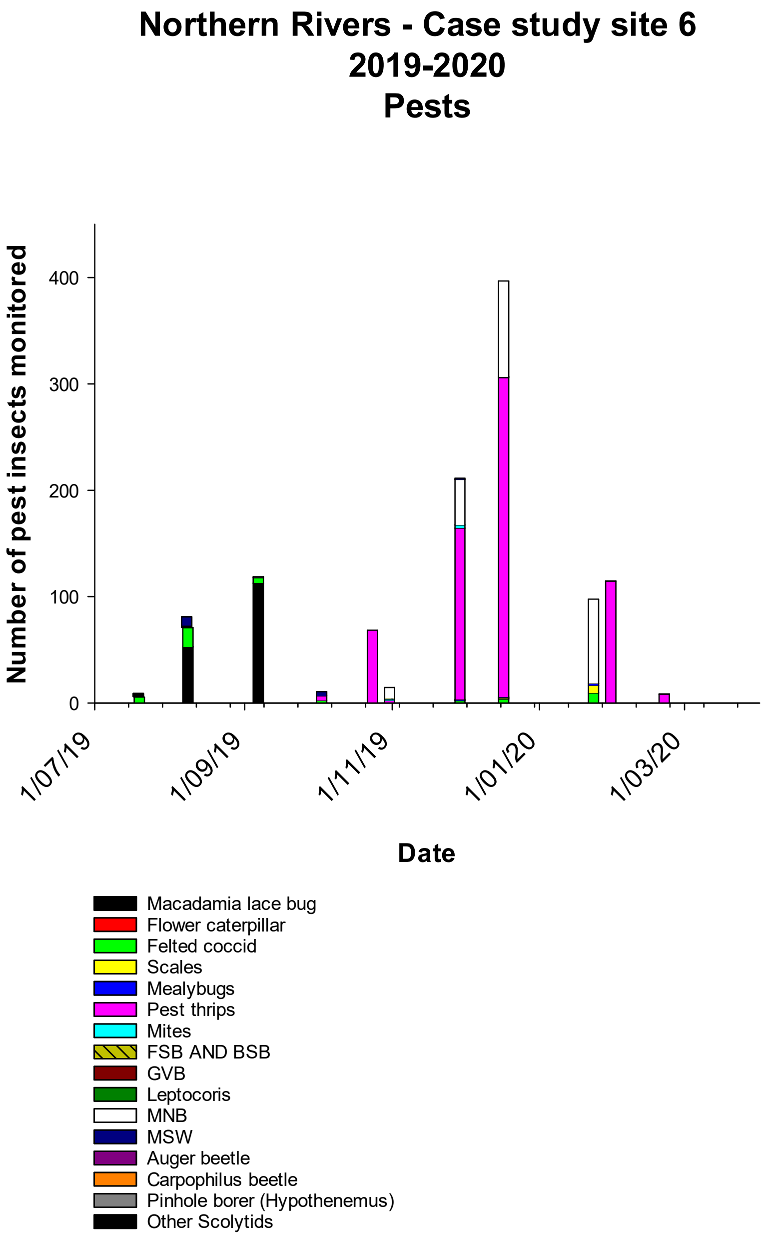


Figure 2.2.1.22.: Pest and beneficials in the Northern Rivers region at case study site 6 during the 2018–2019 season



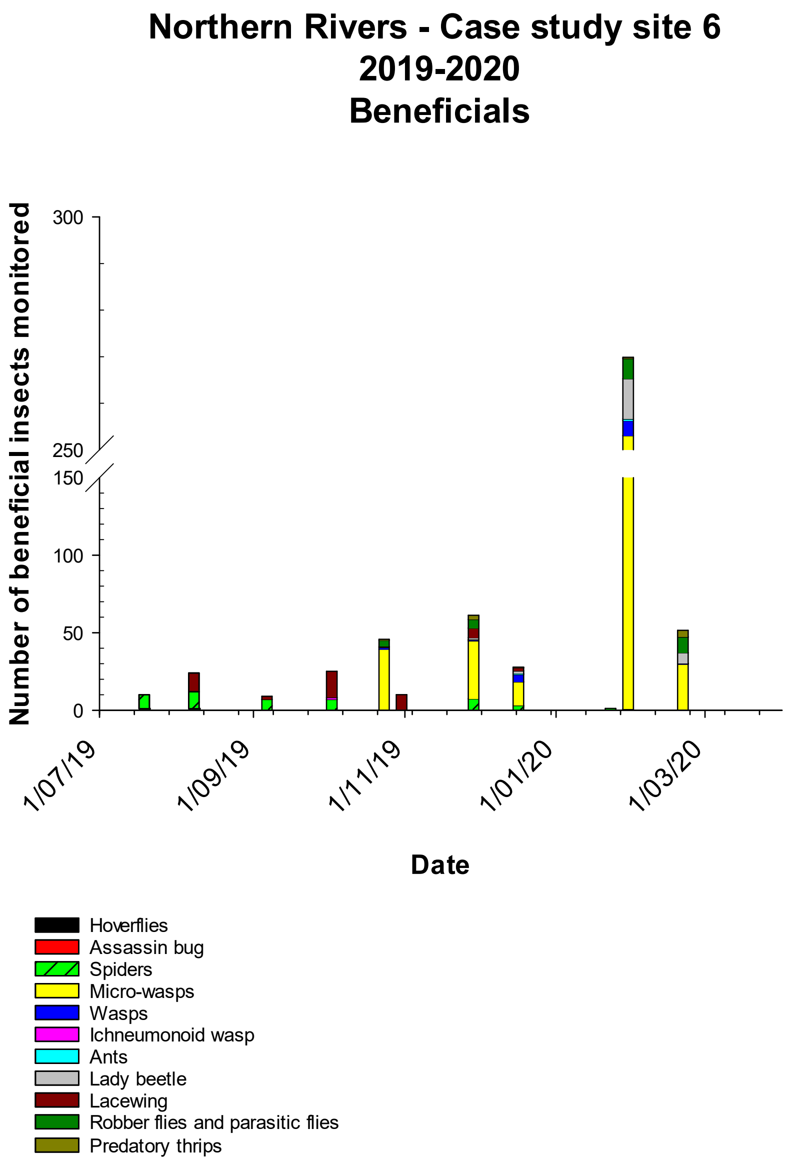
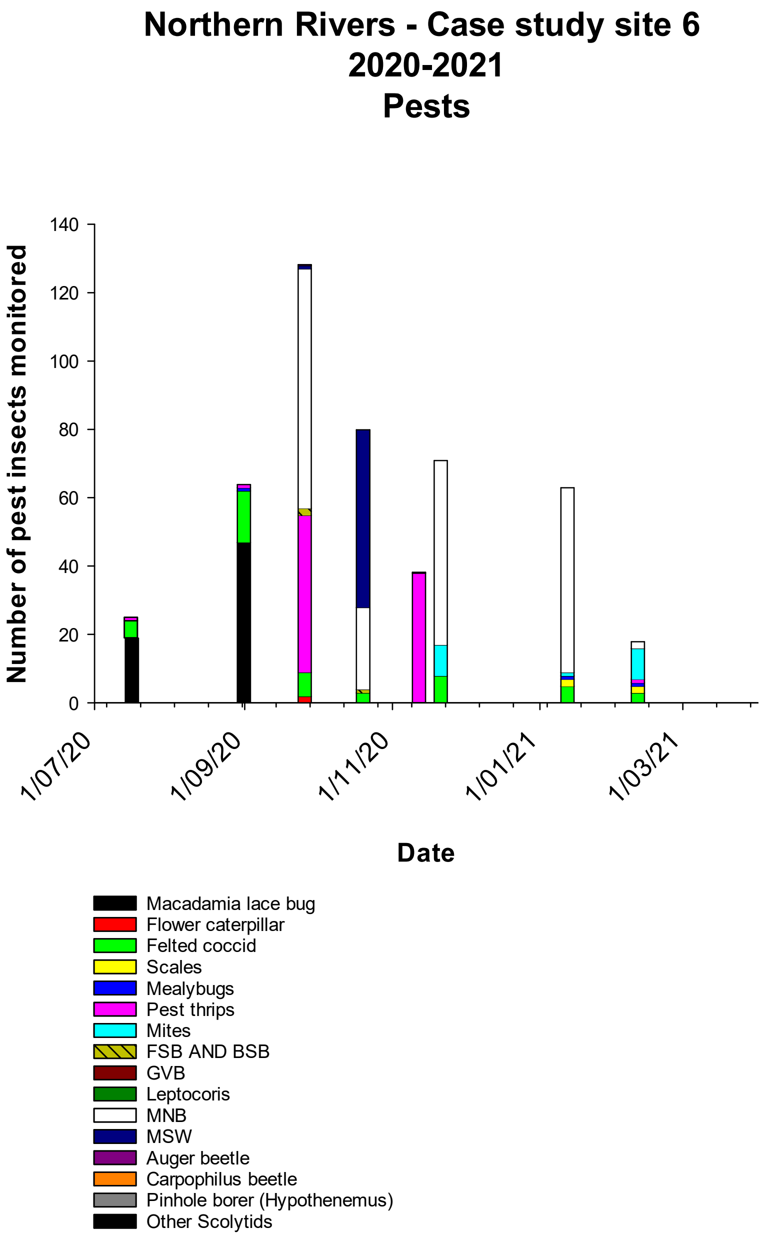


Figure 2.2.1.23.: Pest and beneficials in the Northern Rivers region at case study site 6 during the 2019–2020 season



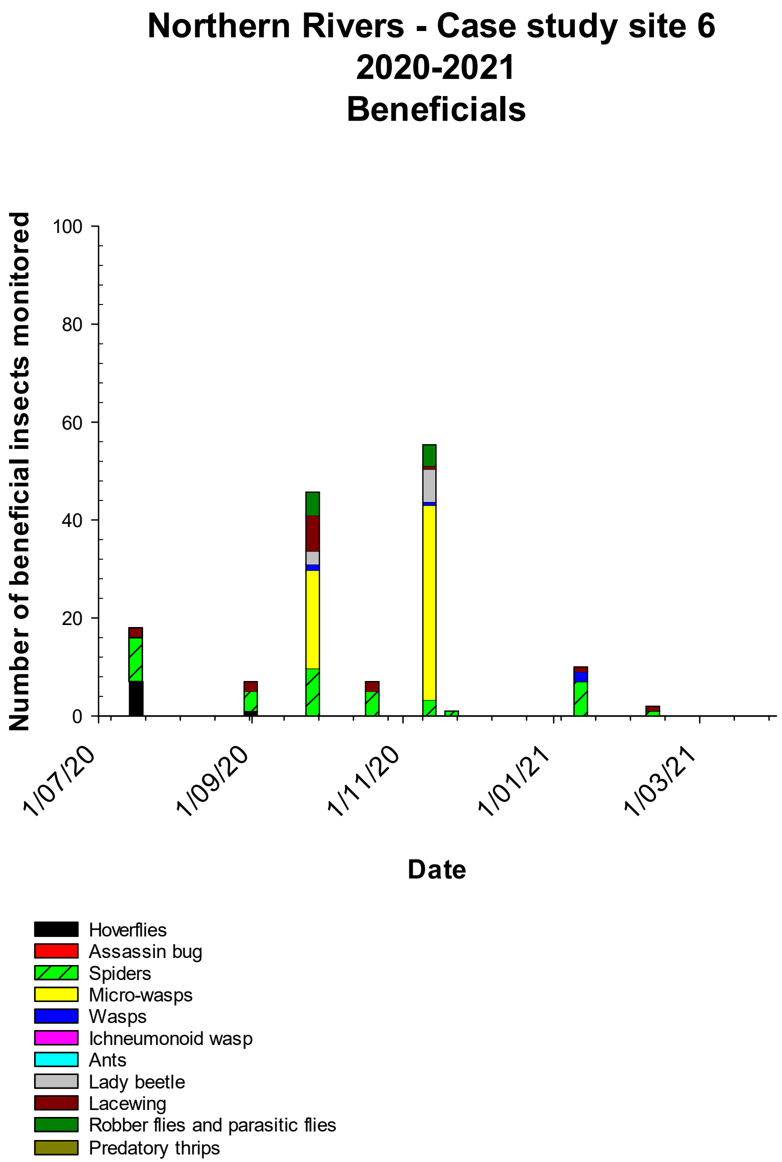


Figure 2.2.1.24.: Pest and beneficials in the Northern Rivers region at case study site 6 during the 2020–2021 season

Table 2.2.1.9.: Key points from Pest and beneficials in the Northern Rivers region during the 2017-2018 season

	Pest and beneficial populations and treatments in the Northern Rivers region - Key points	
	Pests (Table 2.2.1.17.)	**Beneficials (Table 2.2.1.17.)**
Case study site 5 2017-2018	Macadamia seed weevil and macadamia nut borer were the pests with the largest numbers recorded during the season, in addition to low numbers of felted coccid, scales and macadamia lace bug. Two applications of beta-cyfluthrin (September and October) kept pest populations low (Figure 3 and Table.2.2.5.). Spot sprays of acephate in November and beta-cyfluthrin in December reduced MNB numbers Figure 3 and Table.2.2.5.). Without MacTrix, MNB numbers increased again from December onwards.	Different groups of beneficials were present over the season, particularly hover flies, spiders, lacewings and wasps. Beneficial numbers were declining after the beta-cyfluthrin application in October (Figure 3 and Table 1.2.2.5.). There were no egg parasitoids released and therefore no micro-wasps recorded.
	Pests (Table 2.2.1.21.).	**Beneficials (Table 2.2.1.21.)**
Case study site 6 2017-2018	Low numbers of macadamia lace bug, felted coccid, thrips and macadamia seed weevil were recorded early in the season. Macadamia seed weevil increase to November and afterwards the pest complex was dominated by macadamia nut borer. Felted coccid persisted throughout the season and at the end of the season, a small mite population was recorded Macadamia seed weevil was managed with an application of indoxacarb in October (Figure 3 and Table 1.2.2.5.). Numbers declined slowly afterwards. MNB numbers decreased after a trichlorfon application in November, but did not stay down, as there were no egg parasitoids released to keep populations down (Figure 3 and Table 1.2.2.5.)	Populations of beneficials were very low throughout the season. Low levels of spiders and lacewings persisted during the whole season. There were only very few egg parasitoids detected as there were no releases made (Figure 3 and Table 1.2.2.6.).
	Pest and beneficial populations and treatments in the Northern Rivers region - Key points	
Harvest summary	The percentage of nuts with clean husk was higher in case study site 5 (Table 2.2.1.). The percentage of nuts with MNB tunnels on husk and MSW oviposition sites was also higher on case study site 5 (Table 2.2.1.). FS B damage was very low and slightly higher on case study site 6 (Table 2.2.1. and Figure 2.2.2.5.). The yield was twice as high on case study site 6 (Table 2.2.1. and Figure 2.2.2.5.).	

Table 2.2.1.10.: Key points from Pest and beneficials in the Northern Rivers region during the 2018–2019 season

	Pest and beneficial populations and treatments in the Northern Rivers region - Key points	
	Pests (Table 2.2.1.18.)	**Beneficials (Table 2.2.1.18.)**
Case study site 5 2018–2019	Macadamia seed weevil populations increase early in the season despite several lacewing releases and was managed with an indoxacarb application in October. (Figure 3 and Table 1.2.2.5.). Thrips numbers flared up in October, but only very temporarily. One application of trichlorfon in September and a second one in November kept pest populations low (Figure 3 and Table 1.2.2.5.). This included increased macadamia lace bug numbers in November. Felted coccid numbers increased again after the trichlorfon applications (Figure 3 and Table 1.2.2.5.).	Beneficials were present during the season at low levels. Spiders, micro-wasps, lacewings and lady beetles were the main groups of beneficials recorded during the season. Beneficial populations declined after the trichlorfon application in November (Figure 3 and Table 1.2.2.5.). It took until January 2019 for the populations to recover.
	Pests (Table 2.2.1.22.).	**Beneficials (Table 2.2.1.22.)**
Case study site 6 2018–2019	Macadamia seed weevil, thrips, macadamia nut borer and low levels of macadamia lace bug, mites and felted coccid were recorded during the season. A Diazinon spray in early October managed early macadamia lace but and felted coccid population (Figure 3 and Table 1.2.2.6.). An indoxacarb application in late October managed macadamia seed weevil numbers. An additional application of acephate application in November reduced the remaining population (Figure 3 and Table 1.2.2.6.). Felted coccid, thrips and mites increased in January and February. Possibly due to climatic conditions and also beta-cyfluthrin application in December (Figure 3 and Table 1.2.2.6.). A late population of macadamia nut borer was managed by an application of beta-cyfluthrin in February (Figure 3 and Table 1.2.2.6.).	Spiders and also lacewings persisted tin low numbers through most of the season. From late December onwards, micro wasps, larger wasps, lady beetles and robber and parasitic flies were also present and increased in numbers at different levels. Beneficial populations were kept low due to the applications of broad spectrum insecticides (Figure 3 and Table 1.2.2.6.). Numbers of beneficials generally started to increase after the beta-cyfluthrin application in December and were reduced again by a further beta-cyfluthrin application in February (Figure 3 and Table 1.2.2.6.).
	Pest and beneficial populations and treatments in the Northern Rivers region - Key points	
Harvest summary	The percentage of nuts with scale on husk was higher on case study site 6 (Table 2.2.1.). The percentage of nuts with husk spot and percentage of MNB damage in kernel and immaturity was higher on case study site 5. Immaturity was possibly caused by MNB and/or disease (Table 2.2.2. and Figure 2.2.2.5.). The yield is more than double on case study site 6 (Table 2.2.1. and Figure 2.2.2.5.).	

Table 2.2.1.11.: Key points from Pest and beneficials in the Northern Rivers region during the 2019–2020 season

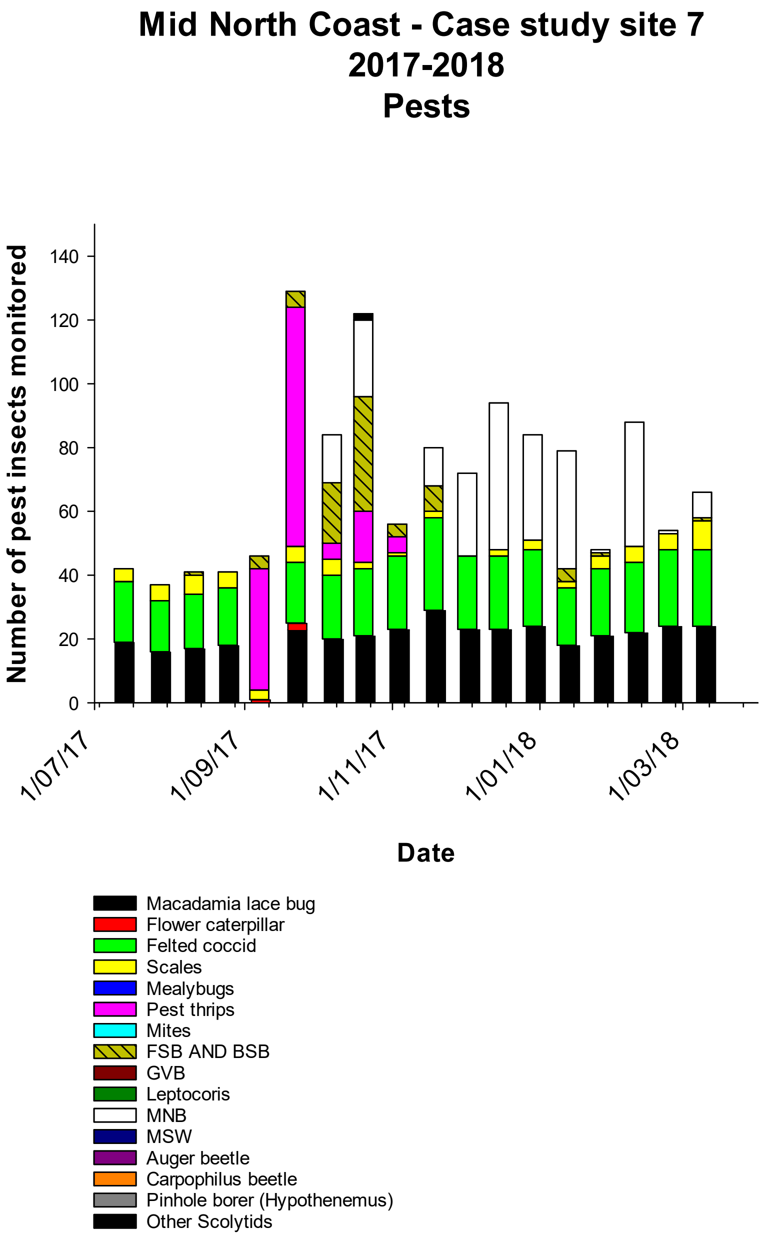
	Pest and beneficial populations and treatments in the Northern Rivers region - Key points	
	Pests (Table 2.2.1.19.)	**Beneficials (Table 2.2.1.19.)**
Case study site 5 2019–2020	Thrips were the main pest recorded during the season. The populations increase to December and then naturally decreased at the end of summer. Early in the season macadamia lace bug pas present. Population levels did not increase, and the pest was managed with several releases of lacewings between March and October (Figure 3 and Table 1.2.2.5.). Macadamia nut borer populations were recorded in December and January that were managed with MacTrix releases from December to February (Figure 3 and Table 1.2.2.5.).	Main groups of beneficials recorded were micro-wasps. There were also low levels of spiders and lacewings and lady beetles. Lacewings and micro-wasps recorded resulted from regular releases (Figure 3 and low levels of spiders Table 1.2.2.5.).
	Pests (Table 2.2.1.23.).	**Beneficials (Table 2.2.1.23.)**
Case study site 6 2019–2020	Macadamia lace bug and low levels of felted coccid were recorded early in the season. Macadamia lace bug was managed with an application of Diazinon in August and trichlorfon application in September (Figure 3 and Table 1.2.2.6.). From October /November to December/January increasing numbers of thrips and macadamia nut borer were detected. Macadamia nut borer was managed with an acephate application in November a beta-cyfluthrin application in December and regular releases of MacTrix between December and February (Figure 3 and Table 1.2.2.6.)	The main group of beneficials recorded was micro-wasps, between October and March. Populations increased particularly after applications of broad spectrum insecticide applications were completed in December and MacTrix releases commenced in January (Figure 3 and Table 1.2.2.6.). There were low levels of spiders and lacewings early in the season and in February /March low levels of lady beetles, larger wasps and robber and parasitic flies were recorded. (Figure 3 and Table 1.2.2.6.).
	Pest and beneficial populations and treatments in the Northern Rivers region - Key points	
Harvest summary	The percentage of nuts with clean husk was higher at case study site 5 (Table 2.2.3.). The percentage of nuts with MNB tunnels husk was minimal but higher at case study site 5 (Table 2.2.3.). The percentage of nuts with thrips and scale on husk was higher at case study site 6 (Table 2.2.3.). The percentage of nuts with husk spot and percentage of MNB damage in kernel and immaturity was higher on case study site 5. Immaturity was possibly caused by MNB and/or disease (Table 2.2.3. and Figure 2.2.2.6.). The yield was lower at case study site 5 (Table 2.2.3. and Figure 2.2.2.6.)	

Table 2.2.1.12.: Key points from Pest and beneficials in the Northern Rivers. region during the 2020–2021 season

	Pest and beneficial populations and treatments in the Northern Rivers region - Key points	
	Pests (Table 2.2.1.20.)	**Beneficials (Table 2.2.1.20.)**
Case study site 5 2020–2021	Macadamia seed weevil was recorded from August to December. An indoxacarb application in mid-October managed the population (Figure 3 and Table 1.2.2.5.) Macadamia lace bug populations were increasing between August and October. Applications of SeroX® and neem in September did not seem to effect populations (Figure 3 and Table 1.2.2.5.) Thrips and felted coccid were recorded at different levels throughout the season. Macadamia nut borer was detected early (September/October), but managed with 12 MacTrix releases (Figure 3 and Table 1.2.2.5.) Small populations of *Leptocoris* were detected between November and February but not specifically treated.	Spiders were present throughout the season, but these were affected by the indoxacarb application in mid-October (Figure 3 and Table 1.2.2.5.) Micro-wasp populations were recorded from October to February and populations particularly increased with the MacTrix releases (Figure 3 and Table 1.2.2.5.).
	Pests (Table 2.2.1.24.)	**Beneficials (Table 2.2.1.24.)**
Case study site 6 2020–2021	Macadamia lace bug and felted coccid were recorded during flowering between July and September. Diazinon was applied for macadamia lace bug management in August which did not stop population increase in September. Therefore, a follow-up spray of trichlorfon was applied in mid-September to manage the pest (Figure 3 and Table 1.2.2.6.). Larger numbers of thrips and macadamia nut borer were recorded in September. This would have recorded the first flight of macadamia nut borer. At that point there were probably no susceptible nuts in the orchard. Macadamia nut borer and macadamia seed weevil were recorded in October. The latter was managed by an application of indoxacarb (Figure 3 and Table 1.2.2.6.). A follow up spray with acephate for both pests was applied in November (Figure 3 and Table 1.2.2.6.). From there on macadamia nut borer was managed with 1 application of beta-cyfluthrin in December and 5 MacTrix releases in January and February (Figure 3 and Table 1.2.2.6.).	Beneficial numbers recorded during the season were very low. There were low numbers of spiders, lacewings, lady beetles and robber and parasitic flies. The main group of beneficials recorded was micro-wasps. Numbers increased during the MacTrix releases (Figure 3 and Table 1.2.2.6.). Populations were not high, despite releases, possibly due to unfavourable conditions at release times. A reduction in micro-wasps in October can possibly be explained with the indoxacarb application in October (Figure 3 and Table 1.2.2.6.) Indoxacarb is known to be toxic parasitic hymenoptera and listed in the IOBC database for toxicity to beneficials (Hassan, S.A. et al 1985).

Table 2.2.1.12.: Key points from Pest and beneficials in the Northern Rivers. region during the 2020–2021 season (cont.)

	Pest and beneficial populations and treatments in the Northern Rivers region - Key points
Harvest summary	The percentage of nuts with thrips on husk was higher on case study site 5 (Table 2.2.2.). The percentage of immature kernel was higher on case study site 5 (Table 2.2.2.) and main contributor to reject kernel, possibly due to environmental factors. The yield was a bit higher on case study site 6 (Table 2.2.2. and Figure 2.2.2.6.).



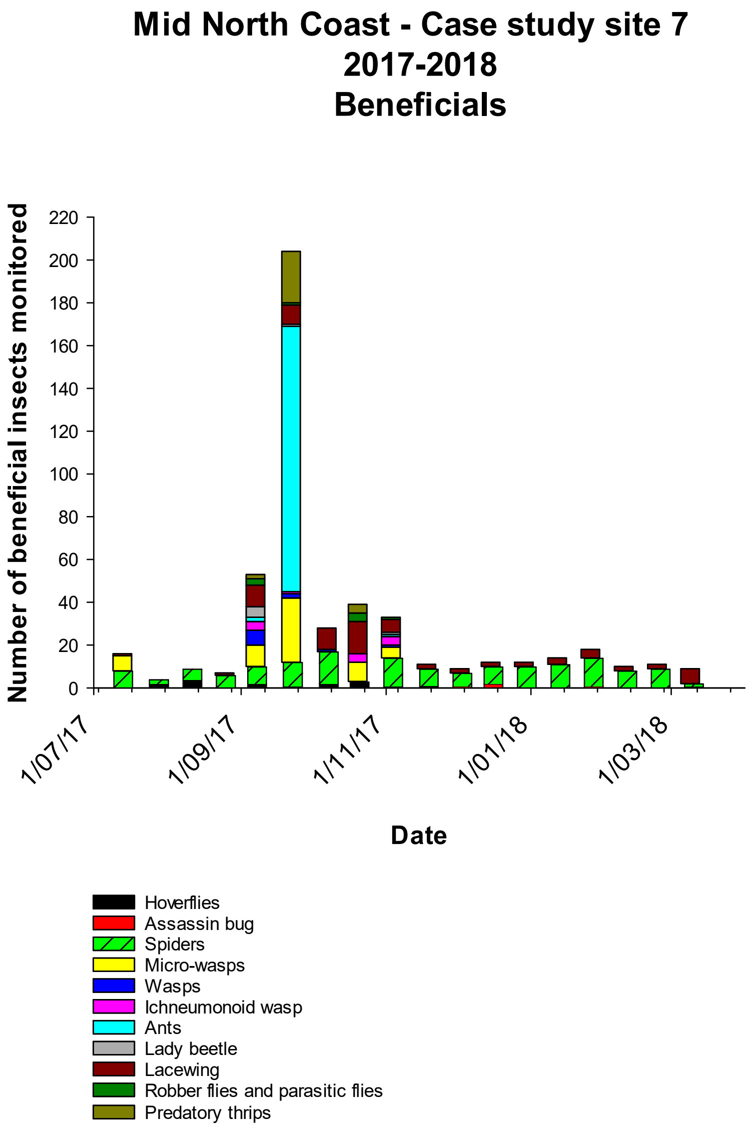
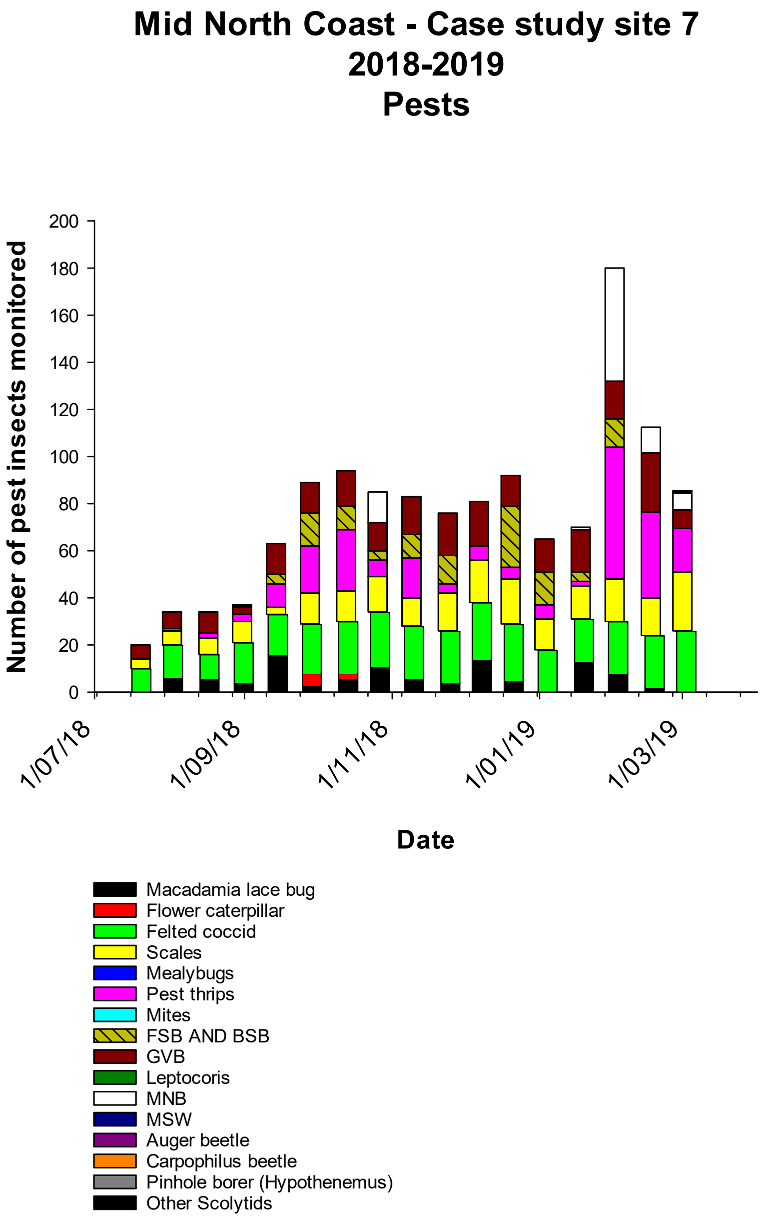


Figure 2.2.1.25: Pest and beneficials in the Mid North Coast region at case study site 7 during the 2017-2018 season



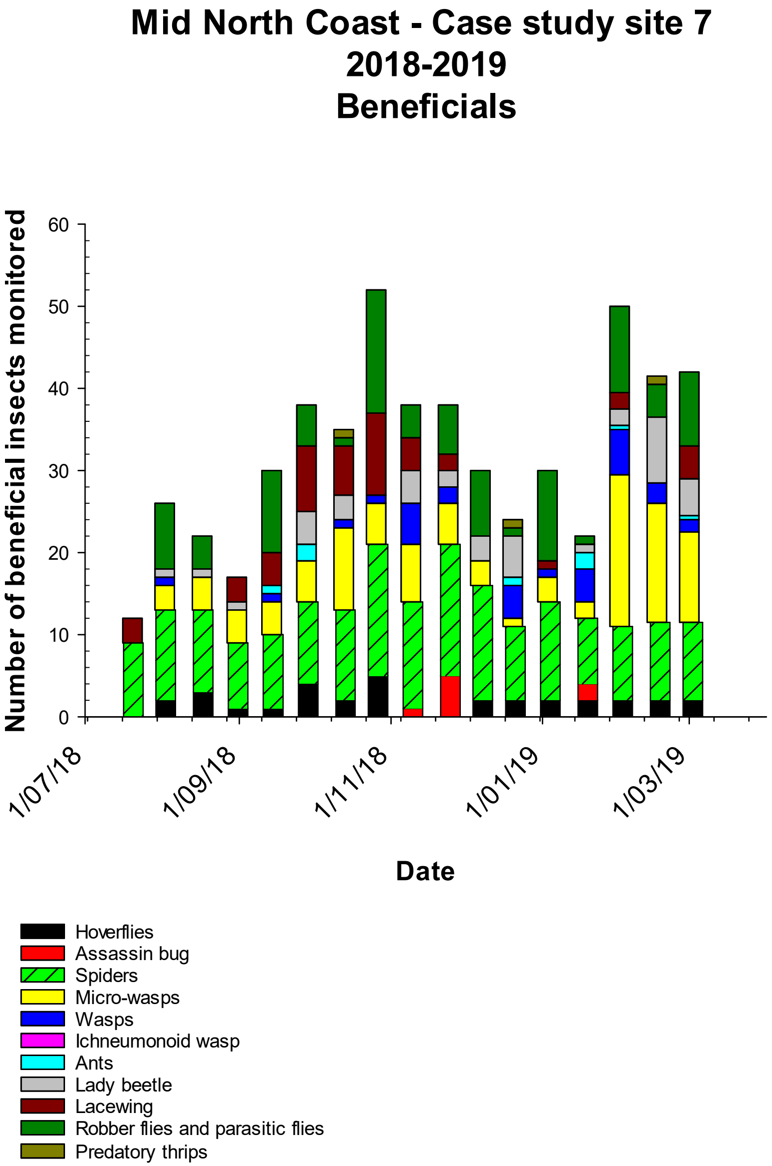
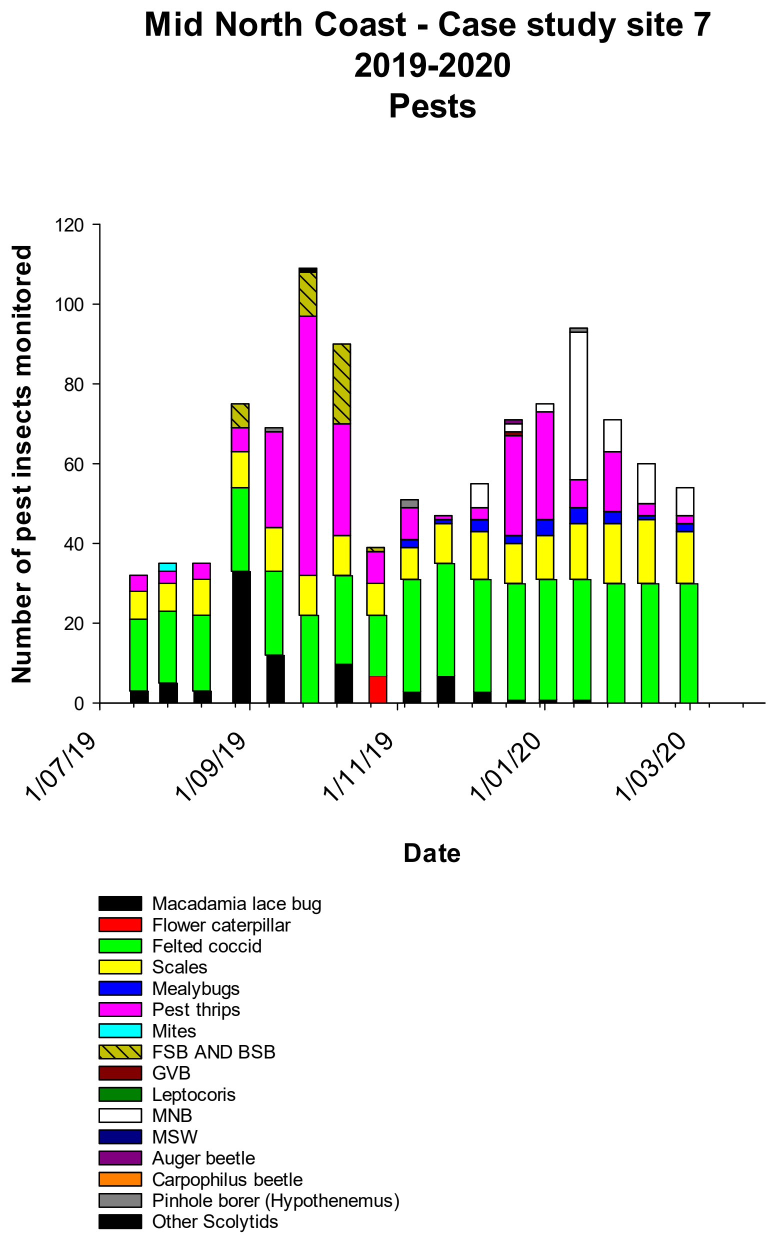


Figure 2.2.1.26.: Pest and beneficials in the Mid North Coast region at case study site 7 during the 2018–2019 season



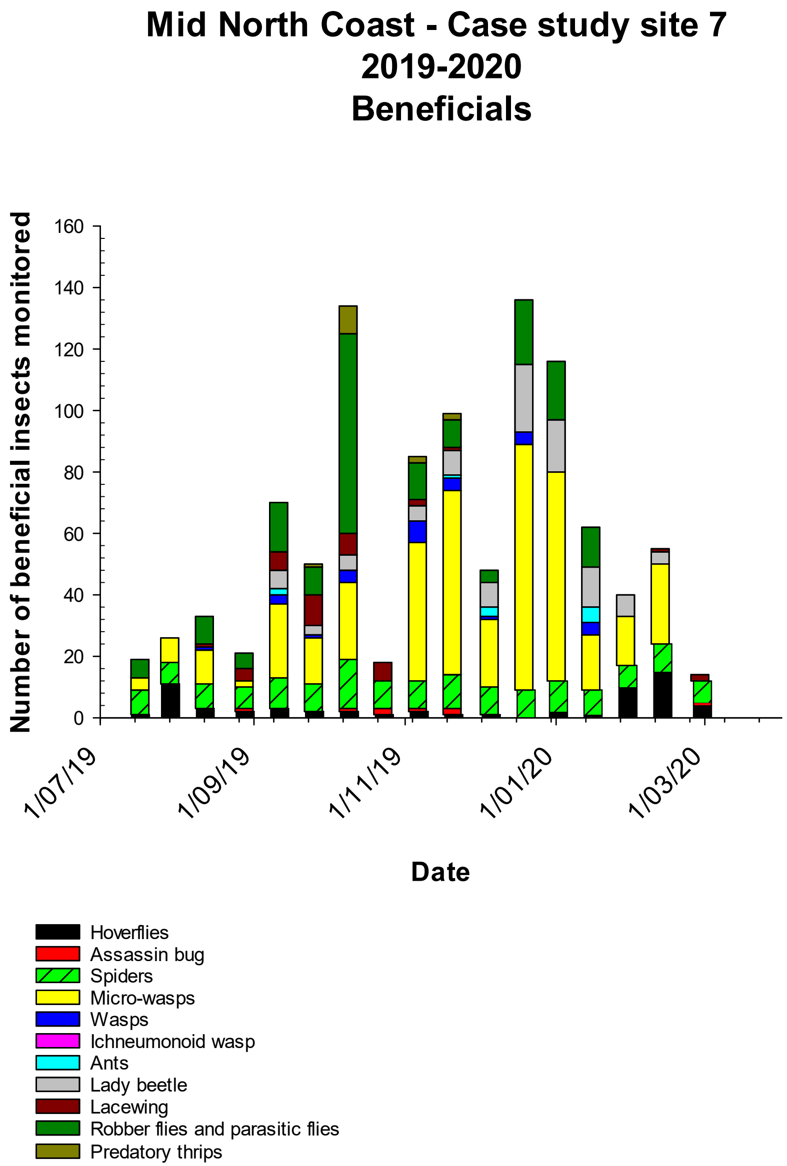
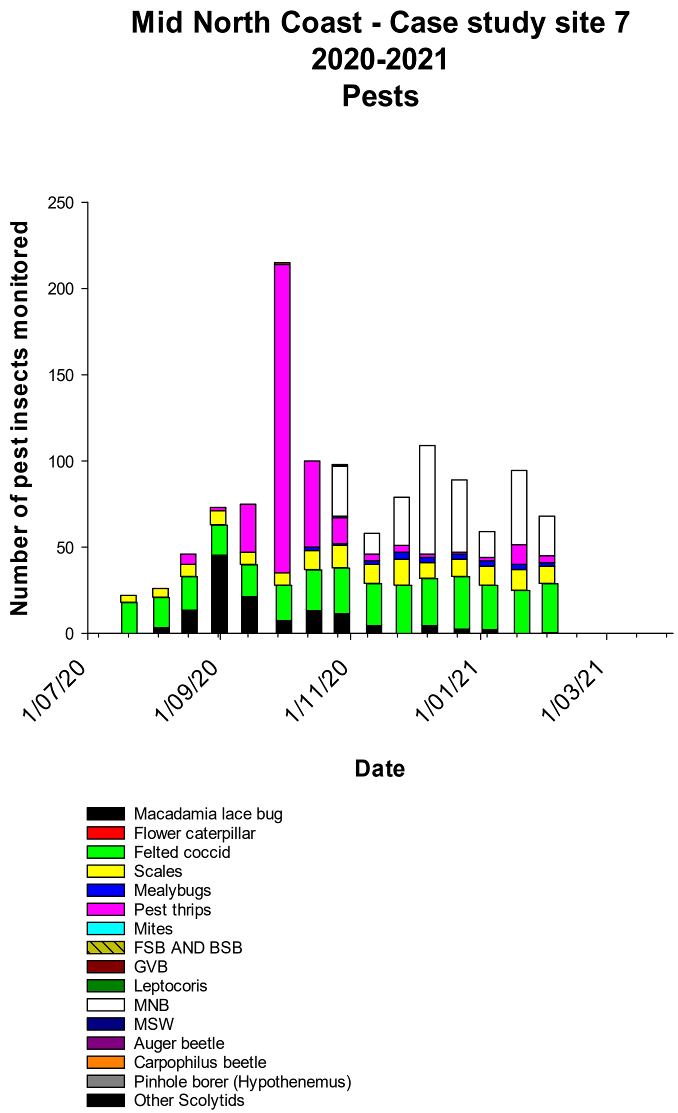


Figure 2.2.1.27.: Pest and beneficials in the Mid North Coast region at case study site 7 during the 2019–2020 season



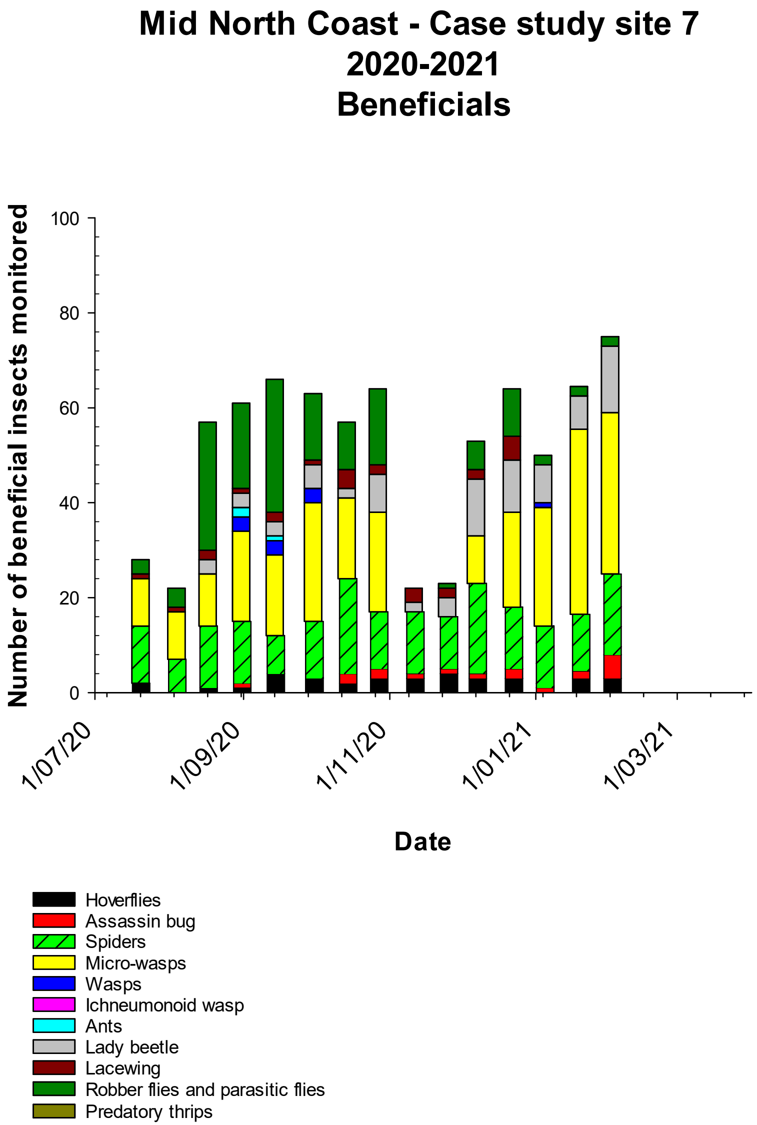
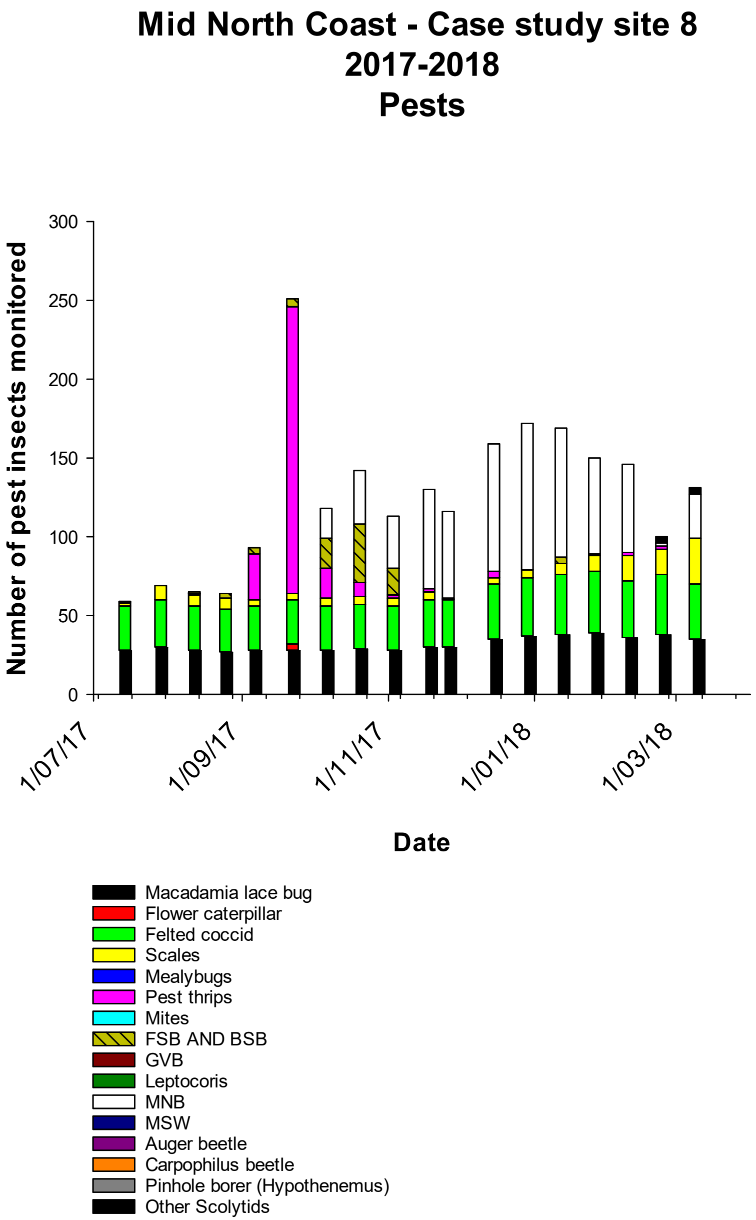


Figure 2.2.1.28.: Pest and beneficials in the Mid North Coast region at case study site 7 during the 2020–2021 season



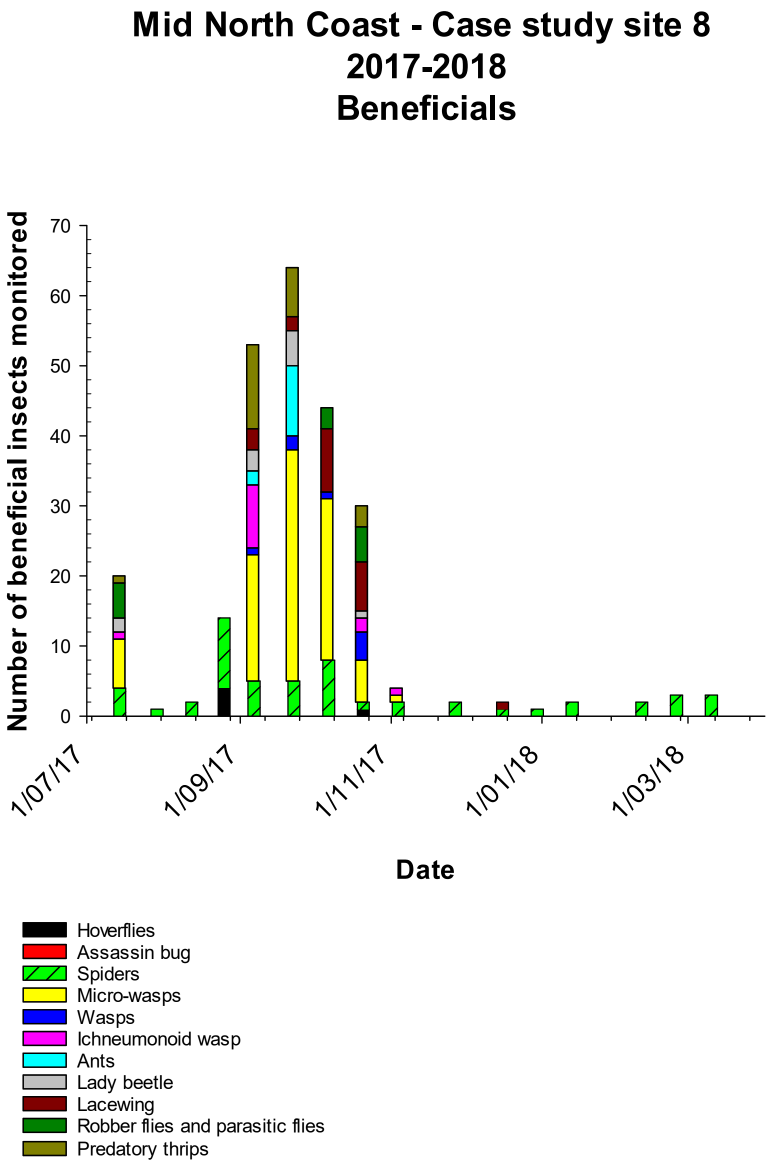
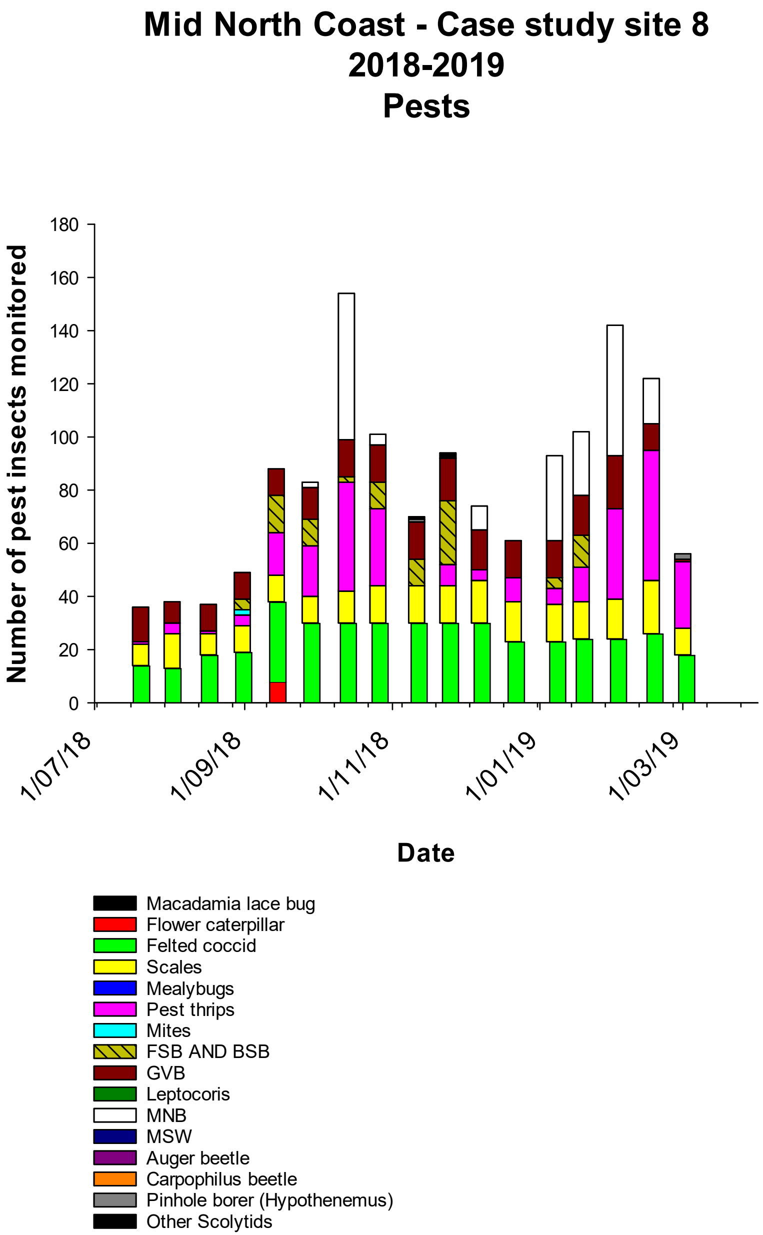


Figure 2.2.1.29.: Pest and beneficials in the Mid North Coast region at case study site 8 during the 2017-2018 season



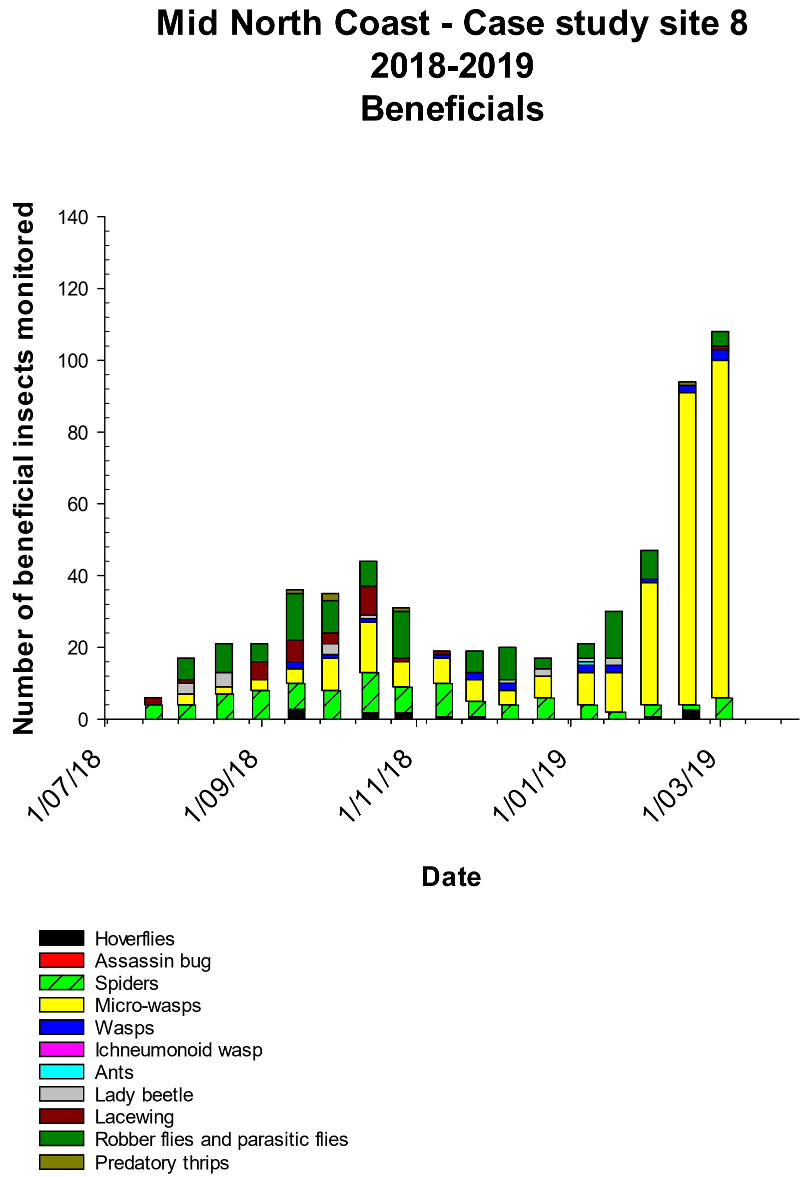
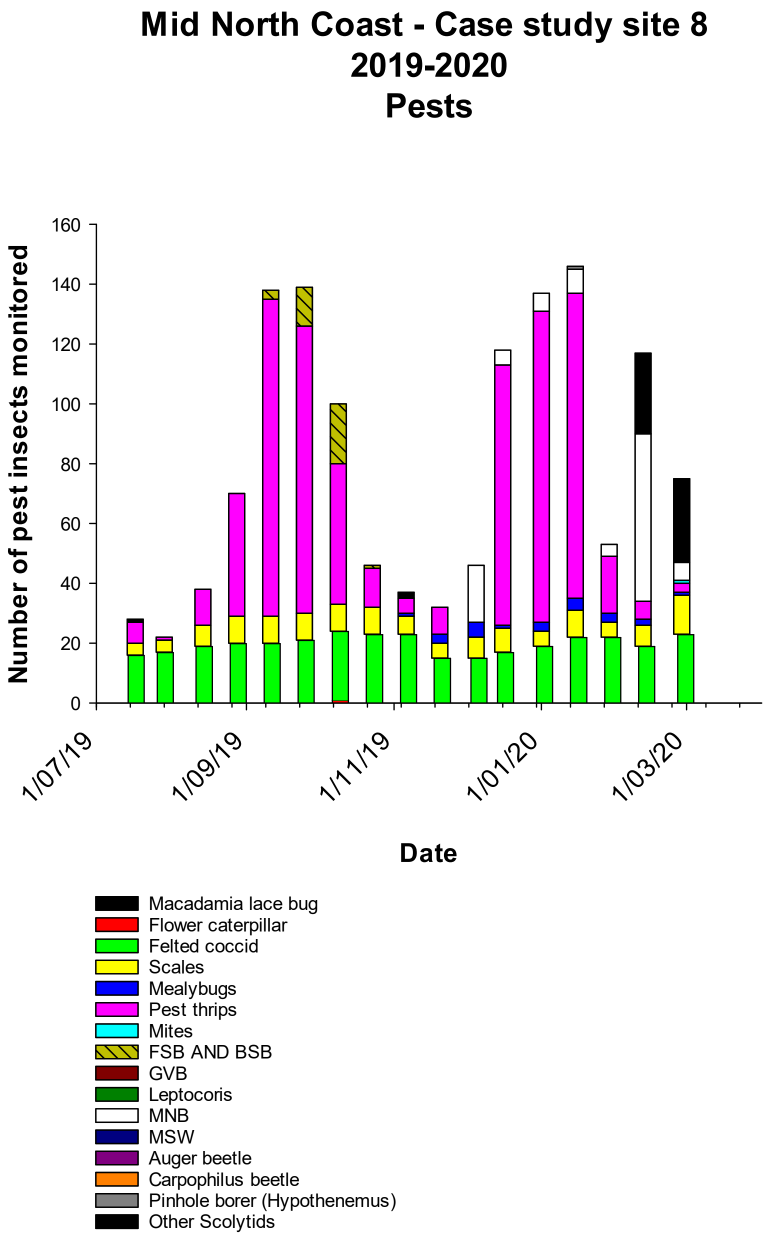


Figure 2.2.1.30.: Pest and beneficials in the Mid North Coast region at case study site 8 during the 2018–2019 season



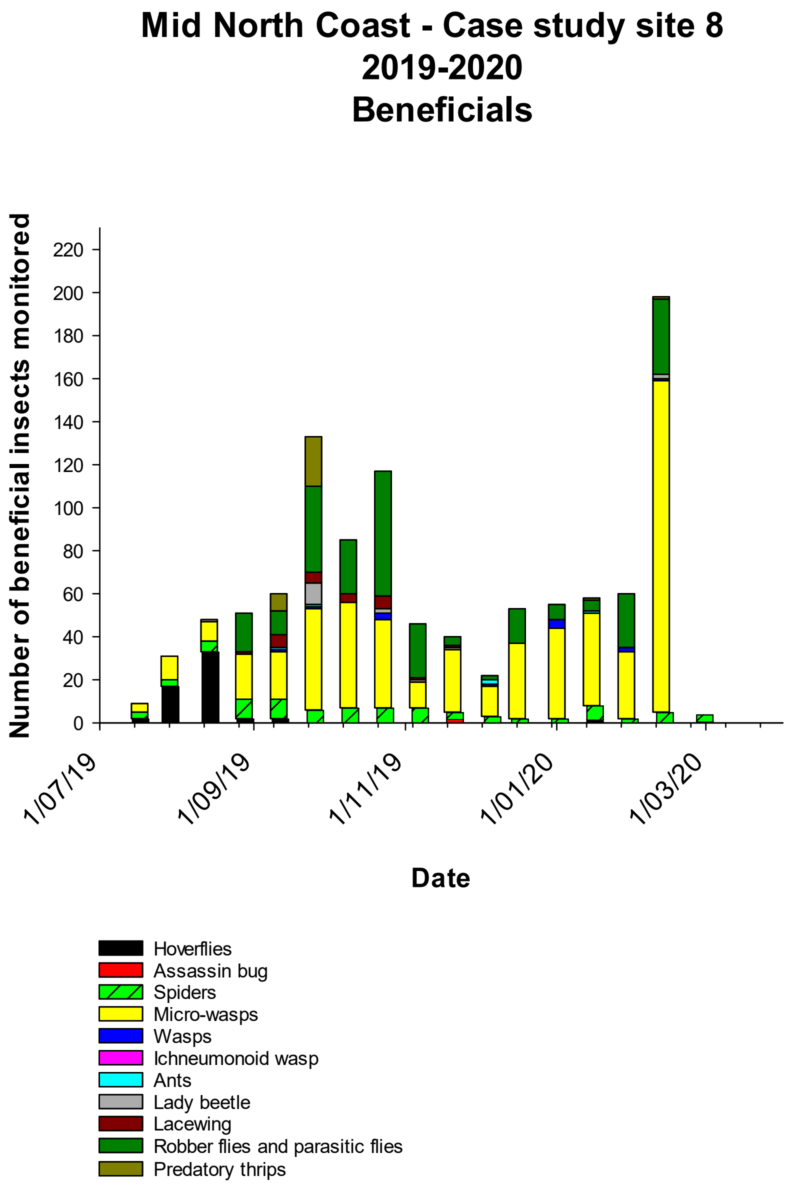
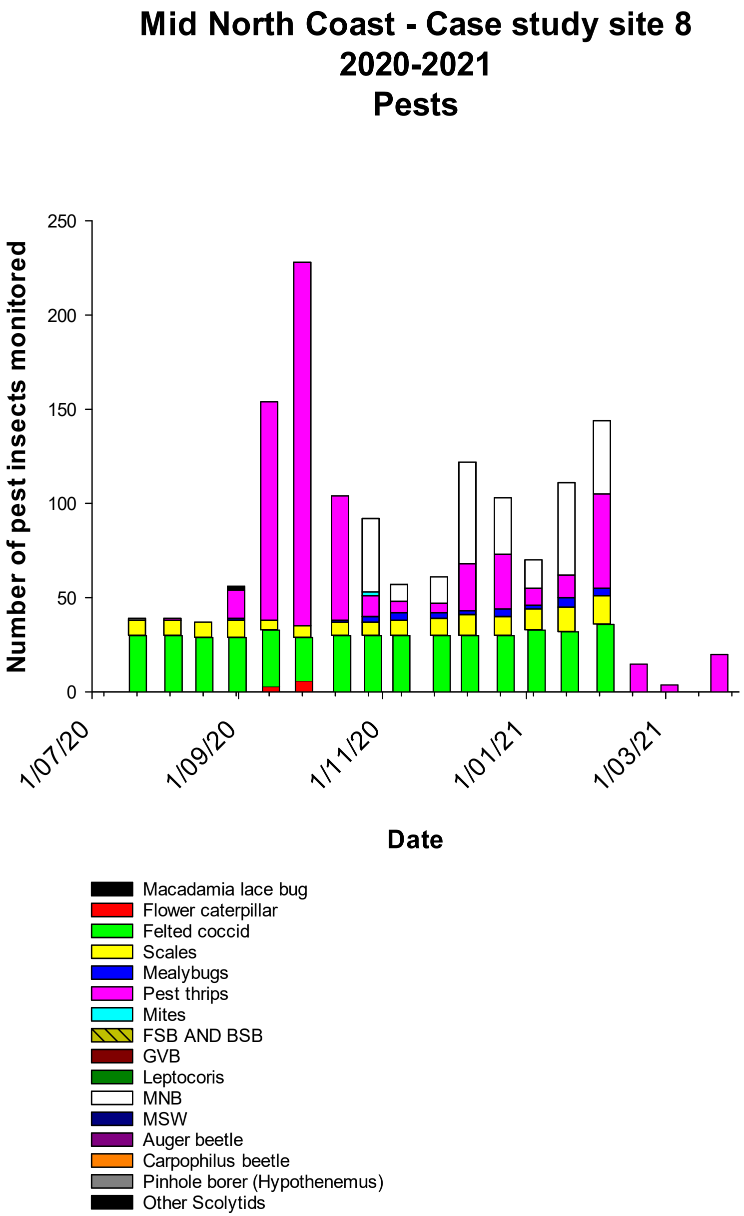


Figure 2.2.1.31.: Pest and beneficials in the Mid North Coast region at case study site 8 during the 2019–2020 season



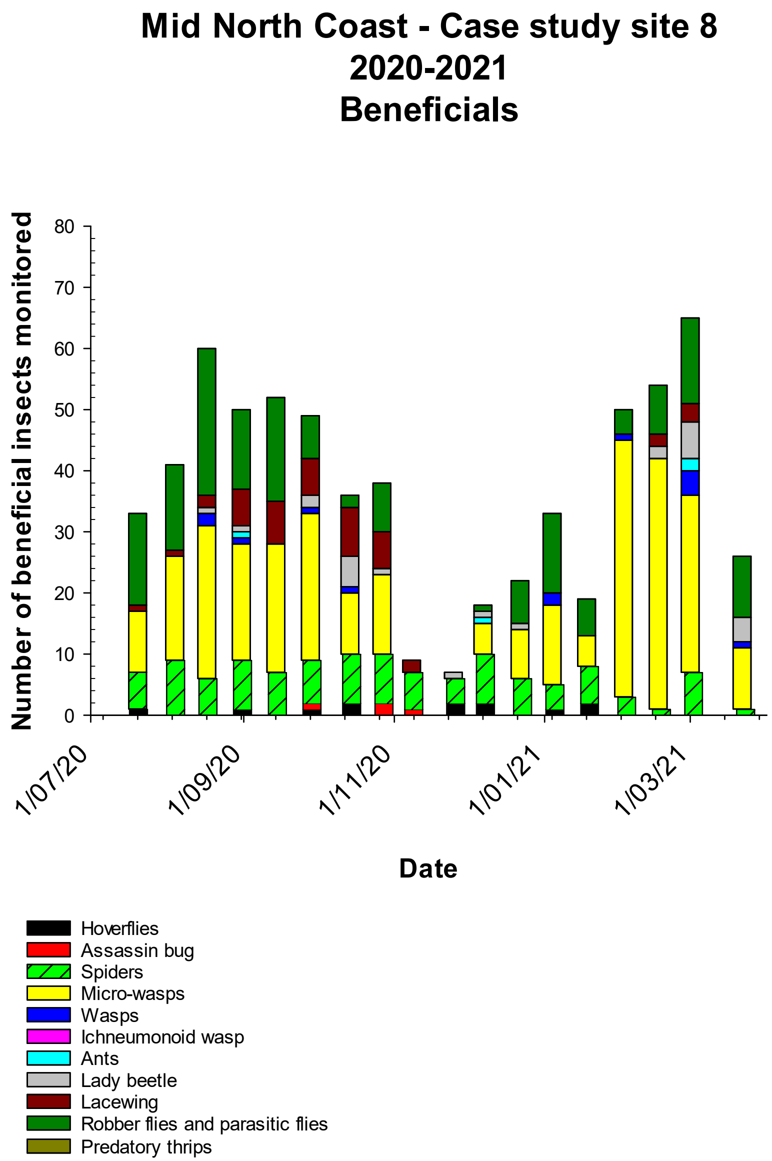


Figure 2.2.1.32.: Pest and beneficials in the Mid North Coast region at case study site 8 during the 2020–2021 season

Table 2.2.1.13.: Key points from Pest and beneficials in the Mid North Coast region during the 2017-2018 season

	Pest and beneficial populations and treatments in the Mid North Coast region - Key points	
	Pests (Table 2.2.1.25.)	**Beneficials (Table 2.2.1.25.)**
Case study site 7 2017-2018	Macadamia lace bug, felted coccid and low levels of scales were recorded throughout the season. Thrips populations increased in September. Pests were managed with two applications of natural pyrethrins. Fruit spotting bugs and macadamia nut borer were managed with several releases of *Anastatus* and MacTrix (Figure 4 and Table 1.2.2.7.). Highest Fruit spotting bug numbers were recorded in October, decreasing in November. Macadamia nut borer numbers were highest between December and February.	Beneficials were recoded throughout the season mostly at low numbers. Populations of spiders were always present and probably contributed to the management of Fruit spotting bugs. Larger numbers of ants were recorded in October. The numbers of micro-wasps recorded stayed low, despite several releases of *Anastatus* and MacTrix (Figure 4 and Table 1.2.2.7.).
	Pests (Table 2.2.1.29.)	**Beneficials (Table 2.2.1.29.)**
Case study site 8 2017-2018	Numbers of different pests recoded at case study site 8, followed a similar pattern to the ones on case study site 7. Macadamia nut borer numbers recorded were a bit higher on this site. Fruit spotting bugs and macadamia nut borer were managed with an acephate and a beta-cyfluthrin application in November and a second beta-cyfluthrin application in December (Figure 4 and Table 1.2.2.8.). Fruit spotting bug numbers decreased, but macadamia nut borer numbers stated to decrease with the MacTrix releases in December and January (Figure 4 and Table 1.2.2.8.).	
	Pest and beneficial populations and treatments in the Mid North Coast region - Key points	
Harvest summary	The percentage of MNB tunnels on husk was higher on case study site 7 (Table 2.2.1.). The percentage of nuts with felted coccid and scales on husk was higher in case study site 8, possibly due to the beta-cyfluthrin application (Table 2.2.1. and Figure 2.2.2.7.). The percentage of FSB damage in kernel was much higher in case study site 7 which could not be prevented by numerous releases of *Anastatus*. Immaturity was also higher in case study site 7. The yield and percentage of sound kernel was lower in case study site 7 due to the effect of particularly Fruit spotting bug (Table 2.2.1. and Figure 2.2.2.7.).	

Table 2.2.1.14.: Key points from Pest and beneficials in the Mid North Coast region during the 2018–2019 season

	Pest and beneficial populations and treatments in the Mid North Coast region - Key points	
	Pests (Table 2.2.1.26.)	**Beneficials (Table 2.2.1.26.)**
Case study site 7 2018–2019	As in the previous season, macadamia lace bug, felted coccid and low levels of scales were recorded throughout the season. Thrip populations increased in September/October and then again in February. From September onwards Fruit spotting bugs and green vegetable bugs were recorded at various levels. Macadamia nut borer records were sporadic, in October and then again in February. Pests were managed with a pyrethrin application at the then of September and repeated releases of different beneficials (lacewings, *Montdorensis* mites, MacTrix and *Anastatus*) (Figure 4 and Table 1.2.2.7.). Lacewings were released in August and September (Figure 4 and Table 1.2.2.7.). Macadamia lace bug numbers recorded in August were low during the time of lacewing releases. MacTrix releases kept macadamia nut borer populations down (Figure 4 and Table 1.2.2.7.).	There was a high diversity of beneficials recorded that was present throughout the season, including spiders, micro-wasps, robber and parasitic flies, lacewings, lady beetles, hoverflies, larger wasps and assessing bugs. Beneficial populations were not disrupted by applications of broad spectrum insecticides. Lacewing populations established with releases and persisted (Figure 4 and Table 1.2.2.7.). Micro-wasp populations established with MacTrix and *Anastatus*, but recorded levels of micro-wasps were not high considering the numbers of egg parasitoids released Figure 4 and Table 1.2.2.7.).
	Pests (Table 2.2.1.30.)	**Beneficials (Table 2.2.1.30.)**
Case study site 8 2018–2019	Populations of felted coccid, thrips, scales and green vegetable bug were recorded throughout the season. Low numbers of FSB were recorded between September and February. A beta-cyfluthrin application in December and a second one at the end of January managed this pest. (Figure 4 and Table 1.2.2.8.).	Low levels of spider and robber and parasitic fly populations were recoded throughout the season, but it reduced after the beta-cyfluthrin applications in December and January (Figure 4 and Table 1.2.2.8.). Populations of micro wasps were also present throughout the season, but they really increased in February, with the increase of macadamia nut borer numbers, after the last beta-cyfluthrin application had been applied and possibly due to favourable environmental factors (Figure 4 and Table 1.2.2.8.).

Table 2.2.1.14.: Key points from Pest and beneficials in the Mid North Coast region during the 2018–2019 season

	Pest and beneficial populations and treatments in the Mid North Coast region - Key points	
	Pests (Table 2.2.1.30.)	**Beneficials (Table 2.2.1.30.)**
Case study site 8 2018–2019	Macadamia nut borer numbers recorded were high in October and then again in January and February (Figure 4 and Table 1.2.2.8.). The beta-cyfluthrin applications in December and January and releases of MacTrix between mid-December and February reduced macadamia nut borer numbers (Figure 4 and Table 1.2.2.8.).	
Harvest summary	The percentage of nuts with clean husk was higher in case study site 8 (Table 2.2.1.). The percentage of husk spot was higher in case study site 7, as there was no treatment applied to manage the disease (Table 2.2.1. and Figure 2.2.2.7.). Fruit spotting bug damage was higher in case study site 7, which could not be prevented by several releases of *Anastatus* (Table 2.2.1.). The yield was higher in case study site 7, but the percentage of sound kernel recovery was higher on case study site 8 (Table 2.2.1. and Figure 2.2.2.7.).	

Table 2.2.1.15.: Key points from Pest and beneficials in the Mid North Coast region during the 2019–2020 season

	Pest and beneficial populations and treatments in the Mid North Coast region - Key points	
	Pests (Table 2.2.1.27.)	**Beneficials (Table 2.2.1.27.)**
Case study site 7 2018–2019	As in previous seasons, populations of felted coccid, thrips at various levels and scales at low levels were recorded throughout the season. Macadamia lace bug was recorded between July and January/ February, but numbers were highest during the flowering period in September. A reduction in canopy density in September most likely contributed to the reduction of the population of macadamia lace bug and also possibly Fruit spotting bug (Figure 4 and Table 1.2.2.8.). Fruit spotting bugs were recorded early in the season during September and October. Several releases of *Anastatus* were made between September and April to manage the pest (Figure 4 and Table 1.2.2.8.). Macadamia nut borer was present from December until the end of the monitoring season in March, but numbers were highest around February. MacTrix was released between December and the end of January to manage the pest (Figure 4 and Table 1.2.2.8.).	There was a good diversity of beneficials at different levels throughout the season and they were not disrupted by the use of broad spectrum insecticides (Figure 4 and Table 1.2.2.8.). The main groups of beneficials were spiders, micro wasps, lady beetles and robber and parasitic flies. Populations of micro-wasps increased with the releases of beneficials (*Anastatus* and MacTrix) (Figure 4 and Table 1.2.2.8.).
	Pests (Table 2.2.1.31.)	**Beneficials (Table 2.2.1.31.)**
Case study site 2019–2020	As in the previous season, populations of felted coccid, thrips and low levels of scales were recorded throughout the season. Thrips were present in high numbers in September and October and again during December and January. Fruit spotting bugs were recorded during October and managed by a sulfoxaflor application in early November. Macadamia nut borer was at different levels between December and March (Figure 4 and Table 1.2.2.8.). The beta-cyfluthrin applications in December and January and releases of MacTrix between mid-December and February reduced macadamia nut borer numbers (Figure 4 and Table 1.2.2.8.)..	Small populations of spiders and various levels of micro-wasps were the main groups of beneficials. Groups of beneficials (i.e. lady beetles, lacewings that were recorded in small numbers earlier, were highly reduced or disappeared the application of different insecticides (Figure 4 and Table 1.2.2.8.). Micro-wasp populations persisted due to several releases of MacTrix and *Anastatus*, but numbers increased in February, as MacTrix populations usually really increase in warm humid conditions once insecticide applications stopped (Figure 4 and Table 1.2.2.8.).

Table 2.2.1.15.: Key points from Pest and beneficials in the Mid North Coast region during the 2019–2020 season

	Pest and beneficial populations and treatments in the Mid North Coast region - Key points
Harvest summary	The percentage of nuts with clean husk was higher on case study site 8 (Table 2.2.1.). The percentage of nuts with felted coccid was higher on cast study site 8 due to the use of broad spectrum insecticides (Table 2.2.2.). The percentage of nuts with scolytid holes in husk was higher on case study site 8. The percentage of husk spot was higher on case study site 7, as there was no treatment. The percentage of kernel with Fruit spotting bug and with *Leptocoris* bug damage was higher on case study site 7 (Table 2.2.2.). *Anastatus* releases were not sufficient for management of fruit spotting bugs (Table 2.2.2.). The yield and sound kernel recovery were higher on case study site 8 (Table 2.2.2. and Figure 2.2.2.8.).

Table 2.2.1.16.: Key points from Pest and beneficials in the Mid North Coast region during the 2020–2021 season

	Pest and beneficial populations and treatments in the Mid North Coast region - Key points	
	Pests (Table 2.2.1.28.)	**Beneficials (Table 2.2.1.28.)**
Case study site 7 2020–2021	Again, felted coccid, macadamia lace bug, thrips, macadamia nut borer and low level of scale were main pests recorded at this site. Felted coccid numbers were fairly constant during the season. A pyrethrin application September for management of macadamia lace bug (Figure 4 and Table 1.2.2.8.). Regular releases of *Anastatus* for management of Fruit spotting bug and regular releases of MacTrix was the pest management strategy at this site (Figure 4 and Table 1.2.2.8.). Numbers of macadamia nut borer recorded were fairly low.	Again, a high diversity of beneficials and good numbers were recorded. Spiders, lacewings, robber and parasitic flies, lady beetles and micro-wasps were the main groups of beneficials. Micro-wasp populations were fluctuating but mostly present throughout the season (Figure 4 and Table 1.2.2.8.). There were no micro-wasps recorded during November and early December, possibly due to some environmental factors. Numbers increased again with follow up releases of MacTrix and *Anastatus* (Figure 4 and Table 1.2.2.8.).
	Pests (Table 2.2.1.32.)	**Beneficials (Table 2.2.1.32.)**
Case study site 8 2020–2021	Felted coccid, thrips, macadamia nut borer and low level of scale were main pests recorded at this site. Felted coccid numbers were mostly constant during the season. An application of beta-cyfluthrin in December and a follow up application in December for management of Fruit spotting bugs and macadamia nut borer reduced macadamia nut borer numbers recorded (Figure 4 and Table 1.2.2.8.). Regular releases of MacTrix also kept macadamia nut borer numbers in check (Figure 4 and Table 1.2.2.8.).	Spiders, micro-wasps, robber and parasitic flies were the main groups of beneficials that were more or less present throughout the season. In addition, there were also smaller numbers of lacewings and lady beetles Numbers of micro-wasps recorded fluctuated and as on case study site 7, there were none during November and early December, possibly due to some environmental factors. Applications of beta-cyfluthrin in November and December also effected in the micro-wasp populations (Figure 4 and Table 1.2.2.8.). With more releases of MacTrix in January and February micro-wasp numbers recorded increased again Figure 4 and Table 1.2.2.8.).
	Pest and beneficial populations and treatments in the Mid North Coast region - Key points	
Harvest summary	The percentage of nuts with clean husk was higher at case study site 8 (Table 2.2.2.). The percentage of nuts with macadamia nut borer tunnels on husk and with husk spot was higher on case study site 7 (Table 2.2.2.). There was no husk spot treatment applied at this site. The percentage of nuts with thrips on husk was higher on case study site 8 (Table 2.2.2.). Fruit spotting bug damage in kernel was higher and the percentage of sounds kernel (due to Fruit spotting bug damage) was lower on case study site 7 (Table 2.2.2. and Figure 2.2.2.8.). Percentage of reject other than immaturity and insect damage was higher on case study site 8 (Table 2.2.2. and Figure 2.2.2.8.). Yields were similar at both sites but (Table 2.2.2. and Figure 2.2.2.8.).	

2.2.2. Beetle trap monitoring results

Detailed results from scolytid beetle trapping on a commercial farm at Peachester, QLD are shown in Tables 2.2.2.1. to 2.2.2. The spin treatment reduced the number of scolytid beetles, as it most likely reduced the fungal food source for the beetle larvae.

Table 2.2.2.1.: Paired branch trial in cv.344 trees at Peachester QLD using approximately 100 ml applied to 5-700mm branch surface and comparing scolytid tunnel attacks over the period from February – May 2020. Treated 23/2/21. Avatar® applied at MSW rate Altacor® applied at Fall army worm rate, Spin Flo® used at the husk spot rate.

Treatment	**Treatment number**	**Number of tree replicates**	**8-March 2020**		**27-April 2020**		**Paired samples**	**Paired samples**
			Blank	**Treated**	**Blank**	**Treated**	**Untreated**	**Treated**
50ml/ 100L Spin Flo® + Designer® 10ml/ 100L	1	9	2	3	14	7	16	10
25g Avatar®+5ml/ 100L Spin Flo® + Designer® 10 ml/ 100L	2	9	2	1	13	7	15	8
25g Avatar®+ Designer® 10ml/ 100L	3	9	4	9	18	18	22	27
18g Altacor®+ Designer®10ml/ 100L	4	9	7	7	12	11	19	18
18g Altacor®+ 50ml/100L Spin Flo® + Designer® 10ml/ 100L	5	9	3	0	12	8	15	8
100ml/ 100L Ethrel® (480) + Designer® 10ml/ 100L	6	9	3	12	8	26	11	38
	Totals	54	21	32	77	77	98	109

Table 2.2.2.2.: Comparative lure and trap catches of the various scolytid species within the Peachester (QLD) block during the period February – July 2021. By far the most common in the tunnels is *Cryphalus subcompactus* (macadamia bark beetle) which is not usually in the traps.

Lure type	**Scolytid**							**Nitilidae**	**Bostrychidae**
	Xylosandrus	***Hypothenemus***	***Euwallacea***	***Xyleborus***	***Cnestus***	***Cryphalus***	**Total Scolytid**	**Carpophilus**	**Auger Beetle**
Alpha -EUW*		1	1				2		
Ambro	323	126	3		7	5	467		1
EUW-Canada*	1	1	4				6		
Flight card	1		1				2		
Methanol: Ethanol	22	29	3	1		2	58	4	
Grand total	347	57	12	1	7	7	535	4	1

*Alpha -EUW = *Euwallacea* lure from AlphaScents US

*EUW-Canada = *Euwallacea* lure from Synergy Semicochemicals, Canada

Table 2.2.2.3.: Comparative lure and trap catches of the various beetle types at Caniaba during period September – December 2020. This area was drought affected from January 2019 until February 2020 tree death has occurred throughout the trapping area of the sprayed macadamia orchard. The bulk of the scolytid capture was *Cnestes solidus.* Significant bostrychid flights in the ME traps (Methanol-Ethanol lure: (3:1)) were detected in September and late October, and the cerambycid beetle traps caught more cerambycids than our scolytid traps. Genus *Syllitus sp.*, *Mesolita sp., Bethelium sp., Callidium sp.*, and *Thoris* sp. were in the cerambycid traps no *Tricheops* was collected during this trapping but was caught on light traps early in spring.

	15/09/2020	29/09/2020	15/10/2020	29/10/2020	10/11/2020	23/11/2020	8/12/2020	21/12/2020	Grand Total
Caniaba INRAE lure	Macadamia sprayed								
Bostrychids	9	28	3	0	0	2	0	0	42
Carpophilus		0	0						0
Cerambycid beetles	1	1	5	3		4	2	2	18
Cnestus solidus	27	45	29	6	10	48	5	1	171
Total scolytids	28	45	29	6	10	48	5	2	173
Caniaba Ambro lure*	Macadamia sprayed								
Bostrychids	1	2	1	4	2	1	1		12
Carpophilus		1					1		2
Cerambycid beetles			1			1	1		3
Cnestus solidus	12	29	26	14	26	53	19	4	183
Total scolytids	17	36	26	16	26	53	20	4	198
Caniaba ME lure*	Macadamia sprayed								
Bostrychids	43	21		34	15	5	3	3	124
Carpophilus	1	2					1		4
Cerambycid beetles		5					1		6
Total scolytids	4	10	1					1	16

*INRAE lure = longicorn beetle lure provided by INRAE, France
*Ambro lure= ambrosia beetle lure from AlphaScents, US
*ME lures = methanol-ethanol mix (3:1)

Different beetles trapped in scolytid and cerambycid pheromone traps at Caniaba and CTH Alstonville are listed in Table 2.2.2.3. and 2.2.2.4. *Cnestus solidus* was the dominant scolytid species caught at Caniaba and Ambro and INFRAE lures caught the largest numbers. Peaks were in late September and November. At CTH *Cnestus solidus* was the dominant scolytid species, but in much lower numbers and also the INRAE lure caught higher numbers of bostrychids at CTH.

Table 2.2.2.4.: Comparative lure and trap catches of the various beetle types at CTH Alstonville during period September – December 2020. Far less beetle activity in the sprayed macadamia orchard, bulk of the scolytid capture was *Cnestes solidus.* Significant bostrychid flights in the rainforest margins and the cerambycid beetle traps caught more than our scolytid traps. Genus *Syllitus* sp., *Mesolita* sp, *Bethelium* sp, *Callidium* sp. and *Thoris* sp. were in the cerambycid trap; no *Tricheops* was collected during this trapping.

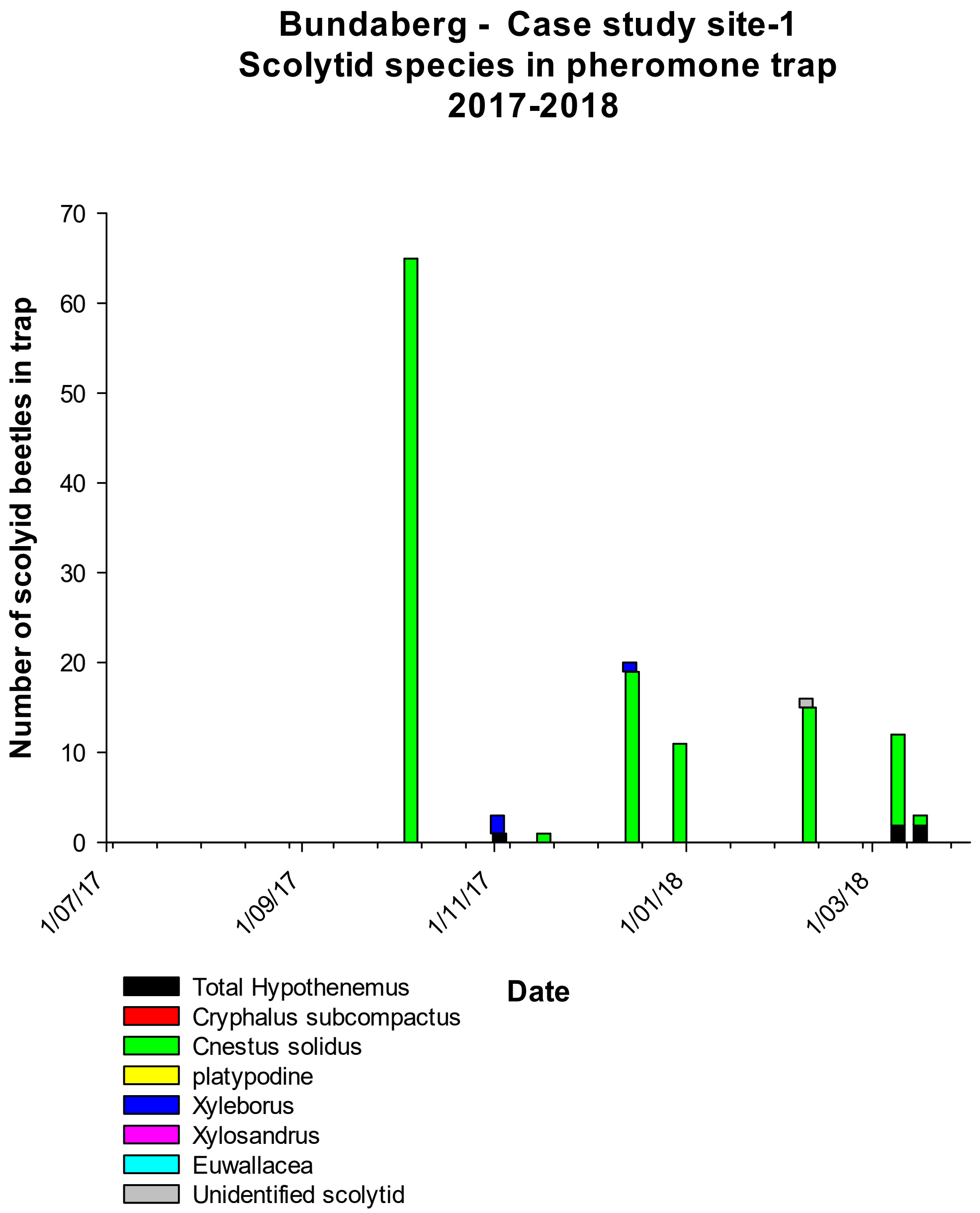
	14/09/2020	28/09/2020	12/10/2020	26/10/2020	9/11/2020	23/11/2020	7/12/2020	21/12/2020	**Grand Total**
CTH INRAE lure	Macadamia sprayed								
Bostrychids	0	0	0	0	0	0	0	0	0
Carpophilus	0	0	0						0
Cerambycid beetles	0	1	3	0	0	0	0	0	4
Cnestus solidus	0	0	0						0
Total scolytids	0	2	1	1	1	7	2	0	14
CTH Ambro lure	Macadamia sprayed								
Bostrychids	0	0	0	0	0	0	0	0	0
Carpophilus									
Cerambycid beetles	0	0	0	0	0	0	0	0	0
Cnestus solidus	7	8	1	2	2			1	21
Total scolytids	9	8	2	2	2	1	1	1	26
CTH ME lure	Macadamia sprayed								
Total scolytids	14	17	18	8	5	7	18	3	90
Cerambycid beetles			1						1
Bostrychids									0
Carpophilus							1	3	4
CTH INRAE lure	Rainforest edge Cedar								
	14/09/2020	28/09/2020	12/10/2020	26/10/2020	9/11/2020	23/11/2020	7/12/2020	21/12/2020	**Grand Total**
Bostrychids	3	113	122	22	16	1	16	2	295
Carpophilus	0	0	0		2			1	3
Cerambycid beetles	0	6	3	1	2	5	1	3	21
Cnestus solidus	17	78	21	17	4	2	2		141
Total scolytids	17	98	56	46	23	27	25	11	303

*INRAE lure = longicorn beetle lure provided by INRAE, France
*Ambro lure= ambrosia beetle lure from AlphaScents, US
*ME lures = methanol-ethanol mix (3:1)

Table 2.2.2.5.: Light trapping catches of different scarab beetle species at Caniaba and CTH Alstonville in 2020

Light trapping	**Caniaba**					**CTH Alstonville**				
Spring 2020	**Argentine scarab**	***Rhopaea* sp.**	**Scarabs**	**Cerambycids**	***Tricheops* sp.**	**Argentine scarab**	***Rhopaea* sp.**	**Scarabs**	**Cerambycids**	***Tricheops* sp.**
21-29/09/2020			34		1					
1-6/10/2020			28							
8-15/10/2020			25					2		
20/10/2020			4							
22/10/2020			122							
23/10/2020			5							
26/10/2020			4							
27/10/2020			19							
29/10/2020			57							
2/11/2020	1		6					3		
6/11/2020			10							
10/11/2020	10		102							
12/11/2020						1	3	28	1	
14/11/2020	3		9							
15/11/2020	9		18							
22/11/2020	2		2							
23/11/2020	26		68	3						
25/11/2020			1			7	67	95		
29/11/2020	6		7							
7/12/2020	13		14							
8/12/2020	7		32							
9/12/2020	2		8							
21/12/2020				1						
Grand Total	79	0	576	4	1	8	70	128	1	

– Results from light trapping at Caniaba and CTH Alstonville are shown in Table 2.2.2.5. Argentine scarabs were the dominant species at Caniaba on black soil and *Rhopaea* sp. were dominant at CTH Alstonville on red soil.



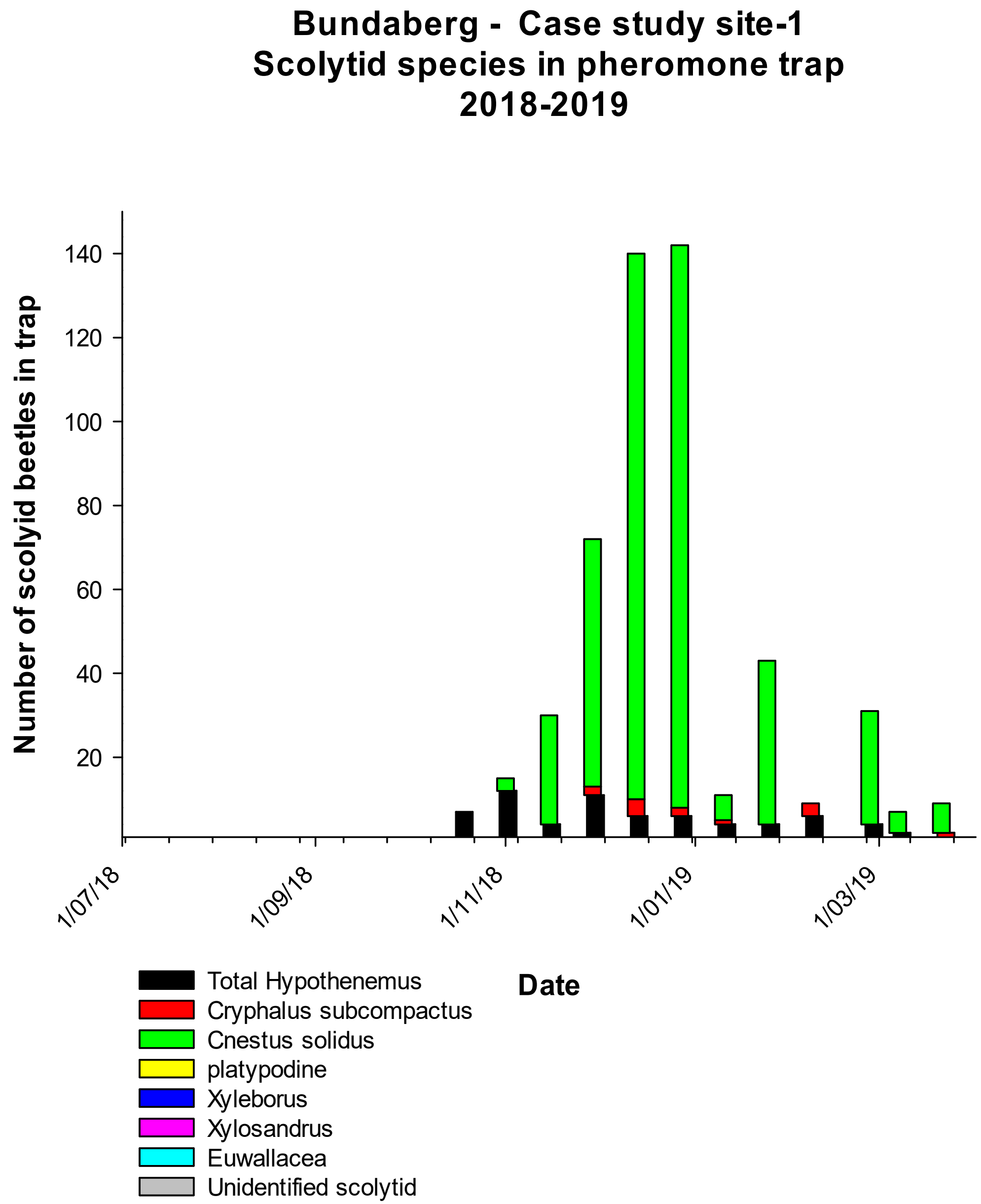
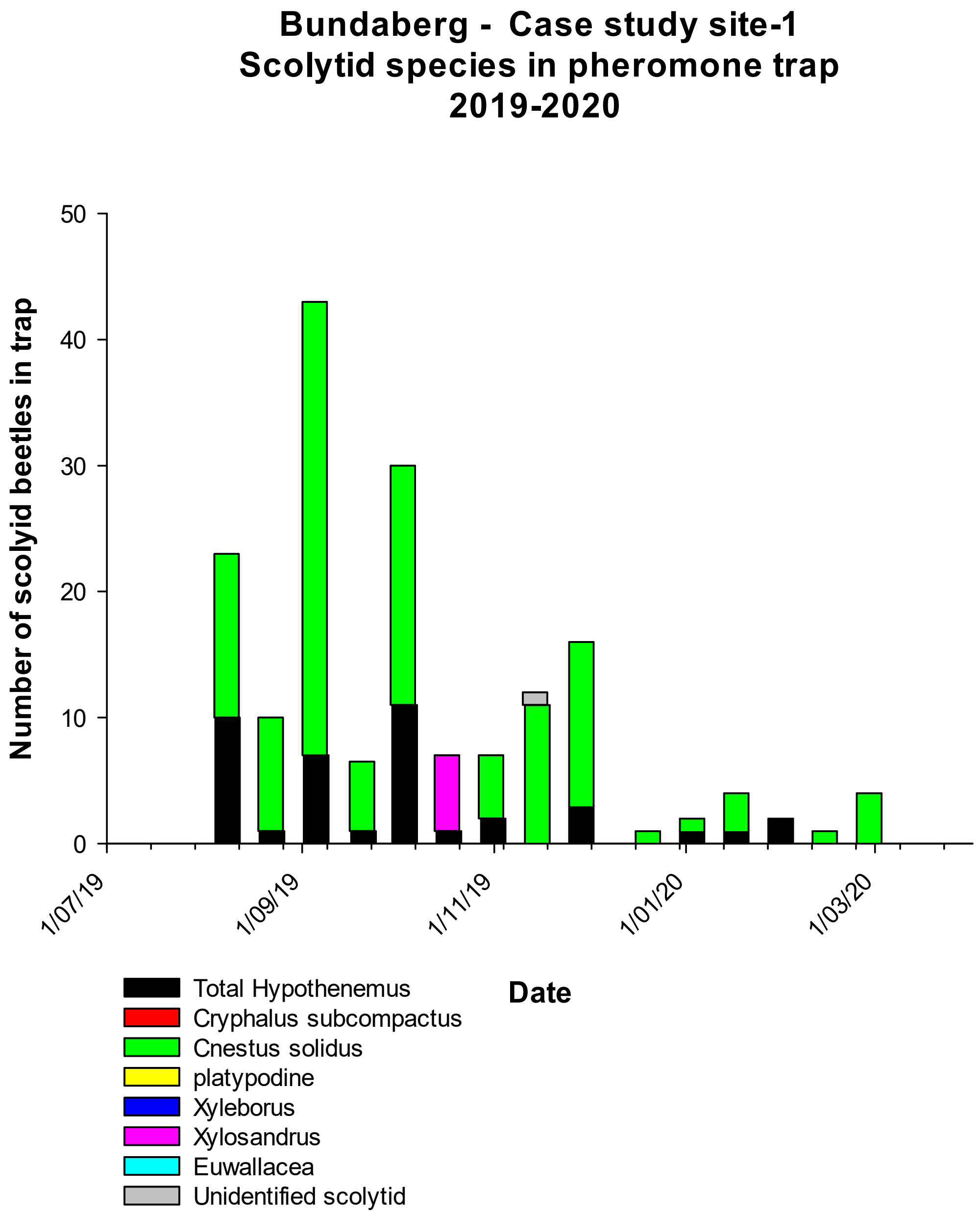


Figure 2.2.2.1.: Scolytid beetle trapping in the Central Queensland Region case study site-1 - 2017-2018 and 2018–2019



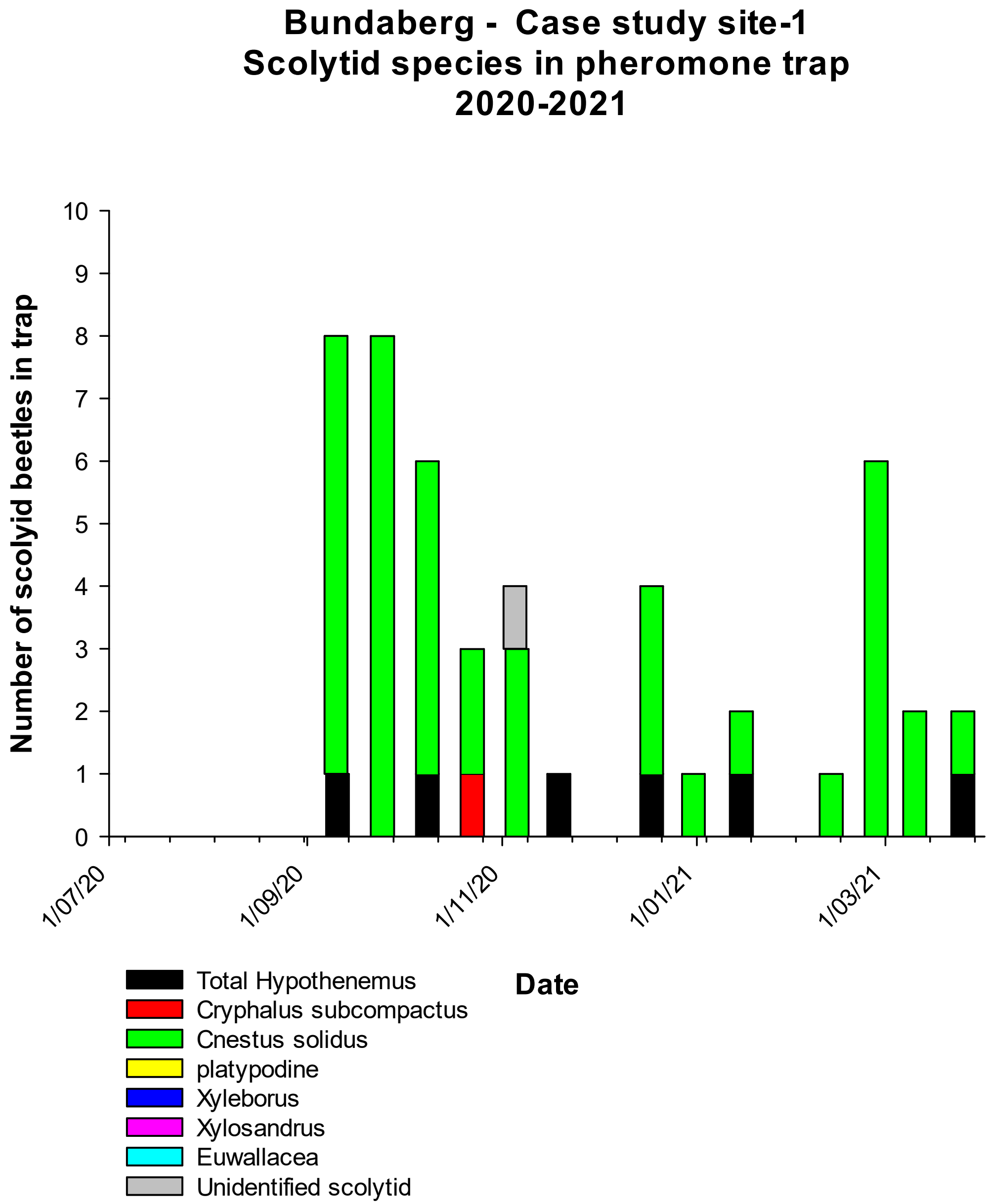
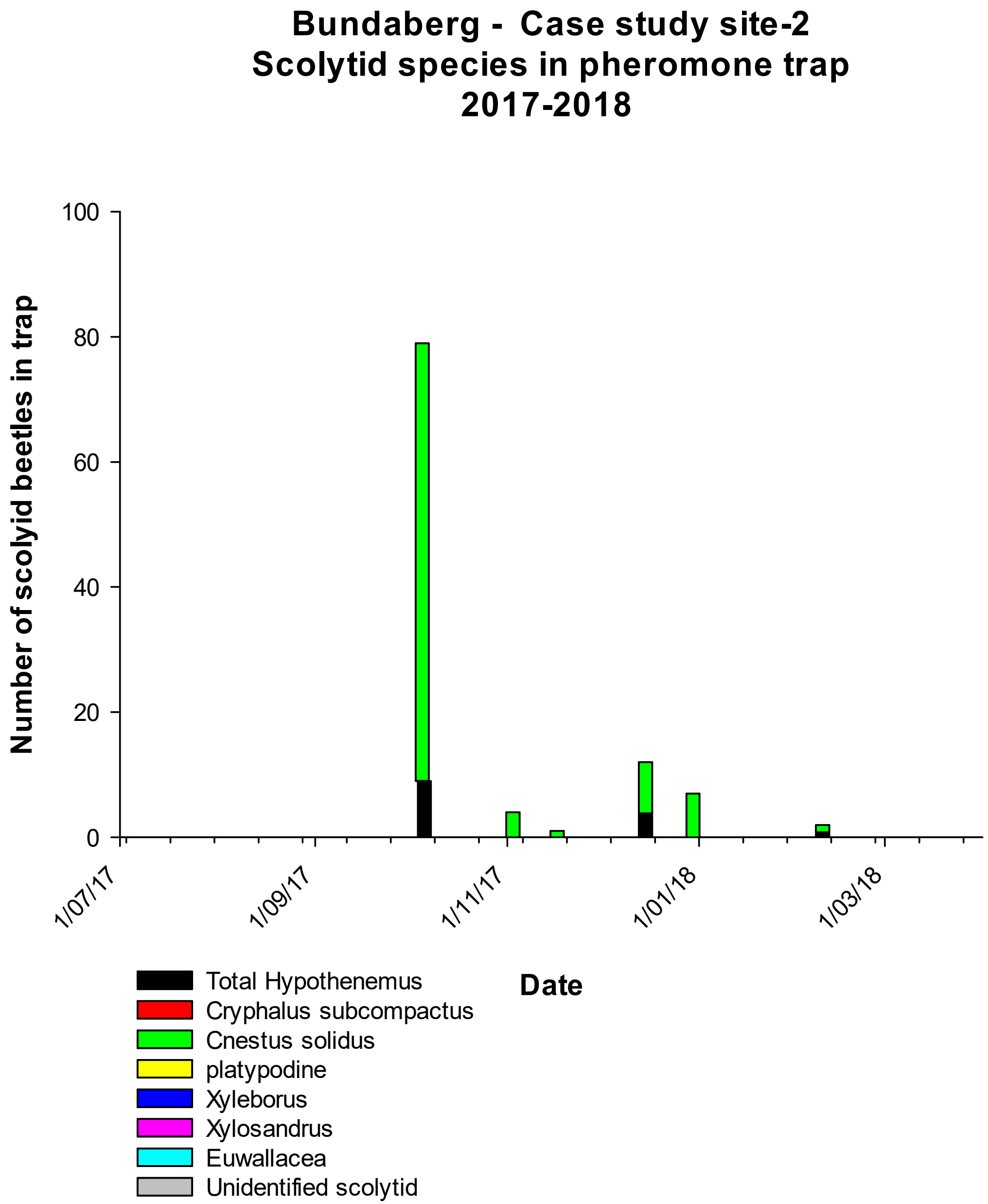


Figure 2.2.2.2.: Scolytid beetle trapping in the Central Queensland Region case study site-1 - 2019–2020 and 2020–2021



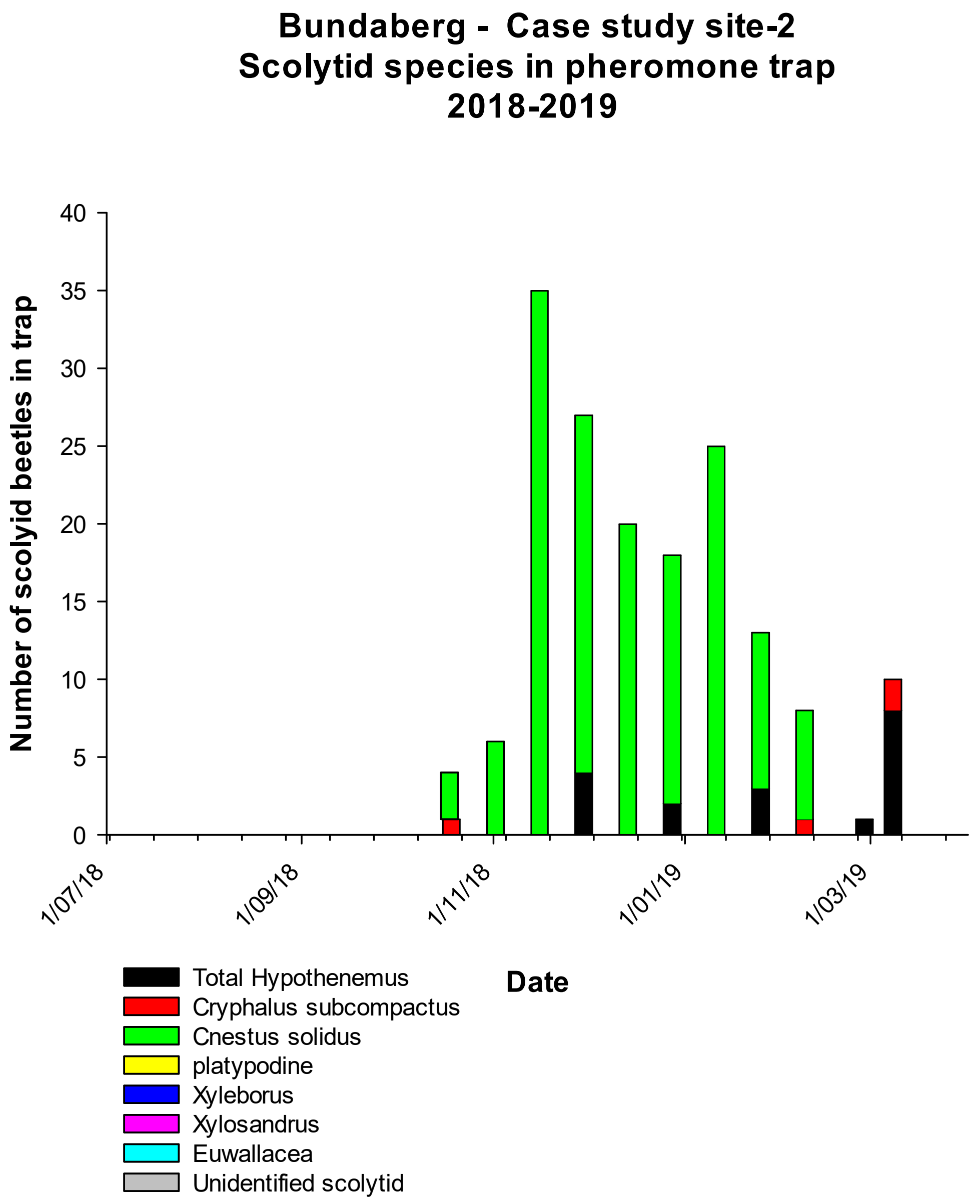
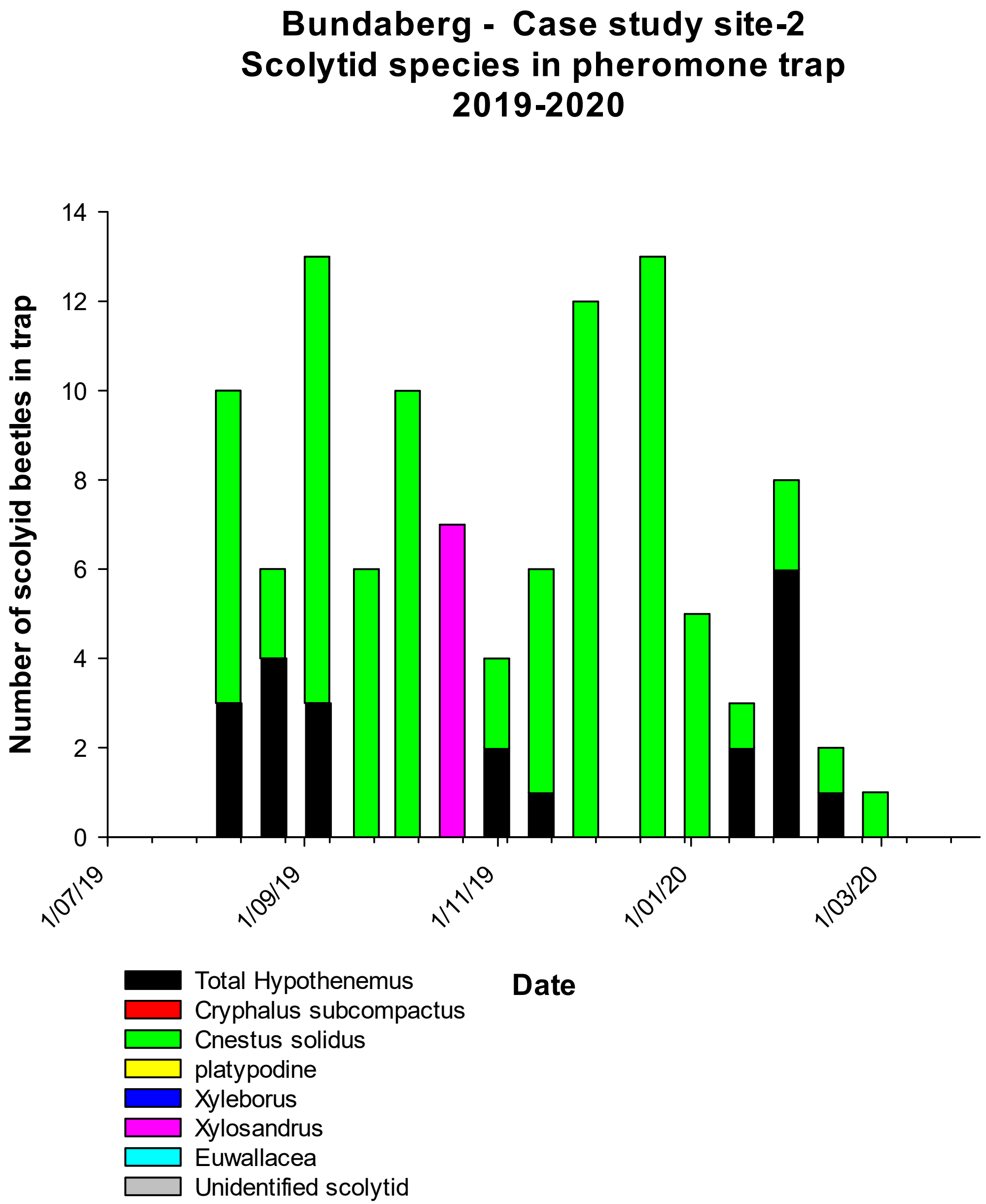


Figure 2.2.2.3.: Scolytid beetle trapping in the Central Queensland Region case study site-2 - 2017-2018 and 2018–2019



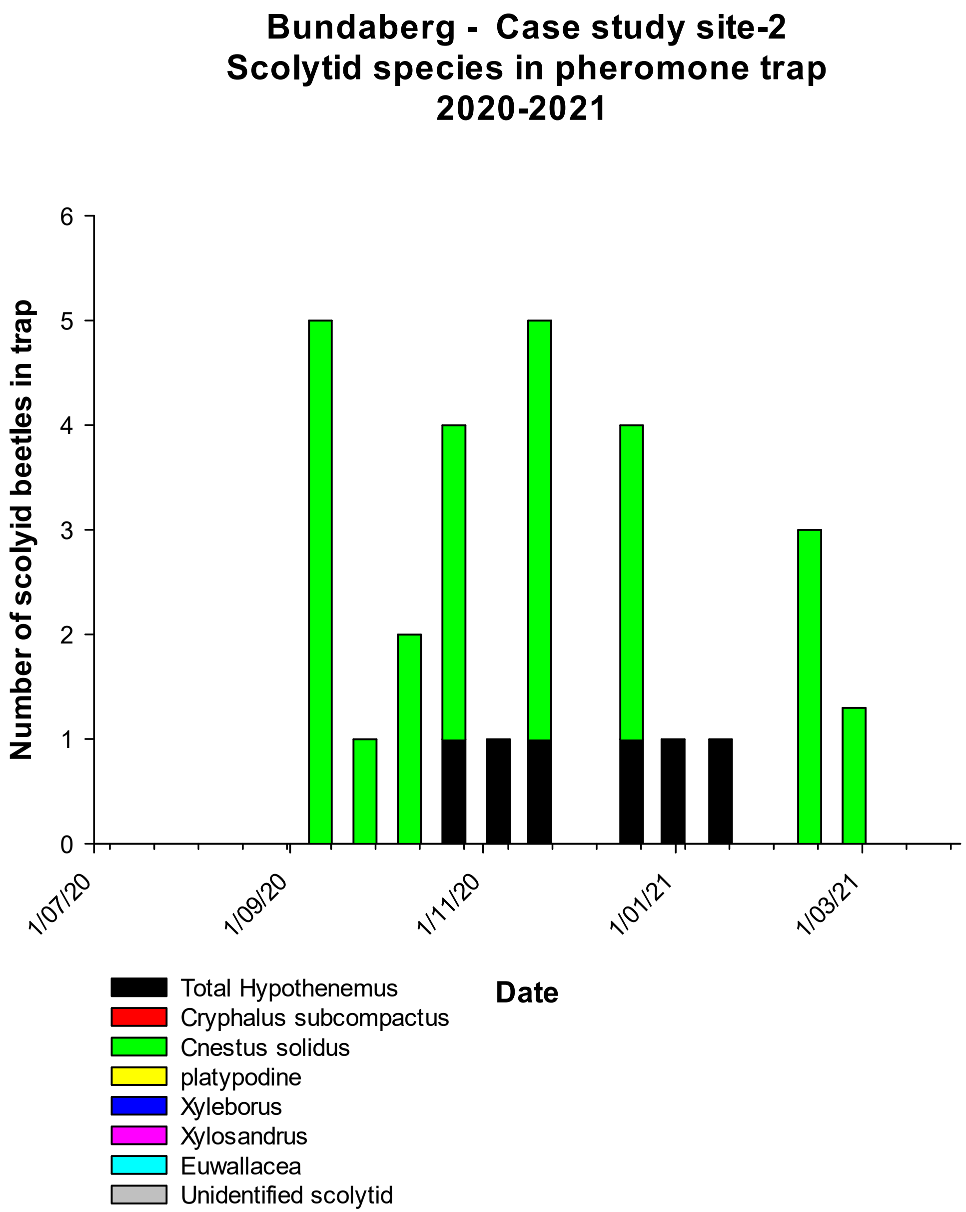
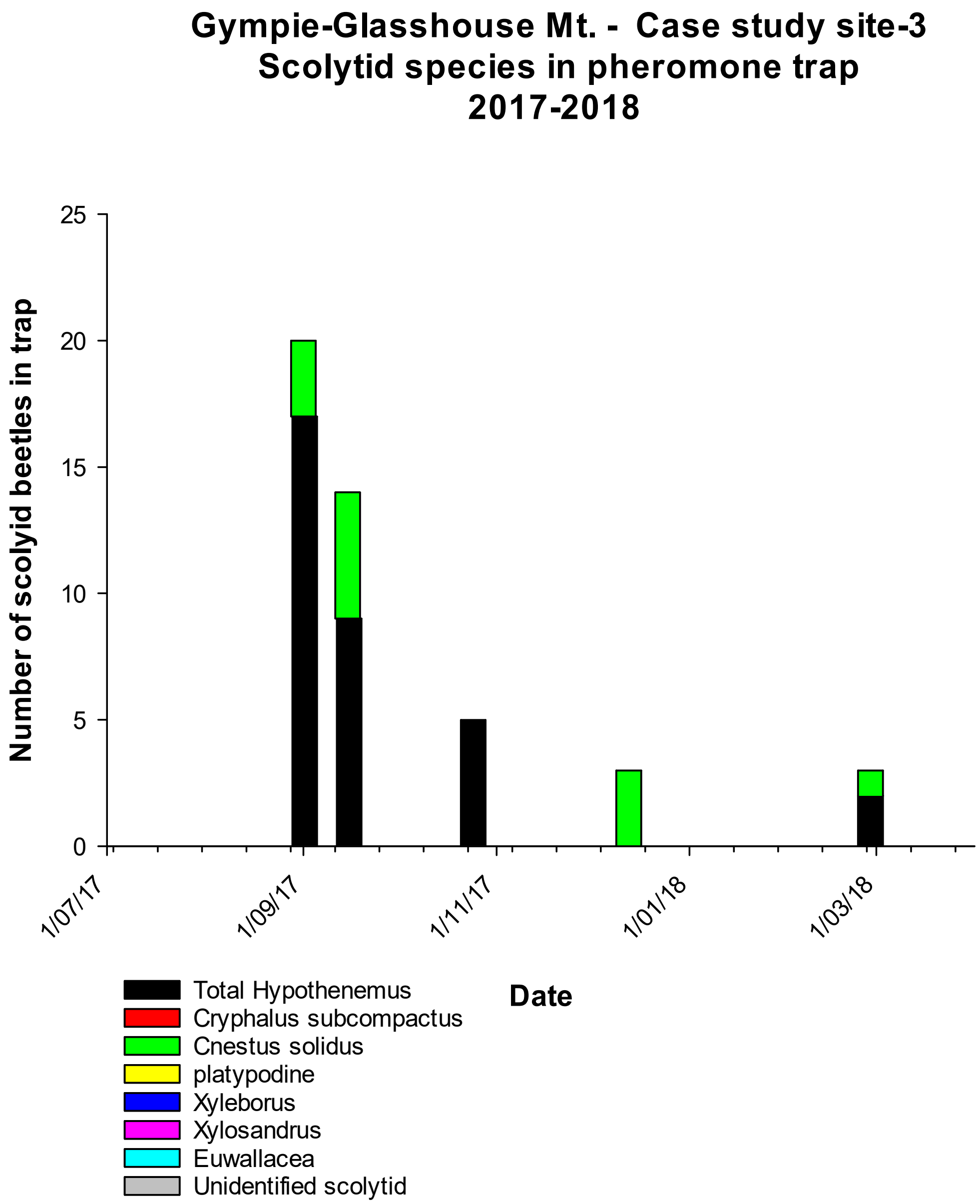


Figure 2.2.2.4.: Scolytid beetle trapping in the Central Queensland Region case study site-2 - 2019–2020 and 2020–2021

Table: 2.2.2.1.: Scolytid beetles trapped at case study sites in the Central Queensland region between 2017 and 2021

Scolytid beetles at case study sites in the Central Queensland region		
Season	**Case study site1**	**Case study site2**
2017-2018	Mainly the trunk borer beetle *Cnestus solidus* for the whole season, with peak in October.	Larger numbers of *Cnestus solidus* were caught in October otherwise only small numbers of *Cnestus solidus* and pinhole borer (*Hypothenemus* spp.).
2018–2019	Scolytids, mainly *Cnestus solidus* were present between October and April, with a peak in December and January. Numbers were twice as high as in the previous season. Bark beetles (*Cryphalus subcompactus*) and pinhole borer (*Hypothenemus* spp.) were present caught at low levels.	*Cnestus solidus* was caught between October and February, with a peak in December. Low number of the pinhole borer and the bark beetle were also caught, particularly around March.
2019–2020	Beetles were caught throughout most of the season, but in lower numbers. Another trunk borer *Xylosandrus* sp. was also present during this season.	Low numbers of beetles were caught, mainly *Cnestus solidus*, with a peak in December and January. There were also low numbers of pinhole borer and some *Xylosandrus* sp. were caught in November.
2020–2021	Beetle numbers were very low, with mainly *Cnestus solidus*, peaking in numbers in October and March and some pinhole borer were also caught throughout the season.	There were only very few numbers of beetles caught. Again, *Cnestus solidus* was the dominating species, with a peak in September. Individual pinhole borer were caught between November and February.
Comments	*Cnestus solidus* was the dominant species at both sites, followed by the pinhole borer (*Hypothenemus* spp.). 2018–2019 was the season with the highest numbers. Case study site 1 generally had the higher numbers with exception of the 2017-2018 season. This season was also the season with the highest beetle numbers caught.	



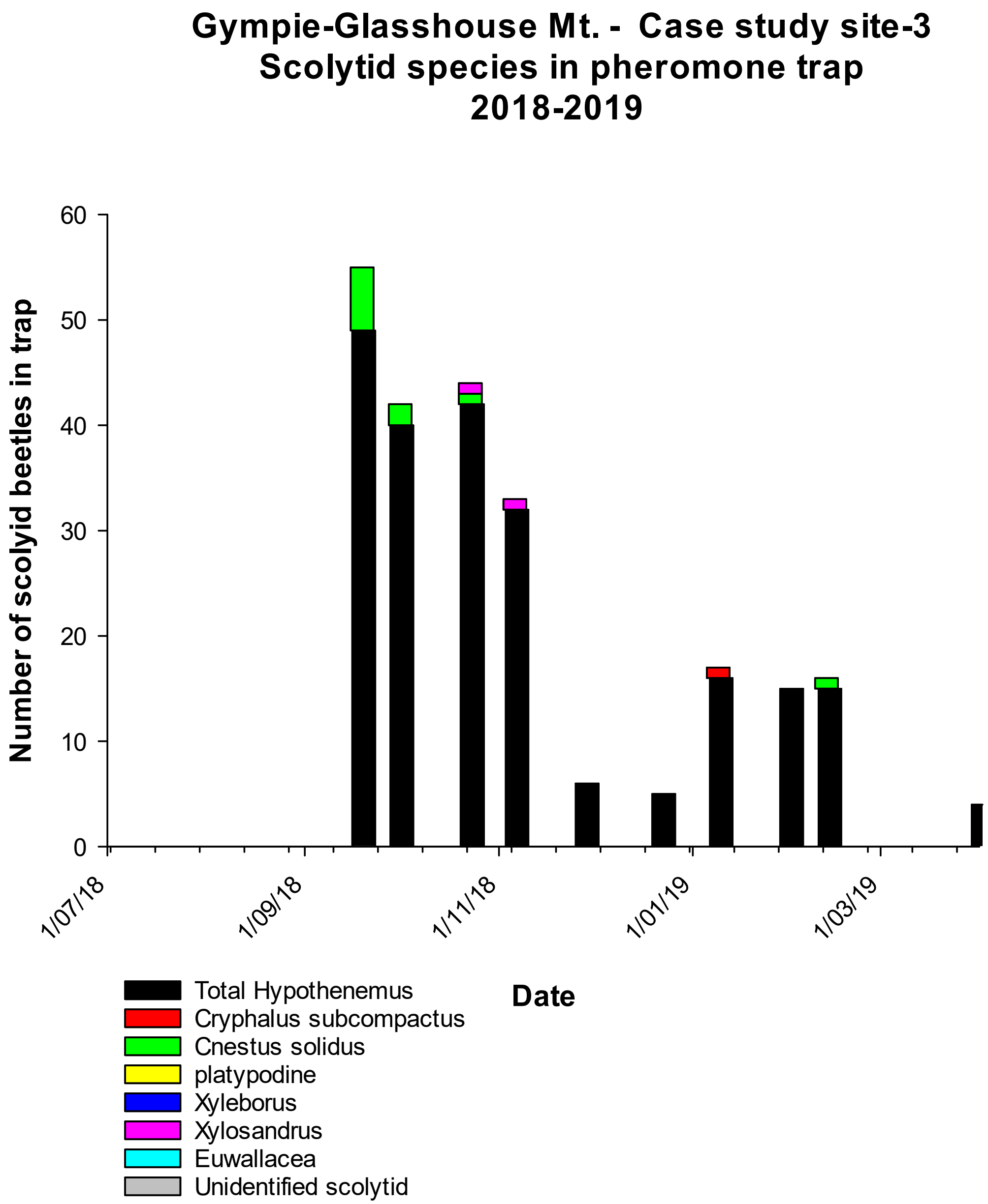
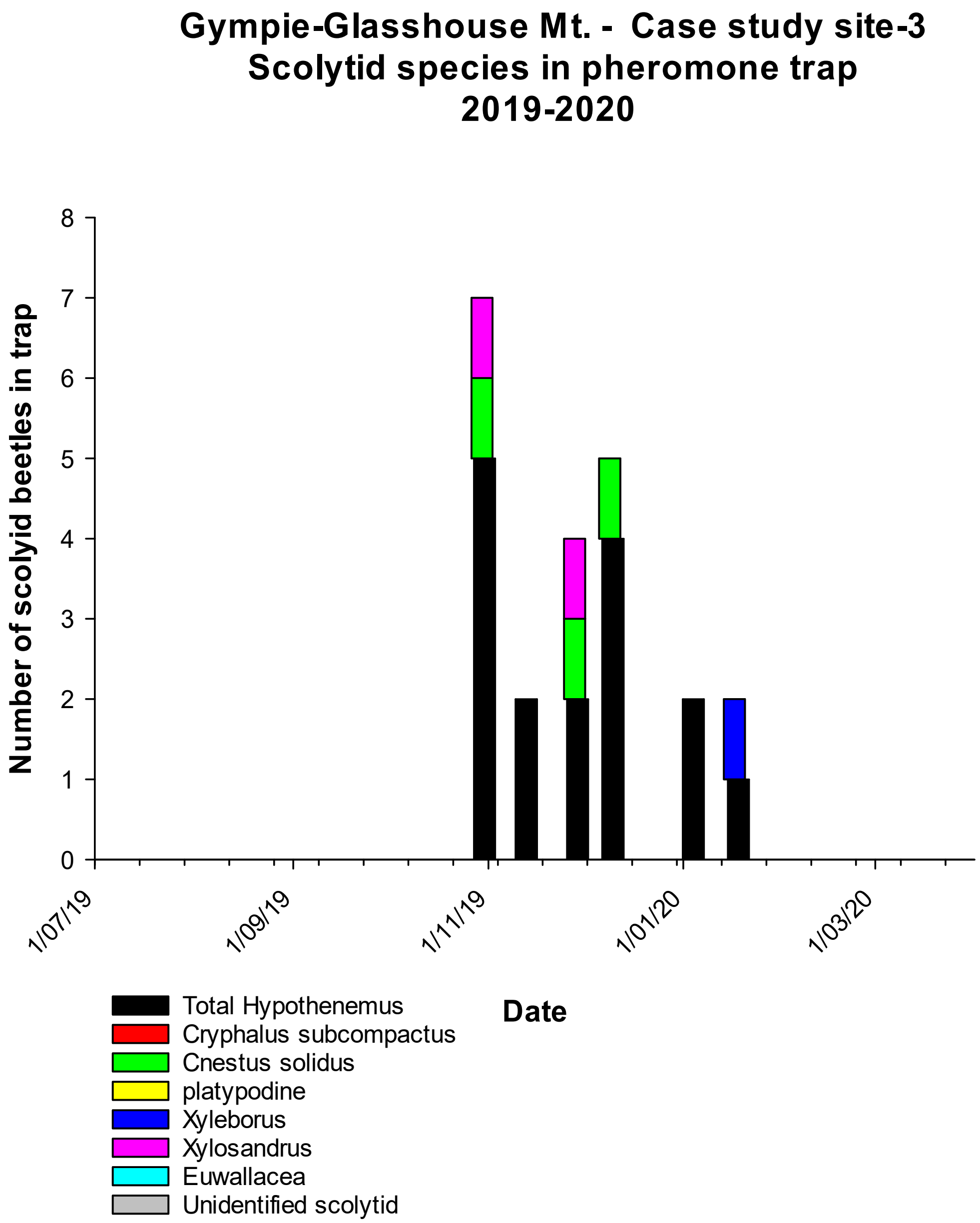


Figure 2.2.2.5.: Scolytid beetle trapping in the Gympie-Glasshouse Mt. Region case study site-3 - 2017-2018 and 2018–2019



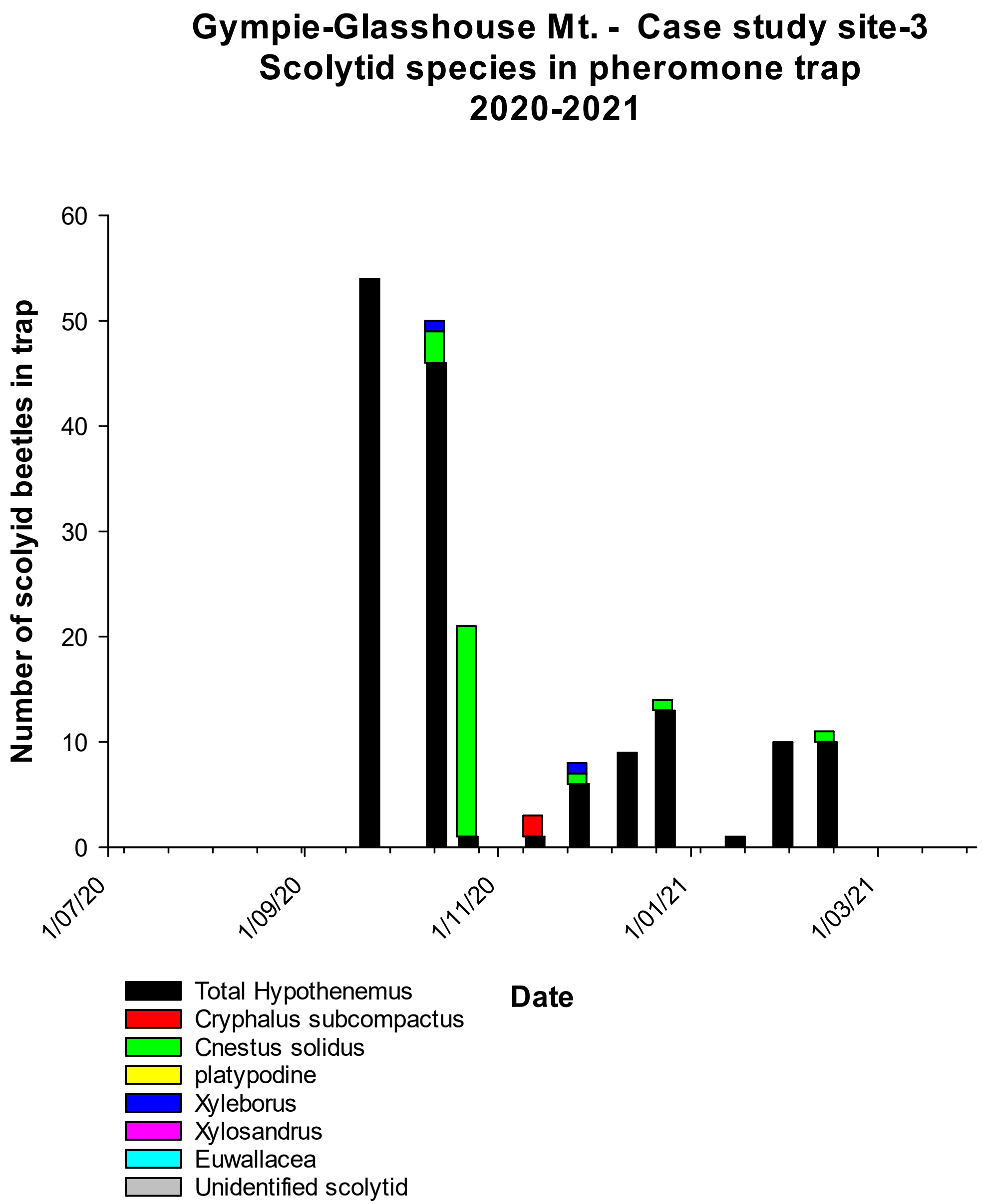
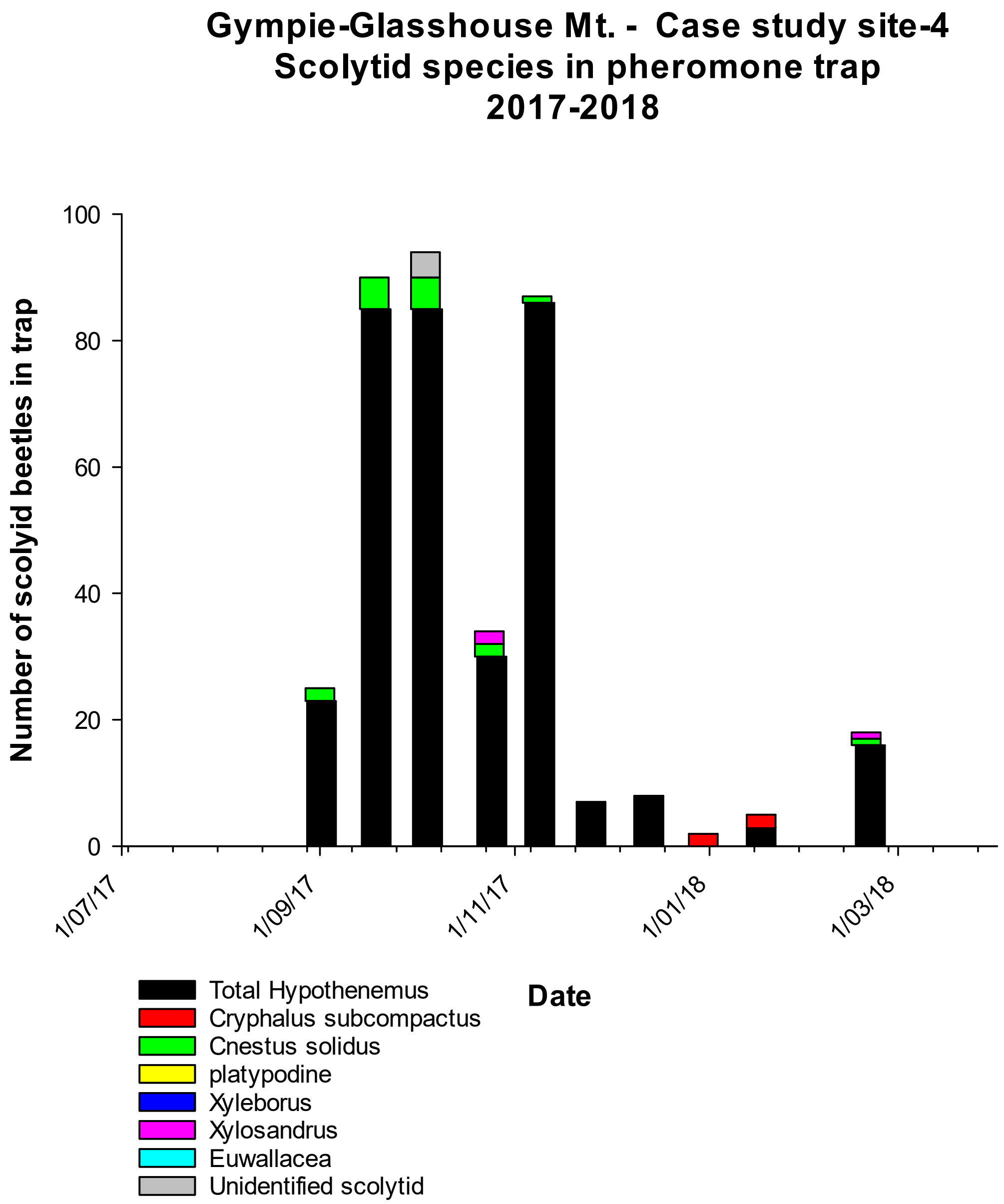


Figure 2.2.2.6.: Scolytid beetle trapping in the Gympie-Glasshouse Mt. Region case study site-3 - 2019–2020 and 2020–2021



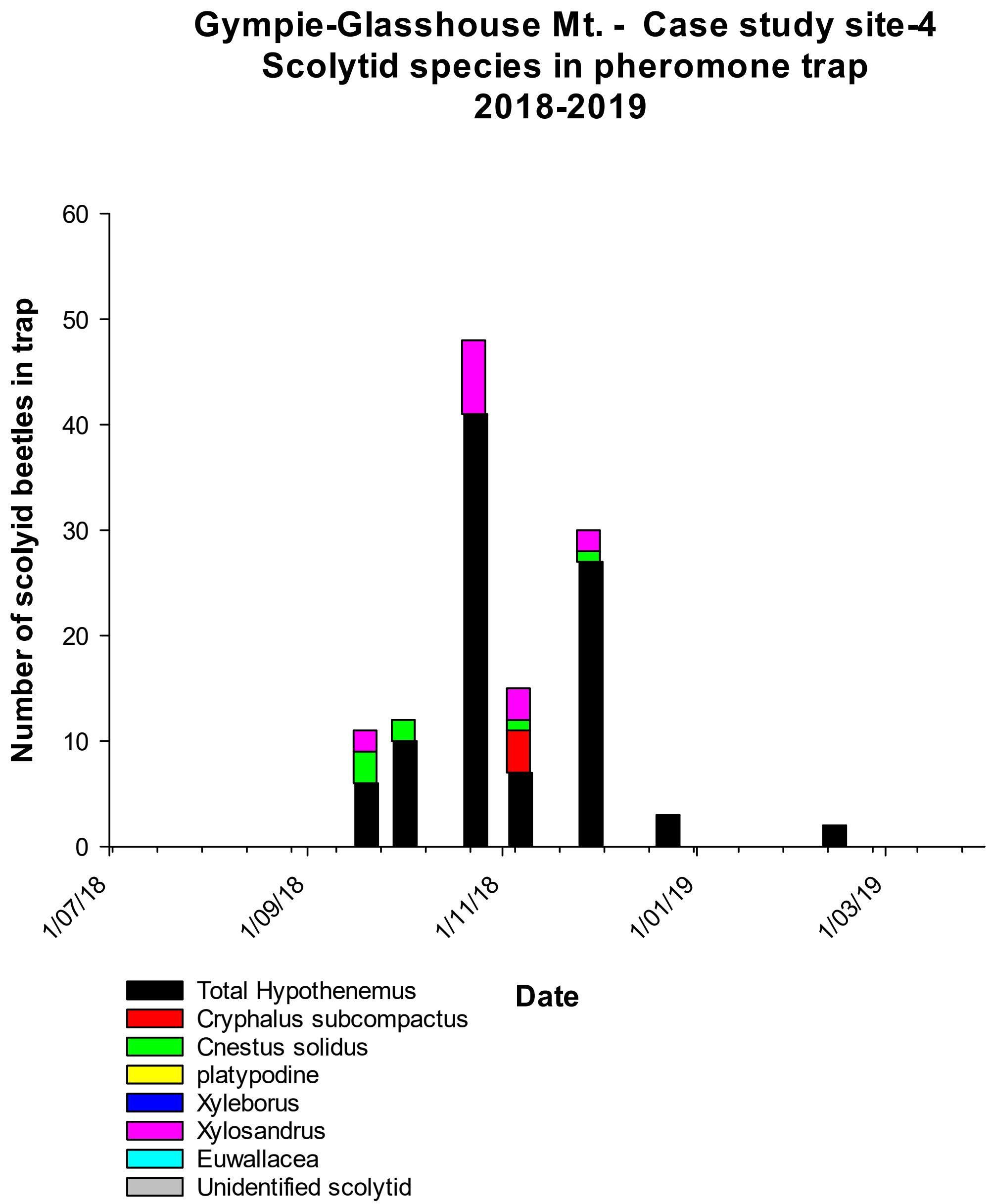
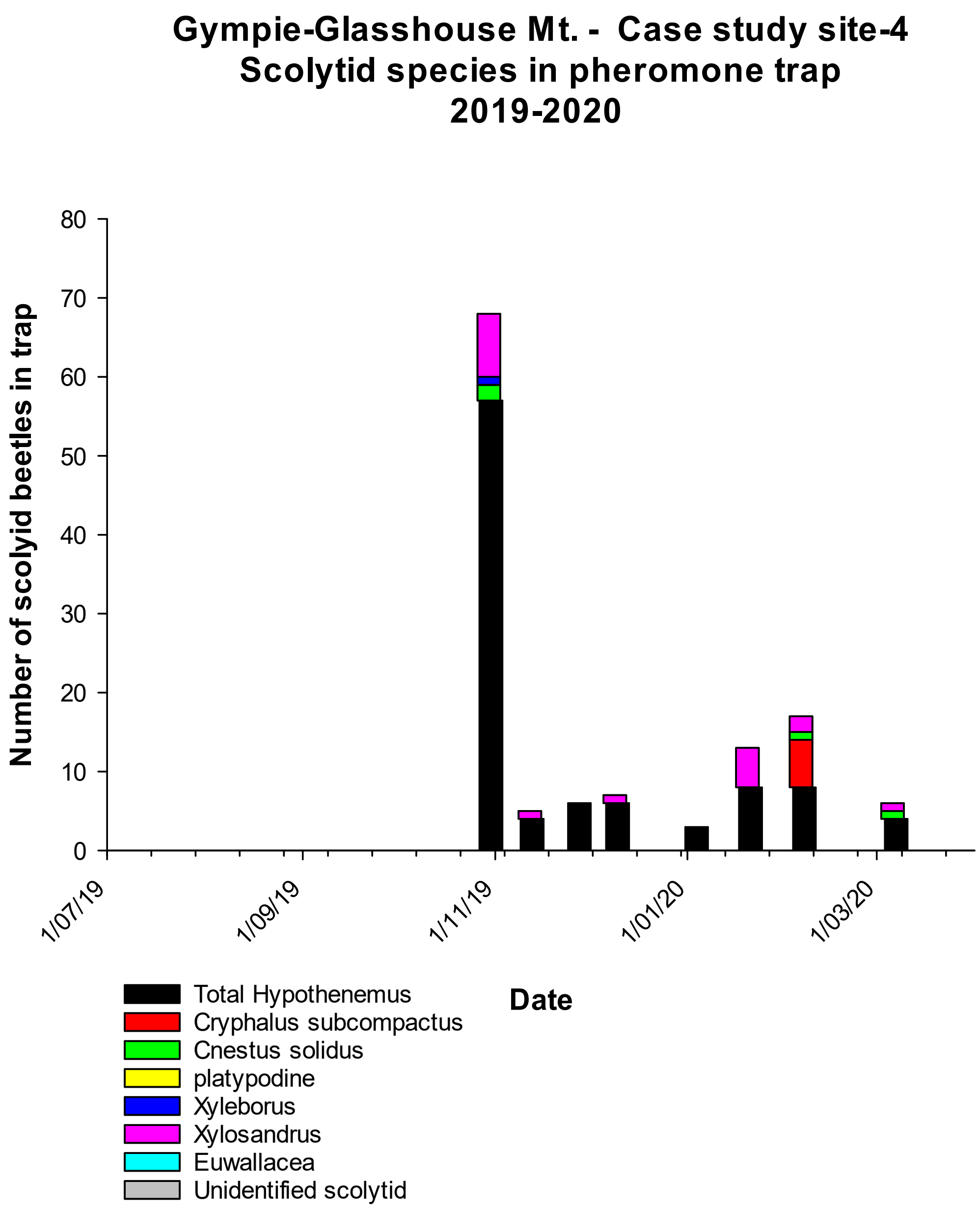


Figure 2.2.2.7.: Scolytid beetle trapping in the Gympie-Glasshouse Mt. Region case study site-4 - 2017-2018 and 2018–2019



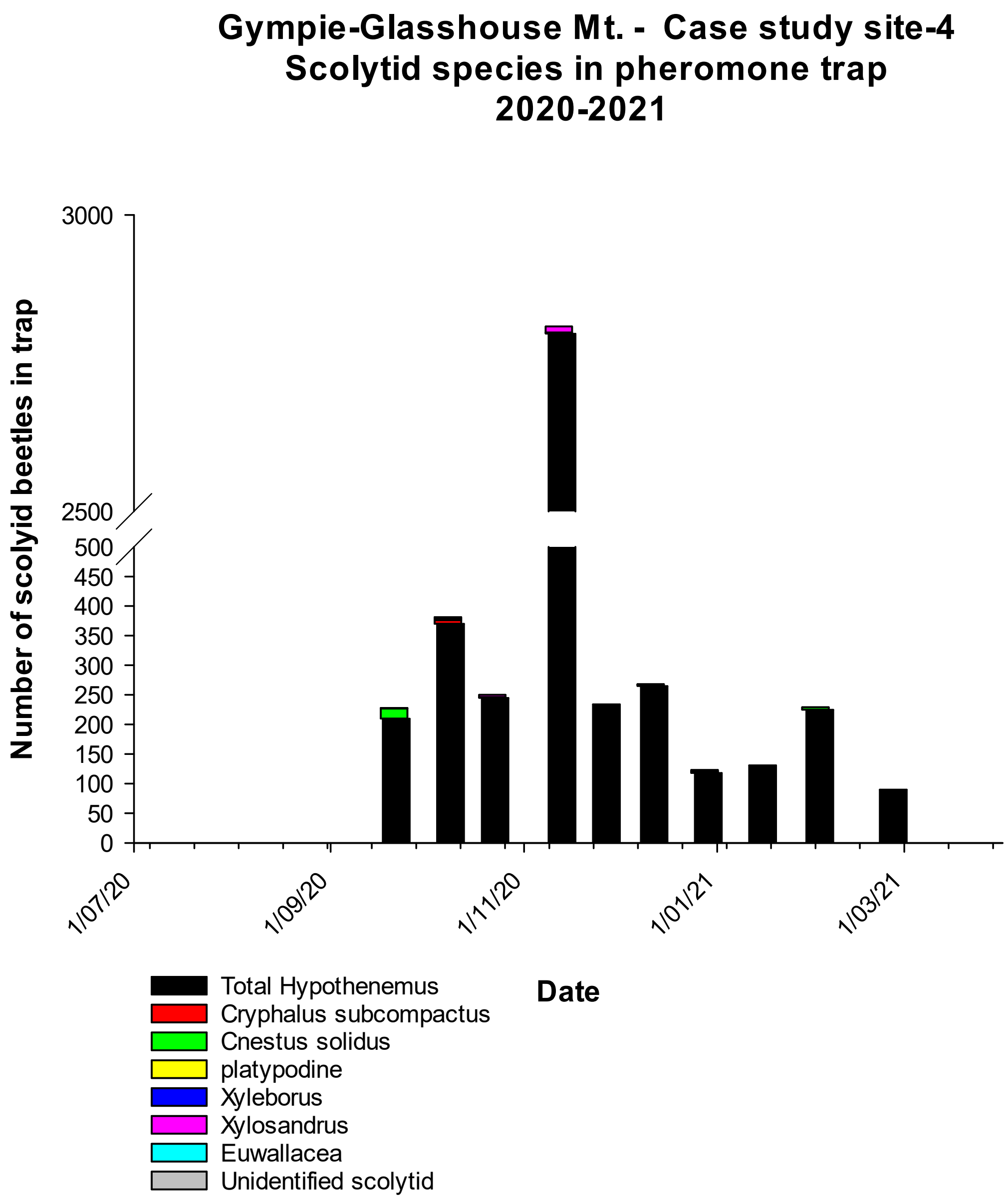
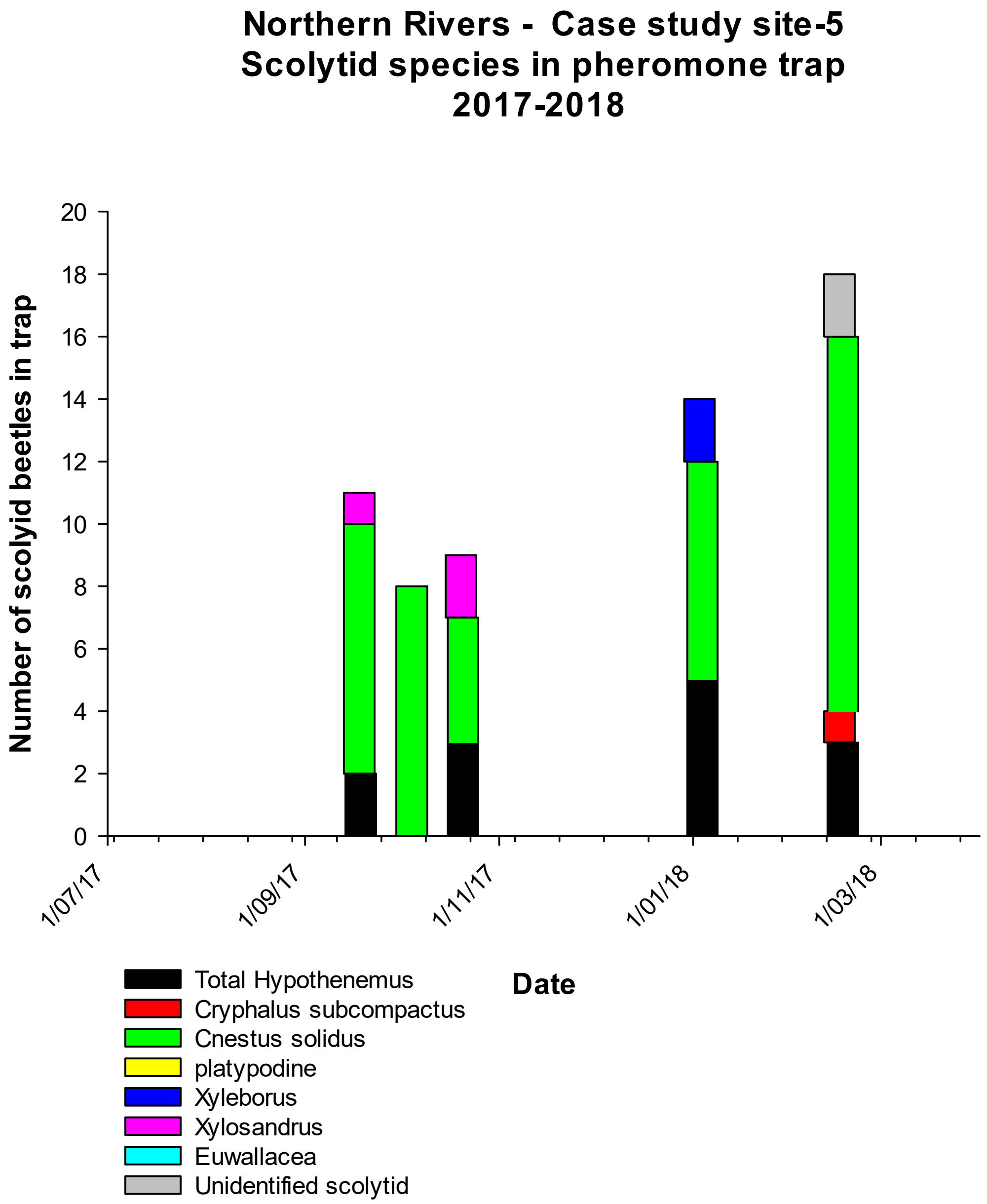


Figure 2.2.2.8.: Scolytid beetle trapping in the Gympie-Glasshouse Mt. Region case study site-4 - 2019–2020 and 2020–2021

Table: 2.2.2.2.: Scolytid beetles trapped at case study sites in the Gympie-Glasshouse Mt. region between 2017 and 2021

Scolytid beetles at case study sites in the Gympie-Glasshouse Mt. region		
Season	**Case study site-3**	**Case study site-4**
2017-2018	Low number of beetles were caught during the season. Mainly pinhole borer (*Hypothenemus* spp.) with a peak in September. Some beetle of the trunk borer *Cnestus solidus* were also caught during the season.	The pinhole borer (*Hypothenemus* spp.,) were present throughout the season and in large numbers during October and November. Some beetle of the trunk borer *Cnestus solidus* and the bark beetle *Cryphalus subcompactus*) were also caught during the season.
2018–2019	Larger numbers of the pinhole borer (*Hypothenemus* spp.) were caught between September and March, with a peak in late September. Very low numbers of *Cnestus solidus* and the bark beetle (*Cryphalus subcompactus*) were also caught.	Beetle numbers were lower during this season and was concentrated between late September and December with the pinhole borer being dominant. Other beetles collected in low numbers were again the trunk borers *Cnestus solidus* and *Xylosandrus* and the bark beetle *Cryphalus subcompactus.*
2019–2020	During this dry season only very low numbers of beetles were caught. The main species again was the pinhole borer, with a peak in November. Individuals of the bark beetle *Cnestus solidus*, the trunk borer X*yleborus* sp. were also caught.	During this dry season, beetles were not caught until late October, which was the peak of the pinhole borer. Again, very small numbers of the trunk borers *Cnestus solidus* and *Xylosandrus* and the bark beetle *Cryphalus subcompactus*. The latter was only caught in February.
2020–2021	During this wetter season, again larger numbers of the pinhole borer (*Hypothenemus* spp.) were caught with a peak in October/November. There were also larger numbers of the trunk borer *Cnestus solidus* in November and incidences of low numbers of the bark beetle and the trunk borer X*yleborus* sp.	During this wet season very high numbers of almost only the pinhole borer were caught, with a high peak of 2800 beetles in the middle of November.
Comments	The pinhole borer (*Hypothenemus* spp.) is certainly the dominant scolytid beetle species in this region. It appears that it prefers the wetter seasons. It can be easily monitored using a trap and a lure with a methanol and ethanol mix (3:1). As it goes into the nut like the tropical nut borer in Hawaii, it is important to keep affected nuts out of silo storage.	



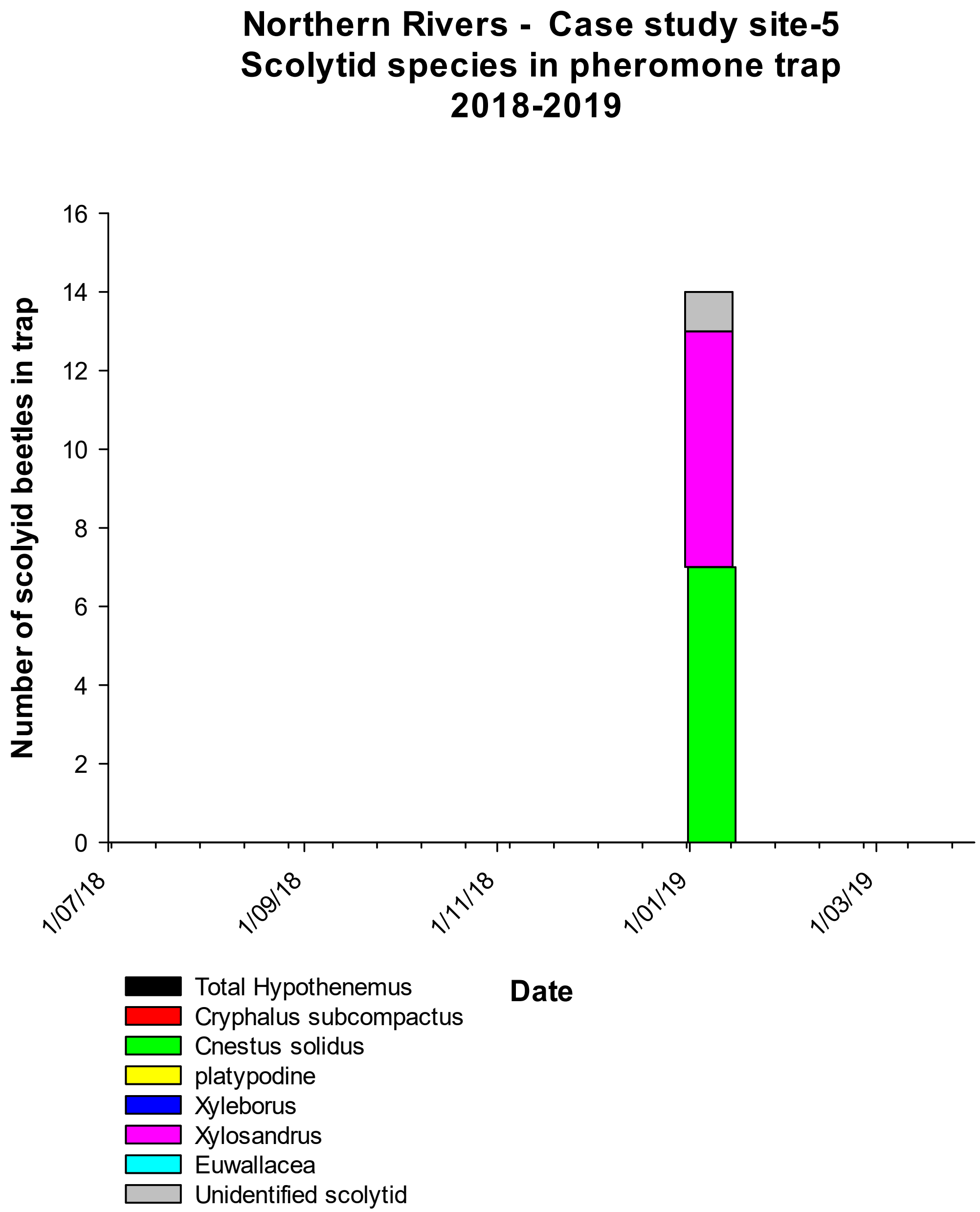
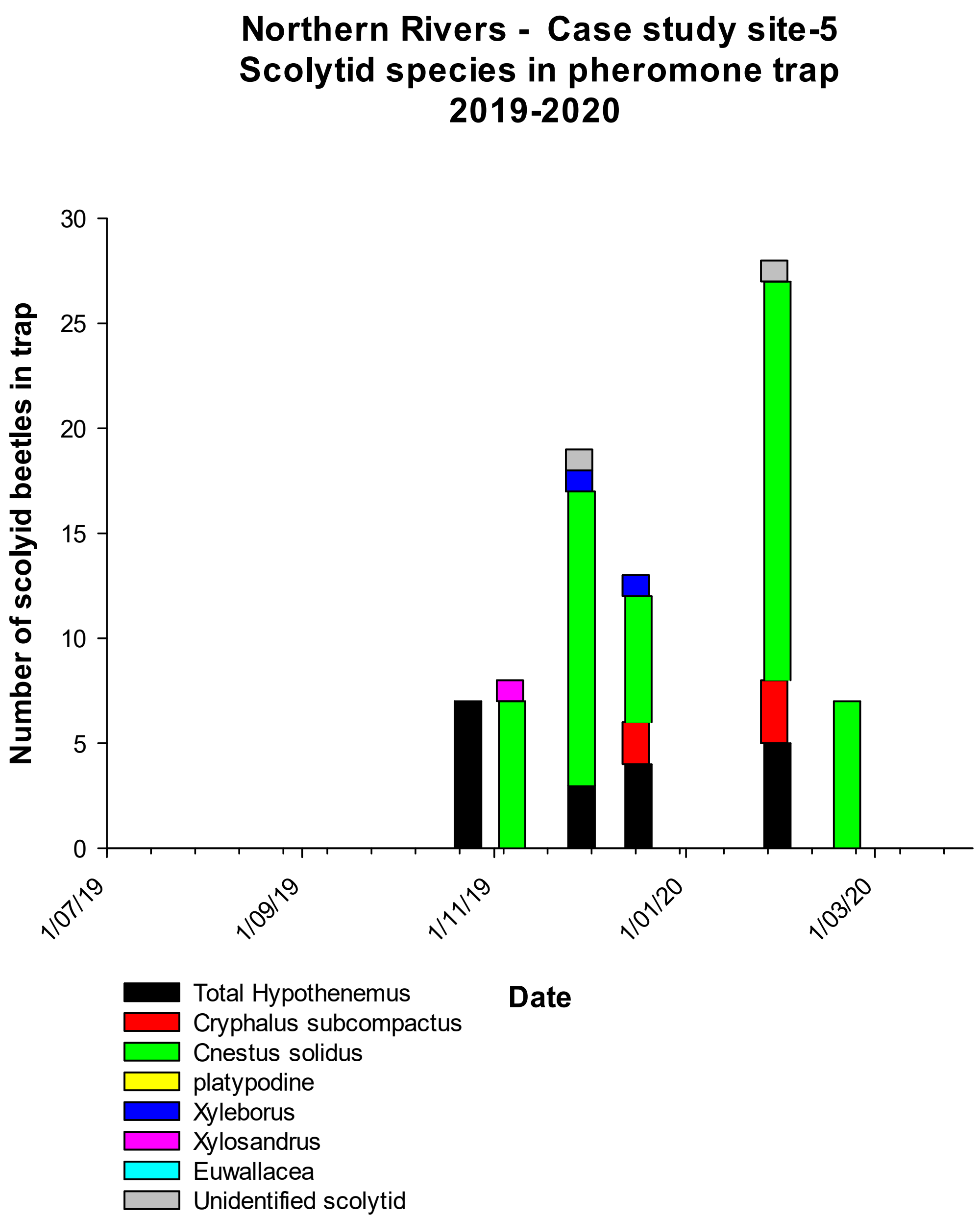


Figure 2.2.2.9.: Scolytid beetle trapping in the Northern Rivers Region case study site-5 - 2017-2018 and 2018–2019



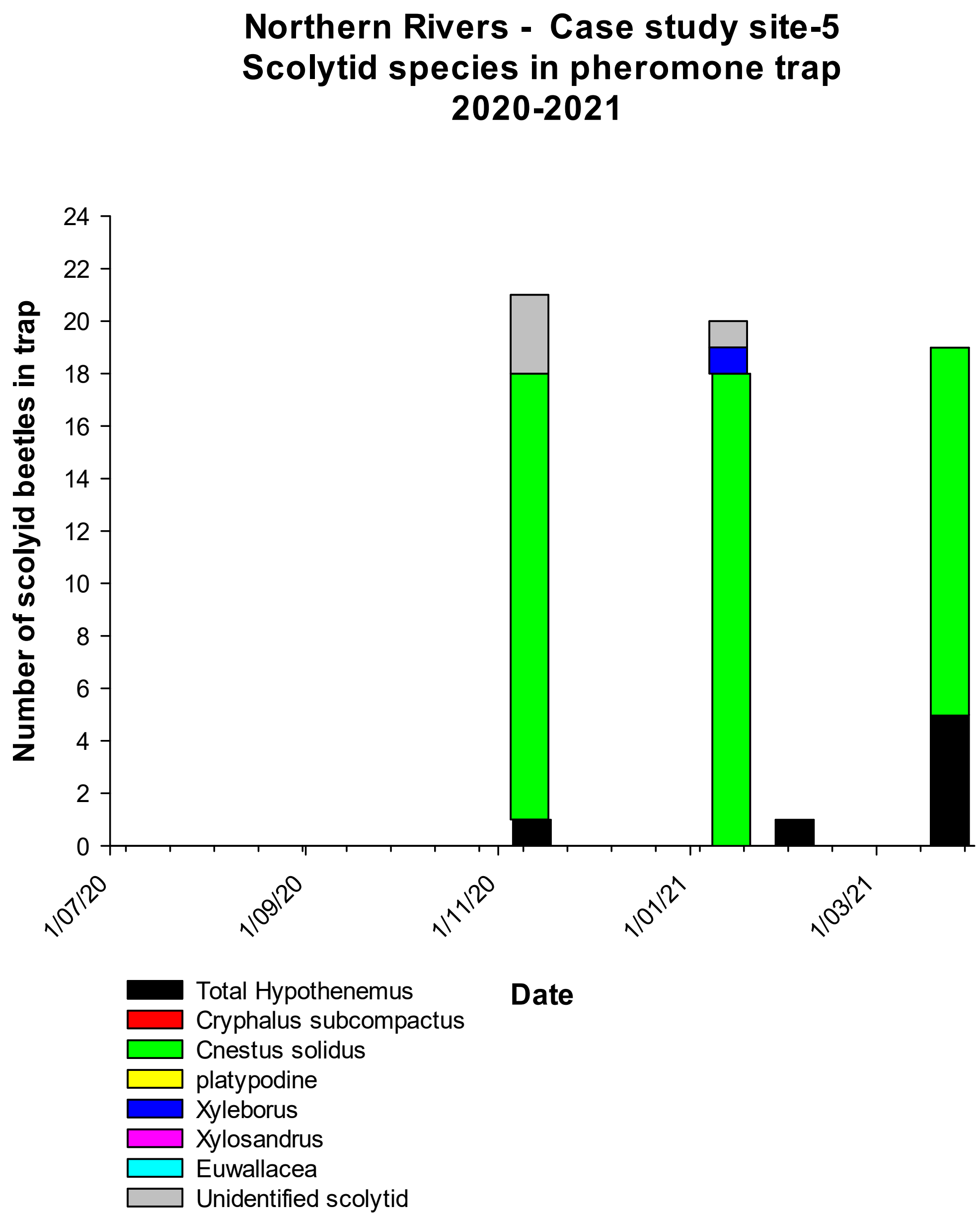
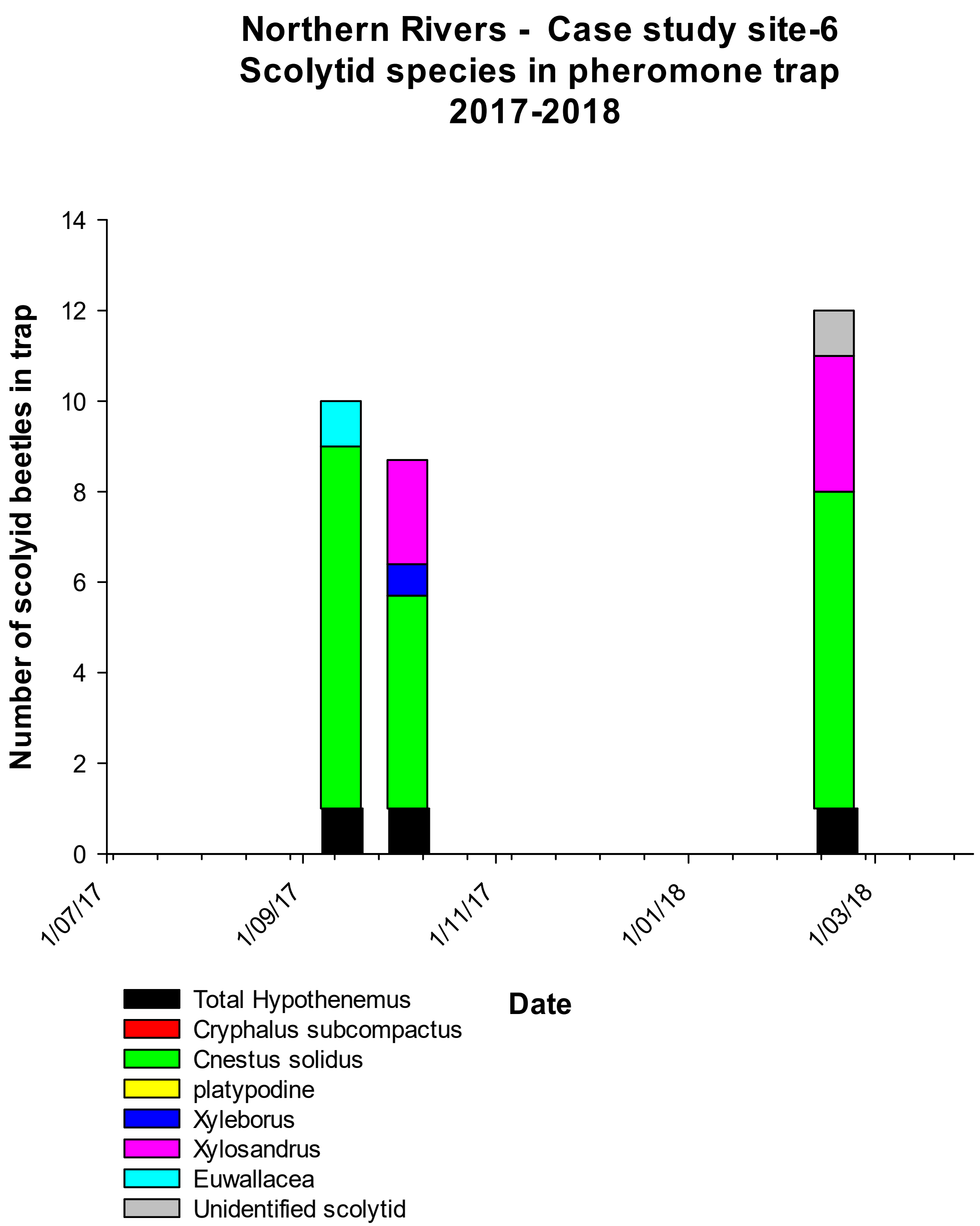


Figure 2.2.2.10.: Scolytid beetle trapping in the Northern Rivers Region case study site-5 - 2019–2020 and 2020–2021



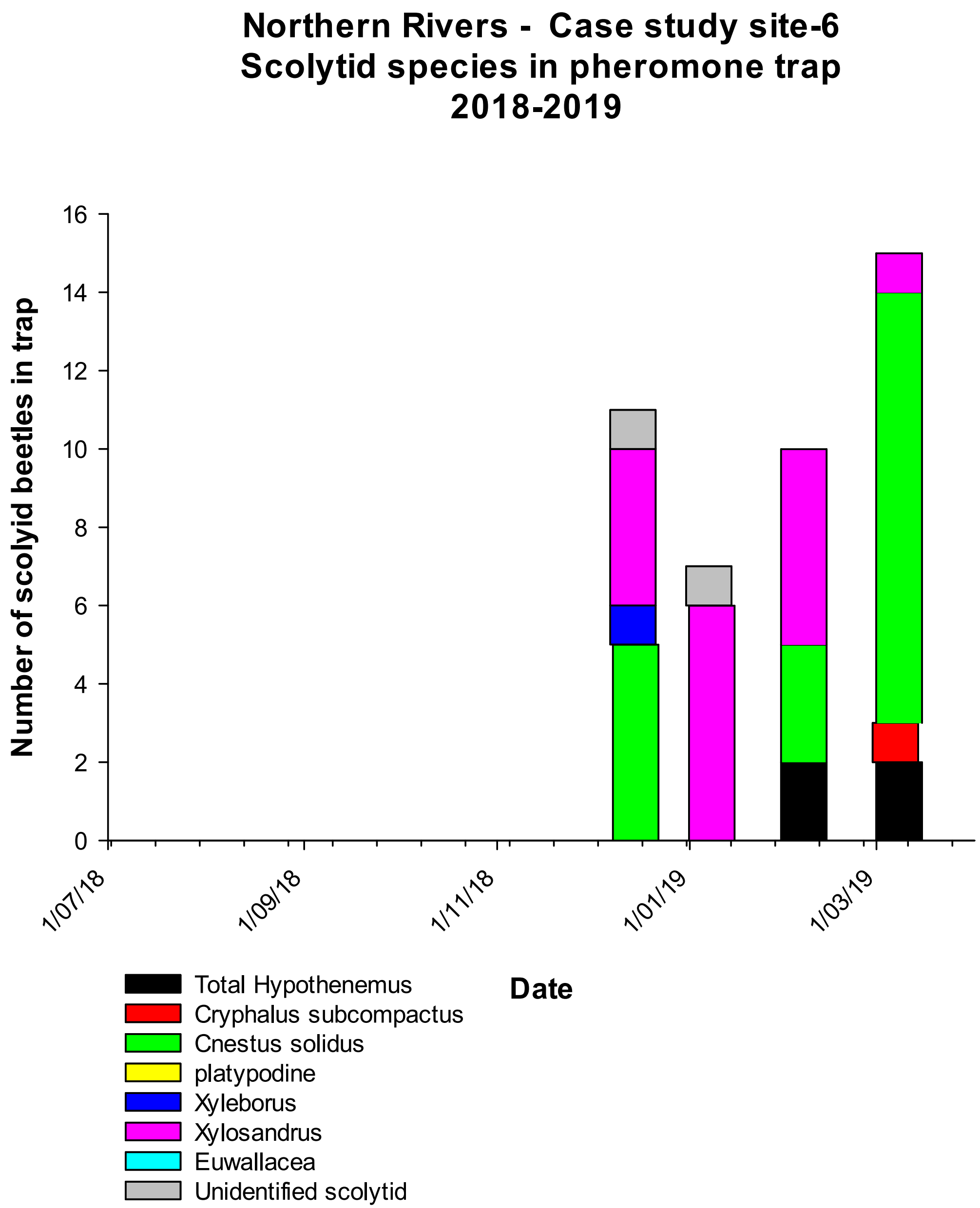
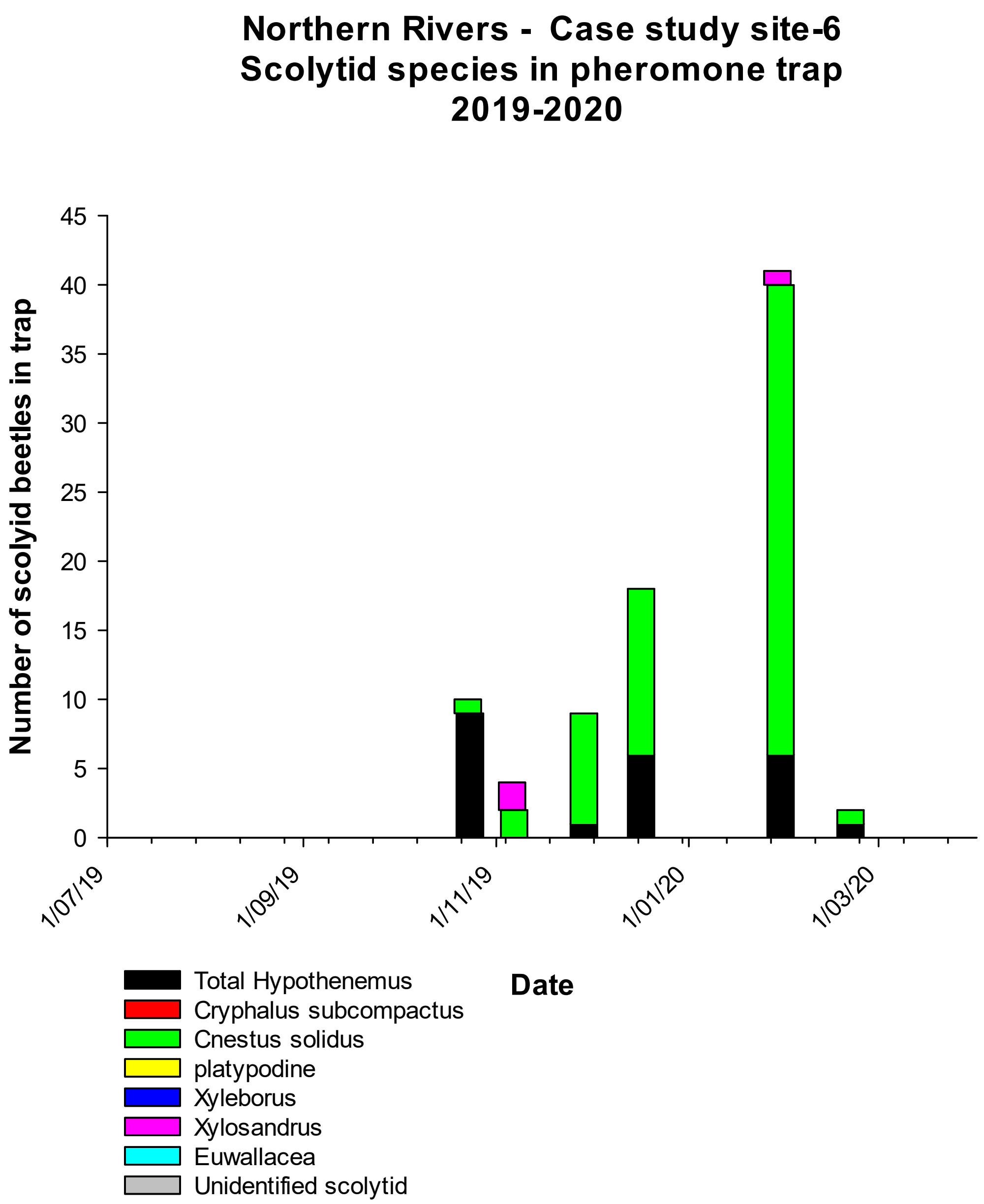


Figure 2.2.2.11.: Scolytid beetle trapping in the Northern Rivers Region case study site-6 - 2017-2018 and 2018–2019



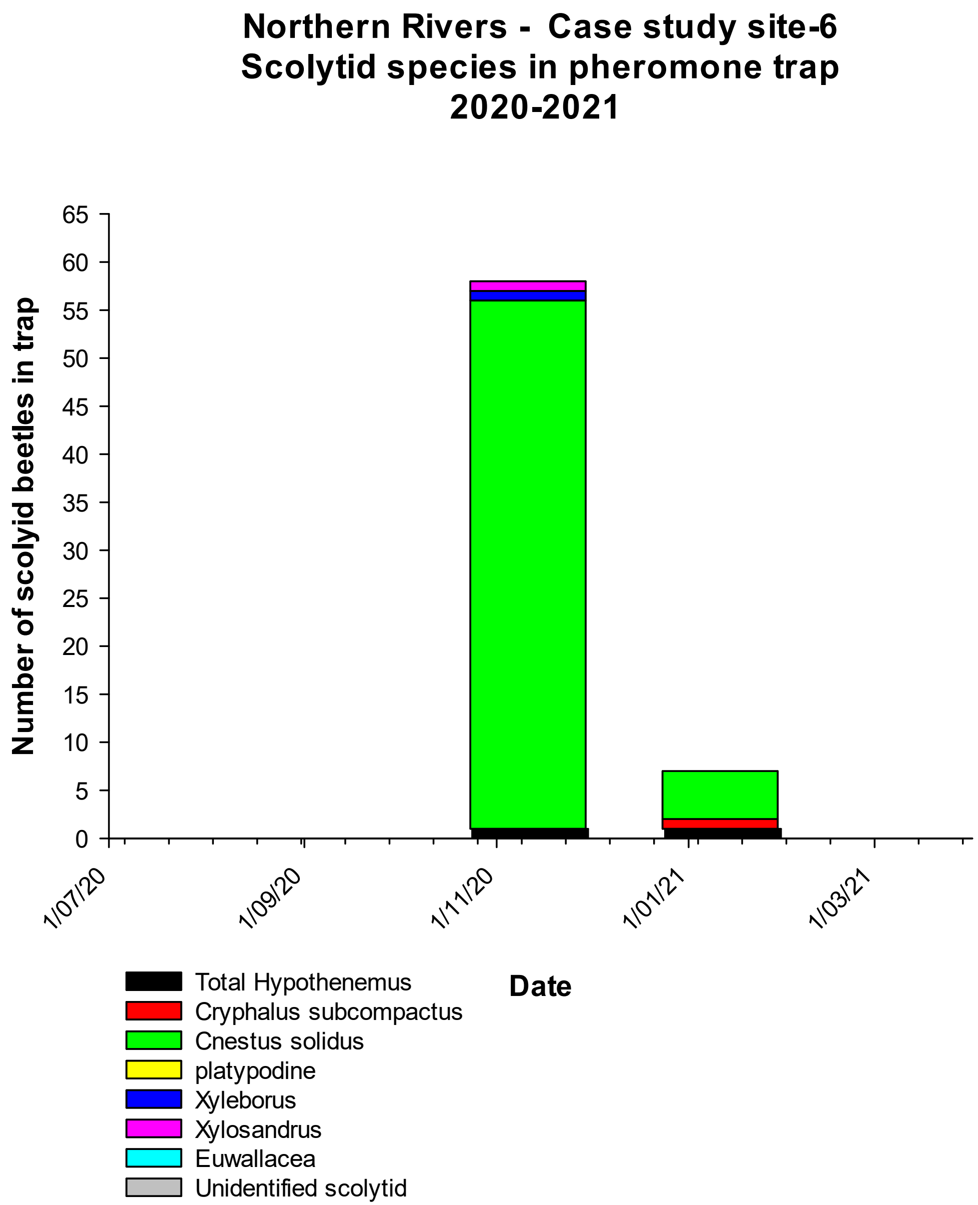
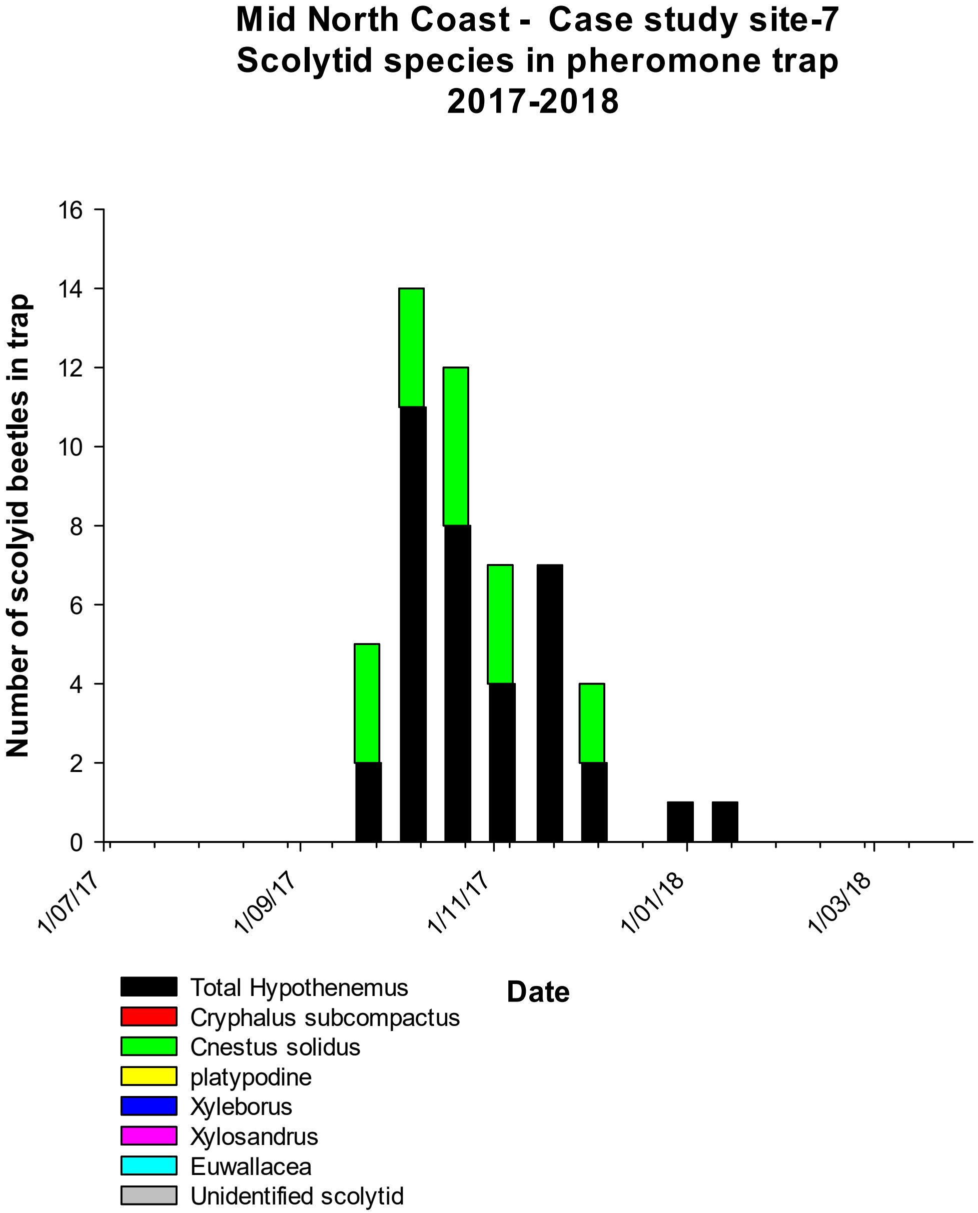


Figure 2.2.2.12.: Scolytid beetle trapping in the Northern Rivers Region case study site-6 - 2019–2020 and 2020–2021

Table: 2.2.2.3.: Scolytid beetles trapped at case study sites in the Northern Rivers region between 2017 and 2021

Scolytid beetles at case study sites in the Northern Rivers region		
Season	**Case study site-5**	**Case study site-6**
2017-2018	Low numbers of beetles were recorded. Mainly bark beetle *Cnestus solidus* (peaking in October and February), some pinhole borer (*Hypothenemus* spp.) and individuals of different trunk borers (*Xylosandrus* sp., *Xyleborus* sp.) and the bark beetle *Cryphalus subcompactus*.	Low numbers of scolytid beetles were caught on three occasions, between September 2017 and March 2018. The trunk borer *Cnestus solidus* was the main species followed by a different trunk borers (*Xylosandrus* sp.). Single specimens of the trunk borers *Xyleborus* sp. and *Euwallacea* sp. were also recorded, as well as the pinhole borer (*Hypothenemus* spp.). The latter was caught on three occasions.
2018–2019	There was only one trapping recorded January with some *Cnestus solidus* and some *Xylosandrus* sp.	Low numbers of scolytid beetles were caught on 4 occasions, between December 2017 and March 2019. The trunk borer *Cnestus solidus* and *Xylosandrus* sp. were the main species. The pinhole borer (*Hypothenemus* spp.). was recorded in February and March. Single specimens of *Xyleborus* sp. and the bark beetle *Cryphalus subcompactus*) were also caught.
2019–2020	Beetles were trapped between October and March. Main species was the bark beetle *Cnestus solidus*. There were small numbers of the pinhole borer (*Hypothenemus* spp.) between October and February and individuals of different trunk borers (*Xylosandrus* sp., *Xyleborus* sp.) and the bark beetle *Cryphalus subcompactus*.	During this dry season, numbers of scolytids recorded were higher, with the trunk borer *Cnestus solidus* as the main species, peaking in February. Smaller numbers of the pinhole borer (*Hypothenemus* spp.) were also caught between November and February as well as single specimens of the trunk borer *Xyleborus* sp.
2020–2021	There were only four trapping records between November and March. Main species again was the bark beetle *Cnestus solidus*. There were small numbers of the pinhole borer (*Hypothenemus* spp.) and an individual of the trunk borer *Xyleborus* sp.	Scolytids were only caught on two occasions once in November and once in January. During this wet season a large number of the trunk borer *Cnestus solidus* was caught in November and a smaller number in January. Single specimens of the pinhole borer (*Hypothenemus* spp.) were recorded on both occasions as well as the trunk borer *Xylosandrus* sp. and a single specimen on the trunk borer *Xyleborus* sp.
Comments	The trunk borer *Cnestus solidus* was the main scolytid species recorded at this site. Scolytid numbers were low until the dry season 2019–2020 when they went up and stayed high during the following wet season	



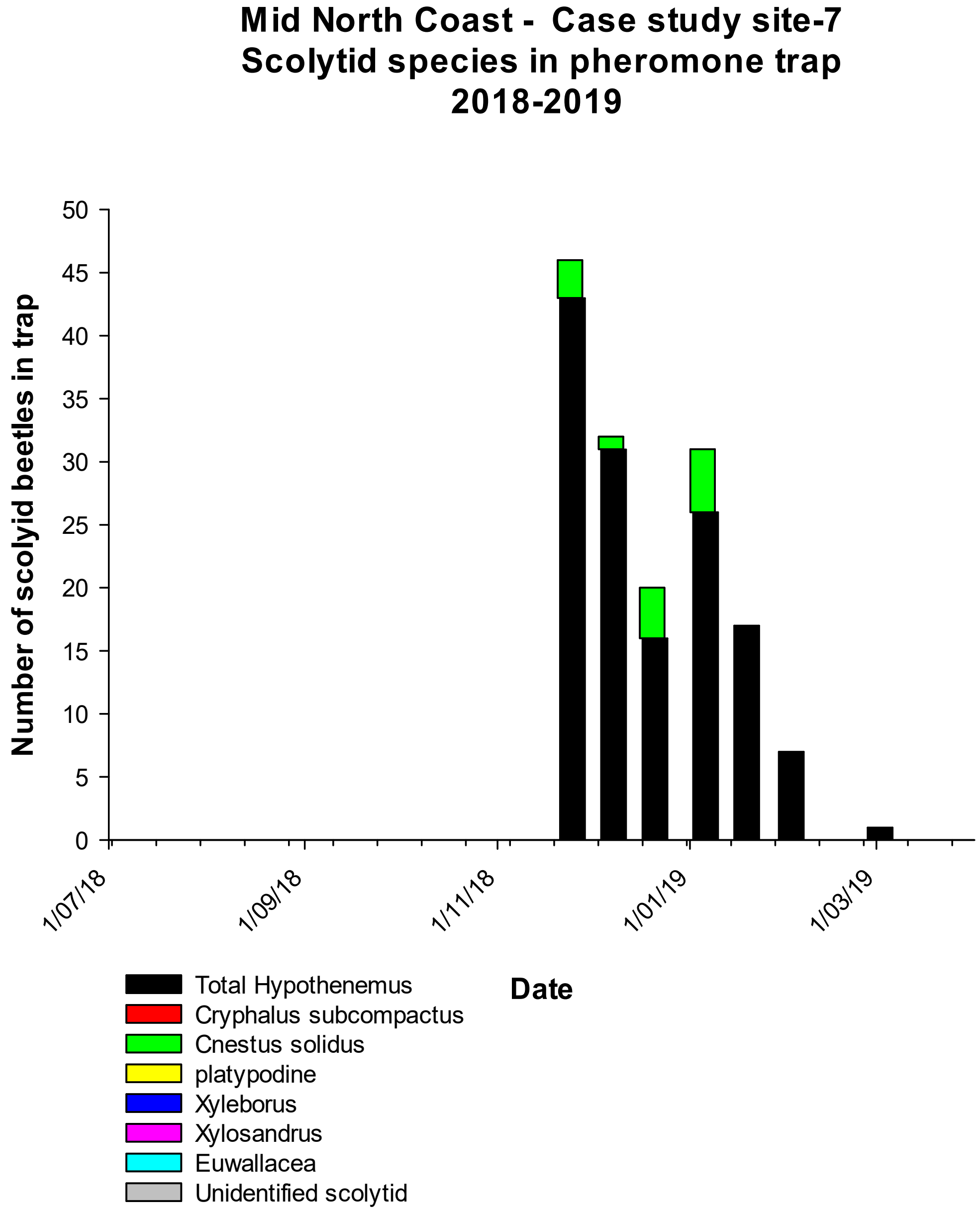


Figure 2.2.2.13.: Scolytid beetle trapping in the Mid North Coast Region case study site-7 - 2017-2018 and 2018–2019

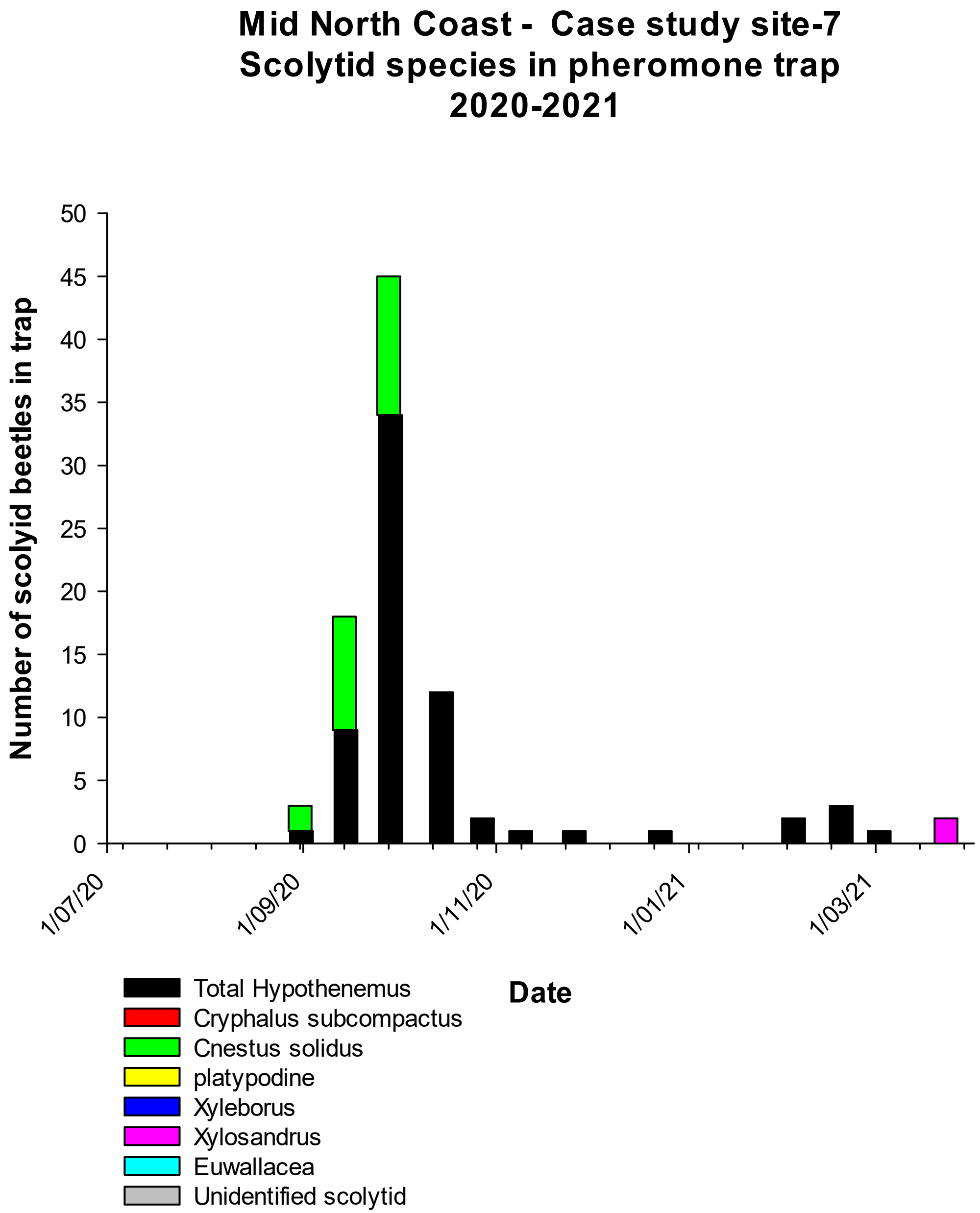


Figure 2.2.2.14.: Scolytid beetle trapping in the Mid North Coast Region case study site-7 - 2020–2021

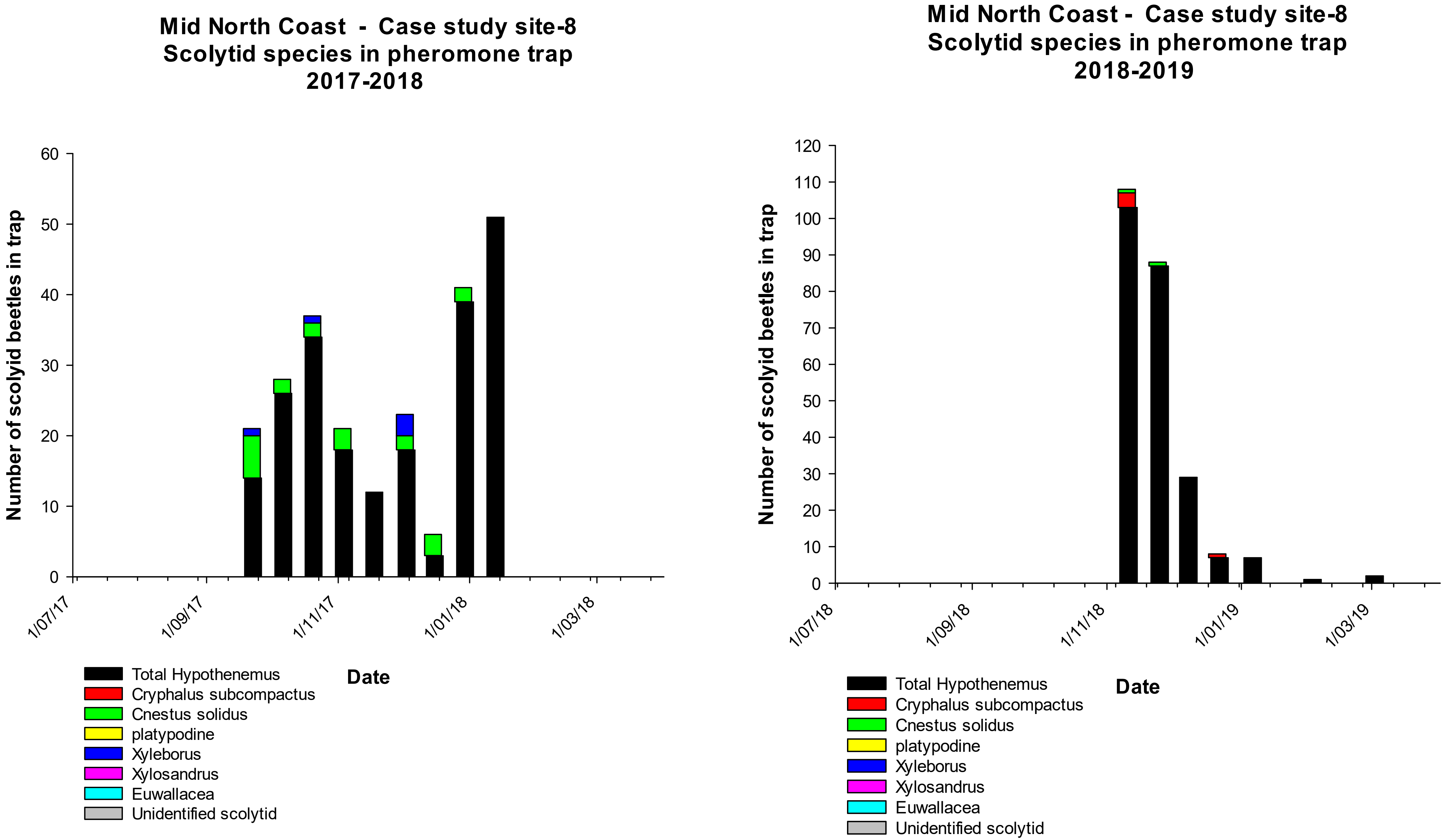


Figure 2.2.2.15.: Scolytid beetle trapping in the Mid North Coast Region case study site-8 - 2017-2018 and 2018–2019

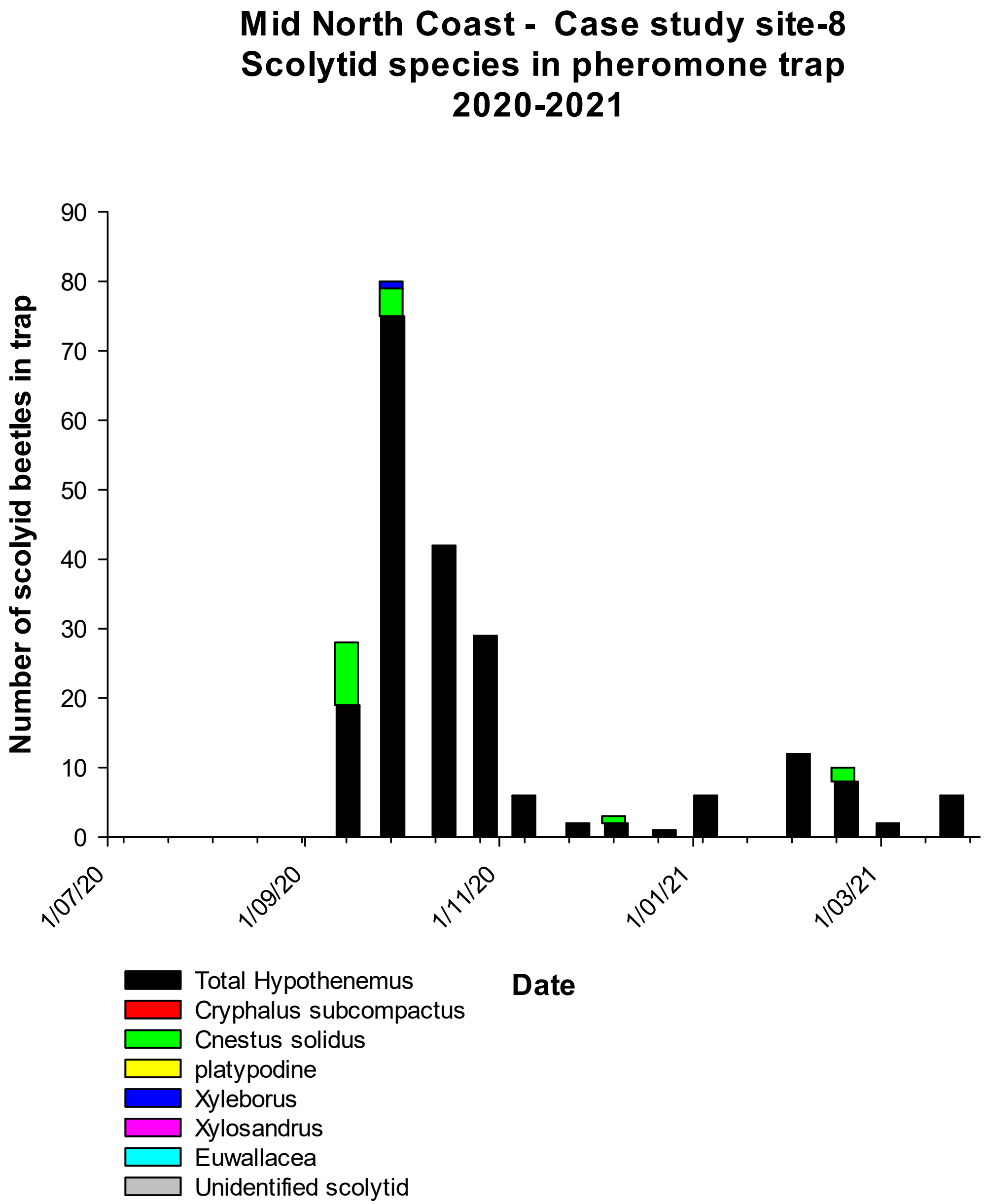


Figure 2.2.2.16.: Scolytid beetle trapping in the Mid North Coast Region case study site-8 - 2020–2021

Table: 2.2.2.4.: Scolytid beetles trapped at case study sites in the Northern Rivers region between 2017 and 2021

Scolytid beetles at case study sites in the Mid North Coast region		
Season	**Case study site-7**	**Case study site-8**
2017-2018	Low numbers of the pinhole borer *Hypothenemus* spp. and the trunk borer *Cnestus solidus* were caught between September 2017 and January 2018. Pinhole borer numbers peaked in October	The pinhole borer *Hypothenemus* spp. was the main scolytid species with a peak in January. Small numbers of the trunk borer *Cnestus solidus* were also recorded throughout the season. In addition, individuals of the trunk borer *Xyleborus* sp. were present.
2018–2019	Higher of the beetles were caught during this second season, mainly the pinhole borer *Hypothenemus* spp. with a peak in December. Only a small number of the trunk borer *Cnestus solidus* was caught.	Larger numbers of the pinhole borer *Hypothenemus* spp. with a peak in November December were recorded. In addition, only small numbers of the trunk borer *Cnestus solidus* and the bark beetles (*Cryphalus subcompactus*).
2019–2020	No records	No records
2020–2021	The pinhole borer *Hypothenemus* spp. was the main scolytid species with a peak in October and only low numbers for the res tot the time. Small numbers of the trunk borer *Cnestus solidus* were recorded at the beginning of the season and a very small number of the trunk borer *Xylosandrus* sp. only at the end (April 2021)	The pinhole borer *Hypothenemus* spp. was recorded throughout the season with a peak in October and small numbers of the trunk borer *Cnestus solidus*.
Comments	The pinhole borer *Hypothenemus* spp. was the dominating scolytid in this region, having implications for post-harvest hygiene measures.	

2.2.3. Harvest results

Results for percentage of kernel recovery (KR), sound kernel, insect damage, other reject and yield for all sites across the seasons are shown in Figures 2.2.3.1. to 2.2.3.8. These show general trends. For each site and season.

- General trends were the following:

  Yields in differently managed sites were comparable.

- "IPM sites" (Minimal pesticide approach – sites 1, 3, 5 and 7)

  Generally higher percentage of insect damage

  Generally higher reject

- "Conventional sites" (Several applications of broad spectrum insecticides - sites 2, 4, 6 and 8)

  Generally higher percentage of sound kernel.

To identify more the cause of the loss and effect of different pests, the results from husk and kernel assessment are important. Results from husk and kernel assessment are shown in Tables 2.2.3.1. and 2.2.3.2.

Husk and kernel assessment

"IPM sites" (Minimal pesticide approach – sites 1, 3, 5 and 7)

- Higher number of nuts with macadamia nut borer tunnels on husk
- Mostly higher percentage of kernel with FSB damage
- Mostly higher percentage of kernel with MNB damage
- Mostly higher percentage of kernel with total insect damage

"Conventional sites" (Several applications of broad spectrum insecticides - sites 2, 4, 6 and 8)

- Generally higher percentage of husk with thrips present
- Mostly higher number of scales
- Mostly higher yield

Table 2.2.3.1.: Results from Husk and Kernel assessment from case study sites 2018 and 2019

Insect damage 2018		Central Queensland		Gympie-Glasshouse		Northern Rivers		Mid North Coast	
		Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8
Husk assessment	HUSK-% Clean	9.0	23.4	58.4	65.7	37.6	28.7	11.9	27.9
	HUSK-%MNB tunnels	16.0	15.3	6.2	4.5	2.2	0.7	7.4	4.7
	HUSK-%Thrip	46.2	29.3	19.1	11.5	36.5	40.6	23.9	33.0
	HUSK-%Felted coccid	1.5	25.9	1.2	0.4	1.0	1.2	1.9	1.7
	HUSK-%Scale	8.5	7.0	6.5	8.9	7.9	12.2	8.5	16.4
	HUSK-%Scolytids	0.2	0.0	0.8	0.3	0.0	0.0	0.3	1.4
	HUSK-%MSW oviposition	0.0	0.0	0.0	0.0	4.5	0.5	0.0	0.0
	HUSK-%MSW Feeding	0.0	0.0	0.8	0.2	20.7	24.2	0.2	0.0
	HUSK-%Husk spot	1.0	6.1	0.3	4.3	6.1	13.8	68.4	69.1
Kernel assessment	KR% FSB damage	**1.0**	**1.4**	**0.2**	**0.0**	**0.2**	**1.3**	**6.1**	**1.0**
	KR% Leptocoris damage	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
	KR% Togal bug damage	1.0	1.4	0.2	0.0	0.2	1.3	6.1	1.0
	KR% MNB damage	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.4
	KR% insect damage	1.1	1.4	0.2	0.0	0.2	1.3	6.1	1.4
	% Immaturity	0.7	0.2	0.6	0.7	0.6	0.0	1.4	0.8
	% Total KR	29.6	32.7	41.3	35.1	39.7	37.7	40.0	41.0
	% Sound KR	27.9	31.2	40.3	32.9	39.0	36.5	32.8	39.3
	Yield -DNIS@10%-T/Ha	1.8	1.5	2.1	3.3	1.6	2.4	3.7	4.4

Insect damage 2019		Central Queensland		Gympie-Glasshouse		Northern Rivers		Mid North Coast	
		Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8
Husk assessment	HUSK-% Clean	73.7	57.3	70.7	78.2	61.0	60.0	49.2	68.0
	HUSK-%MNB tunnels	5.3	3.3	8.0	1.5	2.7	0.0	2.0	1.3
	HUSK-%Thrip	10.7	22.2	7.5	7.8	22.0	29.3	13.5	15.3
	HUSK-%Felted coccid	6.7	2.5	0.8	0.0	0.0	0.3	0.3	0.7
	HUSK-%Scale	2.7	11.0	4.7	8.5	4.7	8.3	1.3	0.8
	HUSK-%Scolytids	0.0	0.0	2.5	0.3	0.0	0.0	0.5	0.5
	HUSK-%MSW oviposition	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	HUSK-%MSW Feeding	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	HUSK-%Husk spot	0.5	0.0	0.7	1.5	6.0	3.7	36.7	8.7
Kernel assessment	KR% FSB damage	**1.1**	**0.5**	**0.8**	**0.2**	**0.9**	**1.1**	**5.0**	**0.7**
	KR% Leptocoris damage	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
	KR% Togal bug damage	1.1	0.5	0.8	0.2	0.9	1.1	5.0	0.7
	KR% MNB damage	1.5	1.1	3.3	0.6	1.0	0.0	0.8	0.5
	KR% insect damage	2.6	1.6	4.0	0.7	1.8	1.1	5.8	1.3
	KR% Immaturity	4.4	1.1	0.5	1.3	3.2	0.2	1.1	0.3
	% Total KR	27.6	32.9	40.9	38.2	36.5	33.8	40.3	39.2
	% Sound KR	24.0	31.4	39.3	37.2	33.6	32.6	35.2	38.4
	Yield -DNIS@10%-T/Ha	<0.5	<0.5	2.6	3.2	1.6	3.9	3.8	3.1

Table 2.2.3.2.: Results from Husk and Kernel assessment from case study sites 2020 and 2021

Insect damage 2020		Central Queensland		Gympie-Glasshouse		Northern Rivers		Mid North Coast	
		Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8
Husk assessment	HUSK-% Clean	74.4	57.9	15.1	15.7	62.7	45.9	41.5	56.3
	HUSK-%MNB tunnels	4.9	22.8	0.8	0.5	1.9	0.2	4.6	1.8
	HUSK-%Thrip	12.7	13.2	14.7	13.2	27.7	35.8	10.5	13.4
	HUSK-%Felted coccid	0.0	0.0	0.5	0.2	0.3	0.5	0.5	0.2
	HUSK-%Scale	0.3	2.8	0.7	1.1	0.8	23.1	0.8	0.8
	HUSK-%Scolytids	0.3	0.3	0.0	0.0	0.0	0.0	0.8	3.3
	HUSK-%MSW oviposition	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0
	HUSK-%MSW Feeding	0.0	0.0	0.0	0.0	3.6	12.4	0.5	0.0
	HUSK-%Husk spot	1.5	0.5	22.5	24.0	2.0	0.8	38.4	21.0
Kernel assessment	KR% FSB damage	**0.4**	**1.0**	**4.4**	**0.9**	**0.6**	**0.6**	**2.9**	**0.2**
	KR% Leptocoris damage	**0.0**	**0.0**	**1.6**	**0.0**	**2.5**	**0.2**	**2.2**	**0.2**
	KR% Togal bug damage	0.4	1.0	6.0	0.9	3.1	0.9	5.1	0.4
	KR% MNB damage	1.4	7.0	0.3	0.2	0.8	0.1	2.0	0.8
	KR% insect damage	1.8	8.0	6.3	1.1	3.9	0.9	7.0	1.2
	KR% Immaturity	5.7	3.5	1.5	2.1	2.6	1.7	2.0	4.3
	% Total KR	28.7	30.7	42.0	41.6	41.0	40.6	42.6	42.6
	% Sound KR	25.0	26.0	35.3	38.8	34.0	37.5	34.1	37.1
	Yield -DNIS@10%-T/Ha	1.4	1.9	2.9	3.5	2.5	4.3	3.7	3.8

Insect damage 2021		Central Queensland		Gympie-Glasshouse		Northern Rivers		Mid North Coast	
		Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8
Husk assessment	HUSK-% Clean	34.9	37.5	70.6	62.6	65.1	66.2	35.9	51.5
	HUSK-%MNB tunnels	21.6	8.8	3.8	4.2	3.7	2.2	5.0	1.3
	HUSK-%Thrip	30.1	22.0	14.9	6.9	21.8	8.1	11.3	27.9
	HUSK-%Felted coccid	0.0	23.2	0.2	0.7	0.2	0.0	1.0	0.7
	HUSK-%Scale	0.7	19.0	3.8	3.3	0.8	6.3	0.3	1.0
	HUSK-%Scolytids	0.2	0.0	0.5	0.5	0.0	0.0	0.3	0.5
	HUSK-%MSW oviposition	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0
	HUSK-%MSW Feeding	0.0	0.0	0.0	0.0	3.0	9.6	0.0	0.0
	HUSK-%Husk spot	0.0	0.2	1.3	1.6	6.3	5.7	37.0	21.2
Kernel assessment	KR% FSB damage	**0.6**	**2.5**	**0.8**	**0.3**	**0.8**	**1.0**	**8.1**	**0.4**
	KR% Leptocoris damage	**0.0**	**0.0**	**0.0**	**0.1**	**0.0**	**0.0**	**0.0**	**0.0**
	KR% Togal bug damage	0.6	2.5	0.8	0.4	0.8	1.0	8.1	0.4
	KR% MNB damage	0.4	0.1	0.1	0.2	0.0	0.0	0.0	0.0
	KR% insect damage	1.0	2.6	0.9	0.6	0.8	1.0	8.1	0.4
	KR% Immaturity	5.2	5.2	0.2	0.9	6.4	1.1	0.8	0.6
	% Total KR	31.2	31.2	36.4	40.2	36.9	36.1	40.4	41.7
	% Sound KR	27.8	26.0	35.1	37.4	32.2	34.0	32.0	38.5
	Yield -DNIS@10%-T/Ha	2.8	2.3	4.0	4.1	2.6	3.4	3.1	3.6

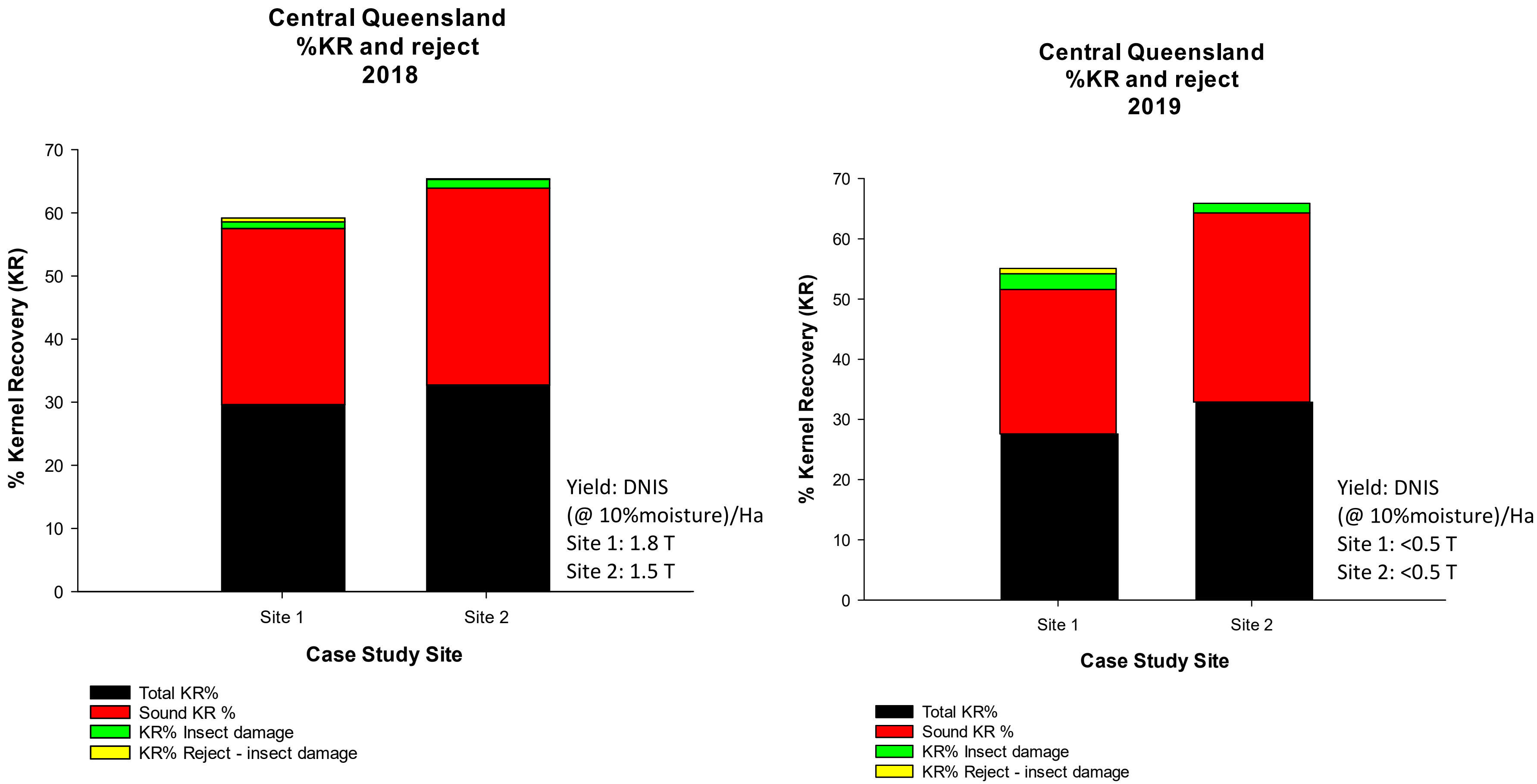


Figure 2.2.3.1.: Kernel Recovery and rejects for Central Queensland case study sites (1+2) from 2018 (left) and 2019 (right) harvest

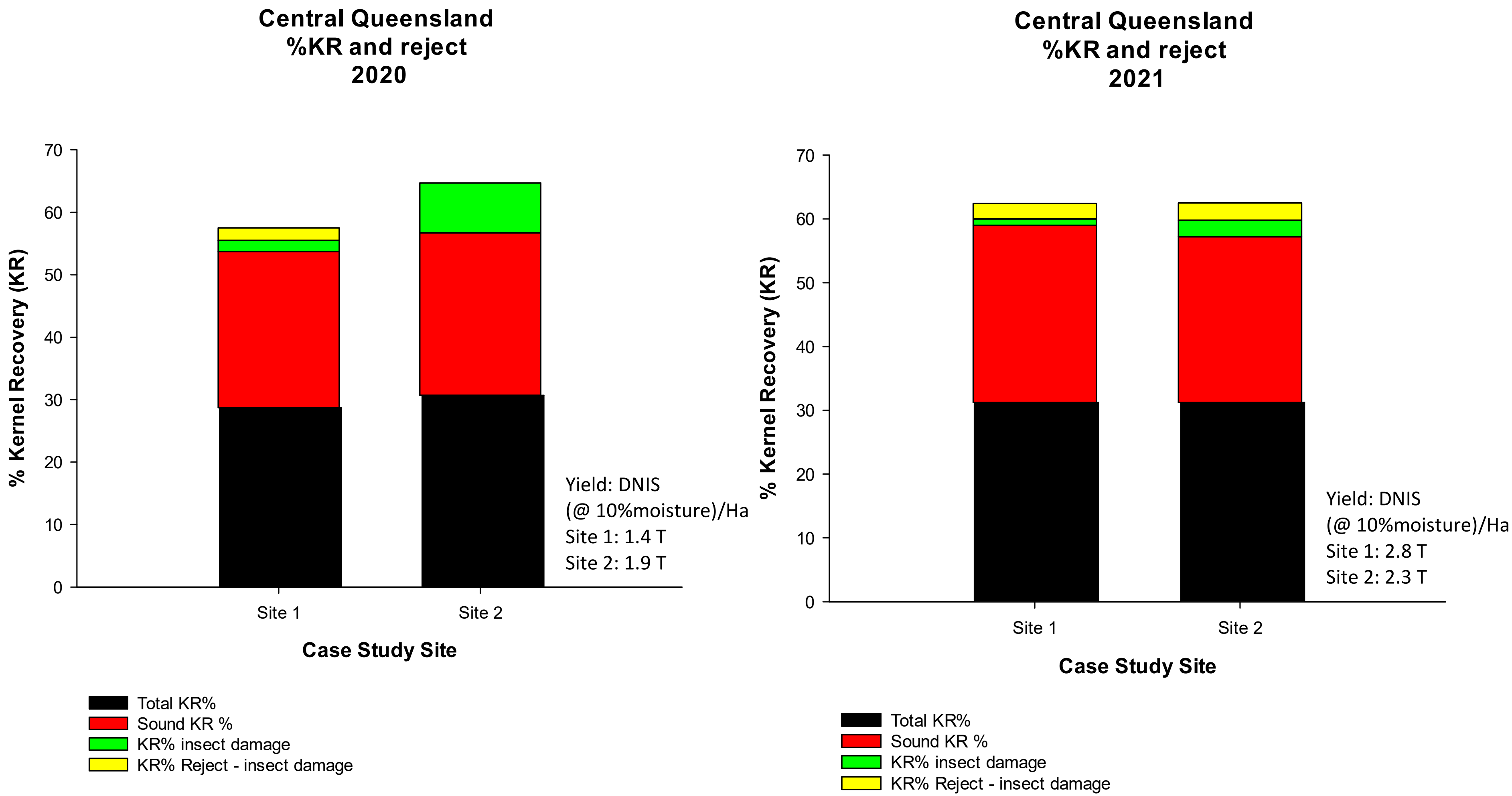
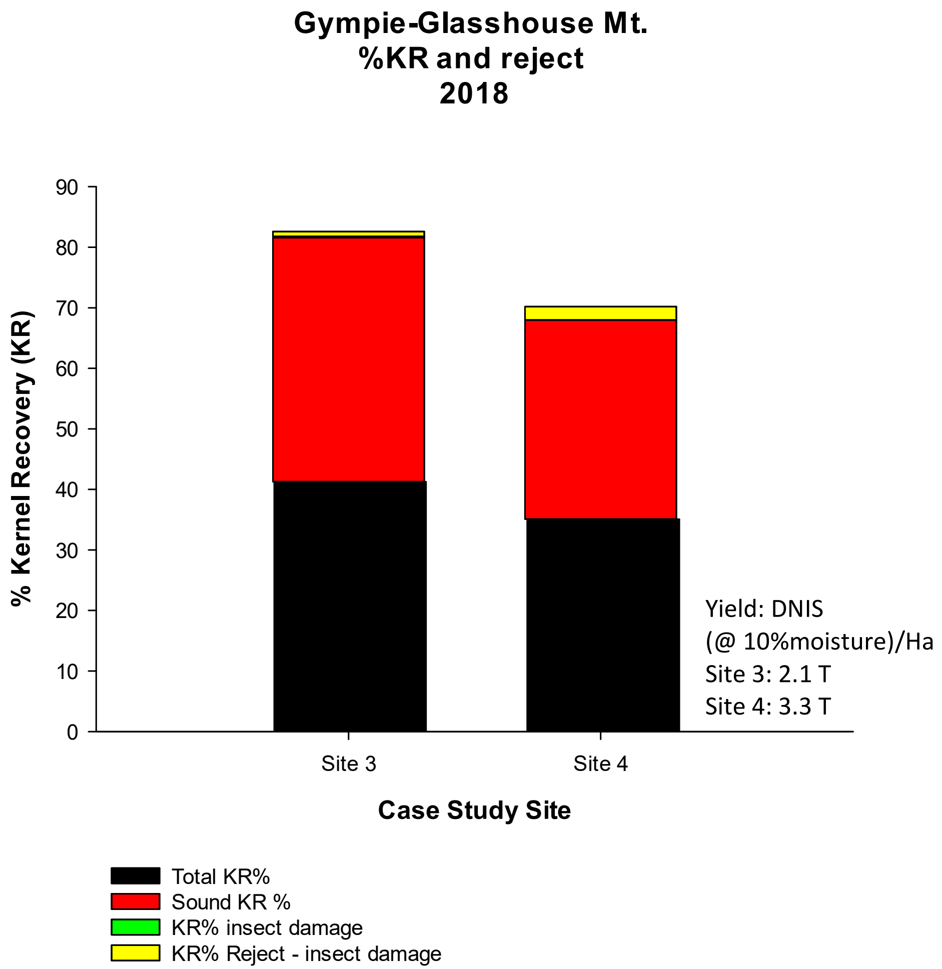


Figure 2.2.3.2.: Kernel Recovery and rejects for Central Queensland case study sites (1+2) from 2020 (left) and 2021 (right) harvest



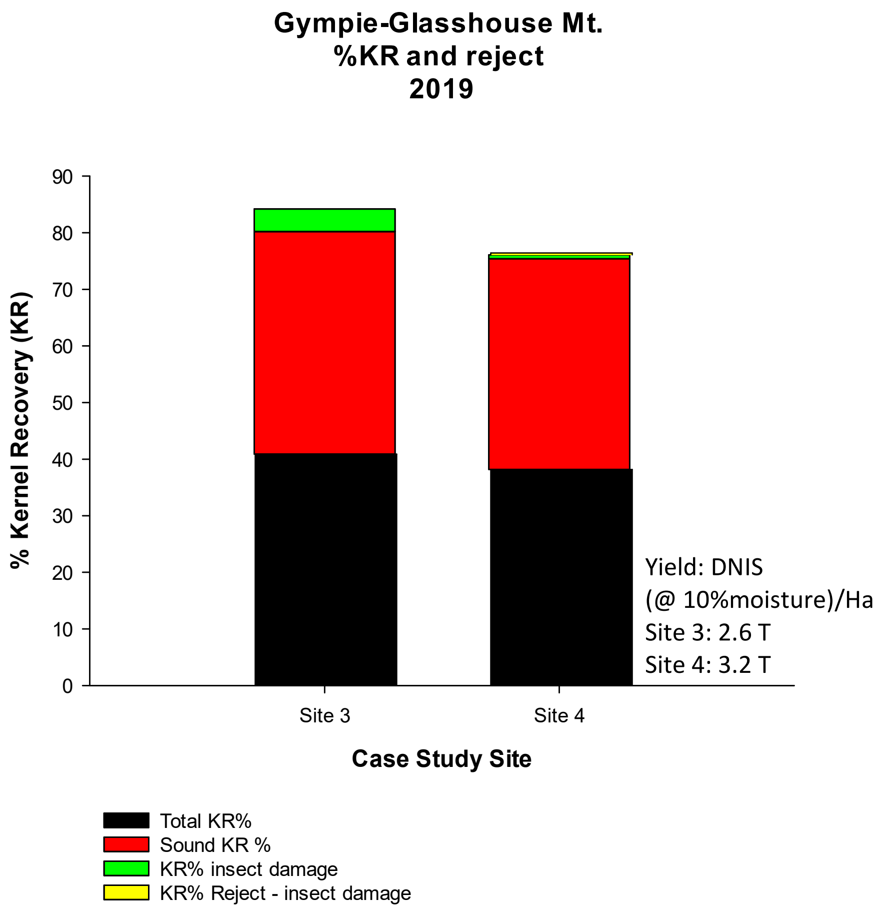


Figure 2.2.3.3.: Kernel Recovery and rejects for Gympie-Glasshouse Mt. case study sites (3+4) from 2018 (left) and 2019 (right) harvest

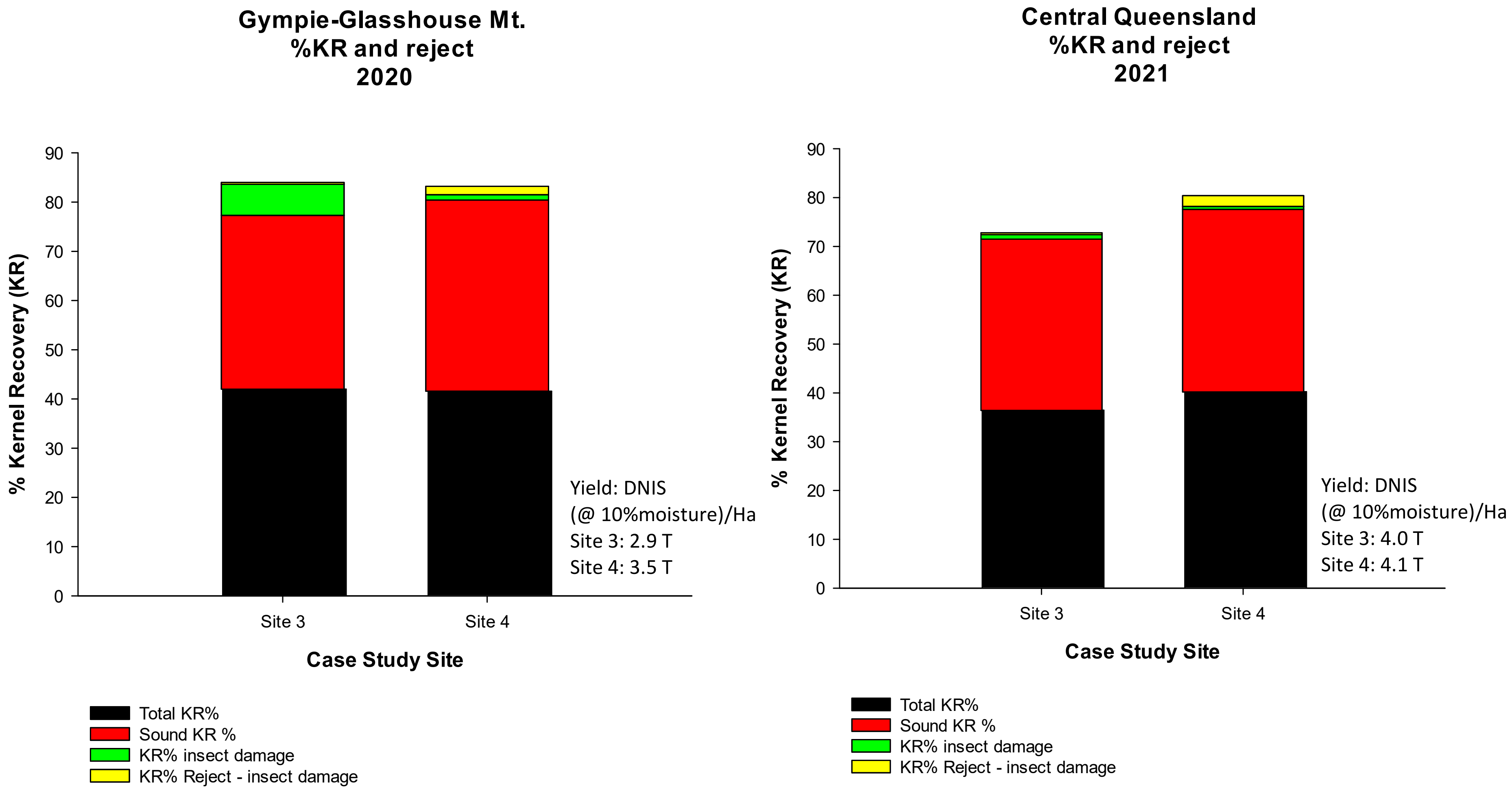
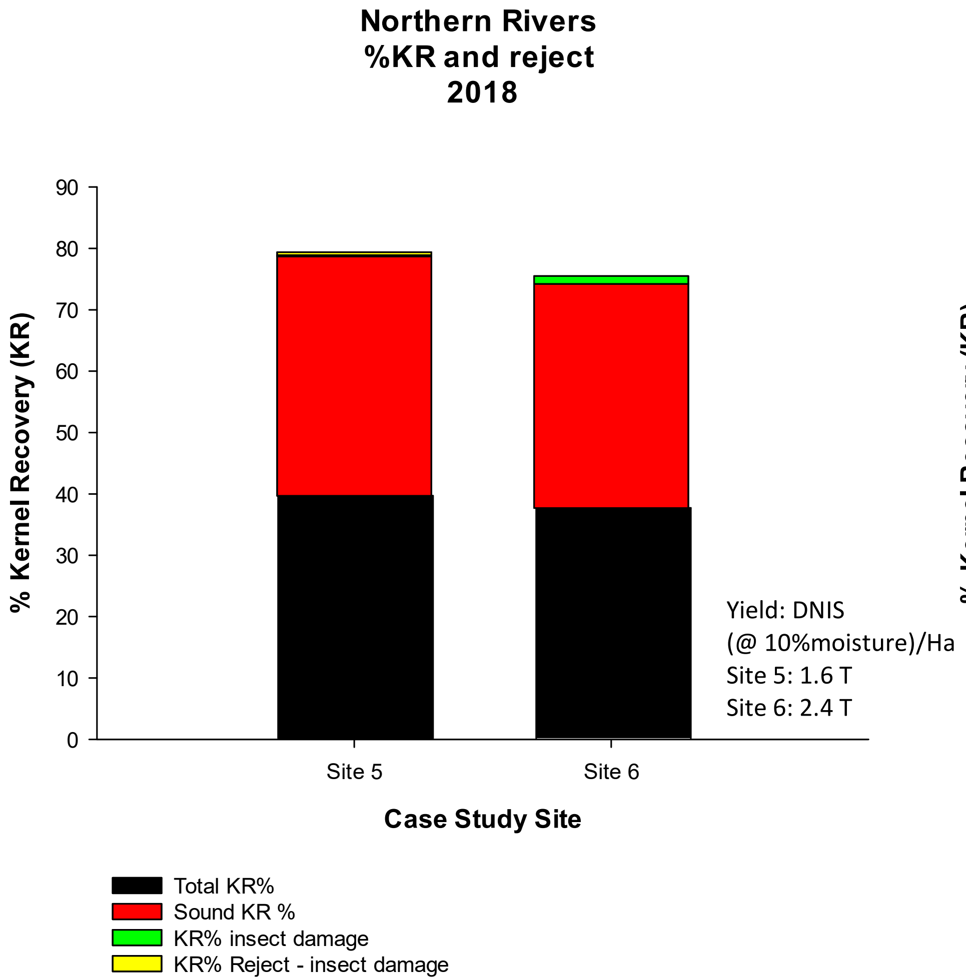


Figure 2.2.3.4.: Kernel Recovery and rejects for Gympie-Glasshouse Mt. case study sites (3+4) from 2020 (left) and 2021 (right) harvest



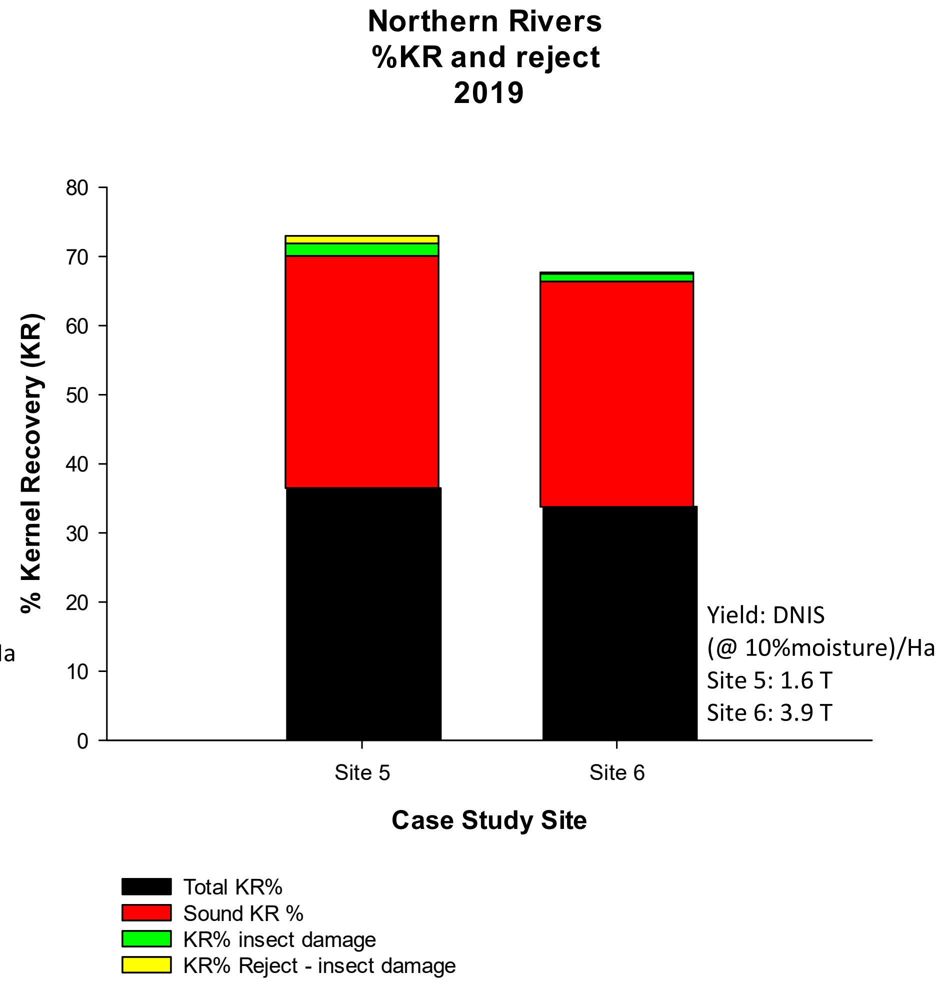
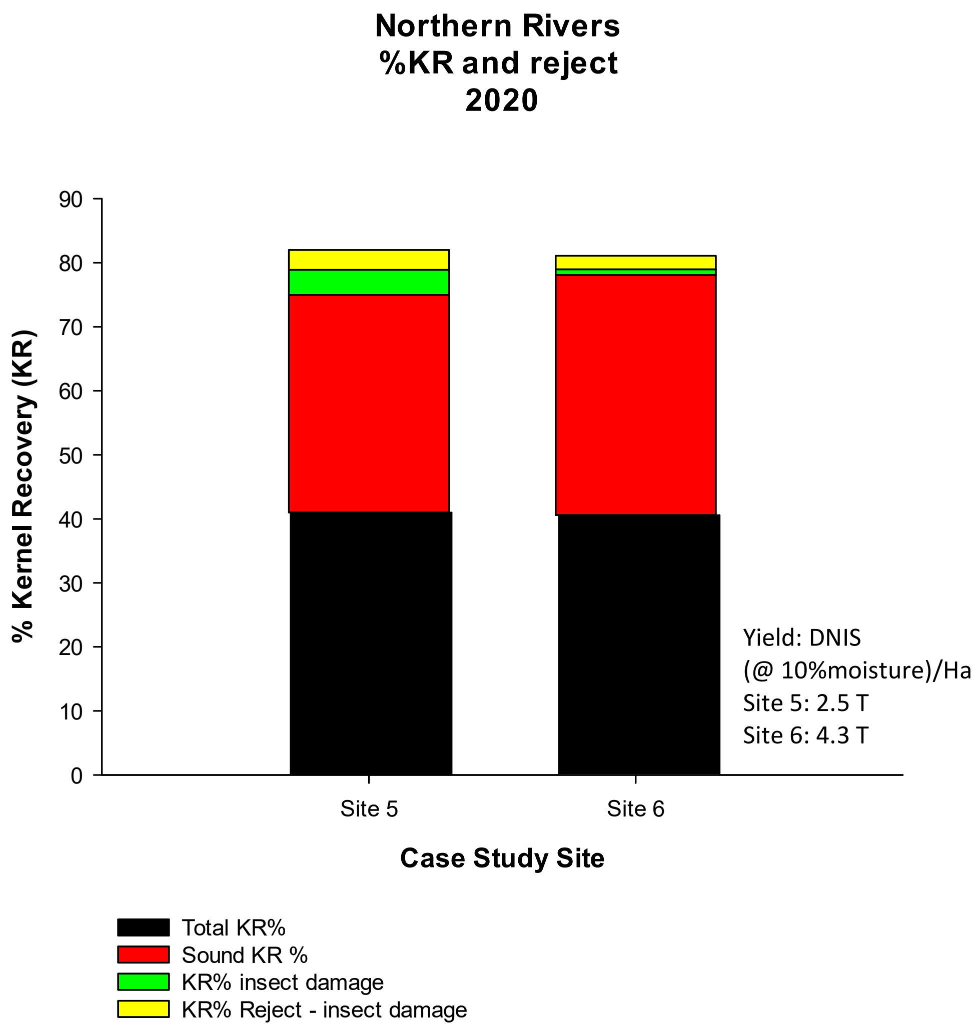


Figure 2.2.3.5.: Kernel Recovery and rejects for Northern Rivers case study sites (5+6) from 2018 (left) and 2019 (right) harvest



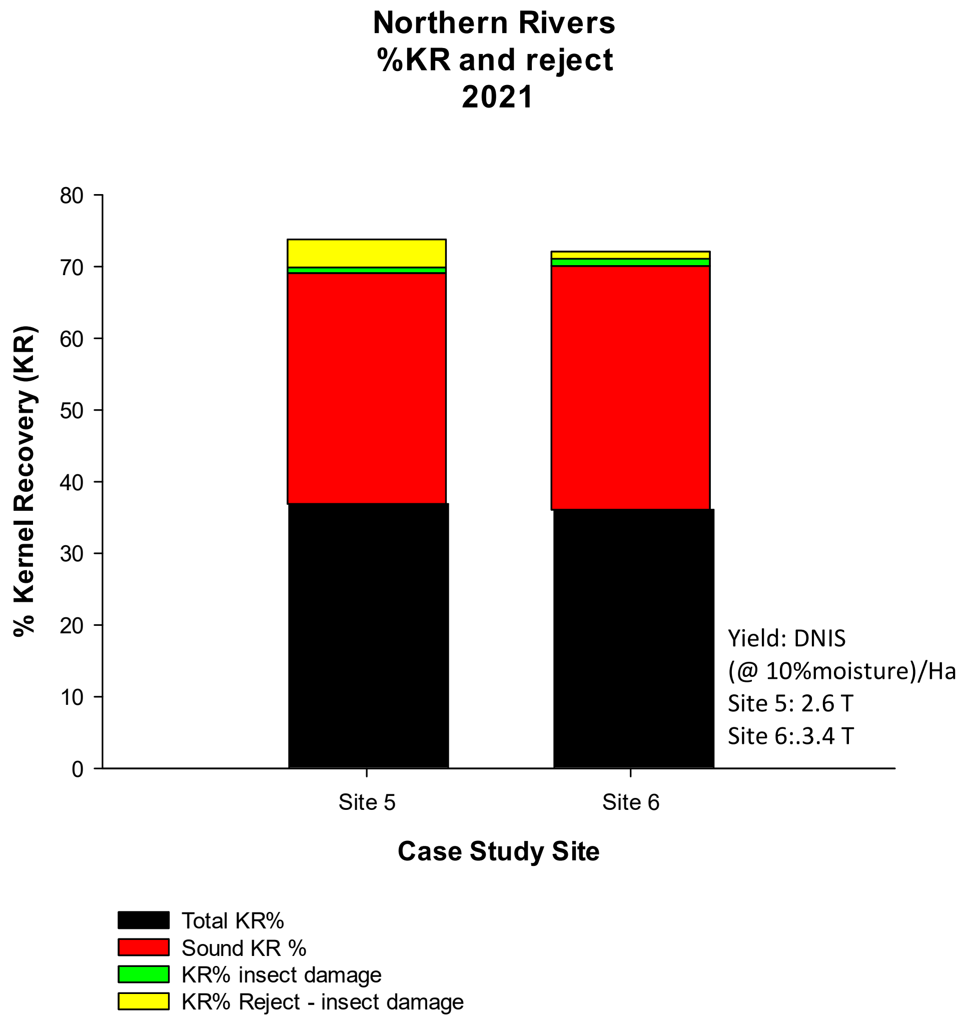
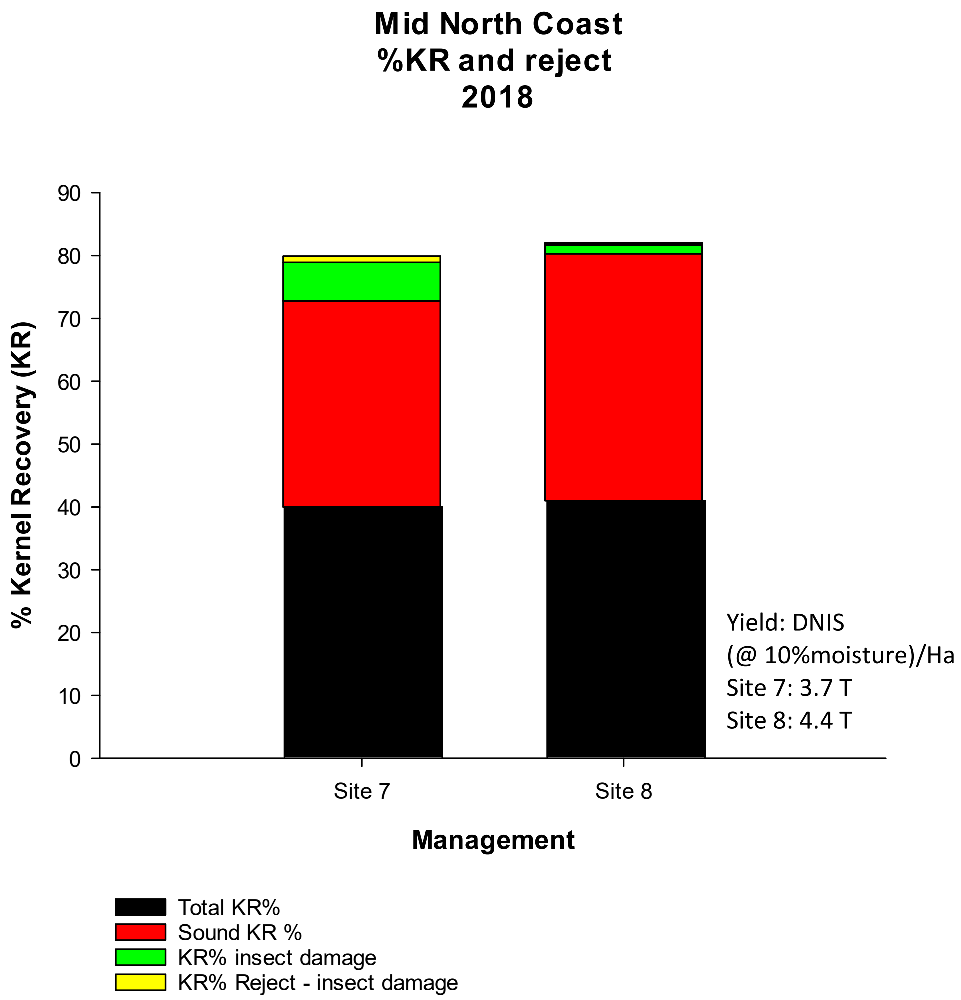


Figure 2.2.3.6.: Kernel Recovery and rejects for Northern Rivers case study sites (5+6) from 2020 (left) and 2021 (right) harvest



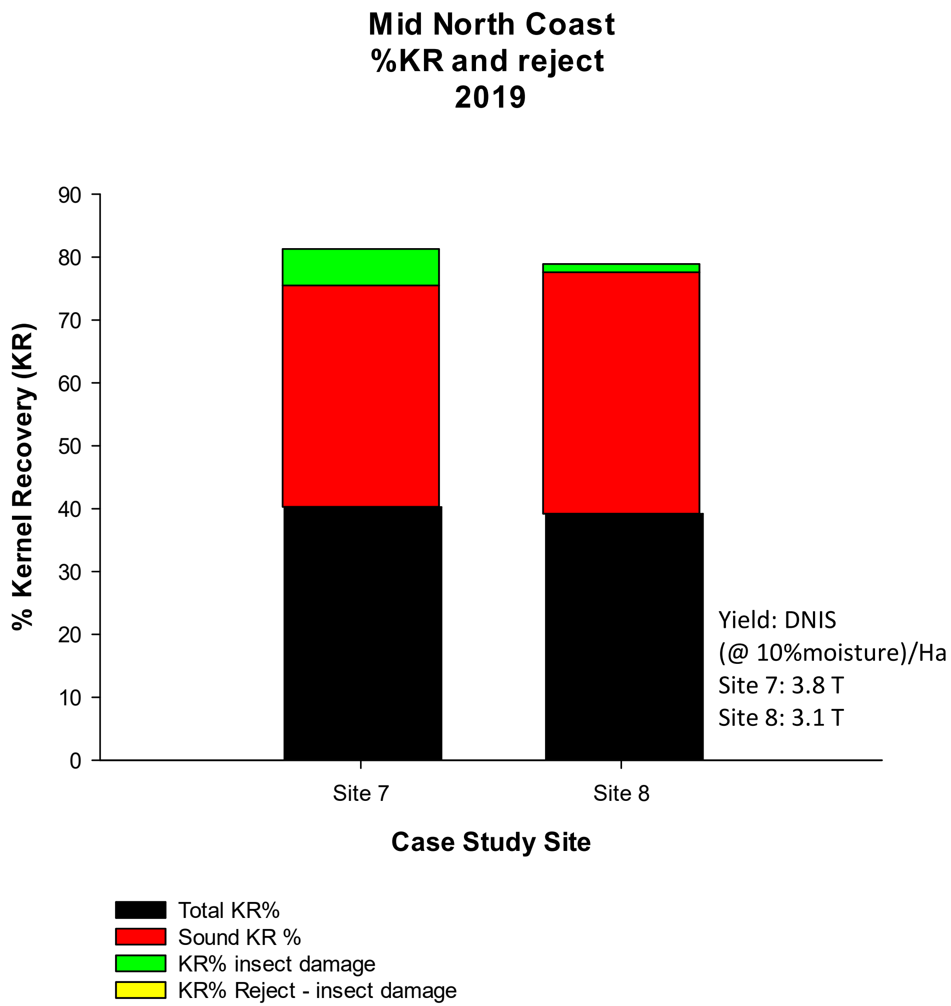
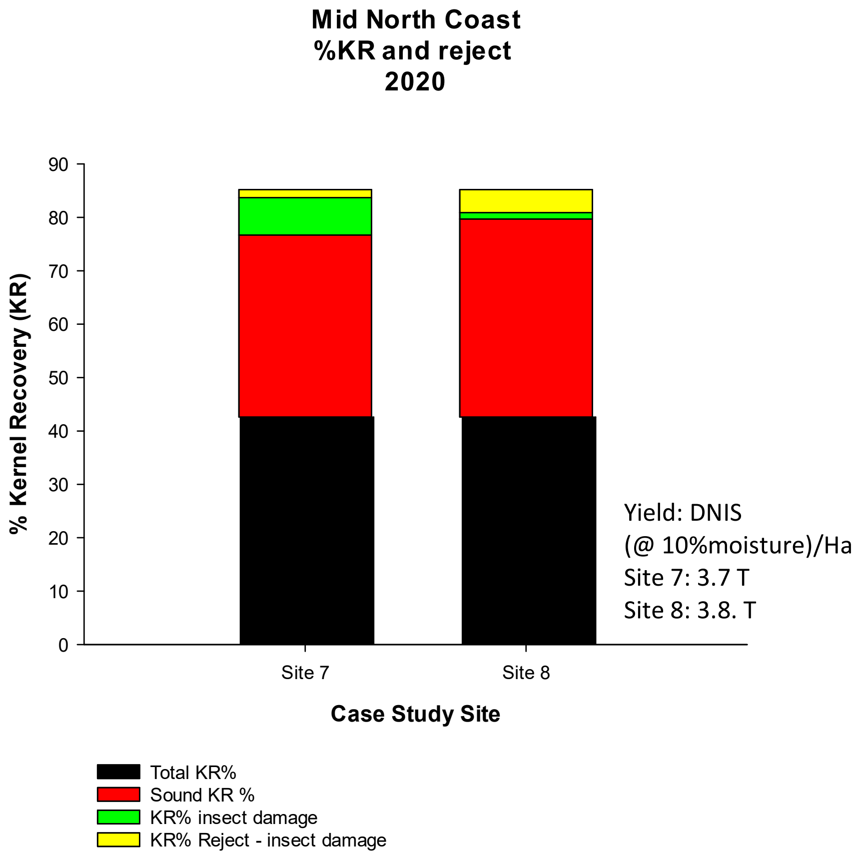


Figure 2.2.3.7.: Kernel Recovery and rejects for Mid North Coast case study sites (7+8) from 2018 (left) and 2019 (right) harvest



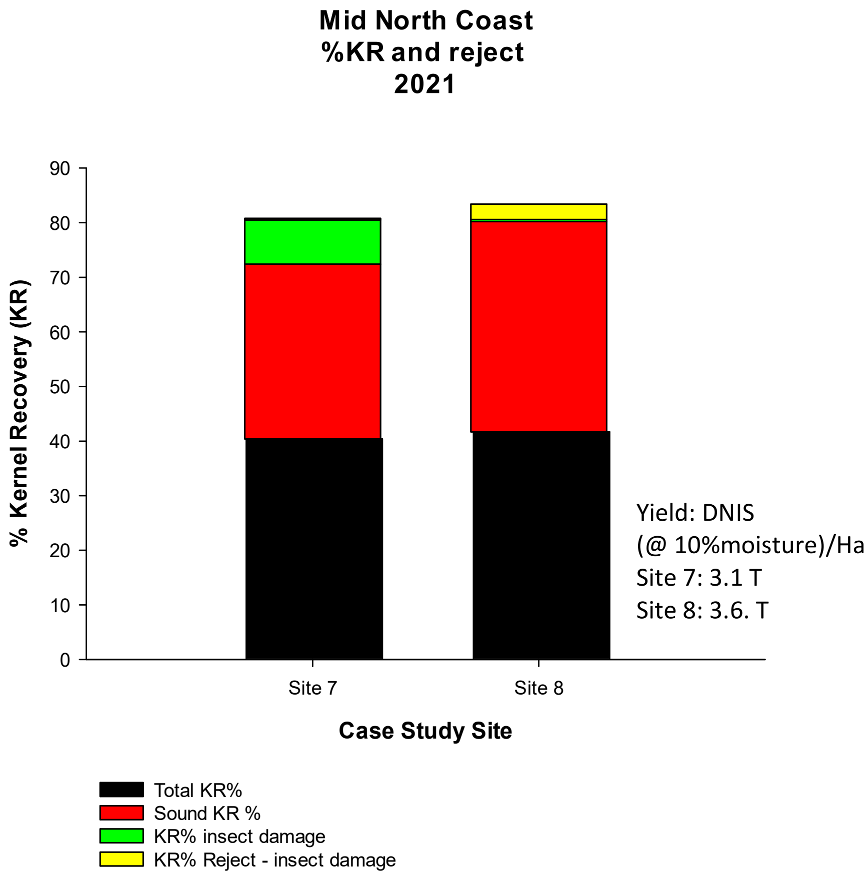


Figure 2.2.3.8.: Kernel Recovery and rejects for Mid North Coast case study sites (7+8) from 2020 (left) and 2021 (right) harvest

2.3. Trials at the Centre for Tropical Horticulture (CTH) at Alstonville (Northern Rivers)

This trial gave us the opportunity particularly to optimise the input of pesticides, comparing treatments with different pesticides rotations, but also the effect of different cultivars.

2.3.1. Main IPM trial

Monitoring:

Results from monitoring using yellow sticky traps and scolytid pheromone traps (BROCAP® traps and "Ambro" lures are discussed.

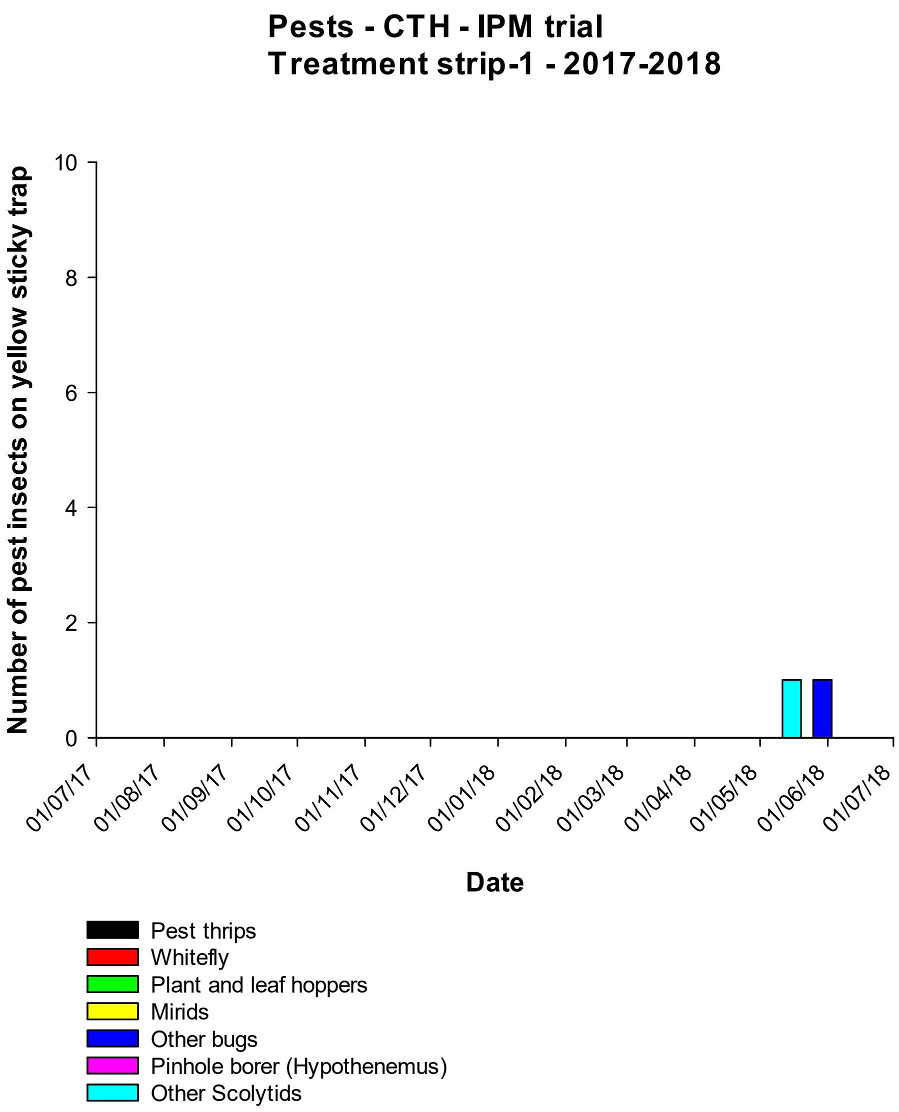
Yellow sticky traps

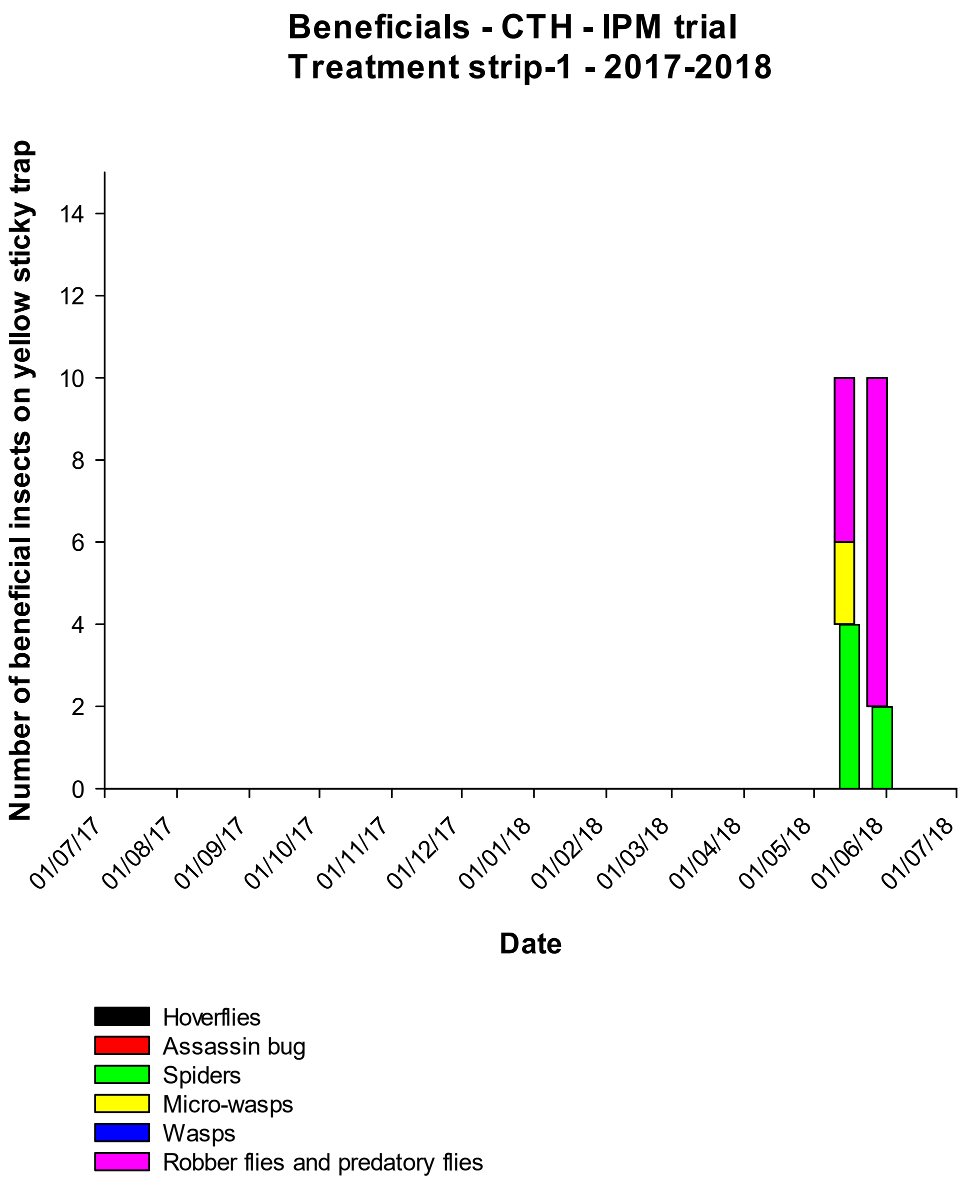
Monitoring with yellow sticky traps only started in June 2018.Summary results for each season of groups of pests and beneficials trapped in different treatment strips between 2017 and 2021 are presented in Tables 2.3.1.1 to 2.3.1.4.

Detailed graphs for each treatment strip and each season are shown in Figures 2.3.1.1. to 2.3.1.16.

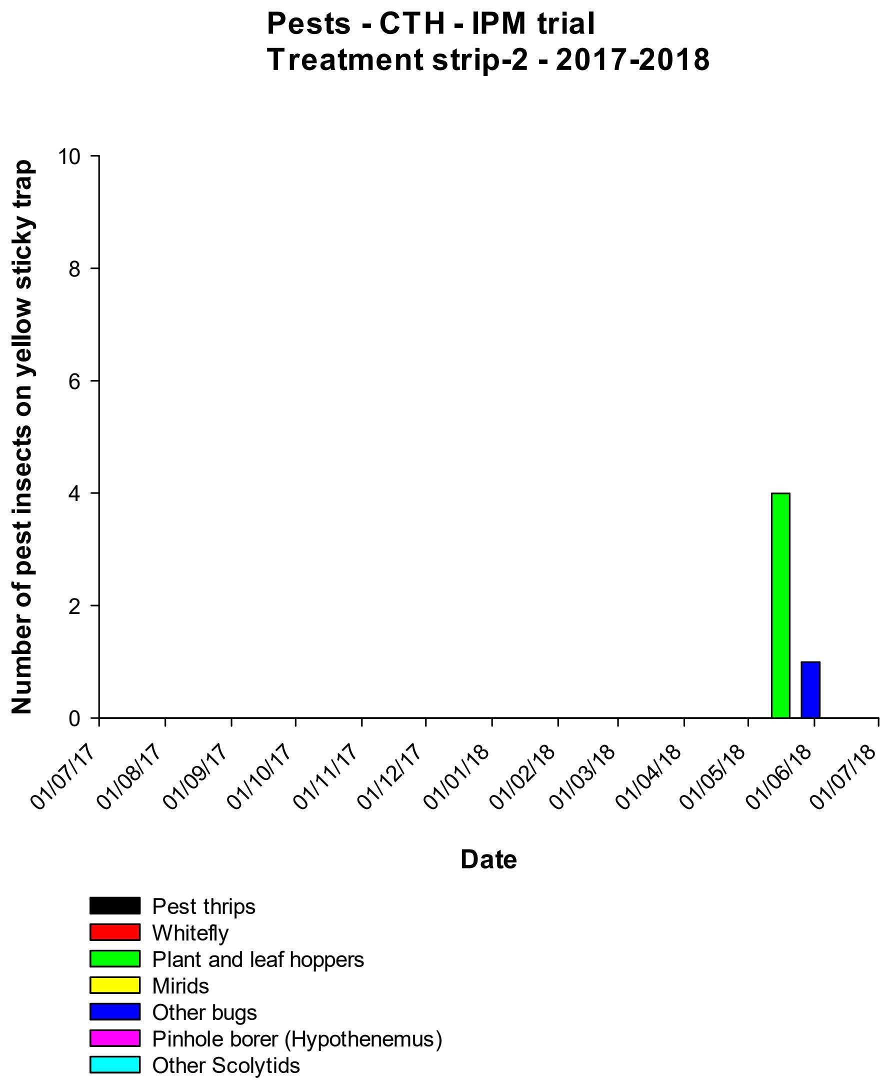
Scolytidae traps

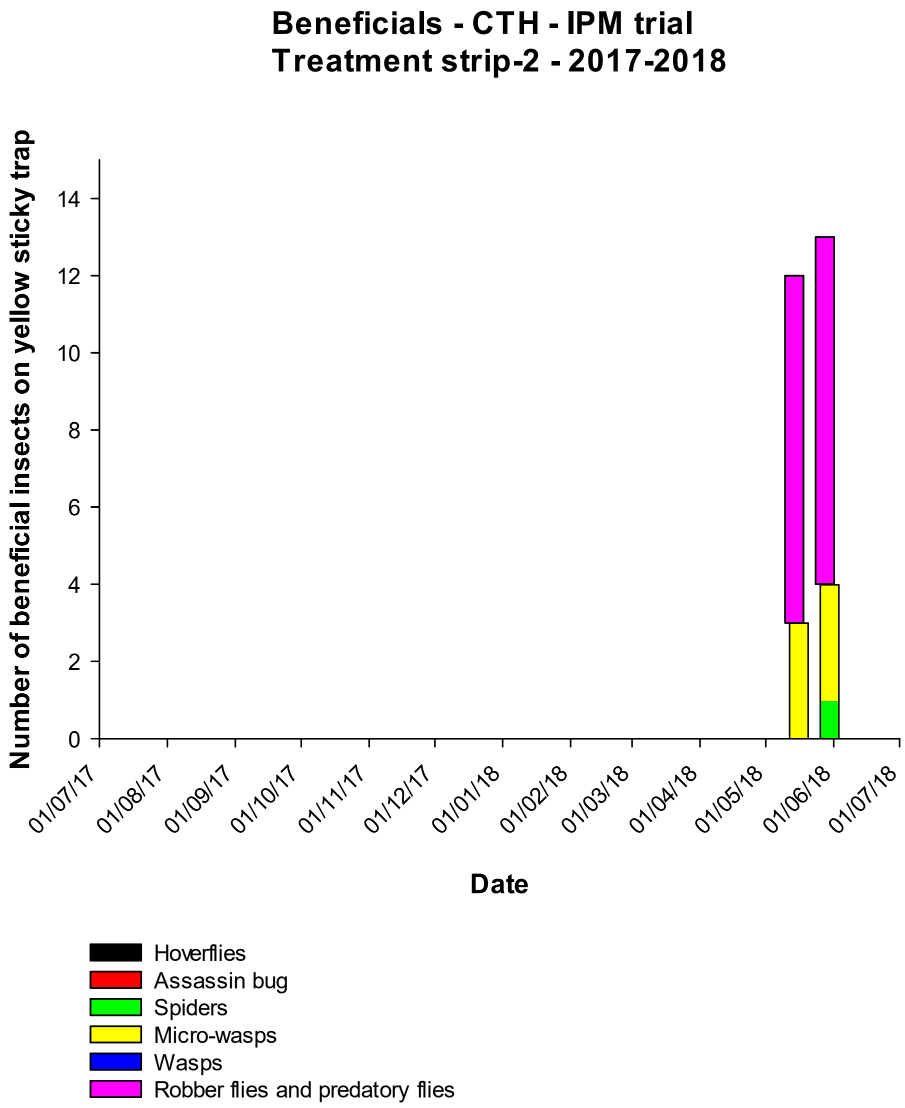
Numbers of different scolytid species captured in the BROCAP® panel trap with "Ambro" lures in the different treatment strips between 2017 and 2021 are shown in Figures 2.3.1.17 to 2.3.1.24.



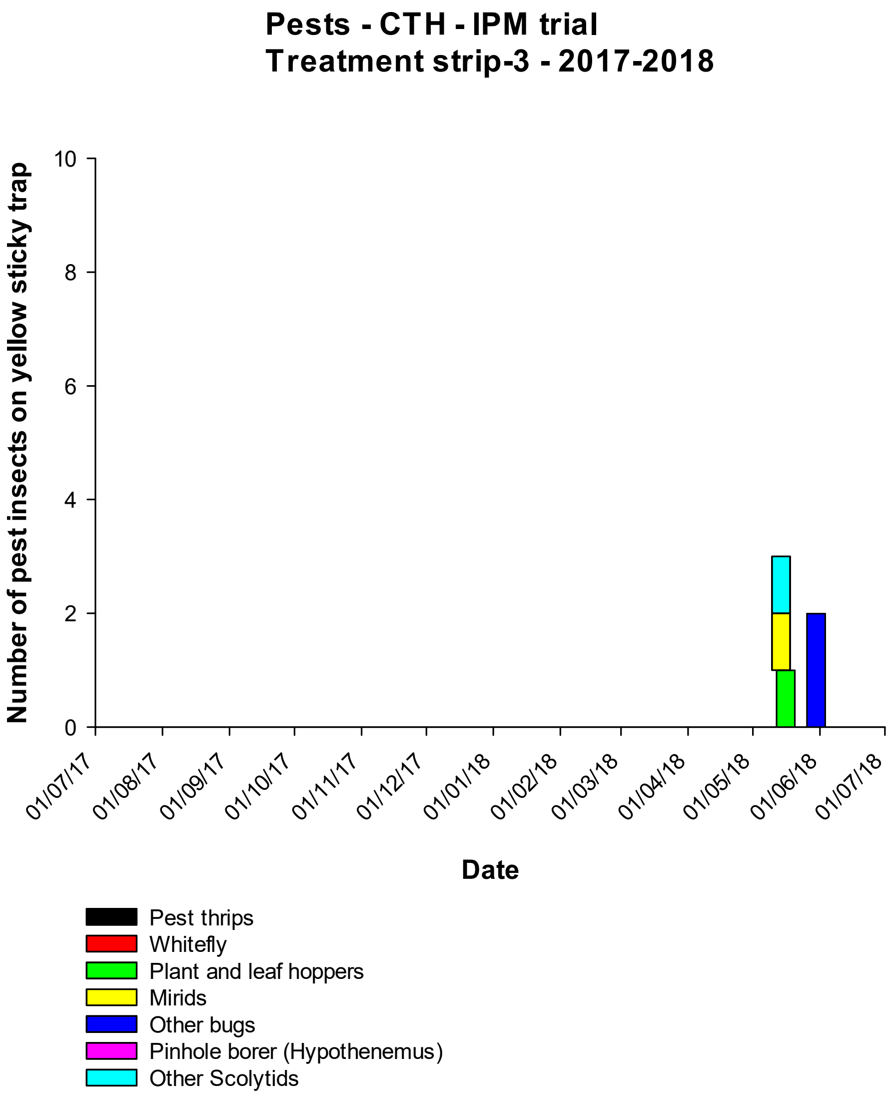


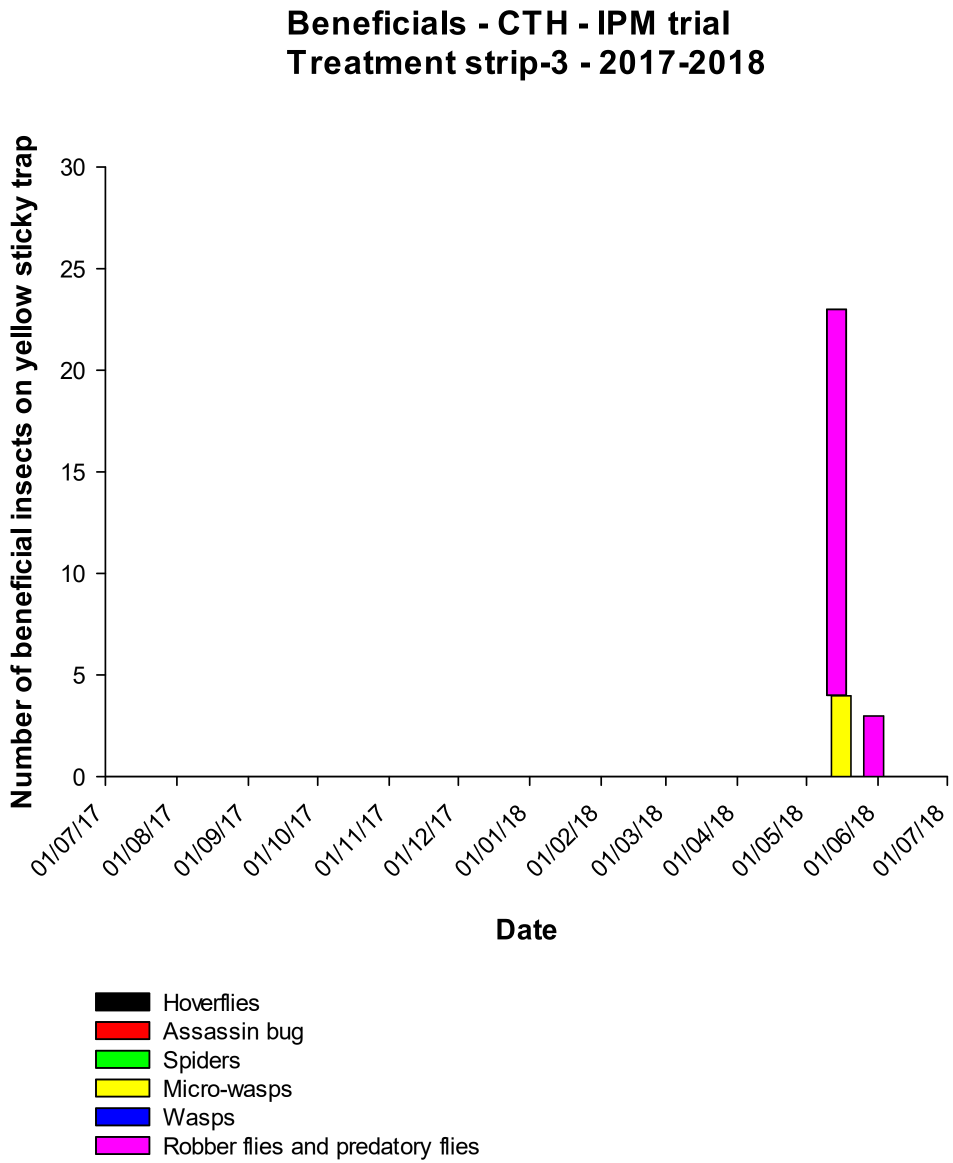
Figures 2.3.1.1.: Pest and beneficials in CTH IPM trial, Treatment strip-1-2017-2018



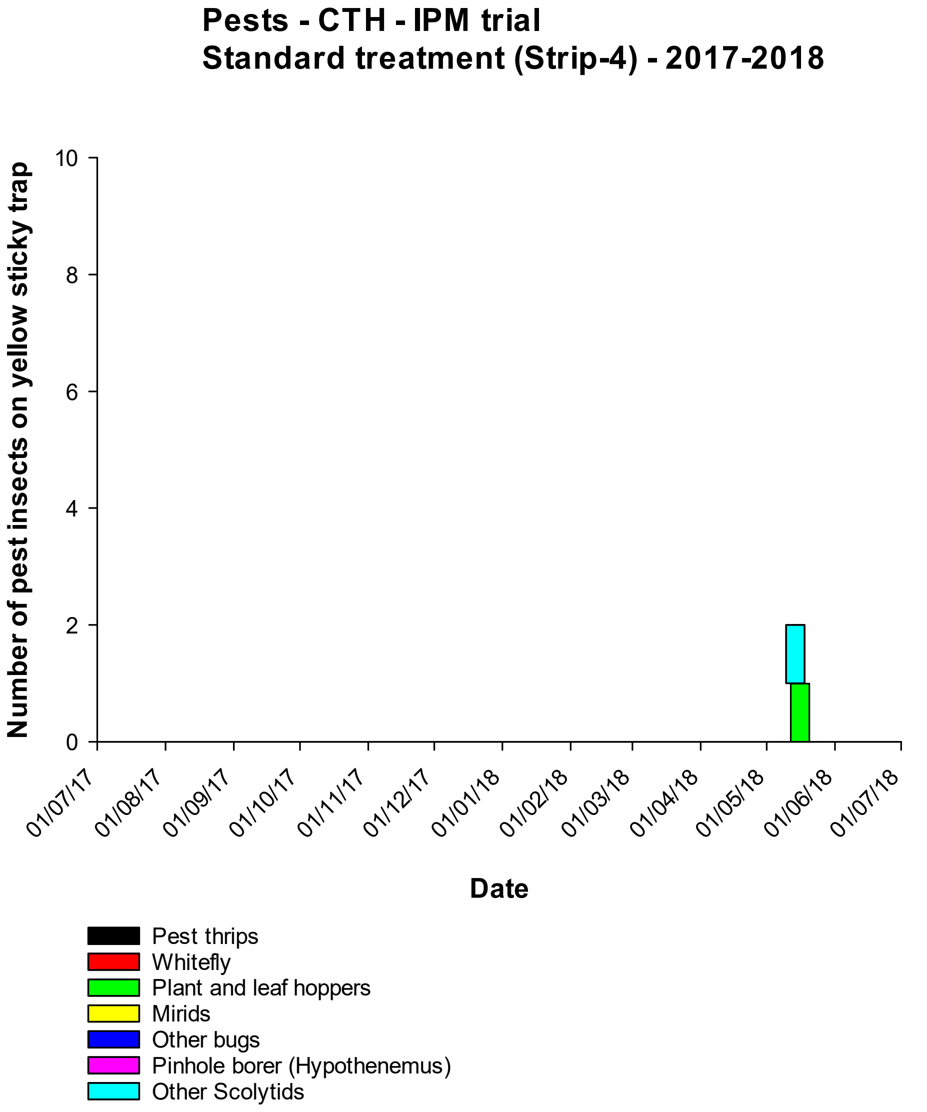


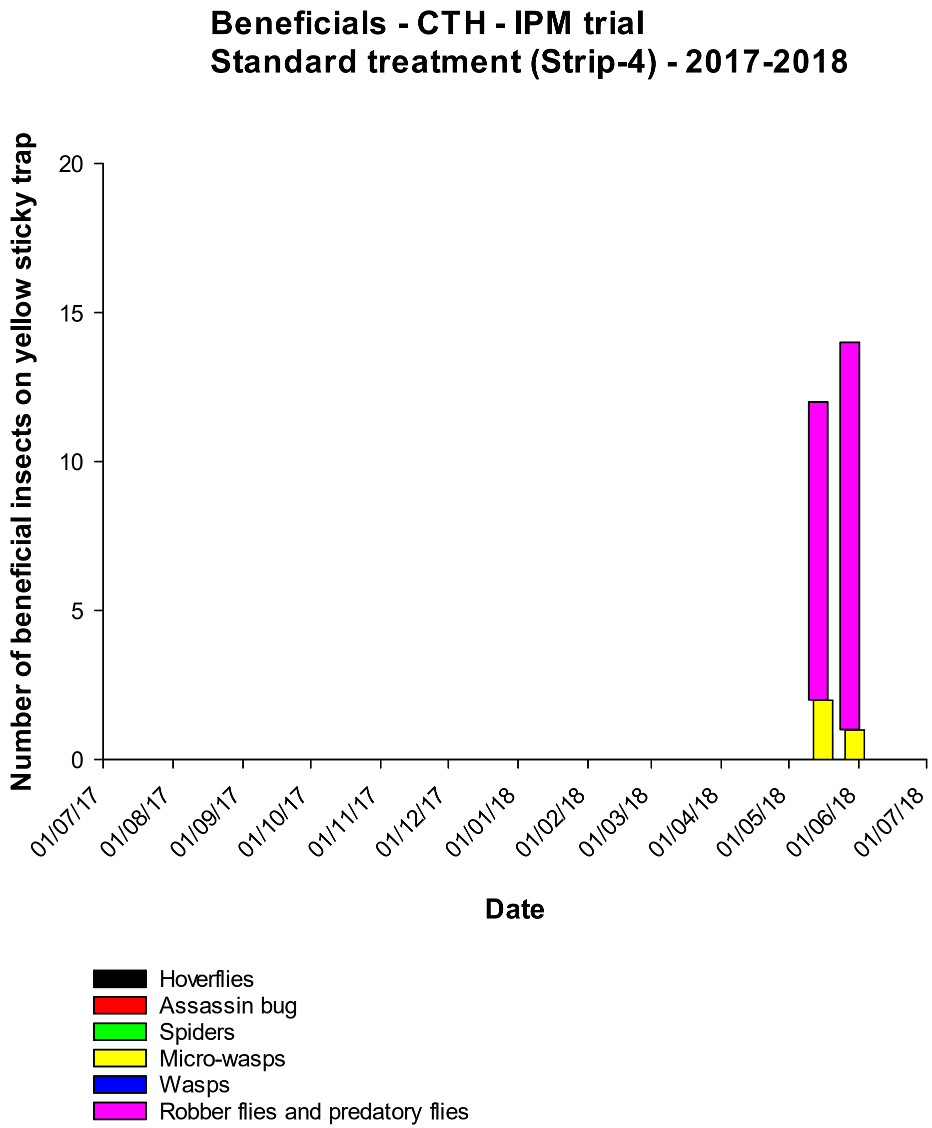
Figures 2.3.1.2.: Pest and beneficials in CTH IPM trial, Treatment strip-2-2017-2018



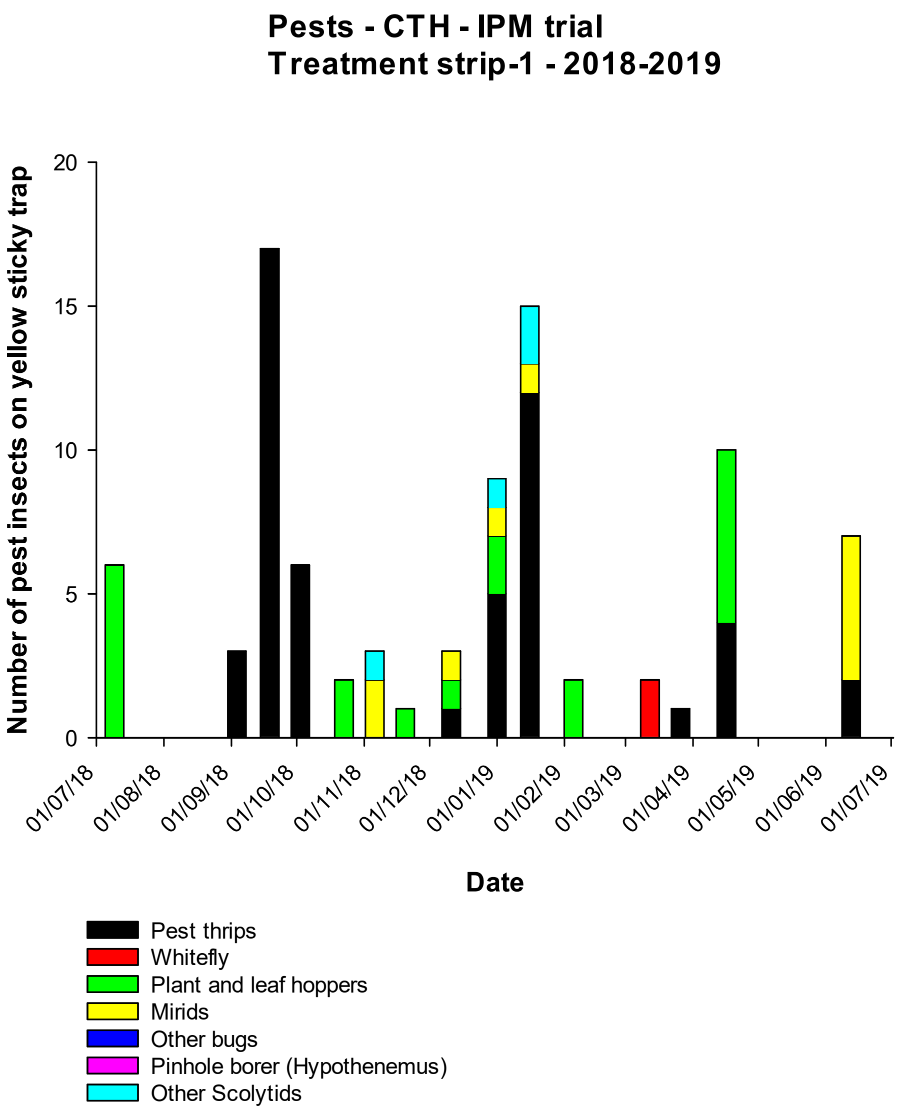


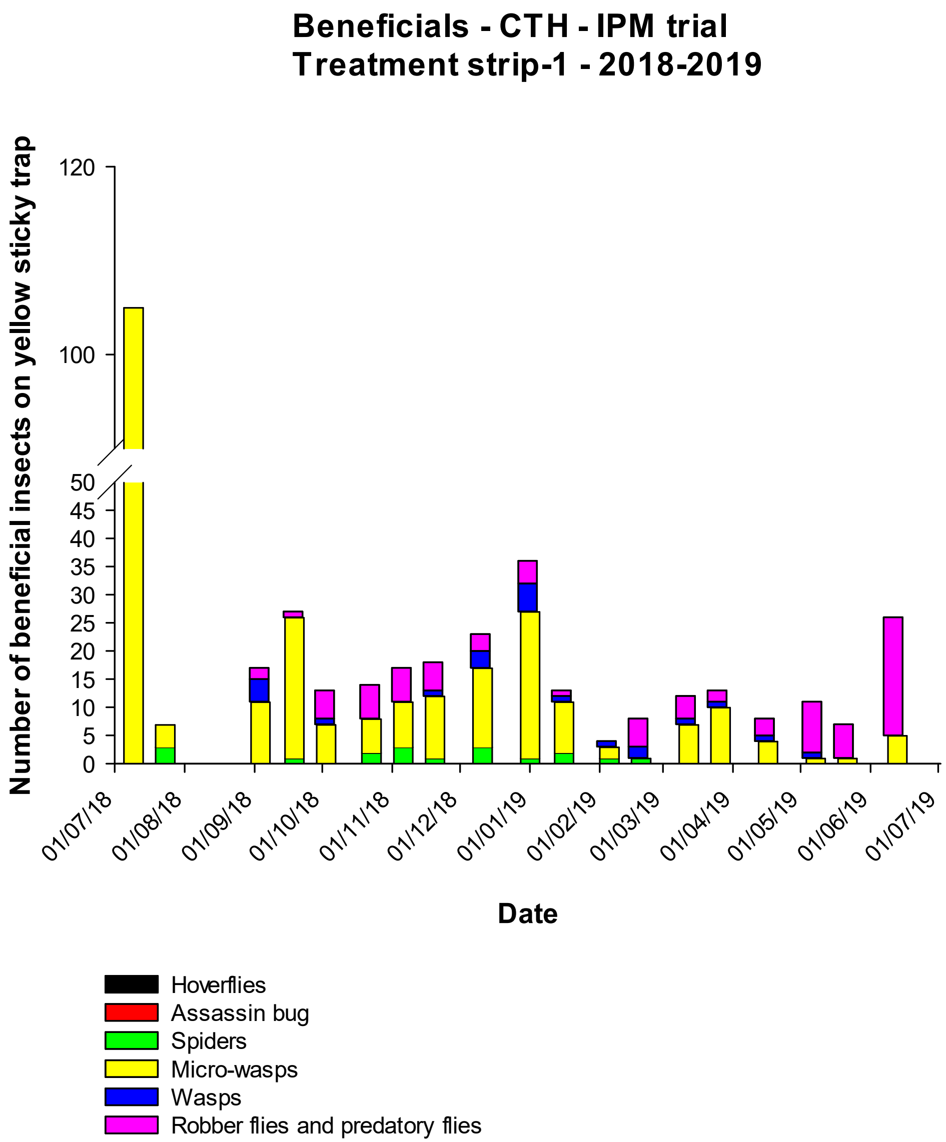
Figures 2.3.1.3.: Pest and beneficials in CTH IPM trial, Treatment strip-3-2017-2018



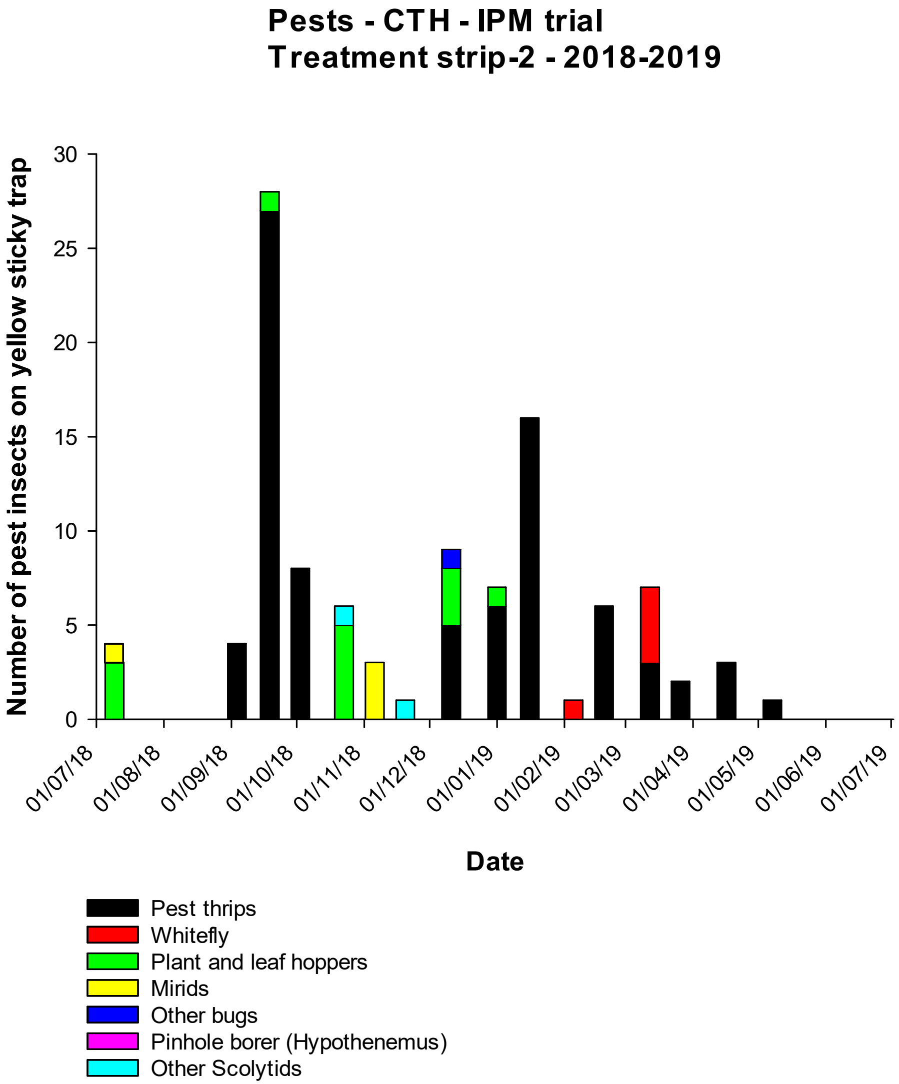


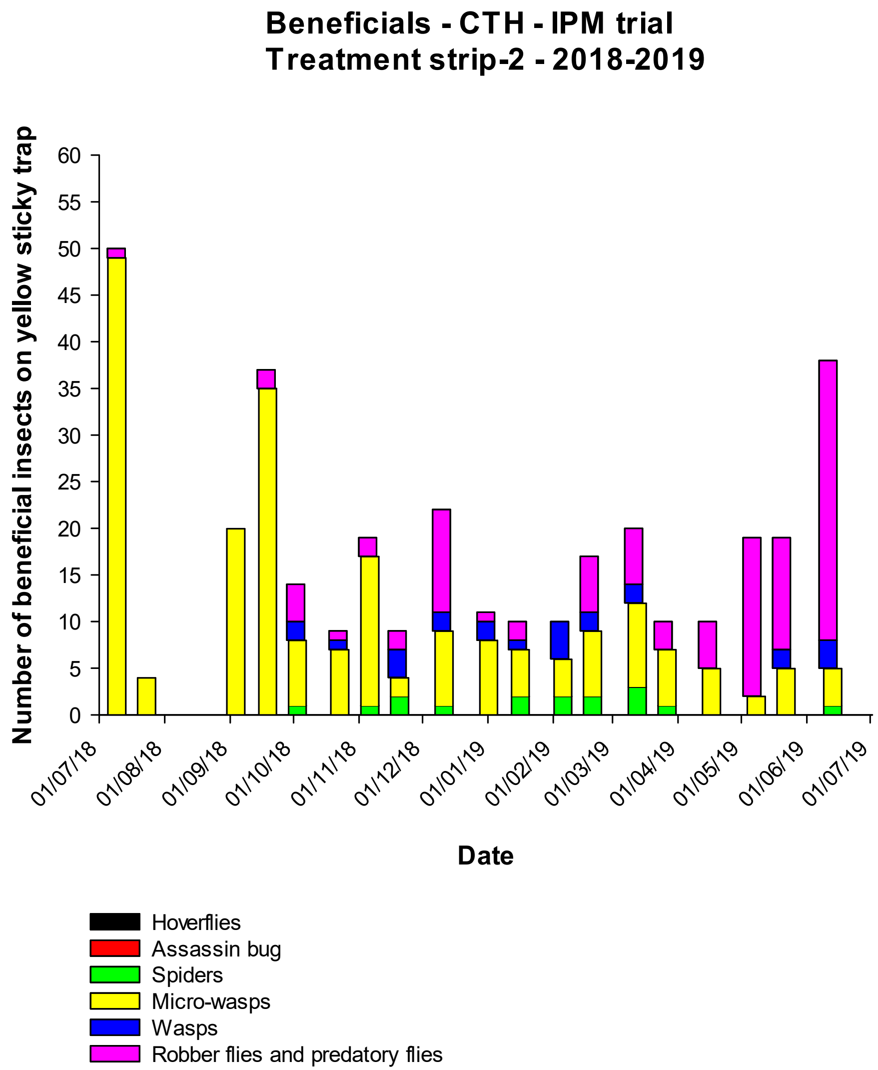
Figures 2.3.1.4.: Pest and beneficials in CTH IPM trial, Treatment strip-4-2017-2018



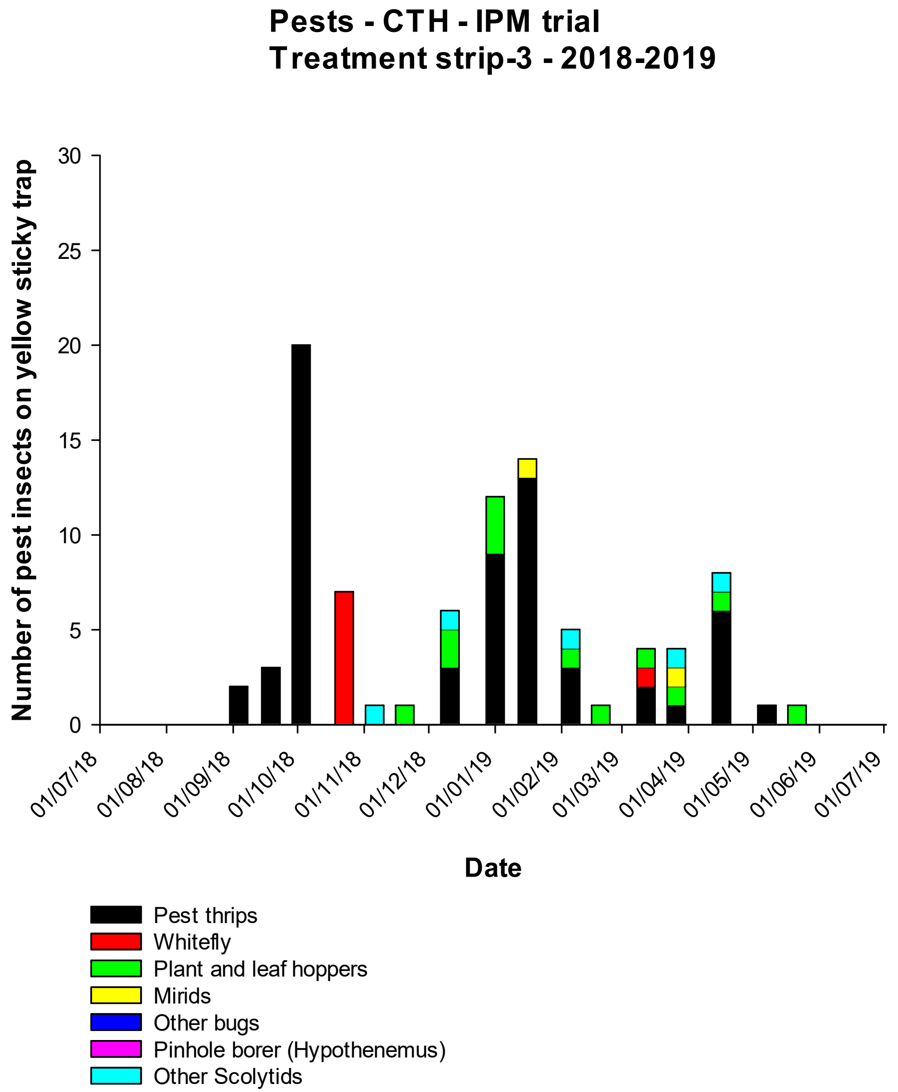


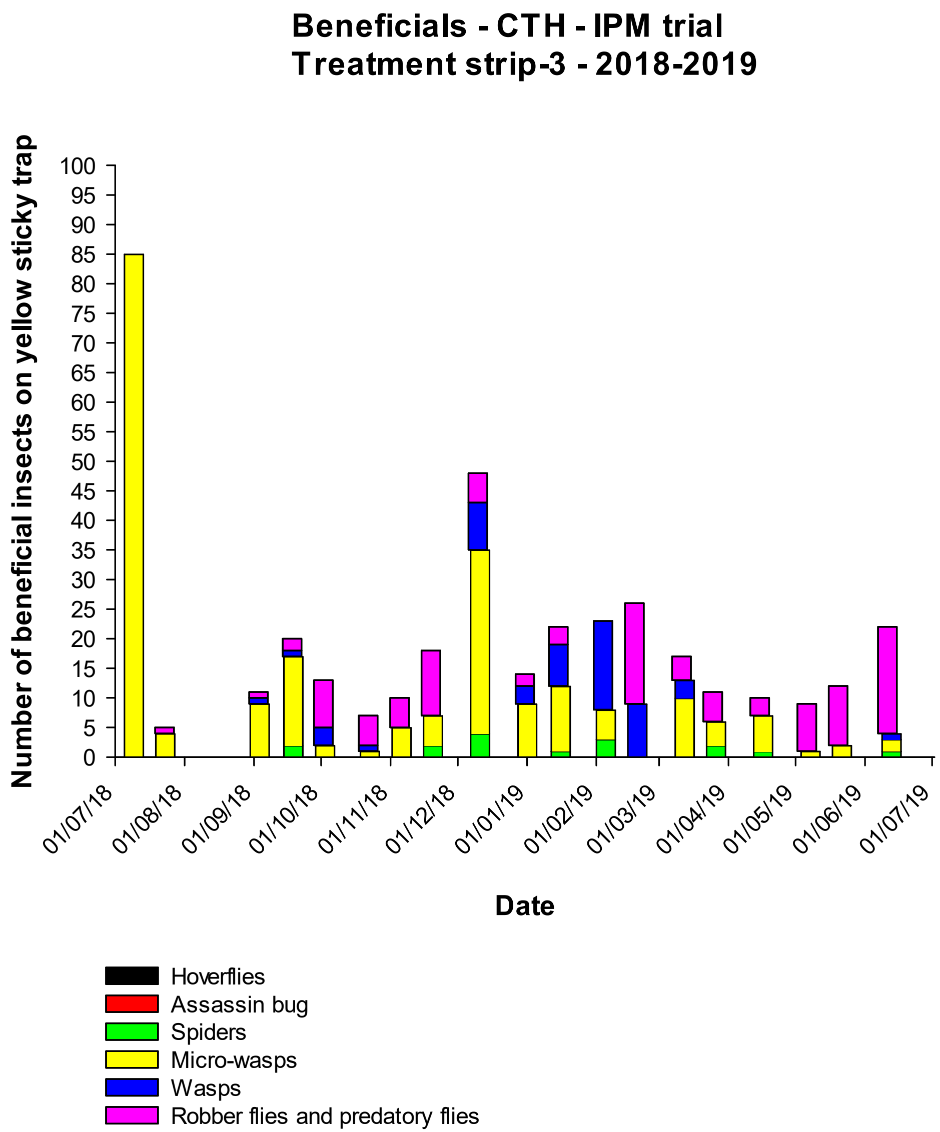
Figures 2.3.1.5.: Pest and beneficials in CTH IPM trial, Treatment strip-1-2018–2019



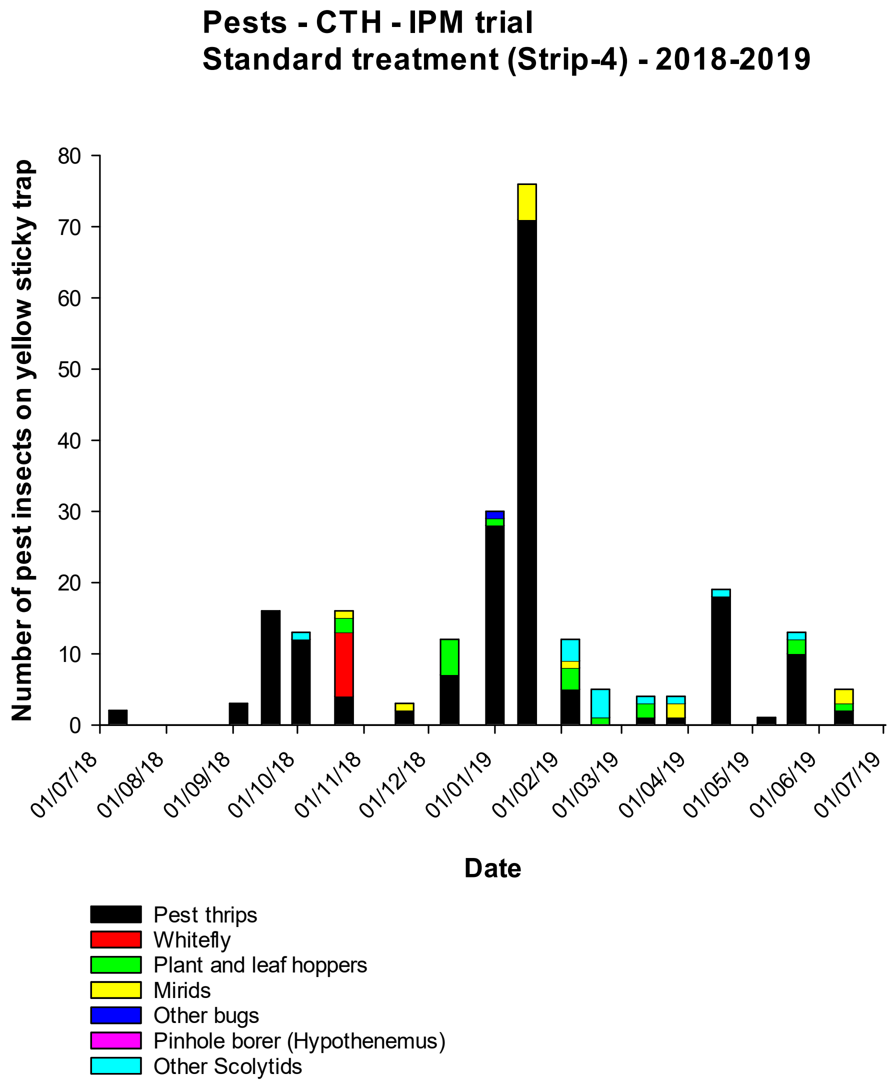


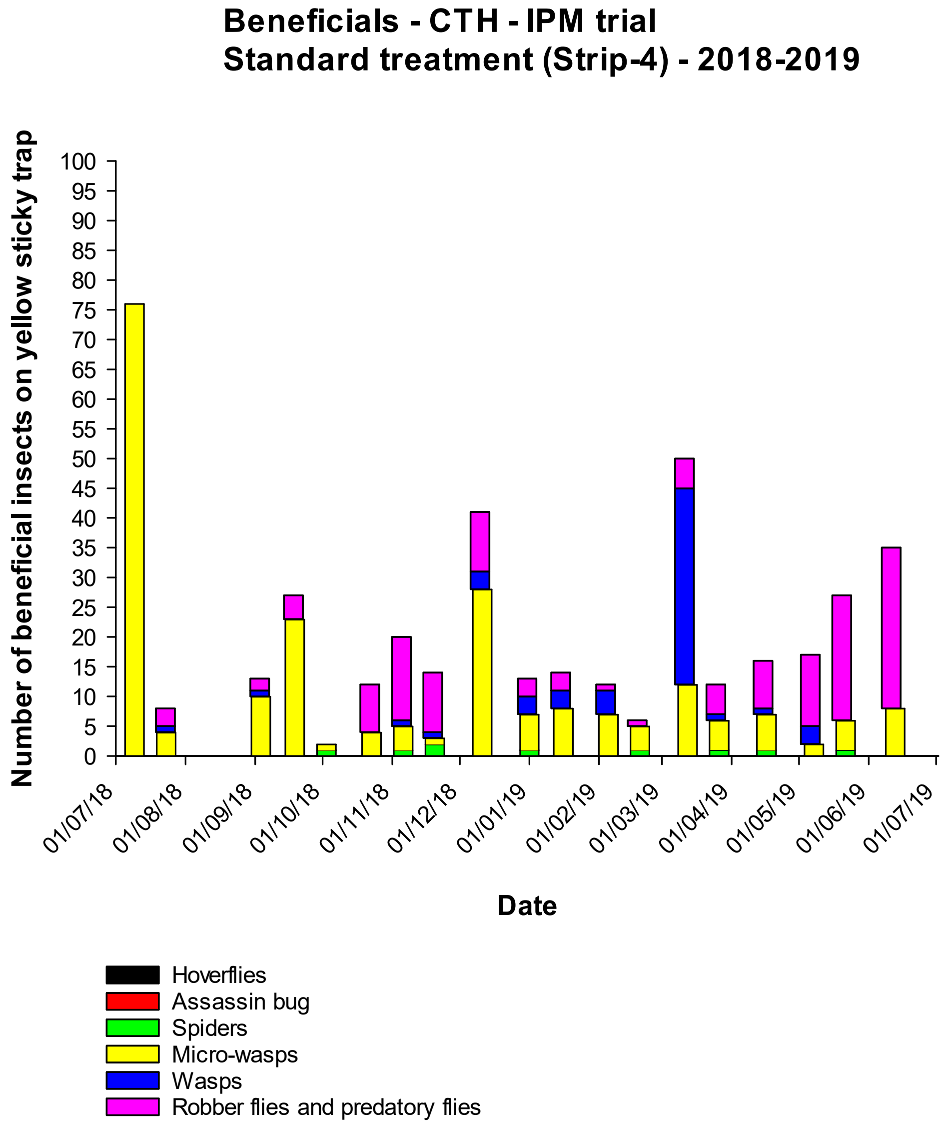
Figures 2.3.1.6.: Pest and beneficials in CTH IPM trial, Treatment strip-2-2018–2019



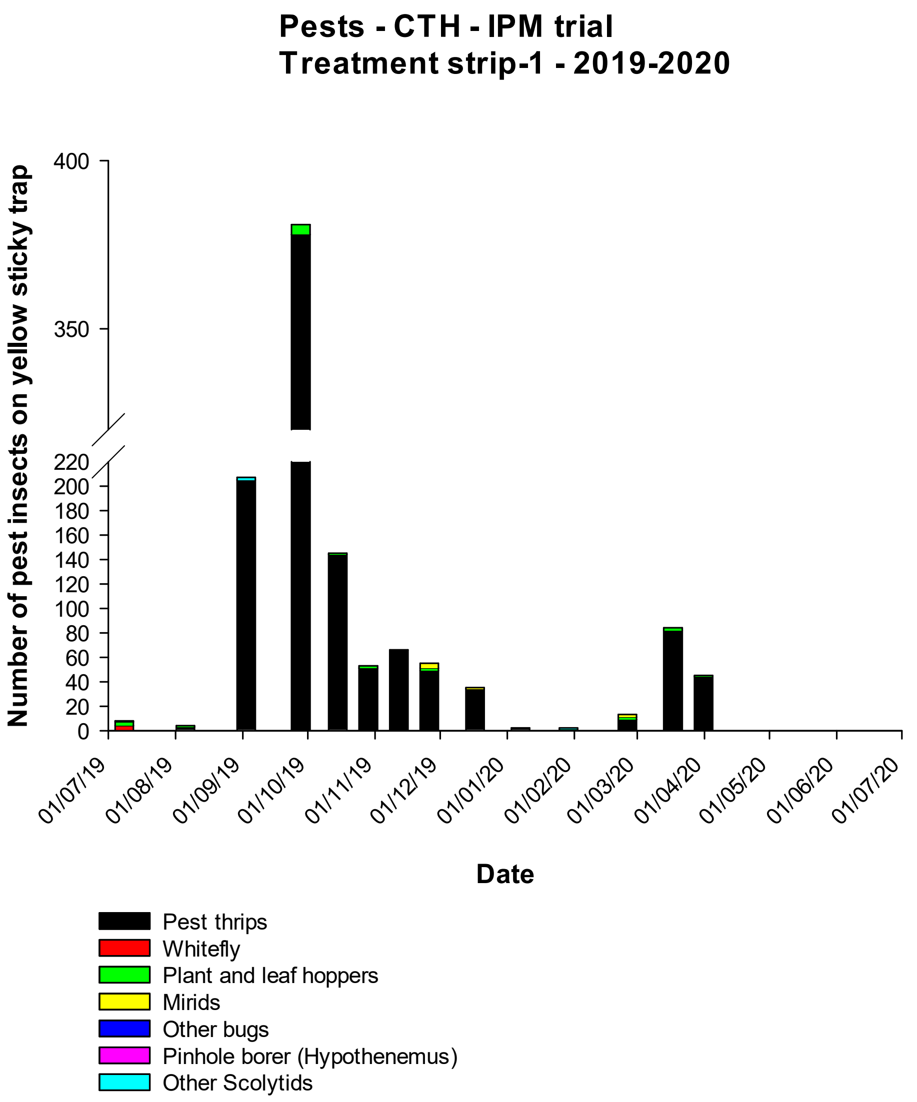


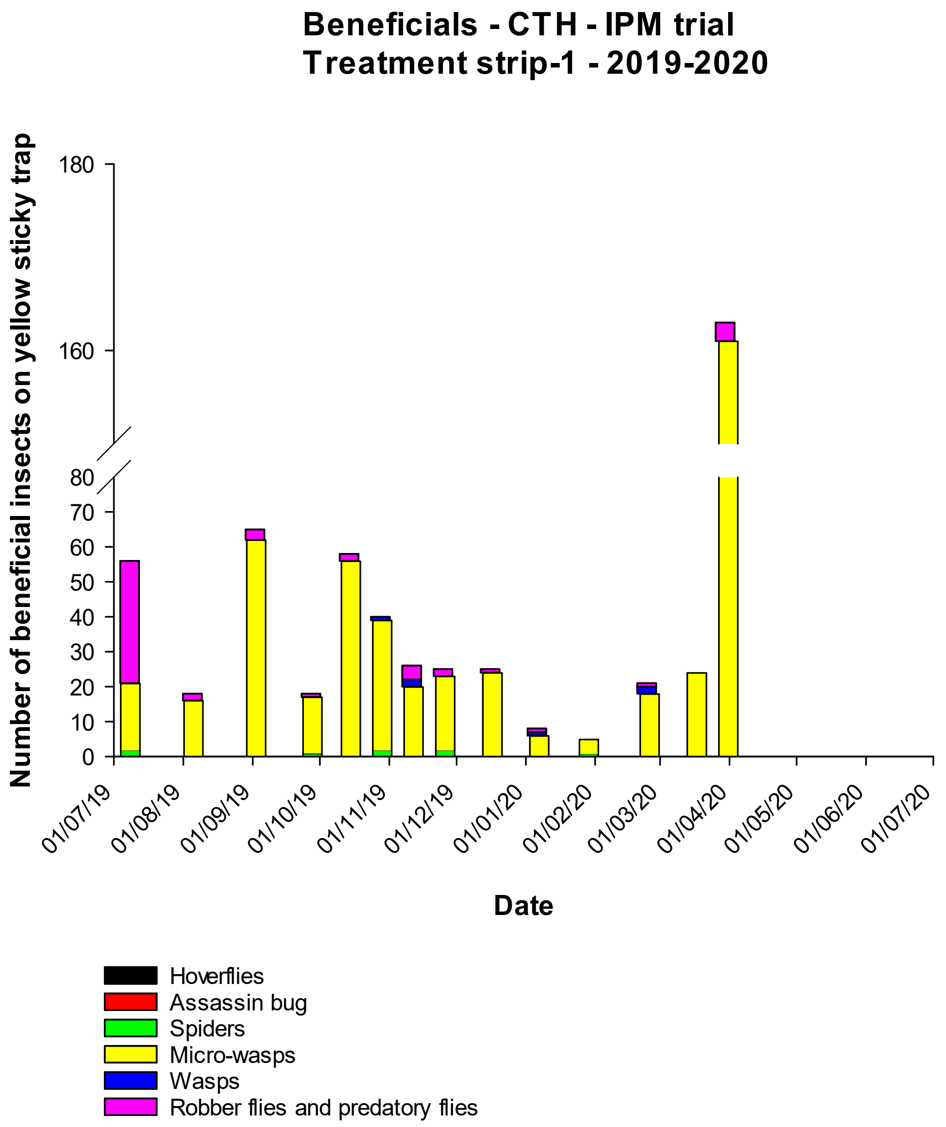
Figures 2.3.1.7.: Pest and beneficials in CTH IPM trial, Treatment strip-3-2018–2019



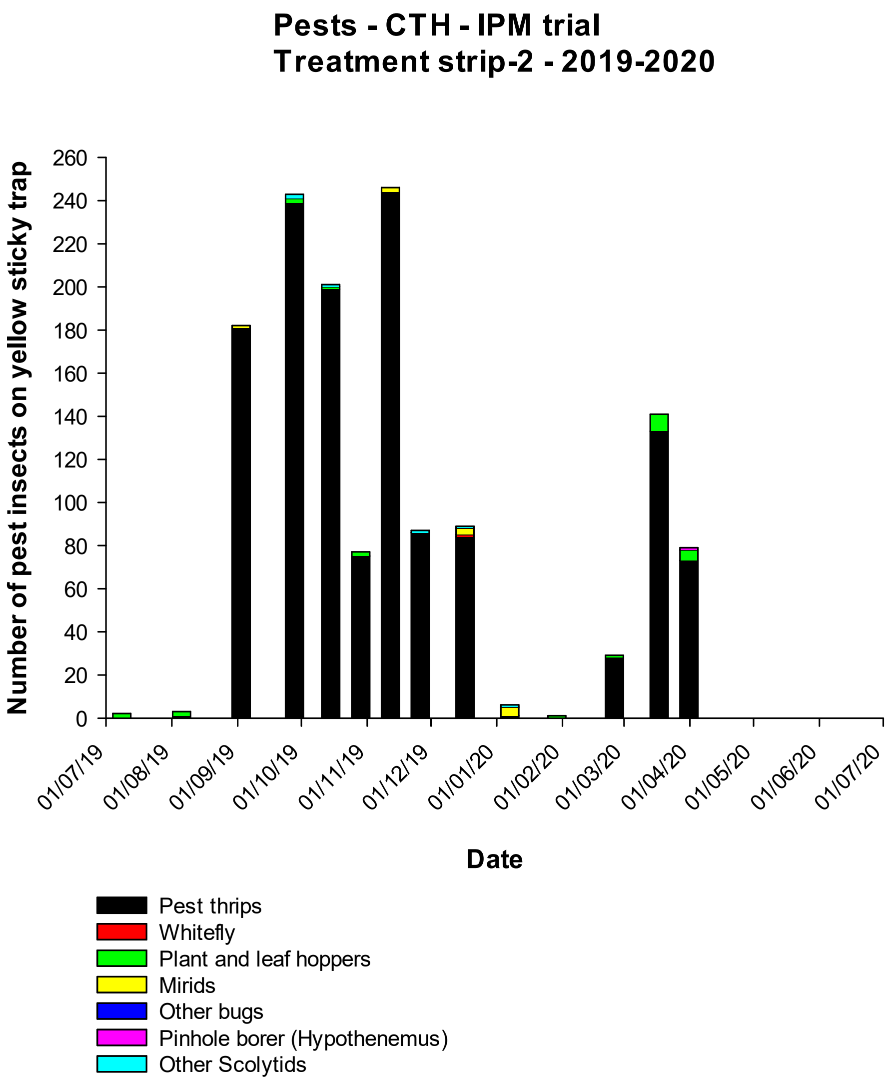


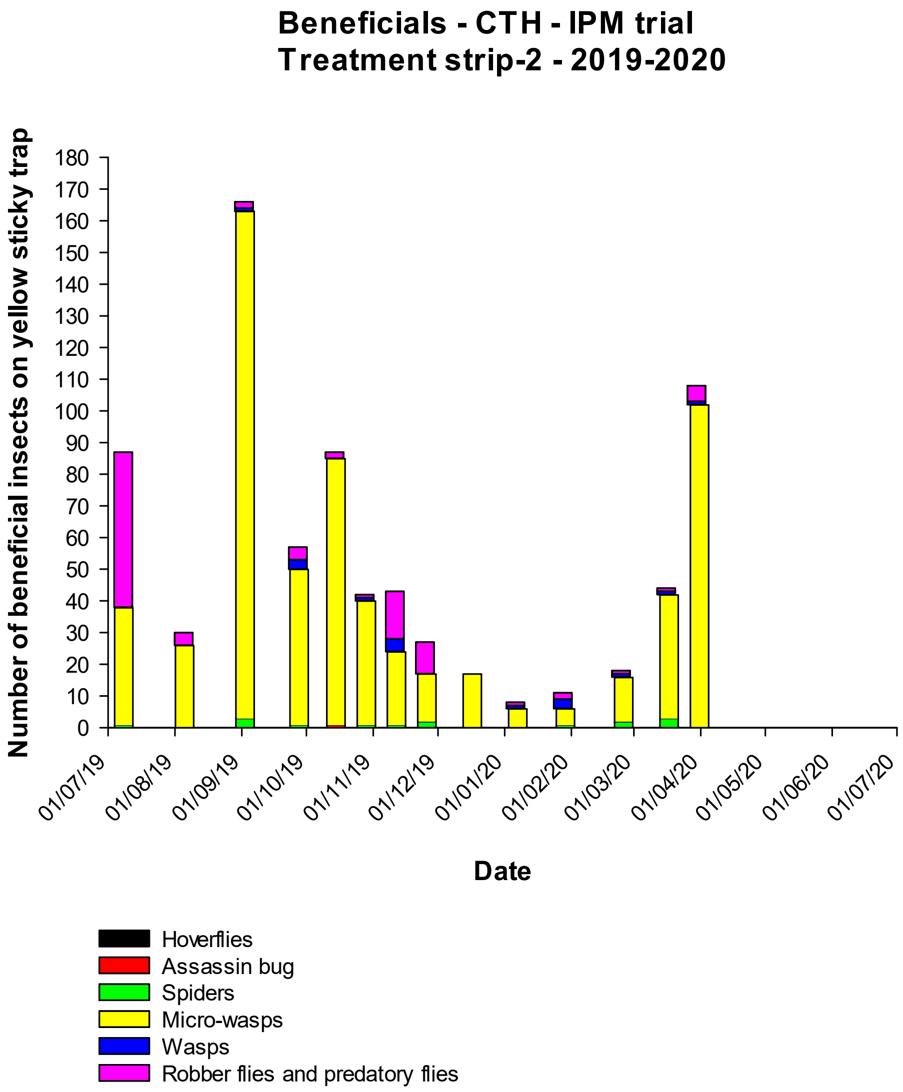
Figures 2.3.1.8.: Pest and beneficials in CTH IPM trial, Treatment strip-4-2018–2019



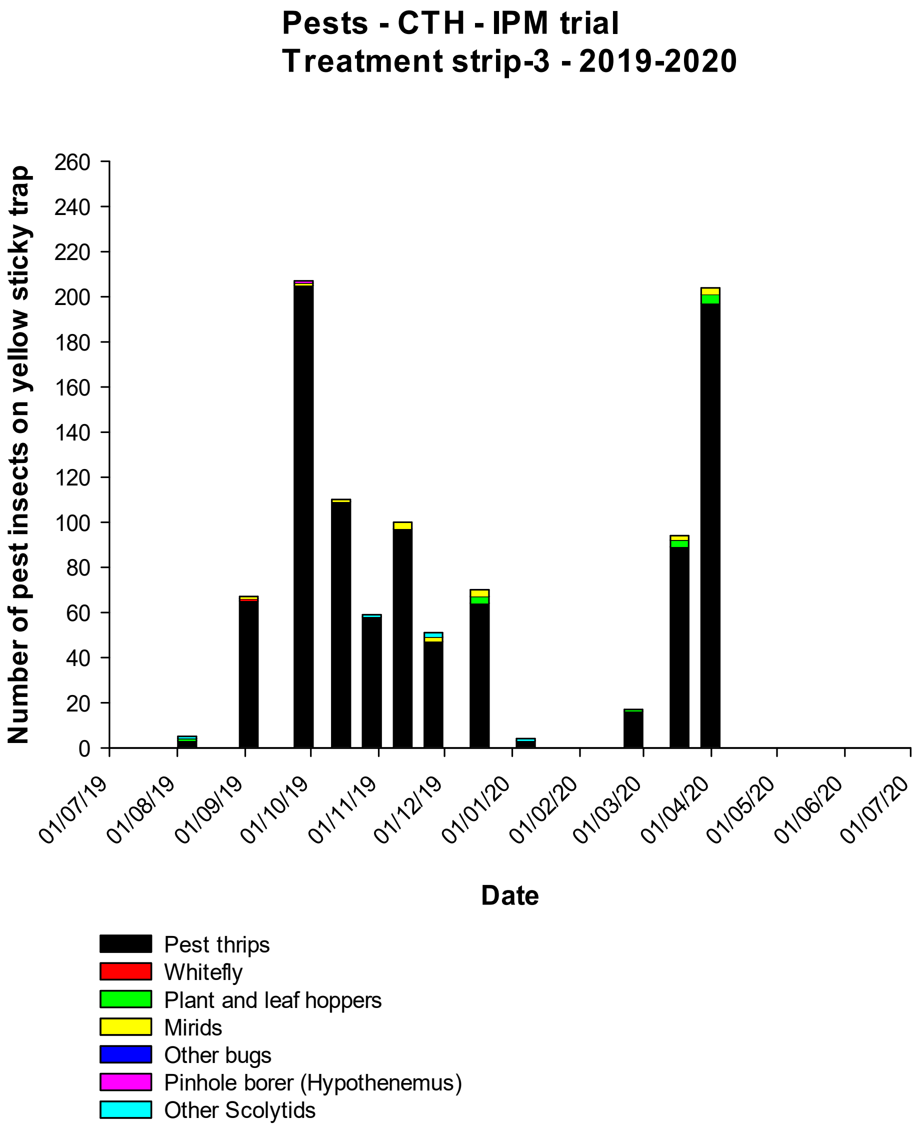


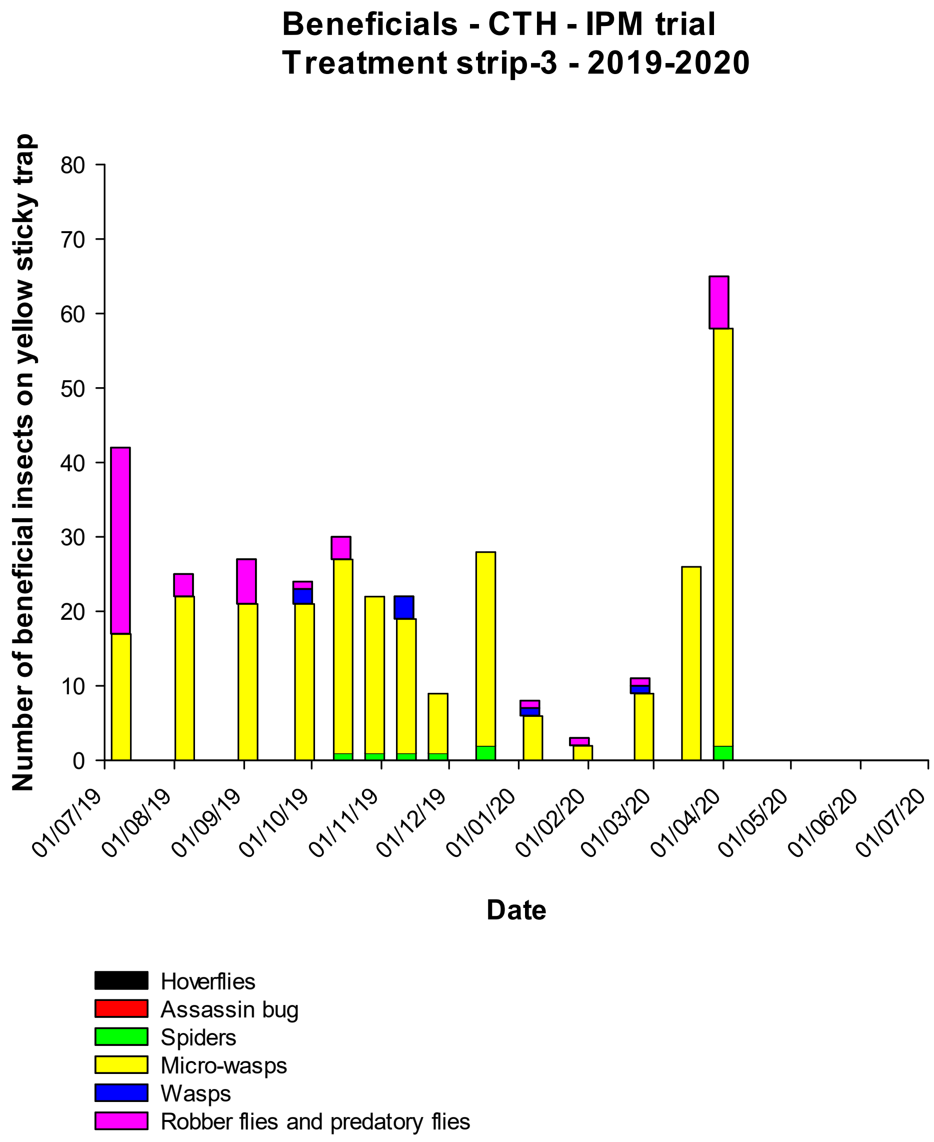
Figures 2.3.1.9.: Pest and beneficials in CTH IPM trial, Treatment strip-1-2019–2020



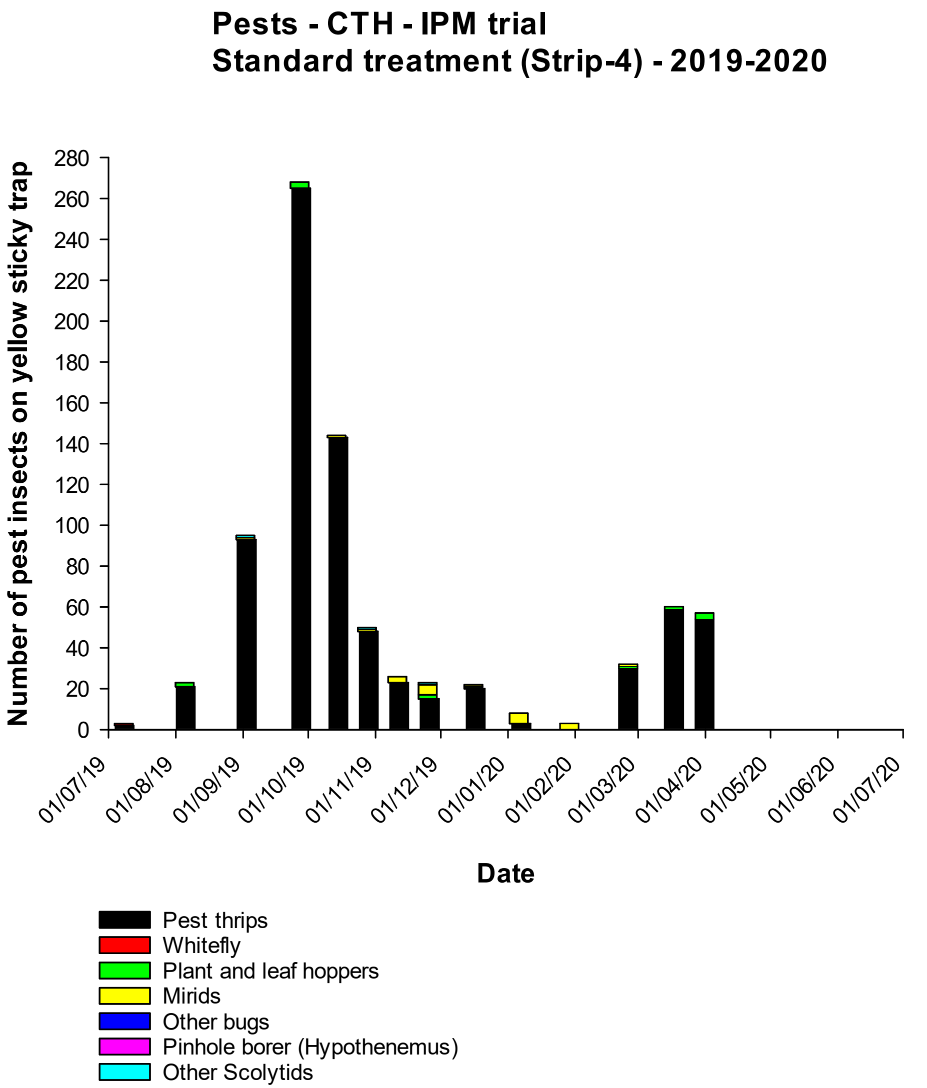


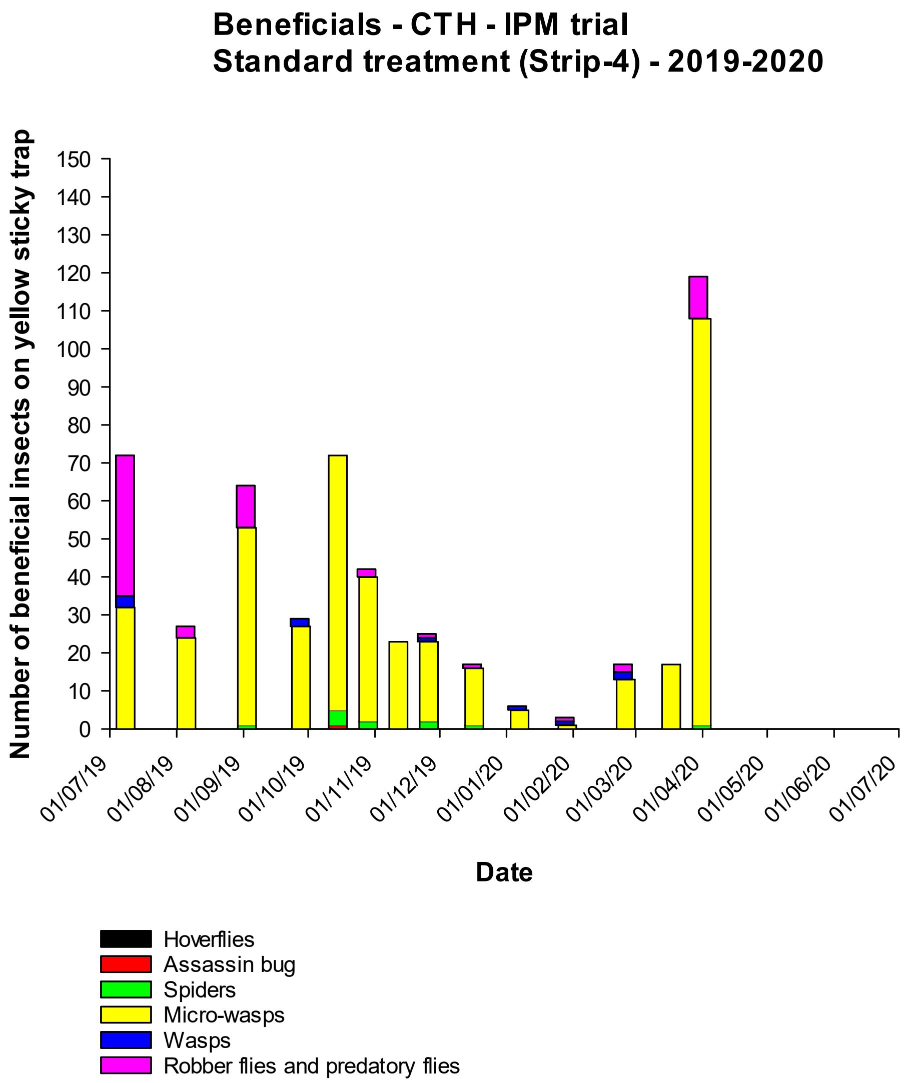
Figures 2.3.1.10.: Pest and beneficials in CTH IPM trial, Treatment strip-2-2019–2020


Pests - CTH - IPM trial
Treatment strip-3 - 2019-2020
Number of pest insects on yellow sticky trap
260
240
220
200
180
160
140
120
100
80
60
40
20
0
01/07/19
01/08/19
01/09/19
01/10/19
01/11/19
01/12/19
01/01/20
01/02/20
01/03/20
01/04/20
01/05/20
01/06/20
01/07/20
Date
Pest thrips
Whitefly
Plant and leaf hoppers
Mirids
Other bugs
Pinhole borer (Hypothenemus)
Other Scolytids

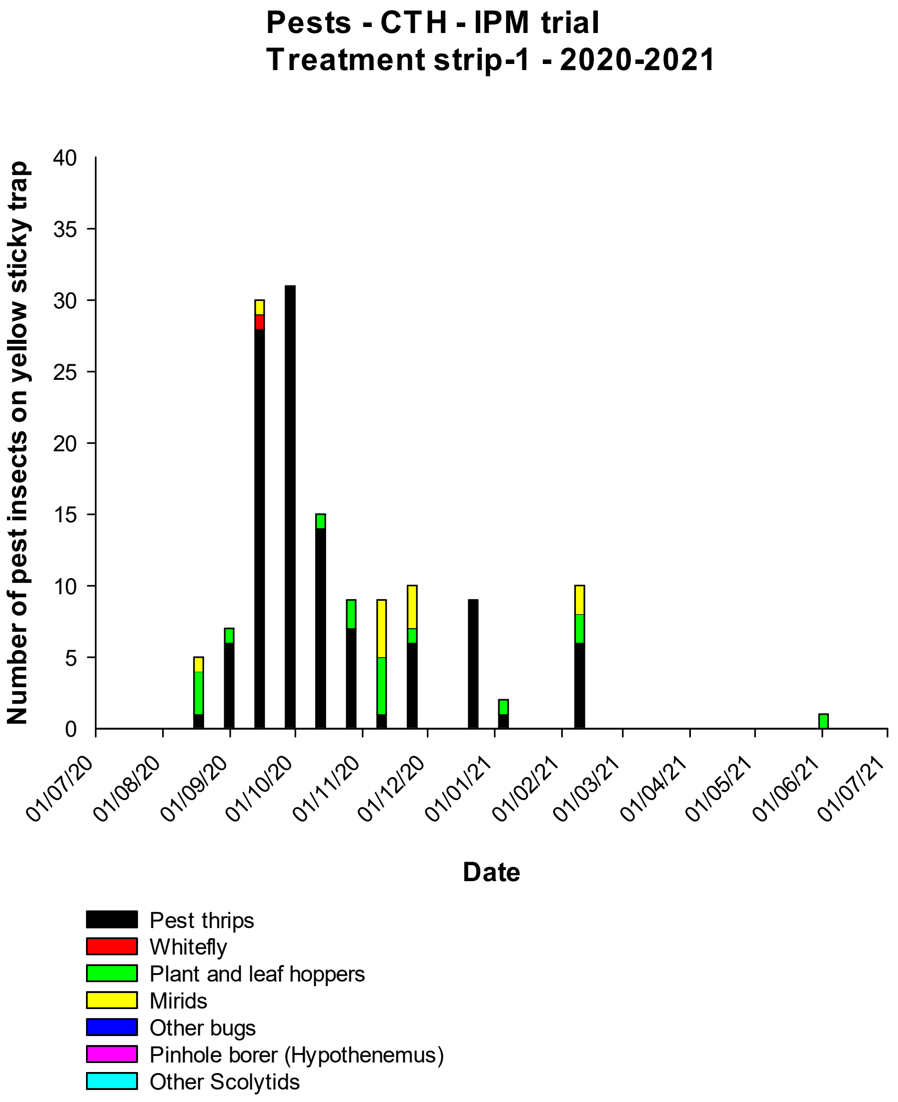

Beneficials - CTH - IPM trial
Treatment strip-3 - 2019-2020
Number of beneficial insects on yellow sticky trap
80
70
60
50
40
30
20
10
0
01/07/19
01/08/19
01/09/19
01/10/19
01/11/19
01/12/19
01/01/20
01/02/20
01/03/20
01/04/20
01/05/20
01/06/20
01/07/20
Date
Hoverflies
Assassin bug
Spiders
Micro-wasps
Wasps
Robber flies and predatory flies

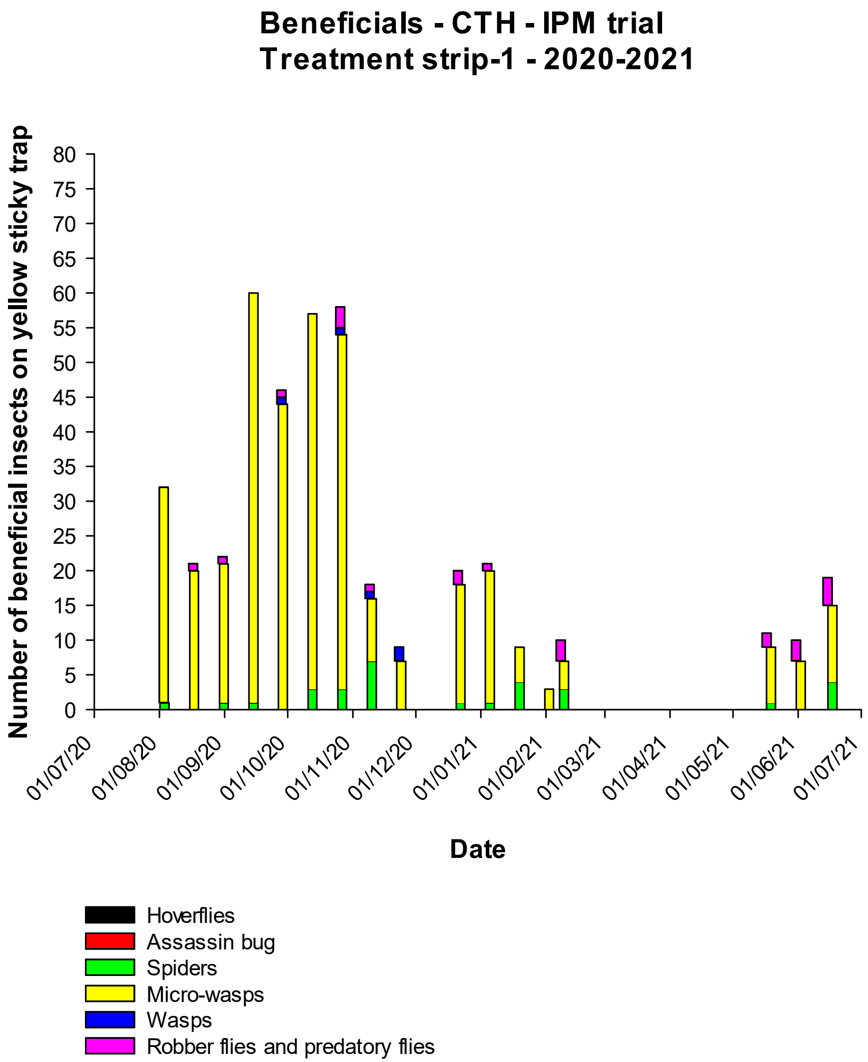
Figures 2.3.1.11.: Pest and beneficials in CTH IPM trial, Treatment strip-3-2019–2020



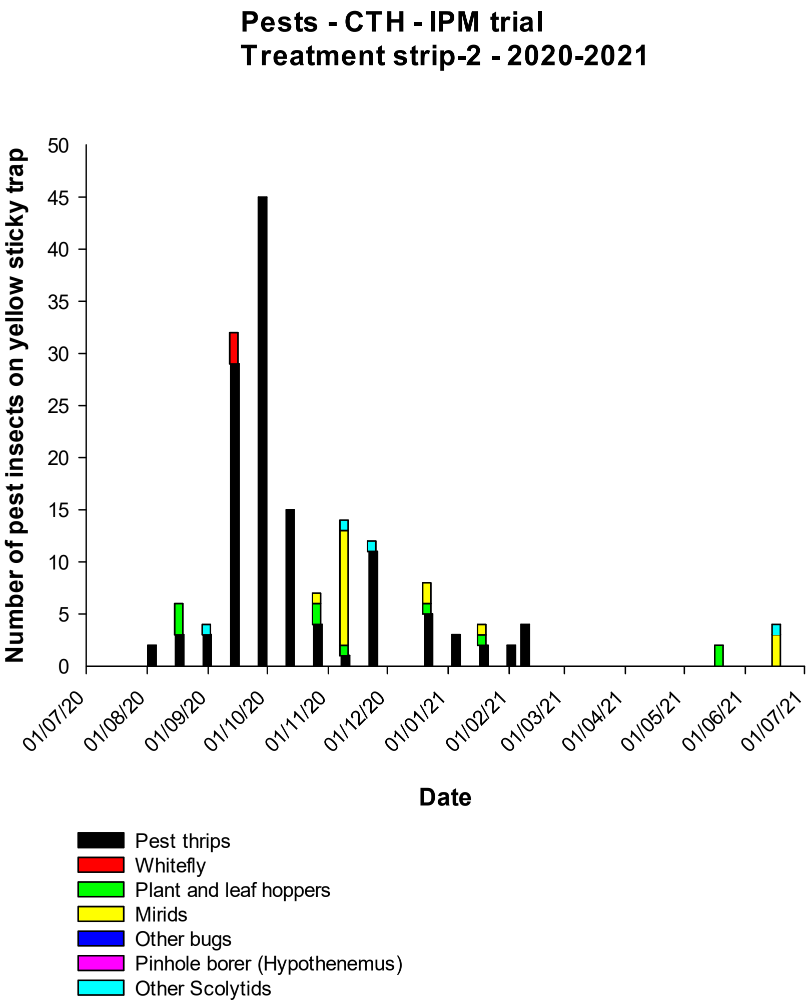


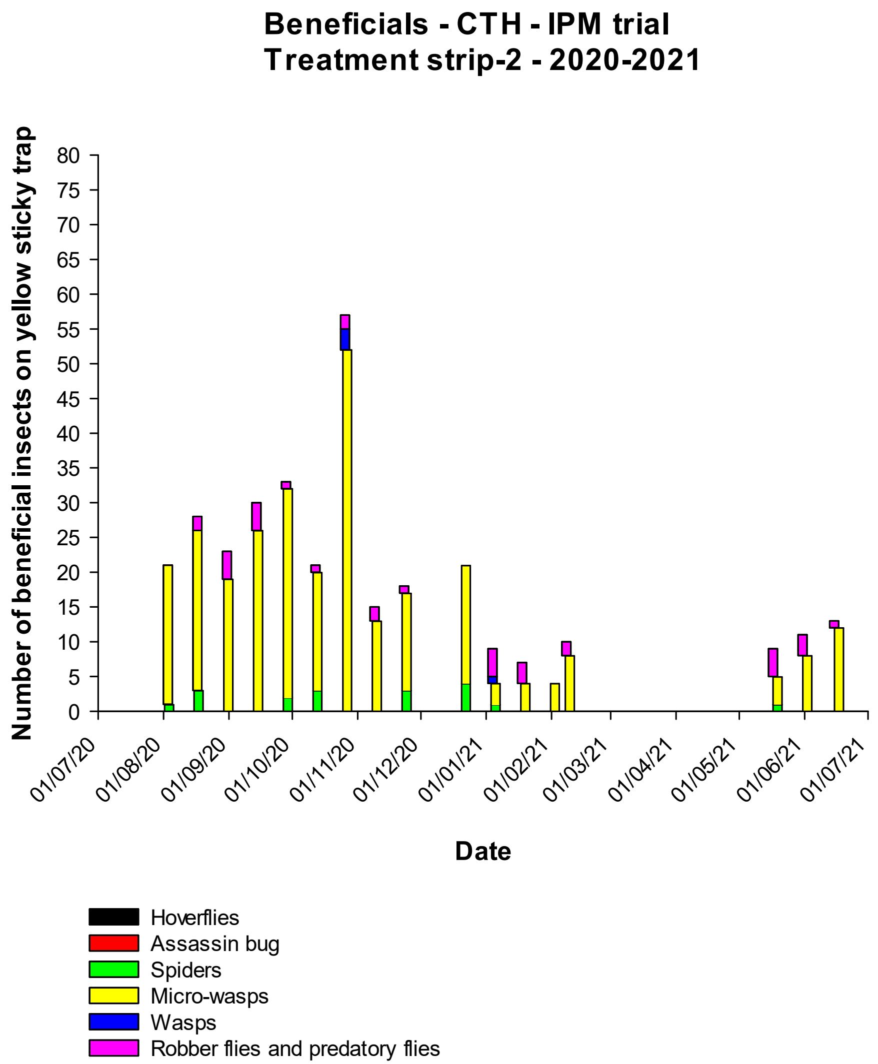
Figures 2.3.1.12.: Pest and beneficials in CTH IPM trial, Treatment strip-4-2019–2020



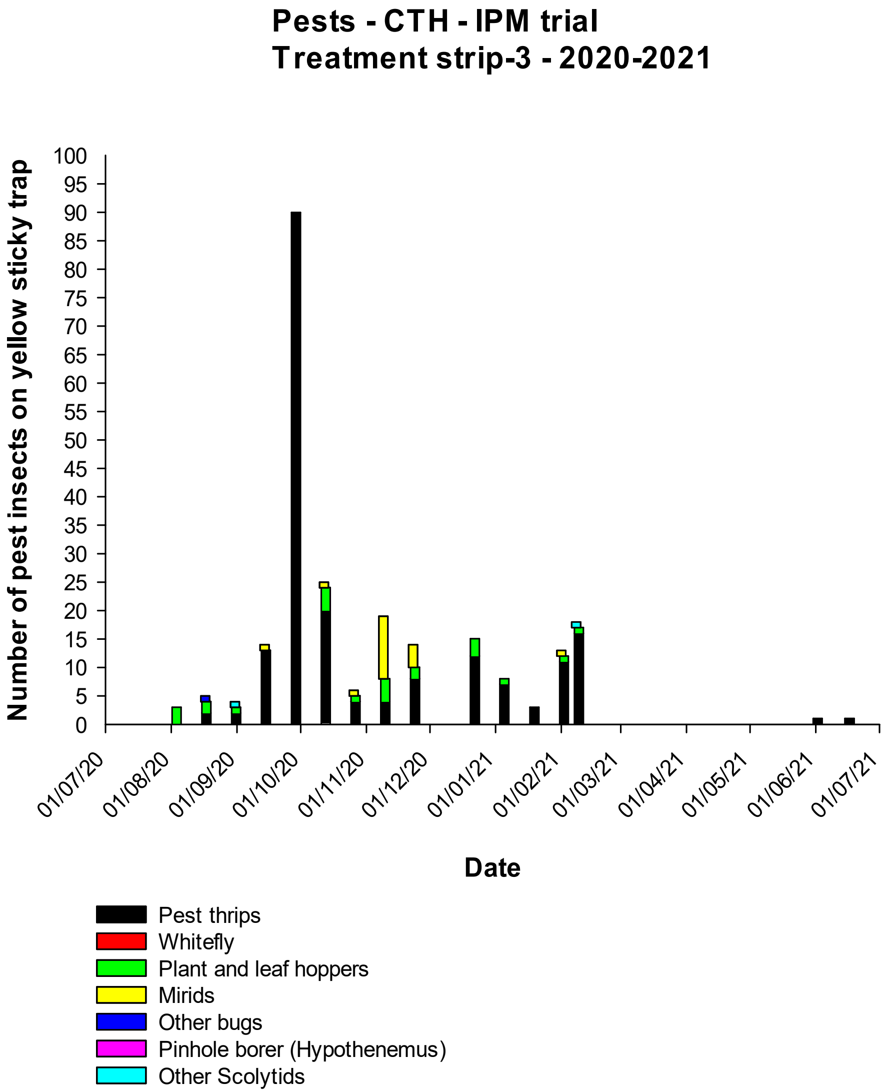


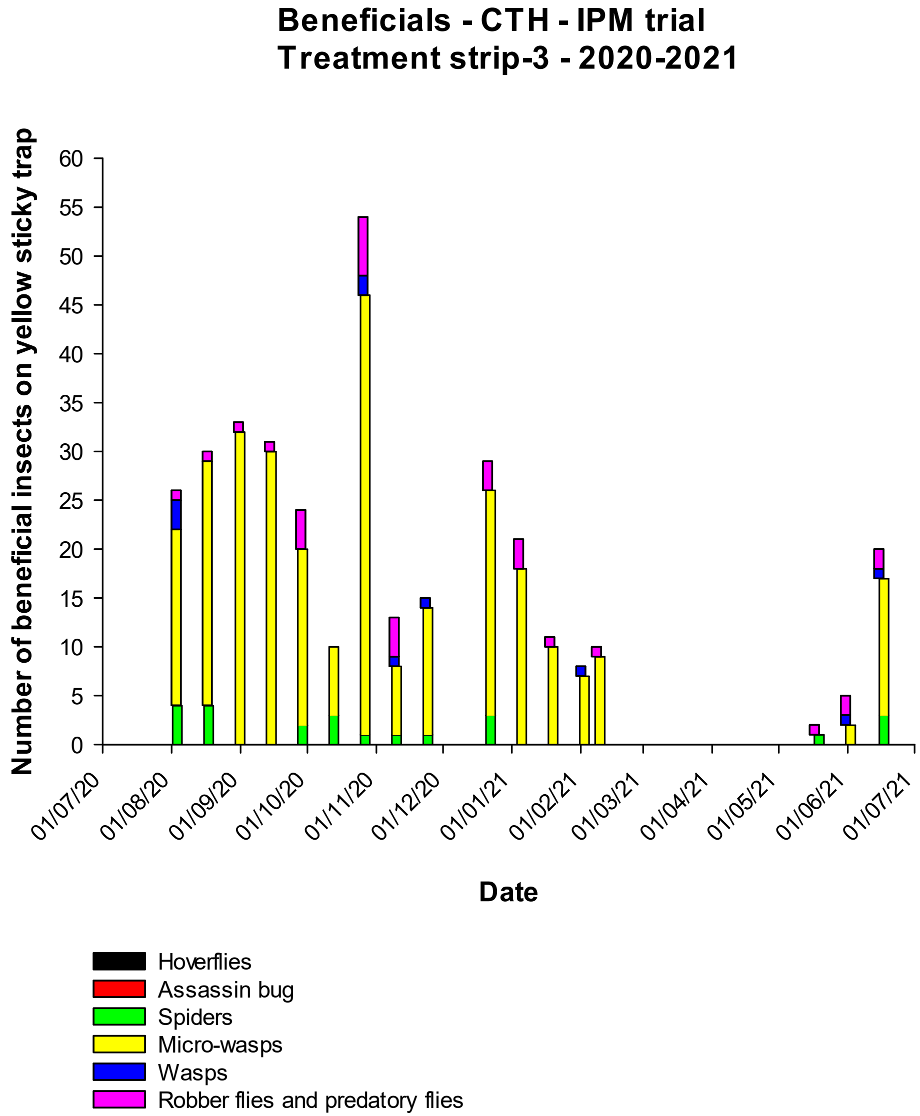
Figures 2.3.1.13.: Pest and beneficials in CTH IPM trial, Treatment strip-1-2020–2021



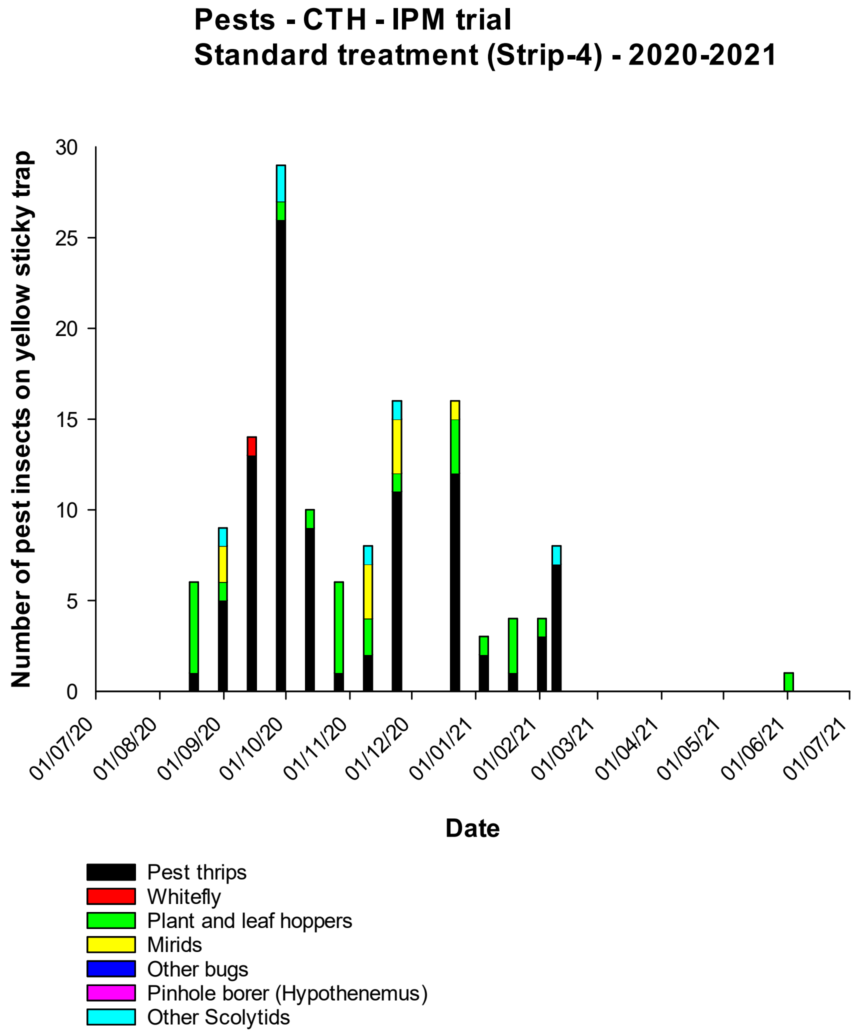


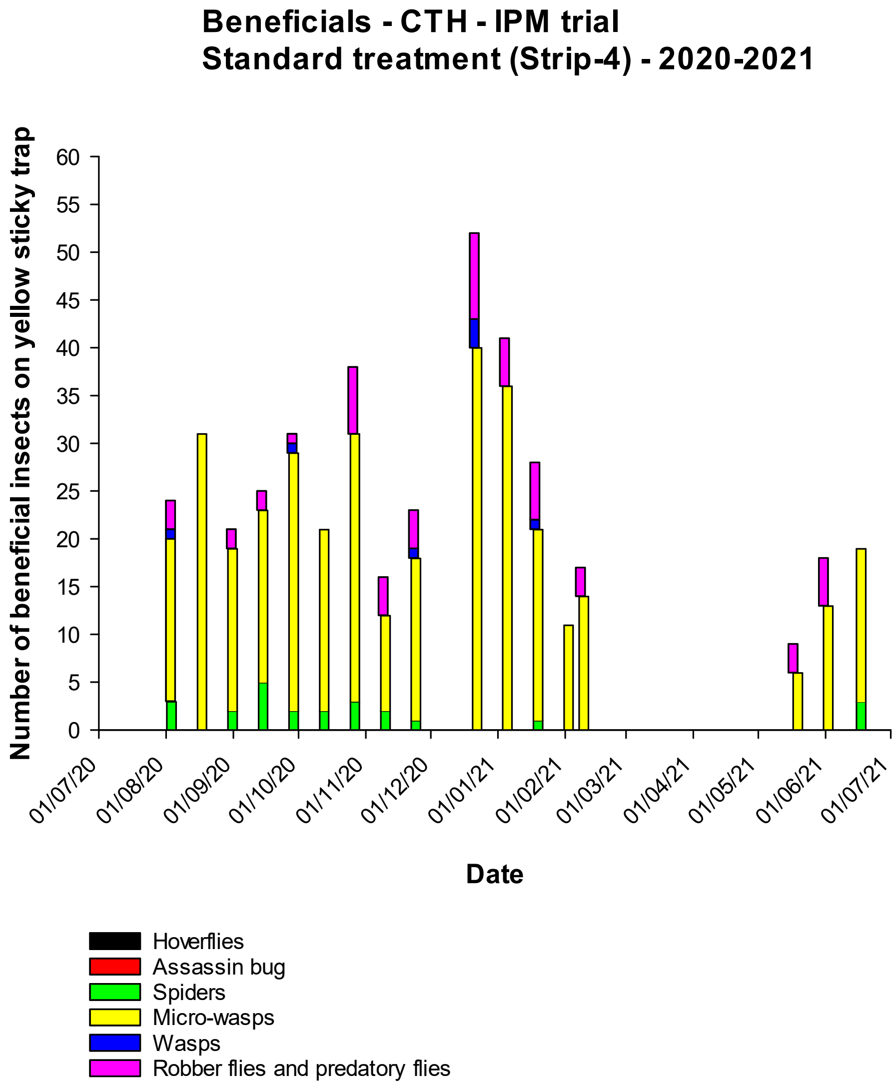
Figures 2.3.1.14.: Pest and beneficials in CTH IPM trial, Treatment strip-2-2020–2021



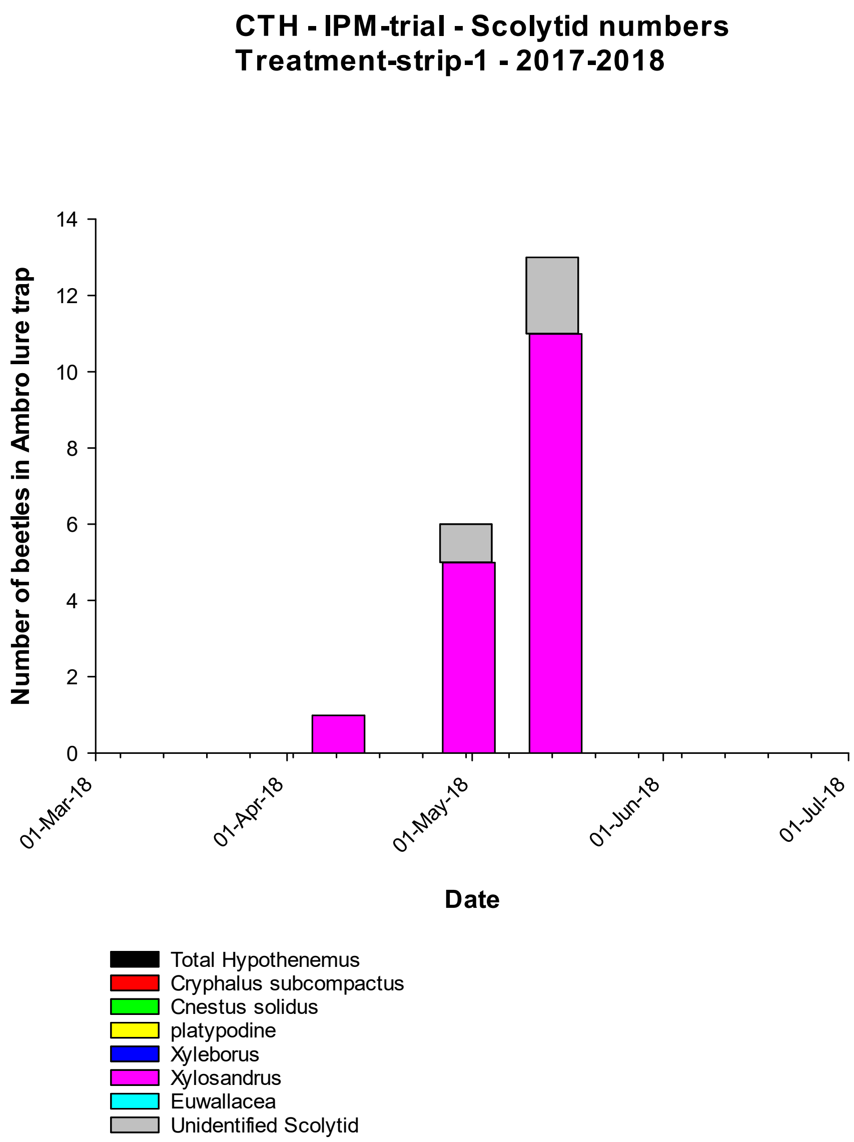


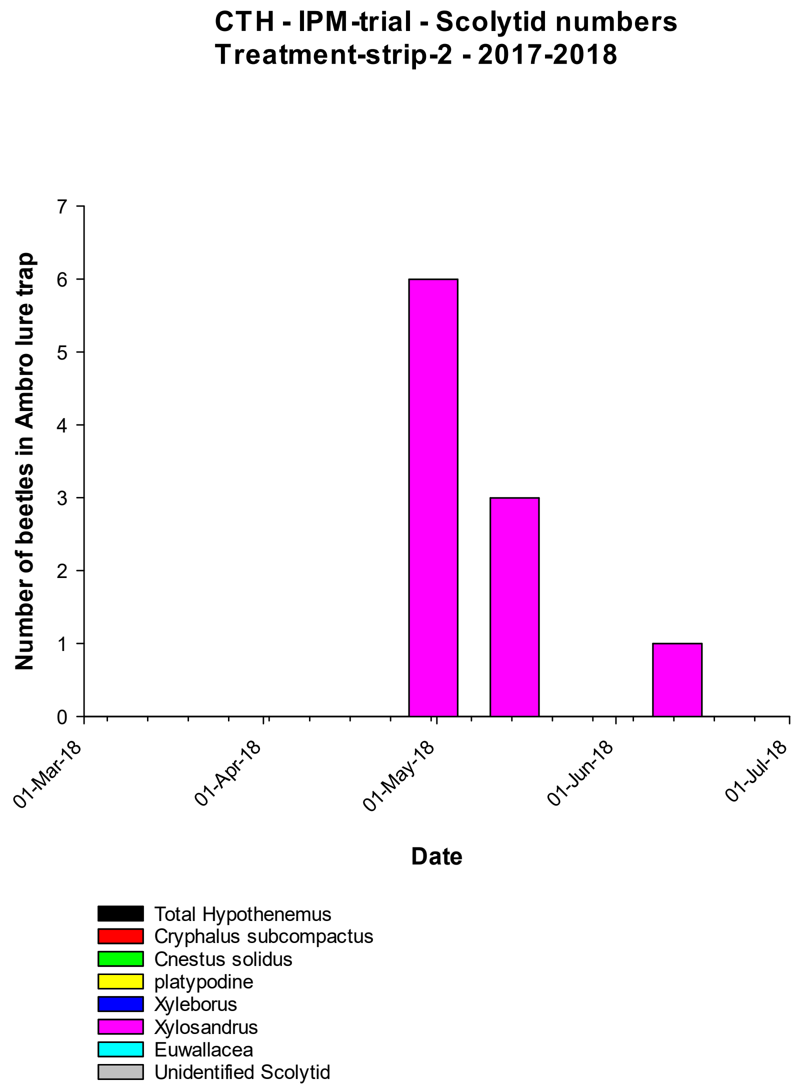
Figures 2.3.1.15.: Pest and beneficials in CTH IPM trial, Treatment strip-3-2020–2021



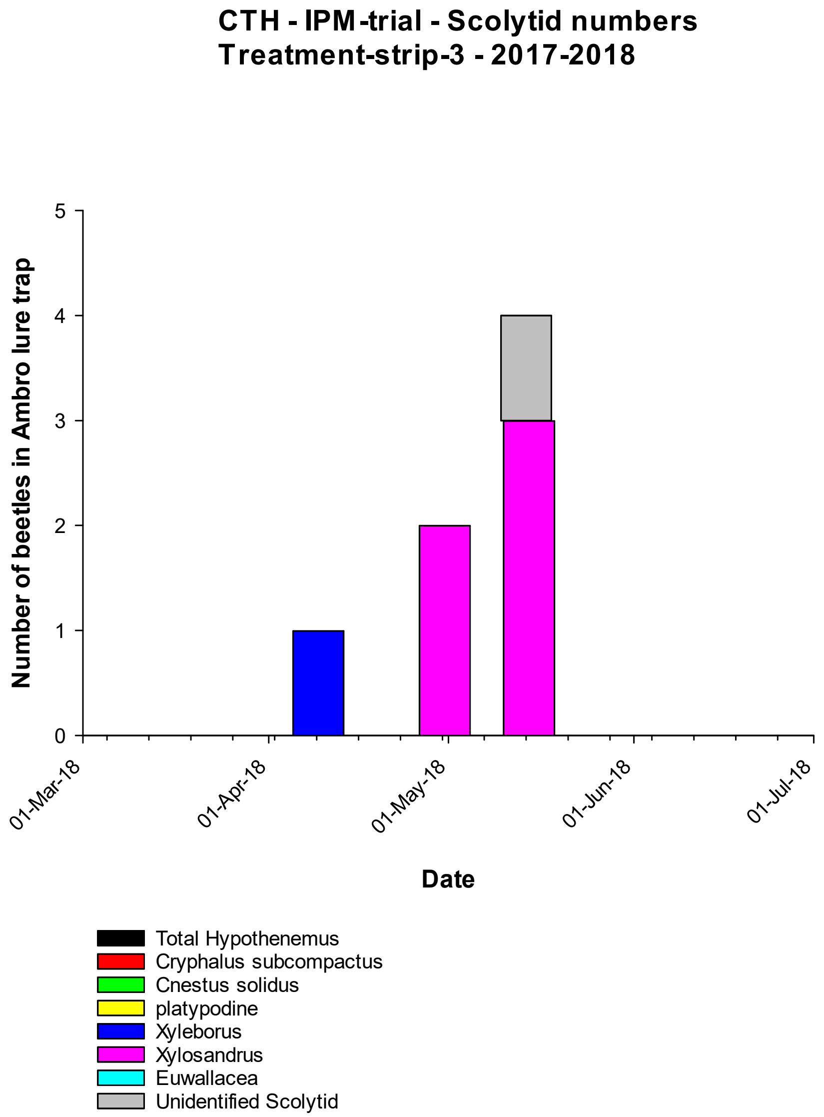


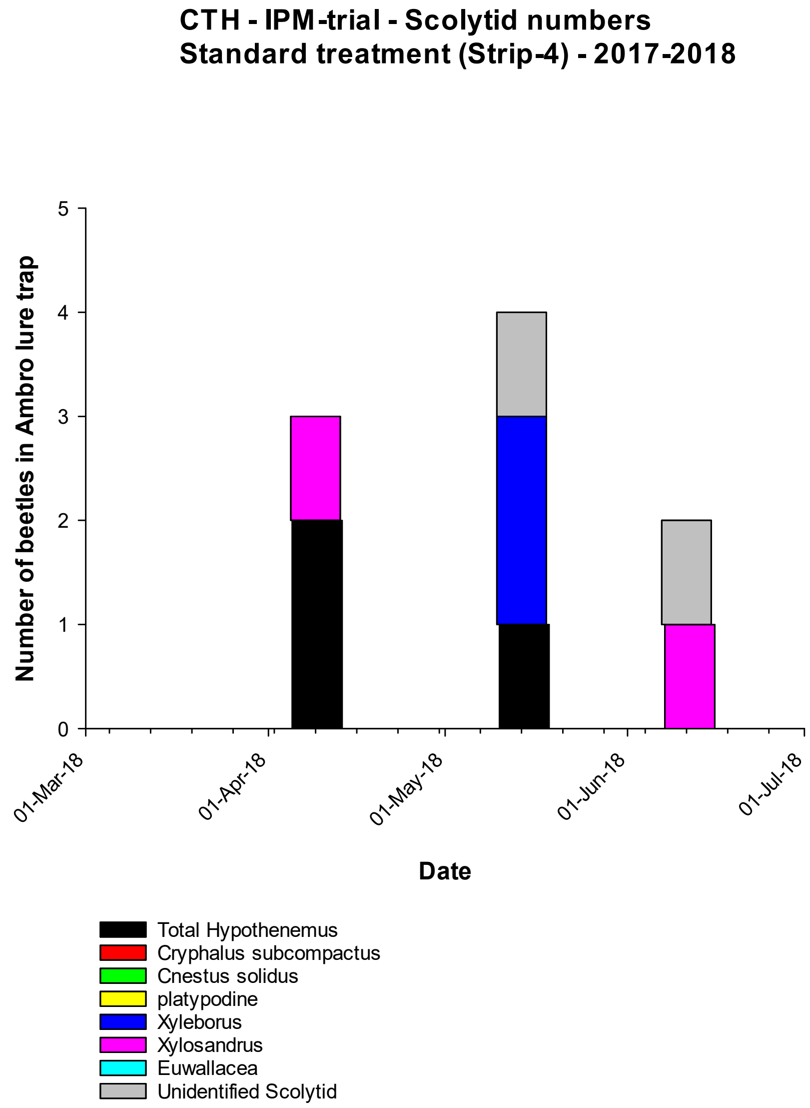
Figures 2.3.1.16.: Pest and beneficials in CTH IPM trial, Treatment strip-4-2020–2021



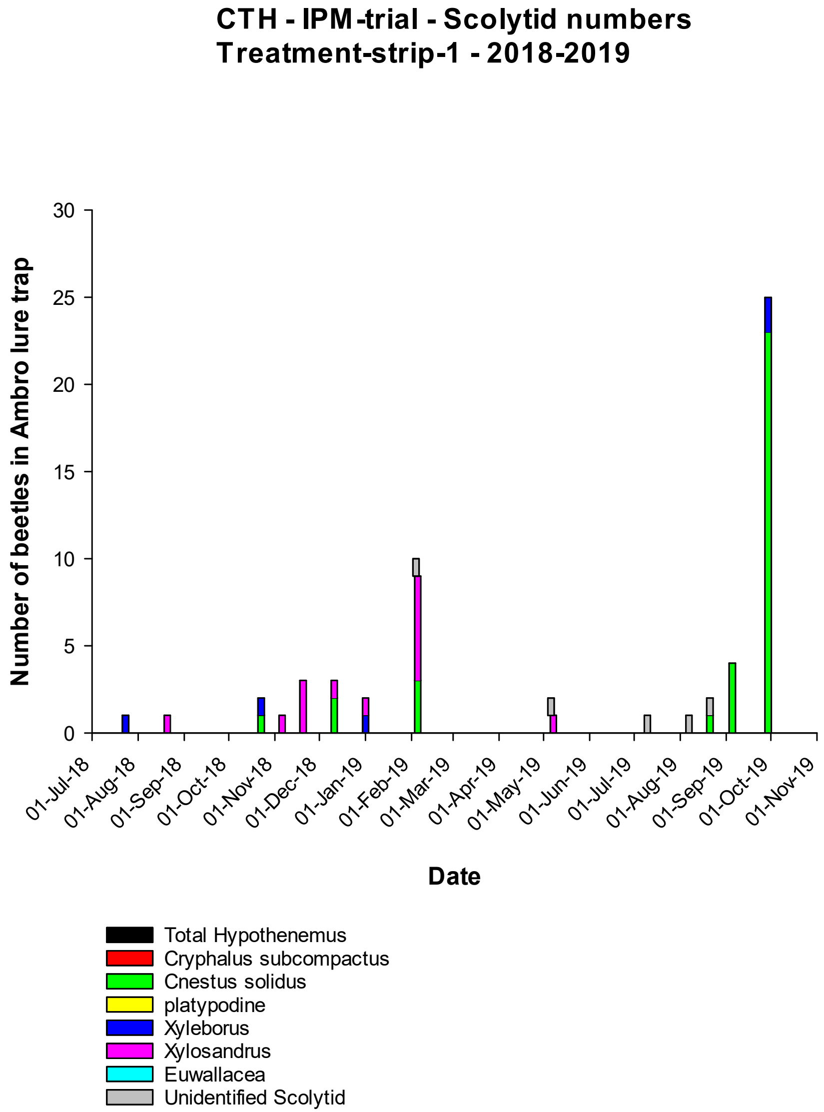


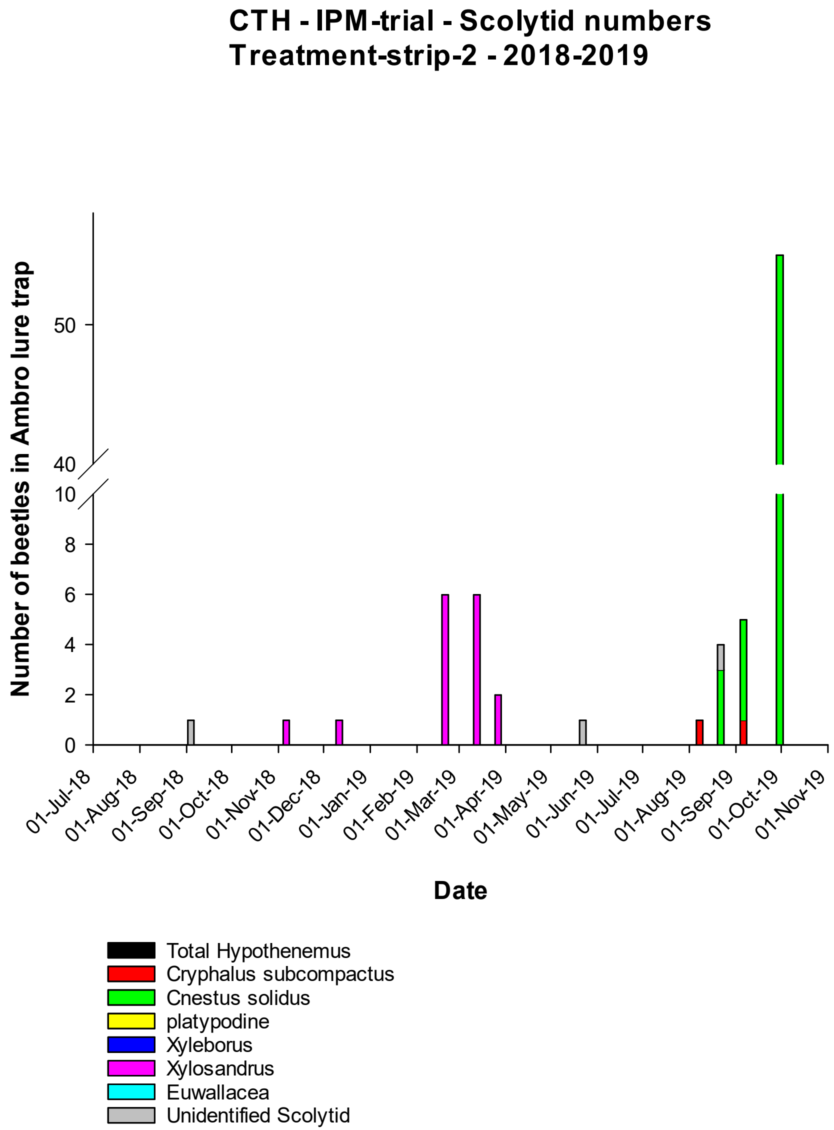
Figures 2.3.1.17.: Different scolytid species in CTH IPM trial, Treatment strip-1 (left) and Treatment strip-2 (right) 2017-2018



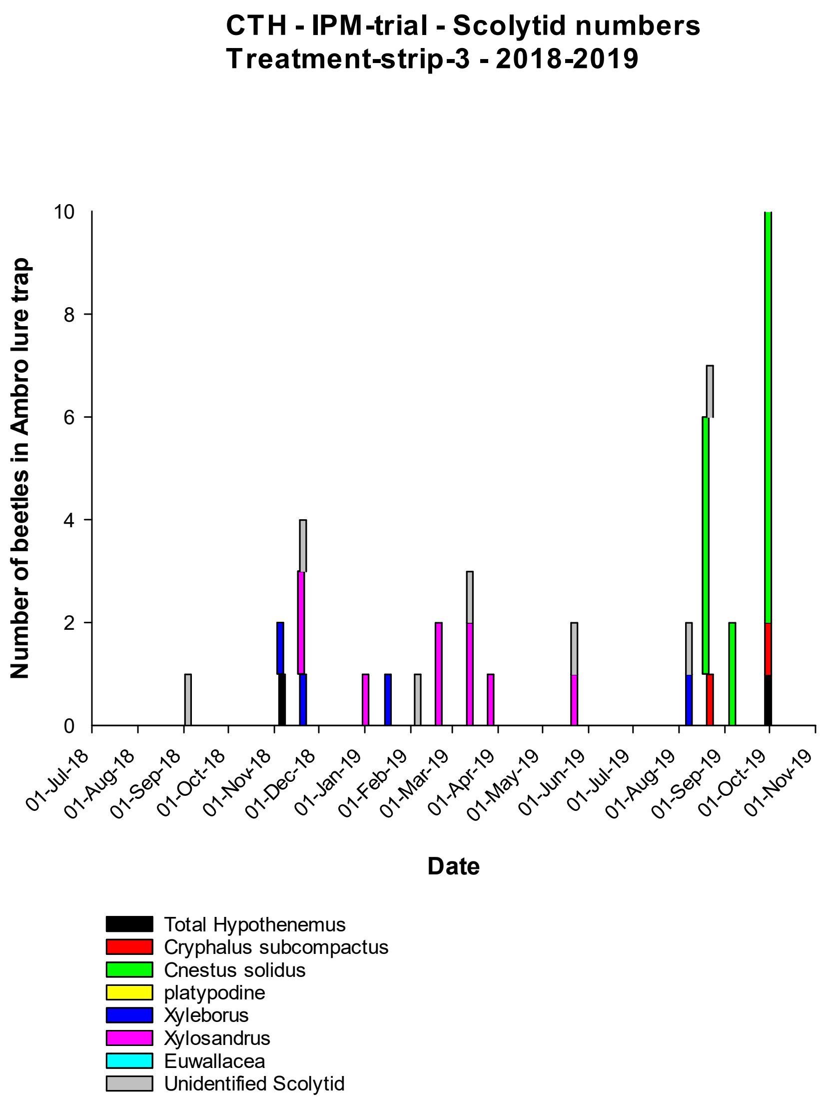


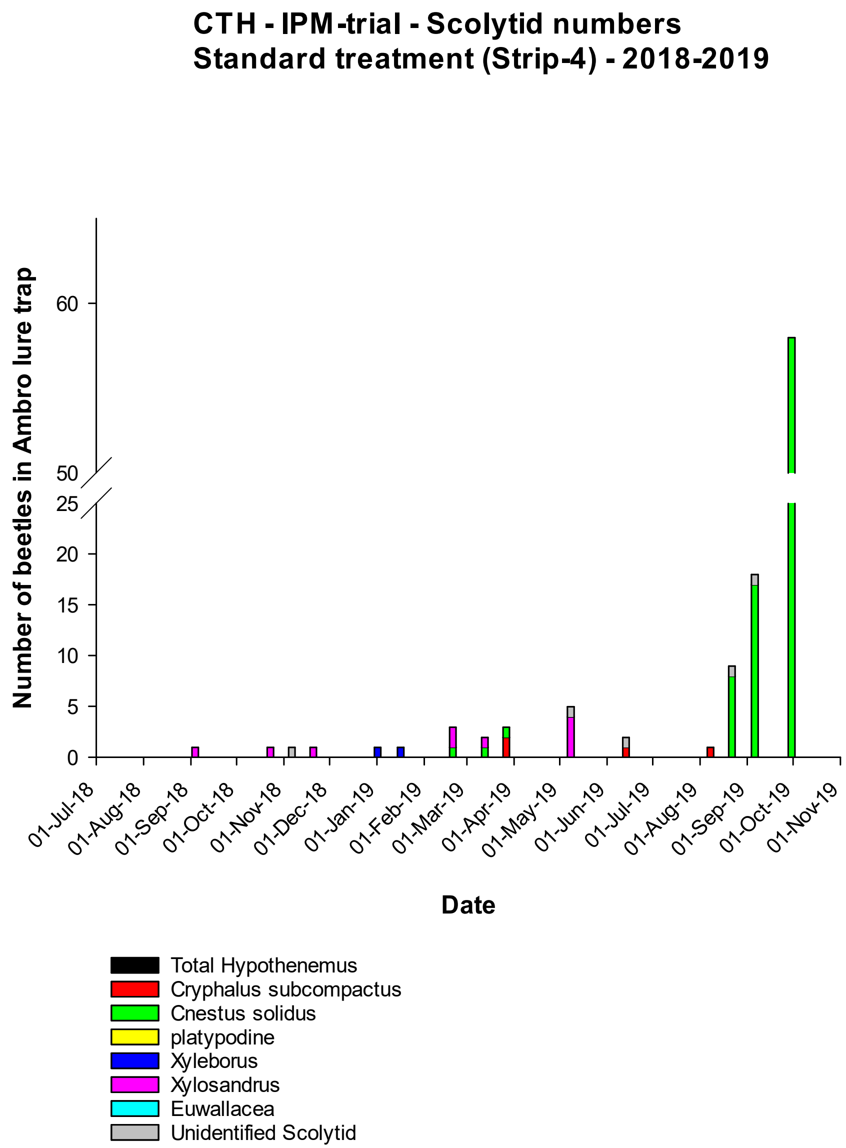
Figures 2.3.1.18.: Different scolytid species in CTH IPM trial, Treatment strip-3 (left) and Treatment strip-4 (right) 2017-2018



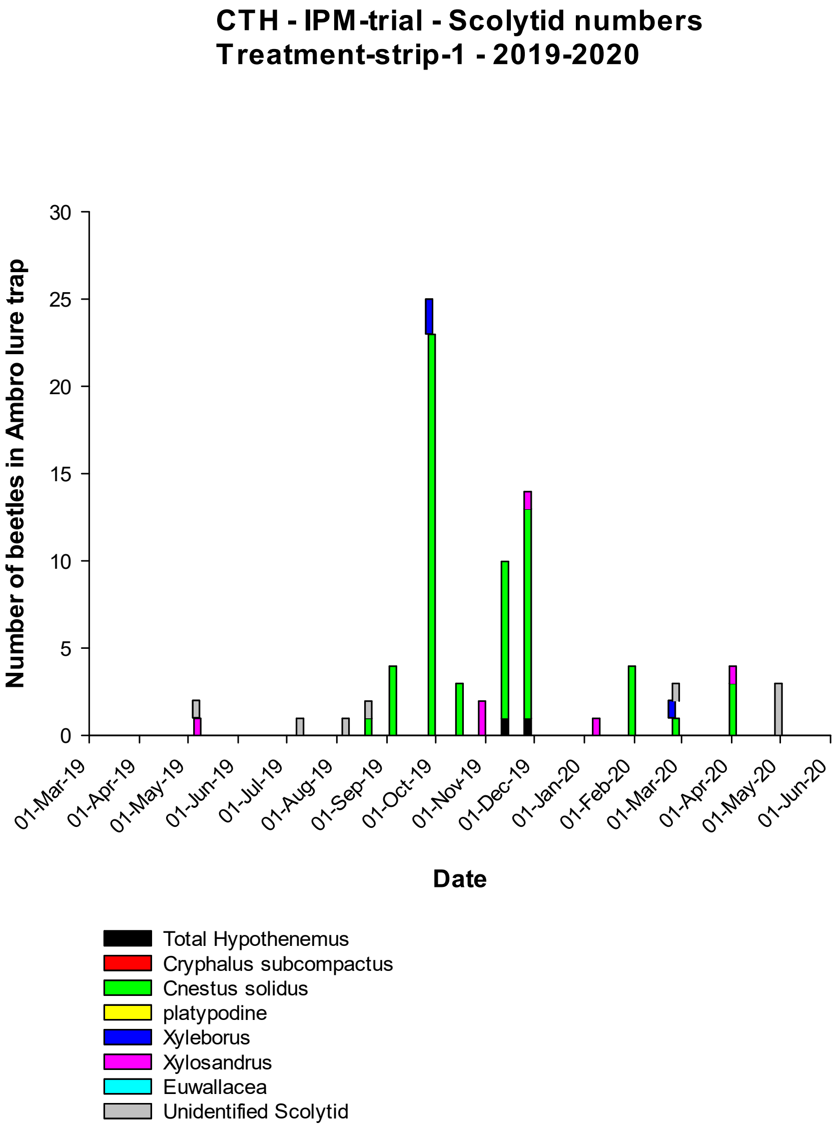


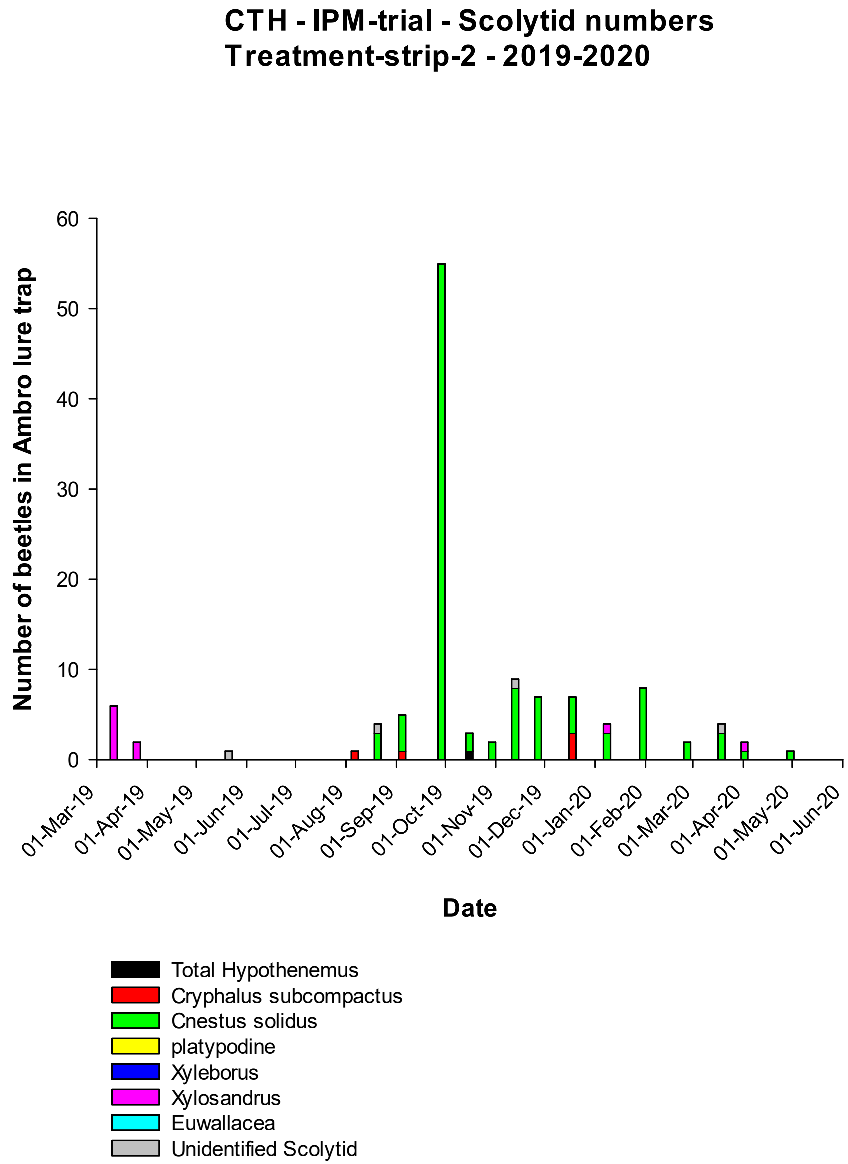
Figures 2.3.1.19.: Different scolytid species in CTH IPM trial, Treatment strip-1 (left) and Treatment strip-2 (right) 2018–2019



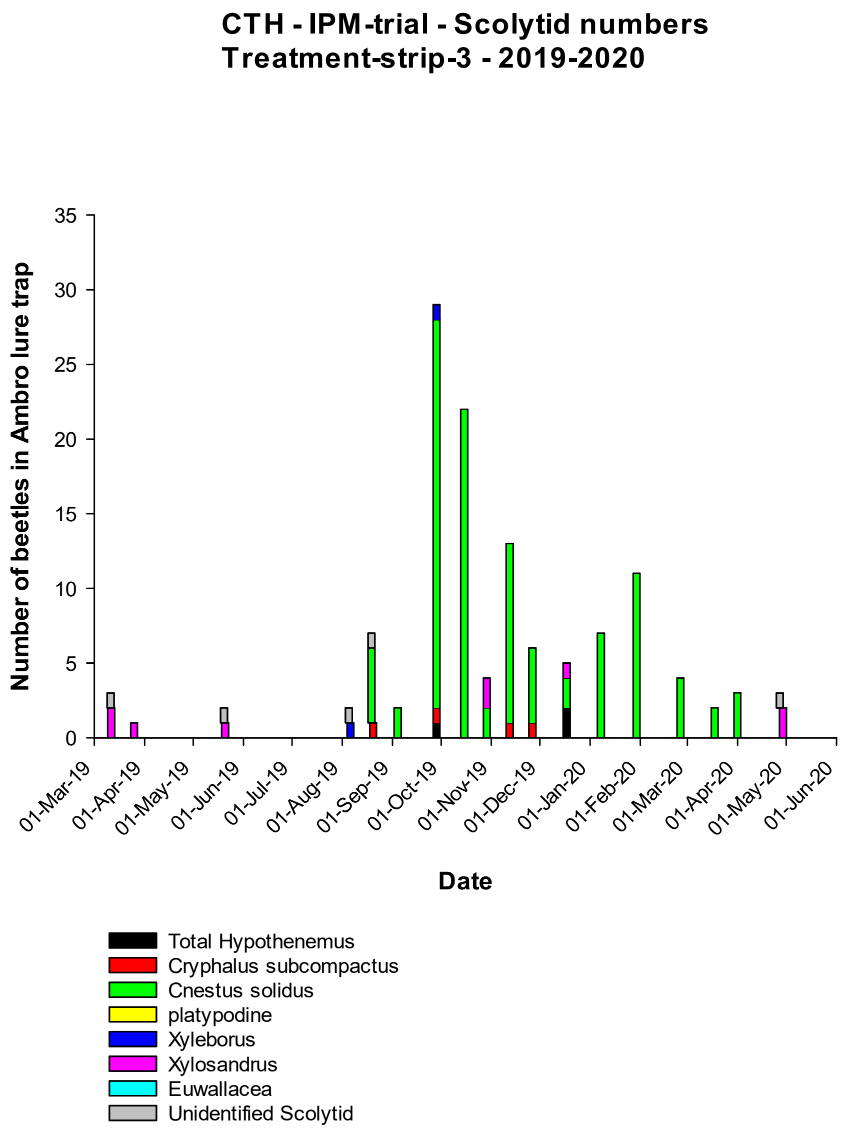


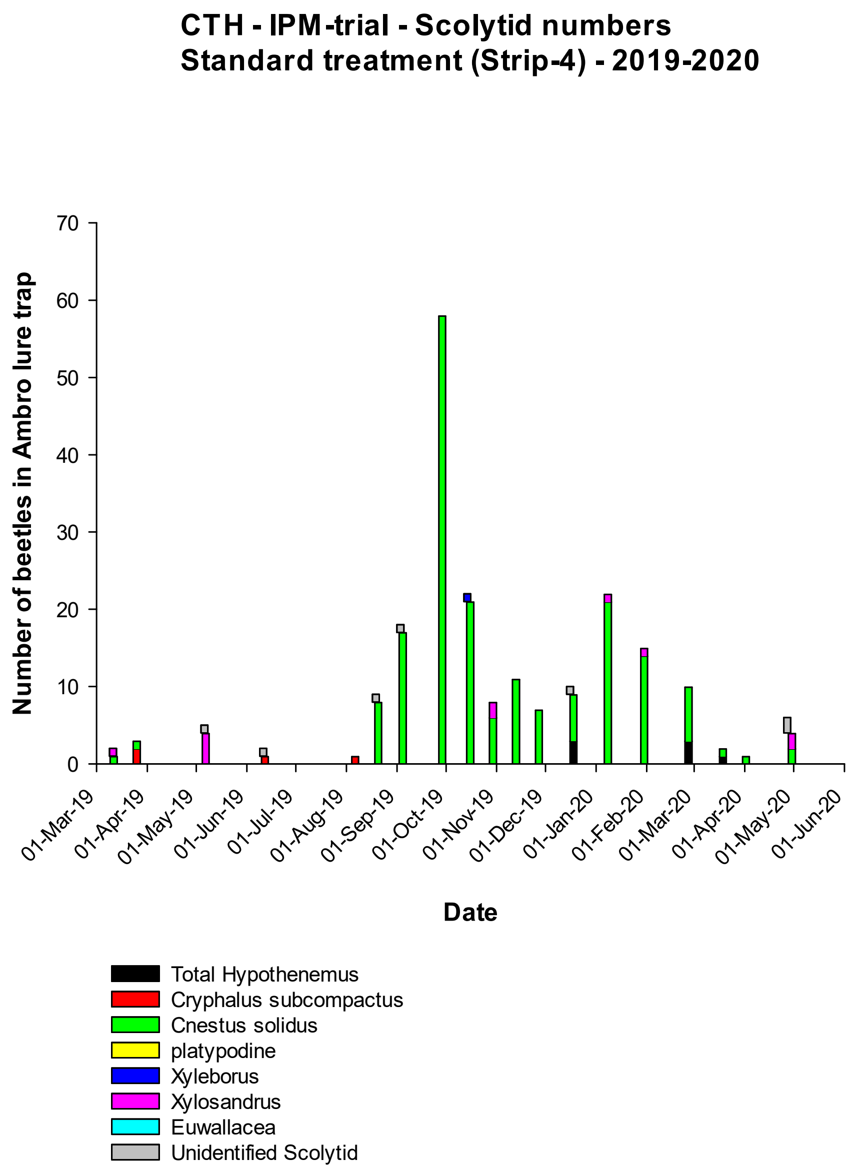
Figures 2.3.1.20.: Different scolytid species in CTH IPM trial, Treatment strip-3 (left) and Treatment strip-4 (right) 2018–2019



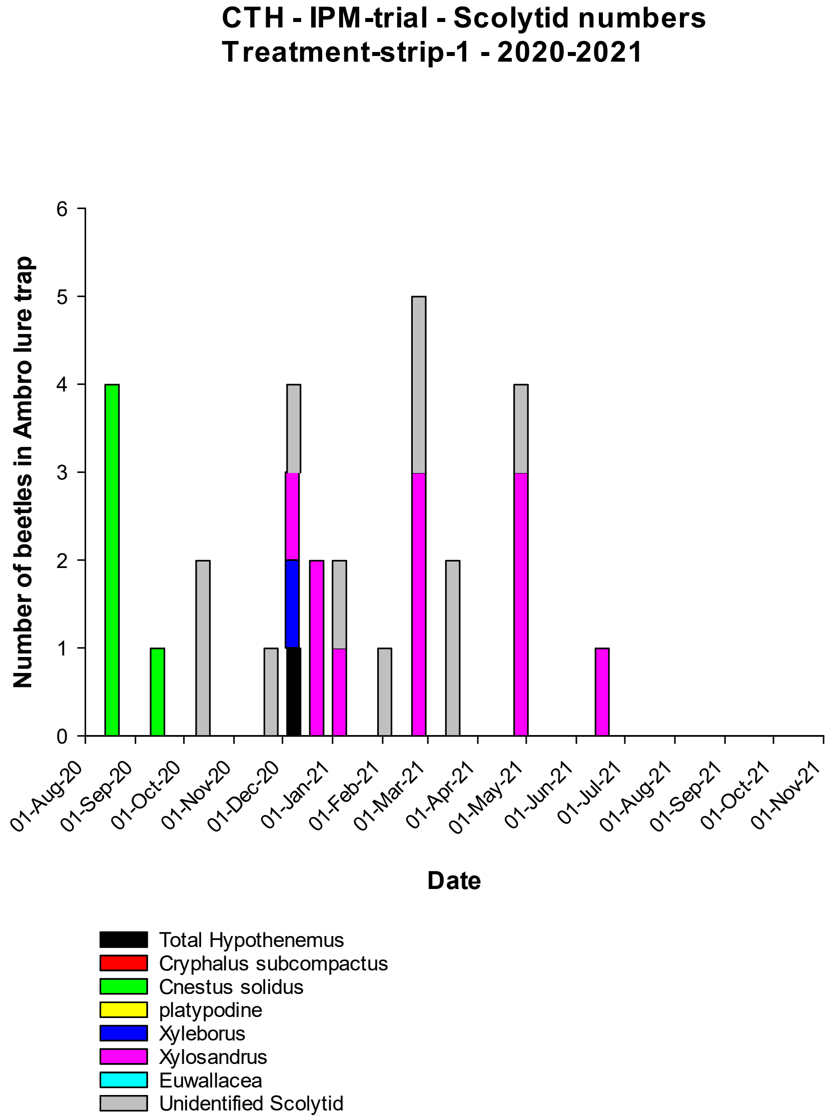


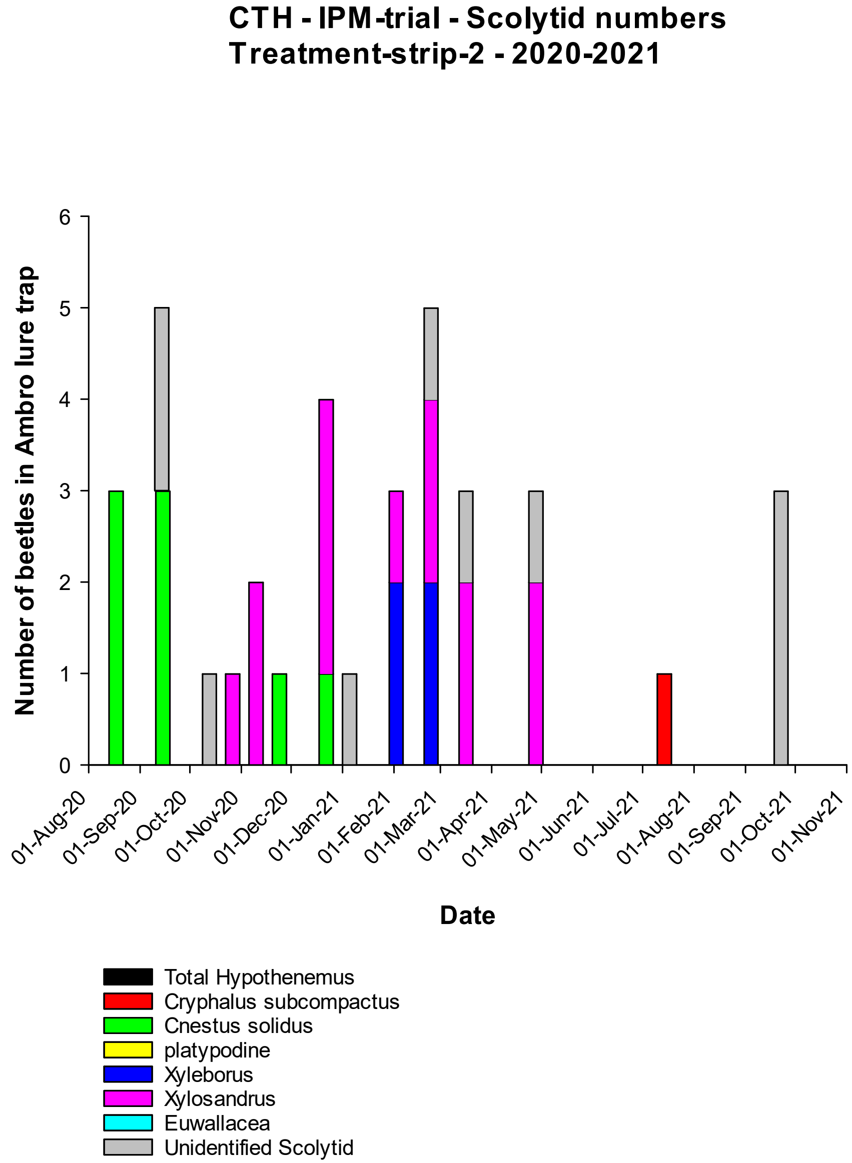
Figures 2.3.1.21.: Different scolytid species in CTH IPM trial, Treatment strip-1 (left) and Treatment strip-2 (right) 2019–2020



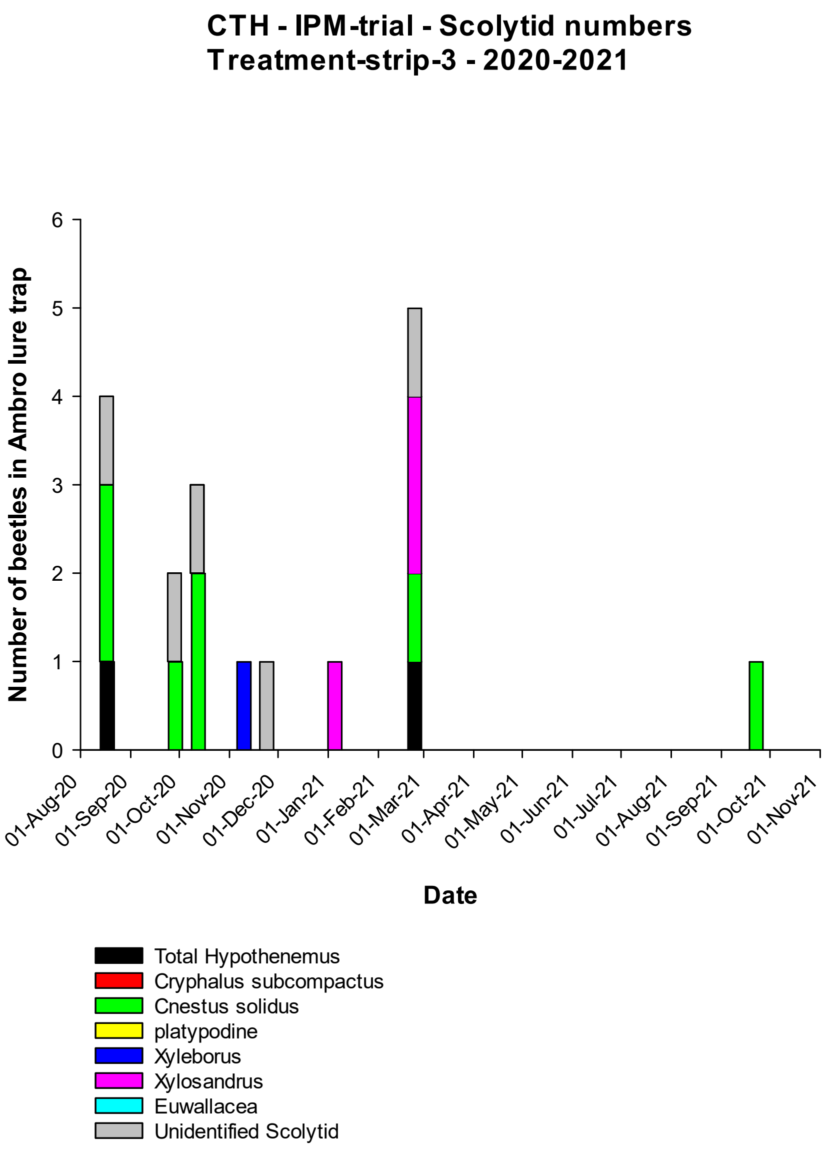


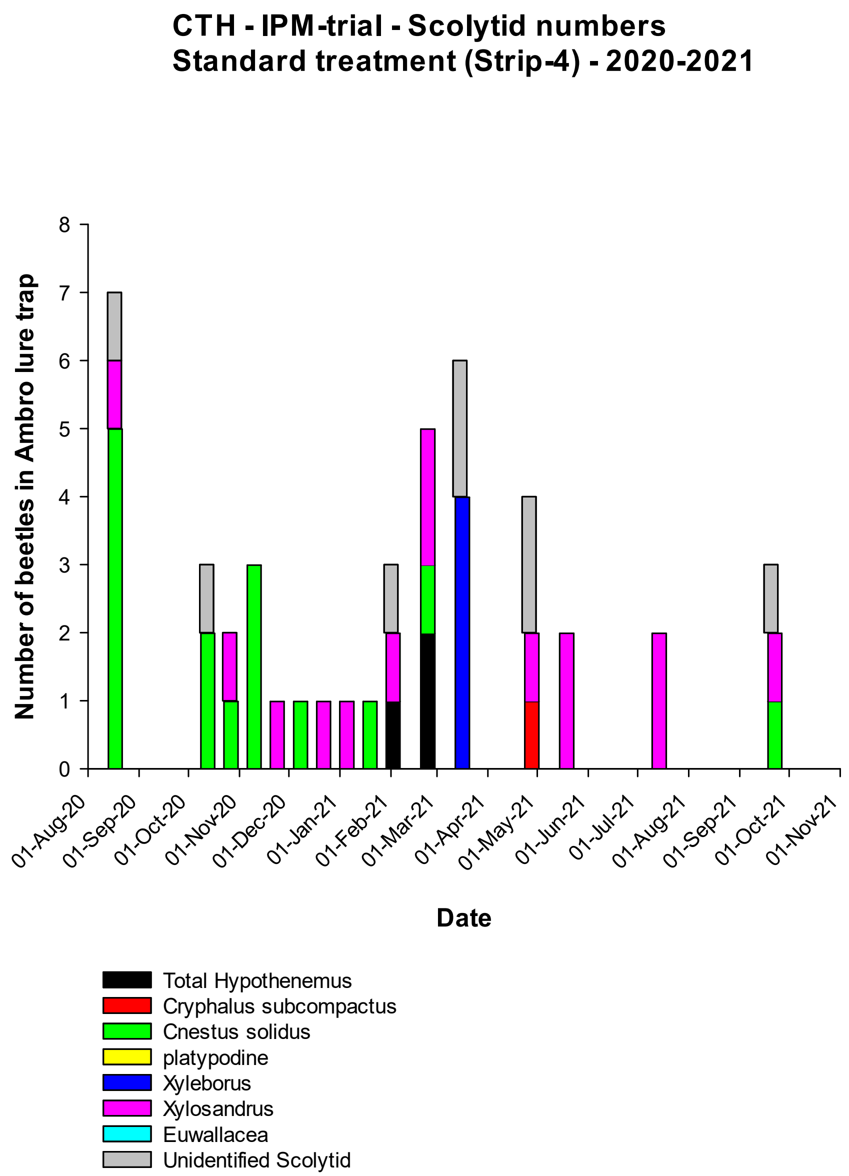
Figures 2.3.1.22.: Different scolytid species in CTH IPM trial, Treatment strip-3 (left) and Treatment strip-4 (right) 2019–2020





Figures 2.3.1.23.: Different scolytid species in CTH IPM trial, Treatment strip-1 (left) and Treatment strip-2 (right) 2020–2021





Figures 2.3.1.24.: Different scolytid species in CTH IPM trial, Treatment strip-3 (left) and Treatment strip-4 (right) 2020–2021

Husk and kernel recovery assessment

Effect of treatment in different treatment strips on husk and kernel damage differed with season. Results for husk and kernel assessment in different treatment strips for each season are shown in Table 2.3.1.1. to 2.3.1.8.

This trial confirmed again that the effect of different cultivars overrides the treatment effect. The thin shell and late maturing cultivars A4 and 849 had the highest FSB damage across all seasons and treatments (Figures 2.3.1.1. to 2.3.1.4.). For these varieties only broad spectrum insecticides managed the FSB damage adequately. Even in the treatments with non or minimal broad spectrum insecticides the two early cultivar 246 and 741, FSB damage was comparatively low. The yield graphs also illustrate the effect of FSB on yield. Highest yields are achieved in the blocks with no or little FSB damage. Effect of cultivars needs to be acknowledged with regards to FSB management.

Table 2.3.1.1.: Husk assessment from different treatments in main IPM trial at CTH Alstonville 2018

Harvest Year	Blocks	Treatment	Treatment number	Tree height	Tree numbers	% Clean husk	Total MNB eggs	% MNB Parasitism	% Husk MNB Tunnels	% Felted Coccid	% Scale	% Thrip	% Pinhole borer	% MSW feeding	% MSW eggs	%Husk spot
2018	**1 to 4**	Treatment strip-1	1	6	12	13.2	1.3	0.0	12.7	0.3	0.0	61.0		24.3	17.6	0.4
2018	**5 to 8**	Treatment strip-2	2	6	12	28.9	13.4	8.7	35.0	0.6	4.2	23.6		11.9	0.8	1.4
2018	**9 to 12**	Treatment strip-3	3	6	12	16.5	14.5	1.7	39.4	0.3	1.1	42.7		16.1	4.5	1.7
2018	**13 to 16**	Standard	4	6	12	35.6	0.9	0.0	4.4	0.0	1.1	49.7		8.1	2.8	0.8
2018	**1 to 4**	Treatment strip-1	1	9	24	11.2	2.0	0.0	11.9	2.6	1.1	66.9		32.7	20.9	0.3
2018	**5 to 8**	Treatment strip-2	2	9	24	29.1	9.1	4.2	23.3	0.8	4.8	35.4		17.7	3.2	1.2
2018	**9 to 12**	Treatment strip-3	3	9	24	13.9	11.4	11.4	31.7	0.1	1.3	50.1		31.4	7.6	2.2
2018	**13 to 16**	Standard	4	9	22	25.7	0.6	0.0	3.0	0.0	0.5	58.6		22.1	5.9	0.9
2018	**19**	Unsprayed	5	9	9	8.1	1.3	0.0	19.0	0.0	1.0	53.5		8.9	61.0	0.0
2018	**20**	Standard	6	9	9	4.1	1.2	0.0	15.7	2.1	0.0	49.8		21.8	62.4	2.0
2018	**1 to 4**	Treatment strip-1	1	Combined average	36	**12.2**	**1.6**	**0.0**	**12.3**	**1.4**	**0.6**	**64.0**		**28.5**	**19.3**	**0.4**
2018	**5 to 8**	Treatment strip-2	2	Combined average	36	**29.0**	**11.2**	**6.4**	**29.2**	**0.7**	**4.5**	**29.5**		**14.8**	**2.0**	**1.3**
2018	**9 to 12**	Treatment strip-3	3	Combined average	36	**15.2**	**13.0**	**6.5**	**35.5**	**0.2**	**1.2**	**46.4**		**23.8**	**6.1**	**1.9**
2018	**13 to 16**	Standard	4	Combined average	34	**30.6**	**0.8**	**0.0**	**3.7**	**0.0**	**0.8**	**54.1**		**15.1**	**4.4**	**0.9**

Table 2.3.1.2.: Kernel assessment from different treatments in main IPM trial at CTH Alstonville 2018

Harvest Year	Blocks	Treatment	Treatment number	Tree height	Tree numbers	% MNB-kernel	% FSB loss	% Leptocoris damage	Total % bug damage	% Total insect damage	% Immature nut	% Mature nut	% Total KR	% Sound KR	Sum of kg DNIS@10%	Average of T/Ha
2018	**1 to 4**	Treatment strip-1	1	6	12	0.7	16.5		16.5	17.2	8.9	93.4	40.3	30.9	29.6	2.8
2018	**5 to 8**	Treatment strip-2	2	6	12	0.1	10.6		10.6	10.6	2.8	98.2	42.8	37.2	36.6	3.5
2018	**9 to 12**	Treatment strip-3	3	6	12	0.1	5.6		5.6	5.7	2.1	98.1	43.6	39.9	39.2	3.7
2018	**13 to 16**	Standard	4	6	12	0.0	1.8		1.8	1.8	2.4	97.7	43.1	41.2	40.3	3.8
2018	**1 to 4**	Treatment strip-1	1	9	24	0.4	16.3		16.3	16.7	9.2	91.9	46.3	29.9	28.3	1.3
2018	**5 to 8**	Treatment strip-2	2	9	24	0.0	12.6		12.6	12.6	2.4	97.9	45.5	37.3	36.6	1.7
2018	**9 to 12**	Treatment strip-3	3	9	24	0.1	6.6		6.6	6.7	2.5	97.8	44.0	40.4	39.5	1.9
2018	**13 to 16**	Standard	4	9	22	0.1	2.5		2.5	2.6	1.8	98.7	43.7	42.0	41.5	2.2
2018	**19**	Unsprayed	5	9	9	0.0	13.2		13.2	13.2	55.5		29.1	8.6	7.7	0.2
2018	**20**	Standard	6	9	9	0.7	5.6		5.6	6.3	46.4	63.8	26.1	16.7	12.3	0.4
2018	**1 to 4**	Treatment strip-1	1	Combined average	36	**0.5**	**16.4**		**16.4**	**16.9**	**9.1**	**92.7**	**43.3**	**30.4**	**29.0**	**2.1**
2018	**5 to 8**	Treatment strip-2	2	Combined average	36	**0.0**	**11.6**		**11.6**	**11.6**	**2.6**	**98.0**	**44.1**	**37.3**	**36.6**	**2.6**
2018	**9 to 12**	Treatment strip-3	3	Combined average	36	**0.1**	**6.1**		**6.1**	**6.2**	**2.3**	**97.9**	**43.8**	**40.1**	**39.4**	**2.8**
2018	**13 to 16**	Standard	4	Combined average	34	**0.0**	**2.1**		**2.1**	**2.2**	**2.1**	**98.2**	**43.4**	**41.6**	**40.9**	**3.0**

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<u>Key points 2018:</u>

<u>Treatment strip-1</u>

No broad spectrum insecticides were used and the percentage of scales on husk was lowest, while percentage of thrips on husk were highest in this treatment. A rotation of SeroX®, Exirel® and Mainman® were not sufficient to manage MNB and FSB. One *Beauveria* was not sufficient to manage MSW.

<u>Treatment strip-2</u>

No broad spectrum insecticides were used. The percentage of scales on husk was highest in this treatment. MSW was well managed with an indoxacarb application, but the management of FSB with SeroX®, Exirel® and Mainman® again was not sufficient. Due to FSB damage, sound KR and yield were low.

<u>Treatment strip-:</u>

Broad spectrum insecticides were used, acephate did not manage MSW as well as indoxacarb. FSB was managed well with Transform and Trivor®. Sound Kernel and yield were higher than in the treatments where no broad spectrum insecticides were used.

<u>Standard</u>

Acephate did reduce feeding of MSW but did not reduce the oviposition of the weevil as much as indoxacarb. FSB was well managed with acephate and beta-cyfluthrin. Yield and sound kernel recovery were highest in this treatment due to better management of MSW and more so FSB.

Table 2.3.1.3.: Husk assessment from different treatments in main IPM trial at CTH Alstonville 2019

Harvest Year	Blocks	Treatment	Treatment number	Tree height	Tree numbers	% Clean husk	Total MNB eggs	% MNB Parasitism	% Husk MNB Tunnels	% Felted Coccid	% Scale	% Thrip	% Pinhole borer	% MSW feeding	% MSW eggs	%Husk spot
2019	**1 to 4**	Treatment strip-1	1	6	12	47.9	4.4	0.0	28.7	0.7	3.3	18.9	0.0	5.0	1.7	1.4
2019	**5 to 8**	Treatment strip-2	2	6	12	21.6	22.8	0.4	66.3	0.0	0.0	7.9	0.0	4.0	1.0	0.0
2019	**9 to 12**	Treatment strip-3	3	6	12	49.0	6.8	4.6	30.7	0.0	0.3	14.5	0.0	5.9	0.6	0.0
2019	**13 to 16**	Standard	4	6	12	35.3	10.5	4.5	40.0	0.0	3.3	19.8	0.0	3.7	2.6	0.5
2019	**1 to 4**	Treatment strip-1	1	9	24	46.9	5.2	0.7	16.1	1.7	3.1	14.4	0.0	13.7	9.0	1.2
2019	**5 to 8**	Treatment strip-2	2	9	24	27.4	17.8	2.8	43.2	0.0	0.4	15.1	0.0	11.5	3.8	0.0
2019	**9 to 12**	Treatment strip-3	3	9	24	57.3	3.5	9.3	10.8	0.0	1.5	21.0	0.0	5.8	1.6	0.6
2019	**13 to 16**	Standard	4	9	22	41.2	9.7	12.2	24.4	0.0	3.2	14.1	0.0	12.1	4.7	0.1
2019	**19**	Unsprayed	5	9	9	64.4	1.2	0.0	9.7	0.0	3.1	20.6	0.0	6.2	0.7	3.8
2019	**20**	Standard	6	9	9											
2019	**1 to 4**	Treatment strip-1	1	Combined average	36	**47.4**	**4.8**	**0.3**	**22.4**	**1.2**	**3.2**	**16.6**	**0.0**	**9.3**	**5.3**	**1.3**
2019	**5 to 8**	Treatment strip-2	2	Combined average	36	**24.5**	**20.3**	**1.6**	**54.7**	**0.0**	**0.2**	**11.5**	**0.0**	**7.7**	**2.4**	**0.0**
2019	**9 to 12**	Treatment strip-3	3	Combined average	36	**53.2**	**5.1**	**7.0**	**20.7**	**0.0**	**0.9**	**17.7**	**0.0**	**5.8**	**1.1**	**0.3**
2019	**13 to 16**	Standard	4	Combined average	34	**38.3**	**10.1**	**8.4**	**32.2**	**0.0**	**3.2**	**17.0**	**0.0**	**7.9**	**3.6**	**0.3**

Table 2.3.1.4.: Kernel assessment from different treatments in main IPM trial at CTH Alstonville 2019

Harvest Year	Blocks	Treatment	Treatment number	Tree height	Tree numbers	% MNB-kernel	% FSB loss	% Leptocoris damage	Total % bug damage	% Total insect damage	% Immature nut	% Mature nut	% Total KR	% Sound KR	Sum of kg DNIS@10%	Average of T/Ha
2019	**1 to 4**	Treatment strip-1	1	6	12	0.1	17.1	0.0	17.1	17.3	6.6	91.0	36.3	28.8	18.6	1.8
2019	**5 to 8**	Treatment strip-2	2	6	12	0.8	11.1	0.0	11.1	11.9	11.2	90.9	37.4	29.3	16.5	1.6
2019	**9 to 12**	Treatment strip-3	3	6	12	0.1	4.4	0.0	4.4	4.5	4.8	93.8	38.3	34.5	30.8	2.9
2019	**13 to 16**	Standard	4	6	12	0.3	4.1	0.0	4.1	4.4	5.7	94.8	38.7	34.5	34.0	3.2
2019	**1 to 4**	Treatment strip-1	1	9	24	0.2	16.6	0.0	16.6	16.9	4.8	92.2	36.5	29.6	75.8	3.6
2019	**5 to 8**	Treatment strip-2	2	9	24	0.6	12.4	0.0	12.4	13.0	9.9	94.1	36.8	29.2	46.7	2.2
2019	**9 to 12**	Treatment strip-3	3	9	24	0.1	4.4	0.0	4.4	4.5	3.9	96.8	38.4	35.6	105.5	5.0
2019	**13 to 16**	Standard	4	9	22	0.5	4.6	0.0	4.6	5.0	4.2	95.5	39.0	35.4	97.9	5.1
2019	**19**	Unsprayed	5	9	9	0.0	4.4	0.0	4.4	4.4	12.5	96.1	28.4	23.0	1.1	0.0
2019	**20**	Standard	6	9	9	0.6	2.1	0.0	2.1	2.7	23.4	93.6	31.0	25.3	5.9	0.2
2019	**1 to 4**	Treatment strip-1	1	Combined average	36	**0.2**	**16.9**	**0.0**	**16.9**	**17.1**	**5.7**	**91.6**	**36.4**	**29.2**	**47.2**	**2.7**
2019	**5 to 8**	Treatment strip-2	2	Combined average	36	**0.7**	**11.8**	**0.0**	**11.8**	**12.5**	**10.6**	**92.5**	**37.1**	**29.2**	**31.6**	**1.9**
2019	**9 to 12**	Treatment strip-3	3	Combined average	36	**0.1**	**4.4**	**0.0**	**4.4**	**4.5**	**4.3**	**95.3**	**38.3**	**35.0**	**68.1**	**4.0**
2019	**13 to 16**	Standard	4	Combined average	34	**0.4**	**4.4**	**0.0**	**4.4**	**4.7**	**5.0**	**95.2**	**38.8**	**34.9**	**65.9**	**4.2**

<u>Key points 2019:</u>

<u>Treatment strip-1</u>

No broad spectrum insecticides were used. Despite an application of indoxacarb, the percentage nuts with MSW feeding and oviposition sites was highest in this treatment. A new compound (DC0163) and was not sufficient to manage FSB damage. Sound kernel recovery and yield were comparatively low.

<u>Treatment strip-2</u>

No broad spectrum insecticides were used. Transform® and Trivor® were used for management later in the season for management of FSB, which was not as successful as using broad spectrum insecticides. The percentage of immature nuts was highest in this treatment and sound kernel and yield were lowest.

<u>Treatment strip-3</u>

Broad spectrum insecticides were used. The trichlorfon spray following the acephate spray appeared did not manage remaining MSW.

<u>Standard</u>

Thrips and scales were high in this treatment. Acephate followed by beta-cyfluthrin gave a better control of MSW. did reduce feeding of MSW but did not reduce the oviposition of the weevil as much as indoxacarb. FSB was well managed with acephate and beta-cyfluthrin. Yield and sound kernel recovery were highest in and comparable in both broad spectrum insecticide treatments due.

Table 2.3.1.5.: Husk assessment from different treatments in main IPM trial at CTH Alstonville 2020

Harvest Year	Blocks	Treatment	Treatment number	Tree height	Tree numbers	% Clean husk	Total MNB eggs	% MNB Parasitism	% Husk MNB Tunnels	% Felted Coccid	% Scale	% Thrip	% Pinhole borer	% MSW feeding	% MSW eggs	%Husk spot
2020	**1 to 4**	Treatment strip-1	1	6	12	23.23	19.17	0.00	55.70	0.0	0.1	2.7	0.0	8.3	0.8	0.0
2020	**5 to 8**	Treatment strip-2	2	6	12	19.17	8.50	1.85	63.61	0.0	0.1	5.3	0.0	8.6	0.0	0.0
2020	**9 to 12**	Treatment strip-3	3	6	12	12.50	23.67	4.95	59.72	0.0	0.1	8.5	0.0	4.2	0.0	0.0
2020	**13 to 16**	Standard	4	6	12	38.78	3.92	10.12	16.39	0.0	0.4	2.5	0.2	30.5	1.4	0.0
2020	**1 to 4**	Treatment strip-1	1	9	24	31.11	12.83	1.68	39.72	0.1	0.3	4.3	0.0	15.0	0.7	0.0
2020	**5 to 8**	Treatment strip-2	2	9	23	27.26	4.74	0.00	41.67	0.0	0.1	5.2	0.0	19.7	0.3	0.0
2020	**9 to 12**	Treatment strip-3	3	9	24	23.11	11.20	4.38	39.22	0.0	1.0	7.7	0.0	13.8	0.4	0.0
2020	**13 to 16**	Standard	4	9	22	44.25	1.50	0.00	6.88	0.0	0.6	2.4	0.1	25.1	1.5	0.0
2020	**19**	Unsprayed	5	9	9	15.93	8.00	1.01	39.26	0.2	0.5	4.1	0.1	33.3	13.7	0.0
2020	**20**	Standard	6	9	9	13.33	10.89	0.00	37.04	0.1	0.2	1.5	0.1	41.9	15.6	0.1
2020	**1 to 4**	Treatment strip-1	1	Combined average	36	**27.2**	**16.0**	**0.8**	**47.7**	**0.0**	**0.2**	**3.5**	**0.0**	**11.7**	**0.8**	**0.0**
2020	**5 to 8**	Treatment strip-2	2	Combined average	35	**23.2**	**6.6**	**0.9**	**52.6**	**0.0**	**0.1**	**5.2**	**0.0**	**14.2**	**0.1**	**0.0**
2020	**9 to 12**	Treatment strip-3	3	Combined average	36	**17.8**	**17.4**	**4.7**	**49.5**	**0.0**	**0.6**	**8.1**	**0.0**	**9.0**	**0.2**	**0.0**
2020	**13 to 16**	Standard	4	Combined average	34	**41.5**	**2.7**	**5.1**	**11.6**	**0.0**	**0.5**	**2.4**	**0.2**	**27.8**	**1.4**	**0.0**

Table 2.3.1.6.: Kernel assessment from different treatments in main IPM trial at CTH Alstonville 2020

Harvest Year	Blocks	Treatment	Treatment number	Tree height	Tree numbers	% MNB-kernel	% FSB loss	% Leptocoris damage	Total % bug damage	% Total insect damage	% Immature nut	% Mature nut	% Total KR	% Sound KR	Sum of kg DNIS@10%	Average of T/Ha
2020	**1 to 4**	Treatment strip-1	1	6	12	0.8	11.7	0.2	11.9	12.7	5.4	79.5	41.8	34.0	58.2	5.5
2020	**5 to 8**	Treatment strip-2	2	6	12	1.1	7.8	0.3	8.0	9.1	5.9	76.8	43.3	34.4	54.7	5.2
2020	**9 to 12**	Treatment strip-3	3	6	12	1.8	10.8	0.1	10.9	12.6	7.2	73.0	44.4	37.6	53.0	5.0
2020	**13 to 16**	Standard	4	6	12	0.6	5.1	0.1	5.2	5.8	9.3	76.0	42.8	33.7	56.2	5.3
2020	**1 to 4**	Treatment strip-1	1	9	24	0.8	7.3	0.2	7.5	8.3	5.6	81.3	42.6	35.7	136.0	6.5
2020	**5 to 8**	Treatment strip-2	2	9	23	1.6	6.4	0.2	6.6	8.2	6.2	78.1	45.8	36.5	112.1	5.8
2020	**9 to 12**	Treatment strip-3	3	9	24	0.9	7.1	0.1	7.3	8.1	6.4	79.0	42.5	34.5	118.0	5.6
2020	**13 to 16**	Standard	4	9	22	0.3	3.5	0.1	3.5	3.9	7.3	81.5	44.1	36.8	97.4	5.0
2020	**19**	Unsprayed	5	9	9	0.9	6.6	0.0	6.6	7.5	16.1	70.7	32.8	24.5	32.2	1.0
2020	**20**	Standard	6	9	9	1.8	4.1	0.0	4.1	5.9	11.2	74.5	33.7	26.6	61.5	1.9
2020	**1 to 4**	Treatment strip-1	1	Combined average	36	**0.8**	**9.5**	**0.2**	**9.7**	**10.5**	**5.5**	**80.4**	**42.2**	**34.9**	**97.1**	**6.0**
2020	**5 to 8**	Treatment strip-2	2	Combined average	35	**1.3**	**7.1**	**0.2**	**7.3**	**8.6**	**6.1**	**77.4**	**44.5**	**35.4**	**83.4**	**5.5**
2020	**9 to 12**	Treatment strip-3	3	Combined average	36	**1.3**	**9.0**	**0.1**	**9.1**	**10.4**	**6.8**	**76.0**	**43.4**	**36.1**	**85.5**	**5.3**
2020	**13 to 16**	Standard	4	Combined average	34	**0.5**	**4.3**	**0.1**	**4.3**	**4.8**	**8.3**	**78.8**	**43.4**	**35.2**	**76.8**	**5.2**

Key points 2020:

Treatment strip-1, Treatment strip-2 and Treatment-strip 3

Were almost identical apart from the macadamia lace-bug treatment (Sivanto® Prime in Treatment-stip-1, trichlorfon in Treatment-strip-2 and sulfoxaflor in Treatment-strip 3. All 3 treatments had adequate MSW control using indoxacarb and adequate FSB control using 1 application of sulfoxaflor and 2 applications of trichlorfon. Sound kernel recovery and yields were highest in these 2 treatments.

Standard

An application of acephate and hygiene were not as successful in managing MSW as an application of indoxacarb. Using 2 applications of acephate and 2 applications of beta-cyfluthrin resulted in lower MNB and FSB damage, however the percentage of sound kernel and yield were not much different from the other two treatments.

Table 2.3.1.7.: Husk assessment from different treatments in main IPM trial at CTH Alstonville 2021

Harvest Year	Blocks	Treatment	Treatment number	Tree height	Tree numbers	% Clean husk	Total MNB eggs	% MNB Parasitism	% Husk MNB Tunnels	% Felted Coccid	% Scale	% Thrip	% Pinhole borer	% MSW feeding	% MSW eggs	%Husk spot
2021	**1 to 4**	Treatment strip-1	1	6	12	14.5	8.0	1.3	21.1	0.0	0.7	3.0	0.0	0.3	7.1	1.4
2021	**5 to 8**	Treatment strip-2	2	6	12	19.2	5.1	2.7	21.7	0.0	0.0	1.8	0.0	0.0	5.0	1.0
2021	**9 to 12**	Treatment strip-3	3	6	12	25.3	1.3	0.0	8.6	0.0	0.3	7.9	0.0	0.0	8.3	2.6
2021	**13 to 16**	Standard	4	6	12	23.2	1.5	0.0	9.6	0.0	0.3	10.7	0.0	0.0	6.7	1.8
2021	**1 to 4**	Treatment strip-1	1	9	24	13.4	5.9	1.8	16.3	0.1	0.3	6.8	0.0	0.2	14.8	2.2
2021	**5 to 8**	Treatment strip-2	2	9	23	21.3	3.9	1.1	15.1	0.0	0.0	5.3	0.0	0.1	7.1	3.0
2021	**9 to 12**	Treatment strip-3	3	9	24	18.6	2.2	0.2	12.0	0.0	0.2	12.0	0.0	0.1	9.3	2.6
2021	**13 to 16**	Standard	4	9	22	20.8	1.2	0.5	7.3	0.1	0.7	12.6	0.0	0.4	11.2	2.0
2021	**19**	Unsprayed	5	9	8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.9
2021	**20**	Standard	6	9	9	11.2	0.0	0.0	17.2	0.0	0.2	0.4	0.0	0.0	11.0	6.0
2021	1 to 4	Treatment strip-1	1	Combined average	36	**14.0**	**7.0**	**1.5**	**18.7**	**0.0**	**0.5**	**4.9**	**0.0**	**0.2**	**10.9**	**1.8**
2021	5 to 8	Treatment strip-2	2	Combined average	35	**20.3**	**4.5**	**1.9**	**18.4**	**0.0**	**0.0**	**3.6**	**0.0**	**0.0**	**6.1**	**2.0**
2021	9 to 12	Treatment strip-3	3	Combined average	36	**21.9**	**1.8**	**0.1**	**10.3**	**0.0**	**0.3**	**10.0**	**0.0**	**0.1**	**8.8**	**2.6**
2021	13 to 16	Standard	4	Combined average	34	**22.0**	**1.3**	**0.3**	**8.5**	**0.0**	**0.5**	**11.7**	**0.0**	**0.2**	**8.9**	**1.9**

Table 2.3.1.8.: Kernel assessment from different treatments in main IPM trial at CTH Alstonville 2021

Harvest Year	Blocks	Treatment	Treatment number	Tree height	Tree numbers	% MNB-kernel	% FSB loss	% Leptocoris damage	Total % bug damage	% Total insect damage	% Immature nut	% Mature nut	% Total KR	% Sound KR	Sum of kg DNIS@10%	Average of T/Ha
2021	**1 to 4**	Treatment strip-1	1	6	12	0.9	11.5	0.0	11.5	12.4	11.0	69.7	37.3	28.7	21.9	2.1
2021	**5 to 8**	Treatment strip-2	2	6	12	0.2	6.6	0.1	6.7	6.9	8.1	77.2	38.8	33.3	36.2	3.4
2021	**9 to 12**	Treatment strip-3	3	6	12	0.1	10.3	0.0	10.3	10.4	3.9	78.6	40.5	34.2	48.0	4.6
2021	**13 to 16**	Standard	4	6	12	0.1	7.2	0.0	7.2	7.3	6.9	76.9	39.3	33.4	50.8	4.8
2021	**1 to 4**	Treatment strip-1	1	9	24	0.3	10.3	0.0	10.3	10.6	10.0	72.1	37.5	29.8	65.8	3.1
2021	**5 to 8**	Treatment strip-2	2	9	23	0.1	9.4	0.0	9.4	9.5	4.1	80.5	40.3	34.7	71.6	3.6
2021	**9 to 12**	Treatment strip-3	3	9	24	0.1	7.4	0.0	7.4	7.5	9.1	77.2	38.1	32.2	92.0	4.4
2021	**13 to 16**	Standard	4	9	22	0.1	7.0	0.0	7.0	7.1	6.0	78.9	39.5	33.3	97.5	5.1
2021	**19**	Unsprayed	5	9	8	0.0	5.9	0.0	5.9	5.9	36.7	48.4	27.0	17.7	0.4	0.0
2021	**20**	Standard	6	9	9	1.1	4.8	0.0	4.8	5.9	38.4	46.0	28.3	16.4	12.5	0.4
2021	1 to 4	Treatment strip-1	1	Combined average	36	**0.6**	**10.9**	**0.0**	**10.9**	**11.5**	**10.5**	**70.9**	**37.4**	**29.2**	**43.8**	**2.6**
2021	5 to 8	Treatment strip-2	2	Combined average	35	**0.2**	**8.0**	**0.0**	**8.0**	**8.2**	**6.1**	**78.8**	**39.5**	**34.0**	**53.9**	**3.5**
2021	9 to 12	Treatment strip-3	3	Combined average	36	**0.1**	**8.8**	**0.0**	**8.8**	**9.0**	**6.5**	**77.9**	**39.3**	**33.2**	**70.0**	**4.5**
2021	13 to 16	Standard	4	Combined average	34	**0.1**	**7.1**	**0.0**	**7.1**	**7.2**	**6.5**	**77.9**	**39.4**	**33.3**	**74.2**	**5.0**

Key points 2021:

Treatment strip-1 and Treatment strip-2

Treatments were identical other than the timing for the macadamia lace bug spray. In Treatment strip-1, all cultivars (246, 741, 849 and A4) were treated at the same time, while in Treatment strip-2 early cultivars (246 and 741) and late cultivars (849 and A4) were treated 2 weeks apart. The split timing gave a higher yield. Using Lepidex and Trivor to manage reduced thrips on husk. MNB and FSB were slightly higher and sounds kernel recovery and yield lower than in Treatment strips 3 and 4.

Treatment strip-3 and Standard Treatment

Treatments were identical other than the timing for the macadamia lace bug spray. In Treatment strip-1, all cultivars (246, 741, 849 and A4) were treated at the same time, while in Treatment strip-2 early cultivars (246 and 741) and late cultivars (849 and A4) were treated 2 weeks apart. The trichlorfon spray following the acephate spray appeared did not manage remaining MSW. Thrips and scales were higher than in Treatment strips-1 and 2. Two acephate applications were needed for adequate MSW management. Insect damage, sound kernel recovery and yield were not much different Treatment strips 1 and 2.

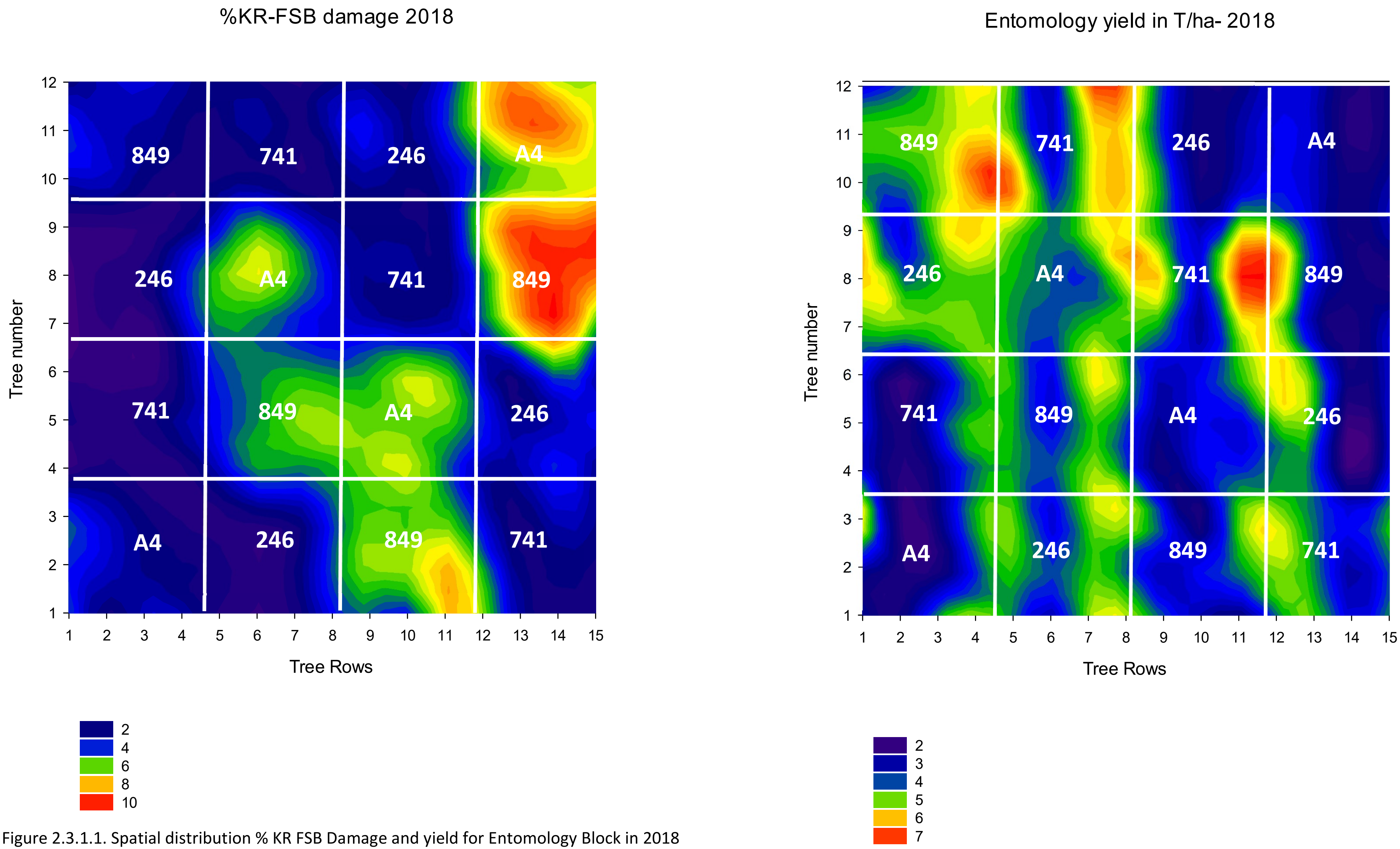
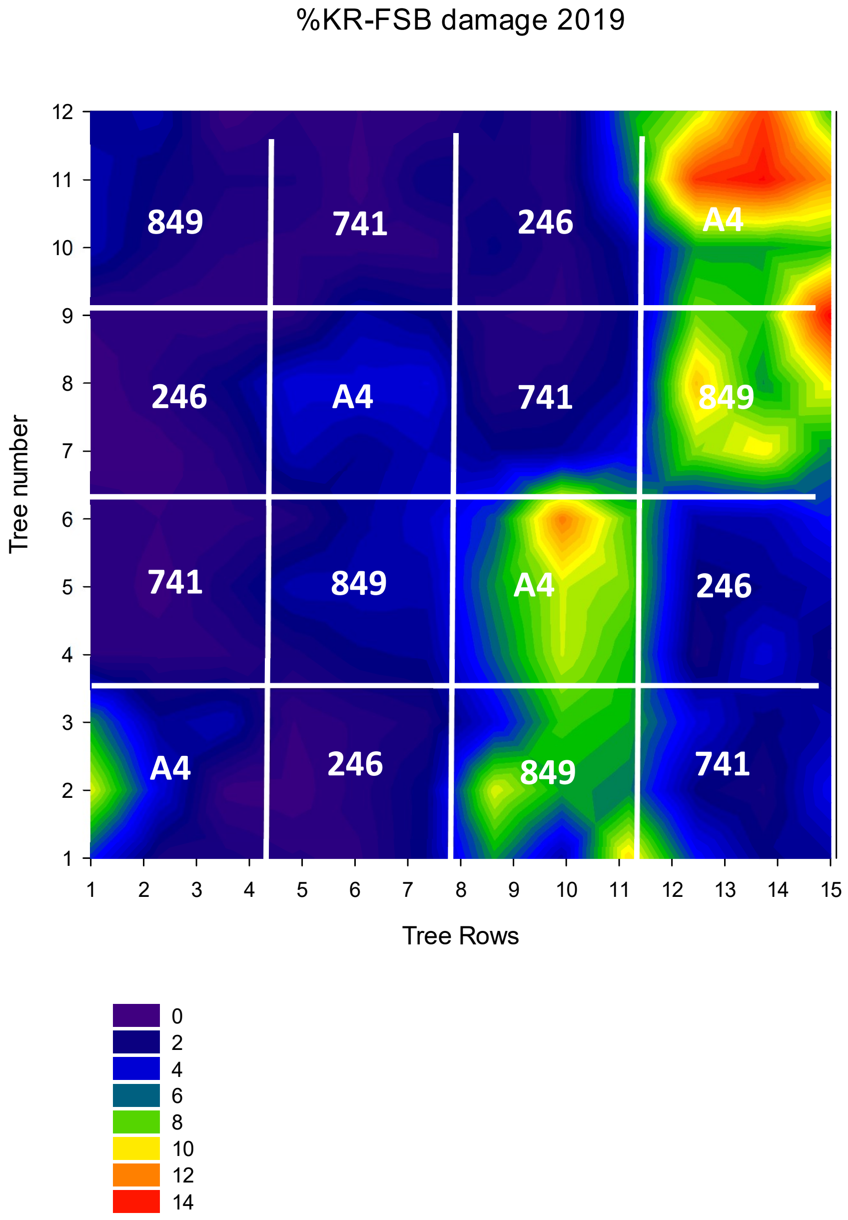


Figure 2.3.1.1. Spatial distribution % KR FSB Damage and yield for Entomology Block in 2018



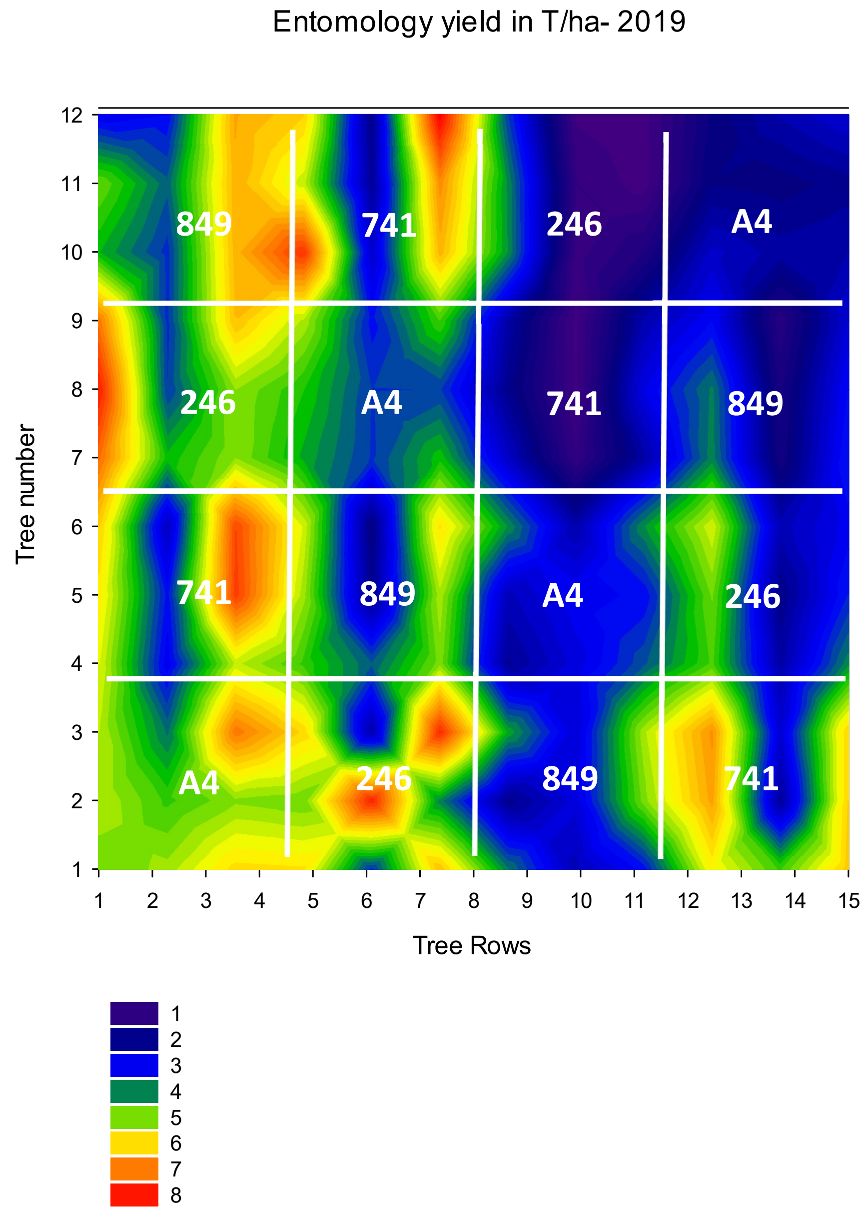
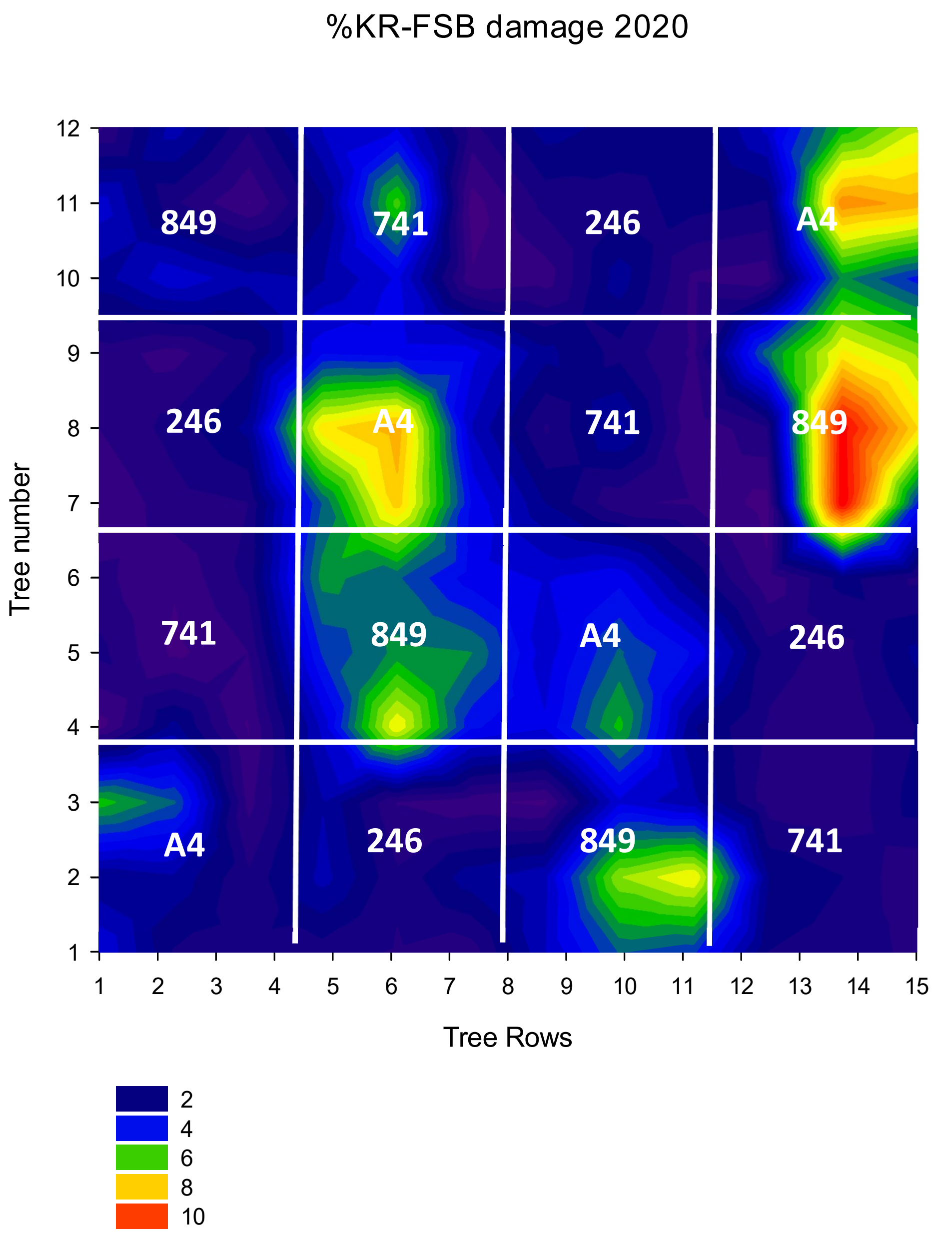


Figure 2.3.1.2.: Spatial distribution % KR FSB Damage and yield for Entomology Block in 2019



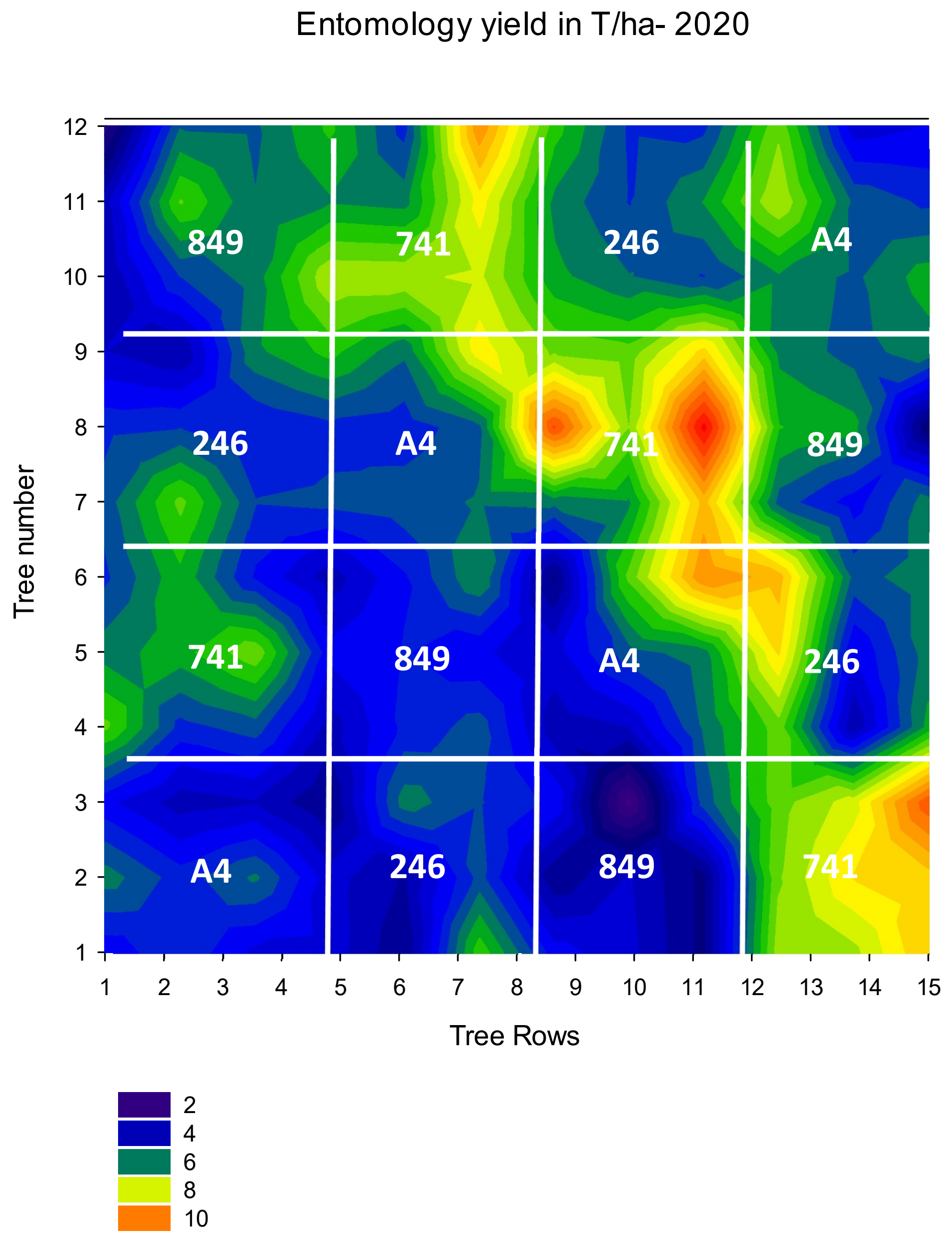
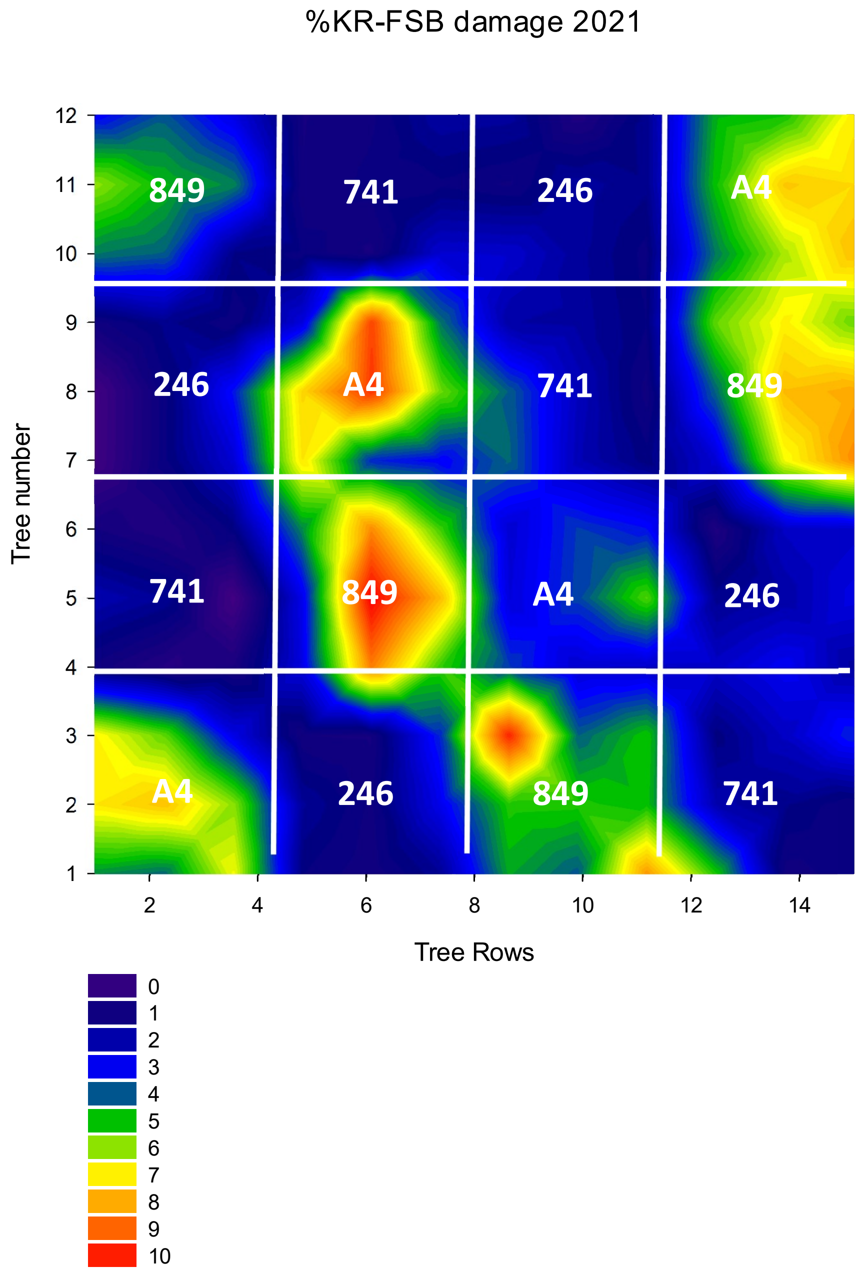


Figure 2.3.1.3.: Spatial distribution % KR FSB Damage and yield for Entomology Block in 2020



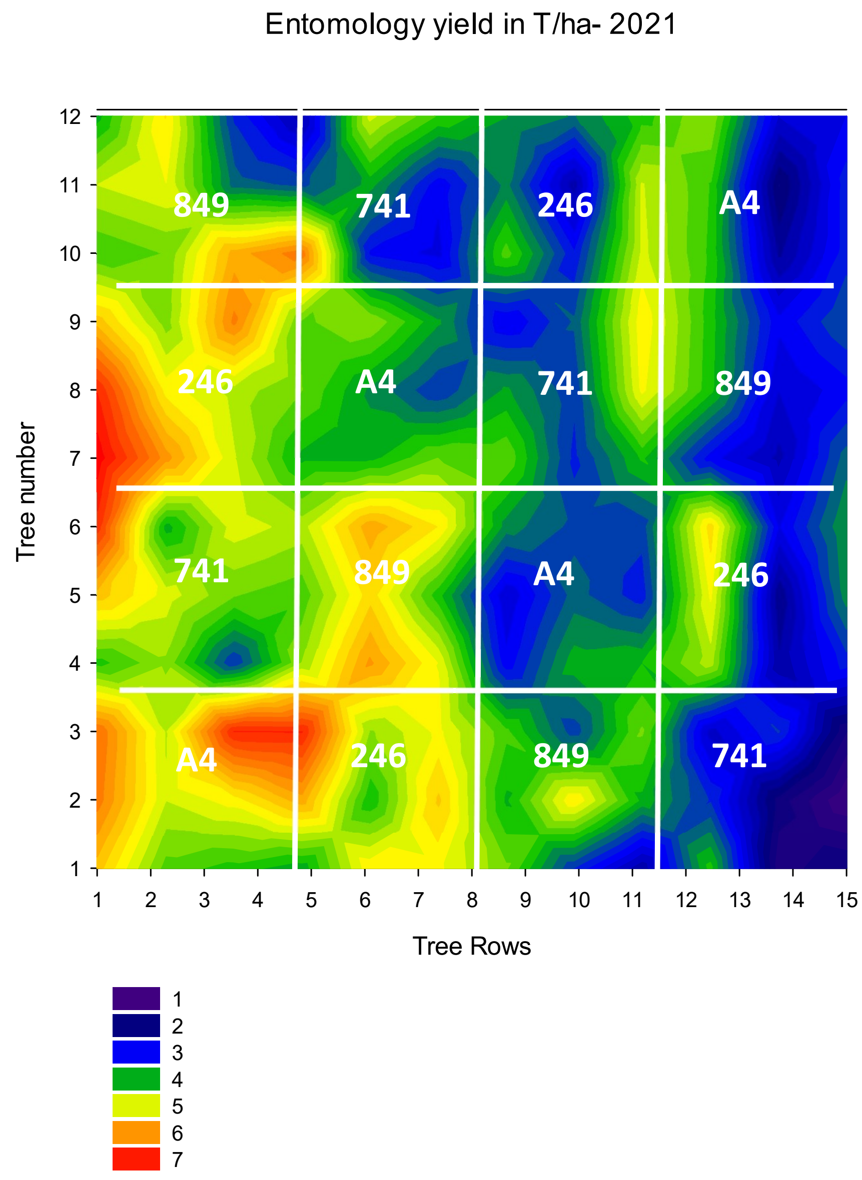


Figure 2.3.1.4.: Spatial distribution % KR FSB Damage and yield for Entomology Block in 2021

Conclusion

The timing of application using Sivanto® Prime with a shorter residual time than Diazinon for macadamia lace bug was critical for successful control. An additional chemical application was needed for MSW control if acephate was relied on. Four applications of broad spectrum insecticides gave a slightly better control of FSB, slightly higher sound kernel recovery and yield in comparison to the 3 applications in Treatment strip 1 and 2.

2.3.2. Biodiversity trial

Monitoring

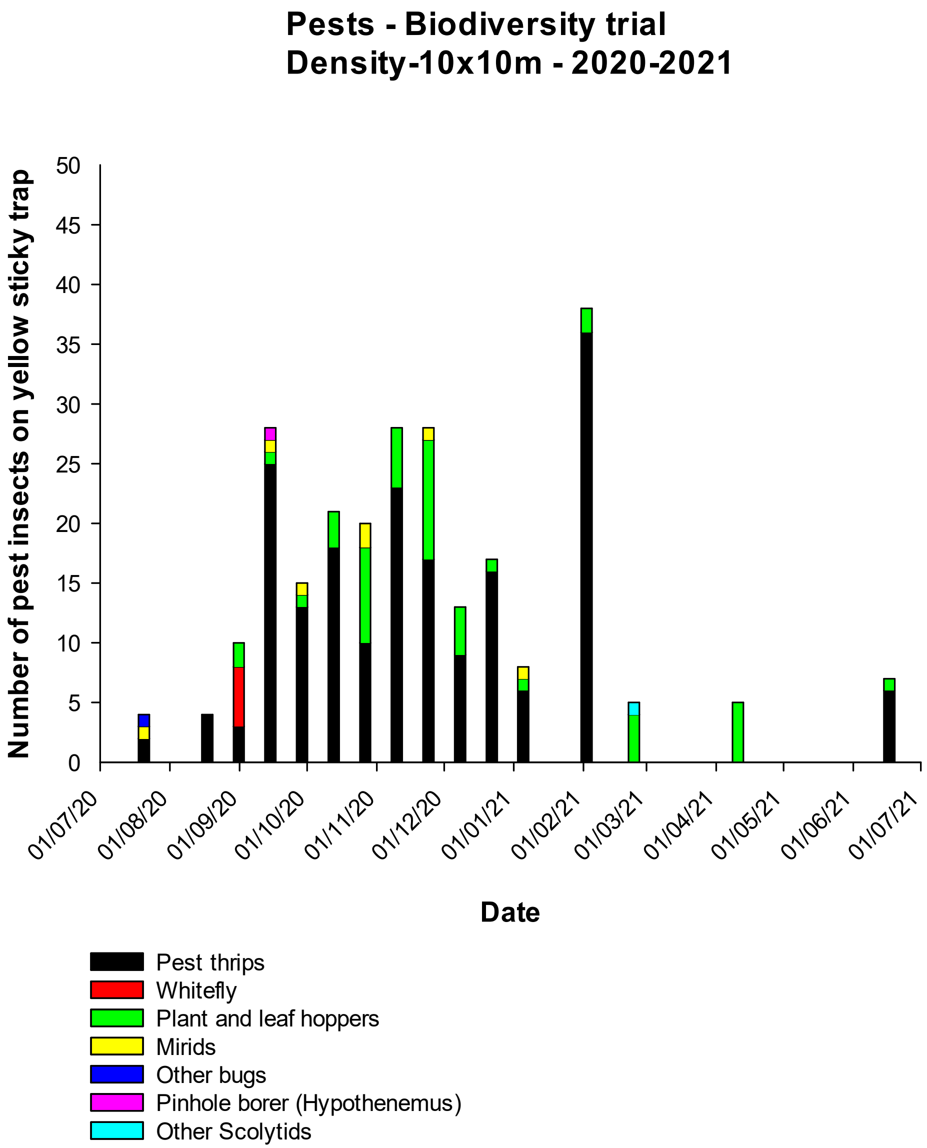
Monitoring results of pests and beneficials from trapping with yellow sticky traps in different densities are shown in Figures 2.3.2.1. to 2.3.2.3.

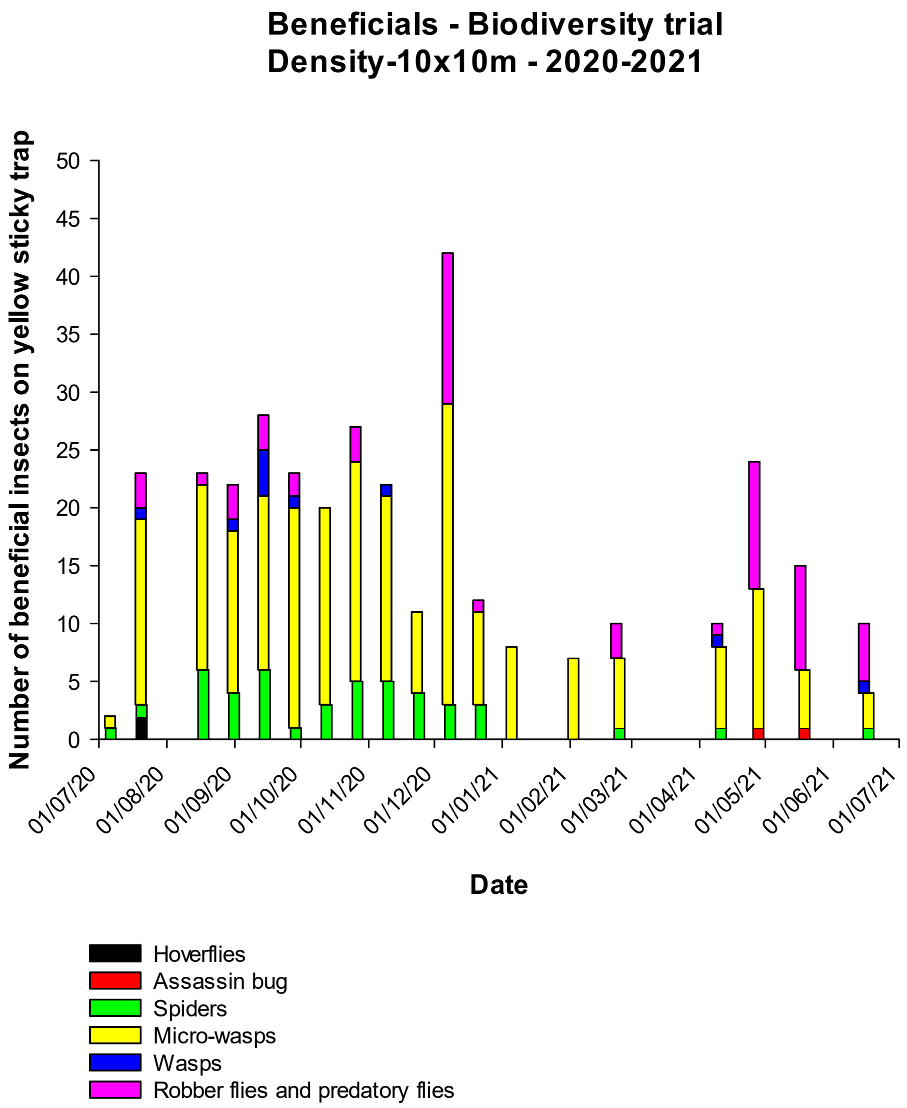
Husk and kernel recovery assessment

The effect of the inter-rows in the biodiversity trial only come into effect with the 2020–2021 harvest. In 2020 the block had a crop again after several year of total crop loss due to macadamia lace bug there was hardly any set. What left, dropped prematurely due to macadamia seed weevil and FSB.

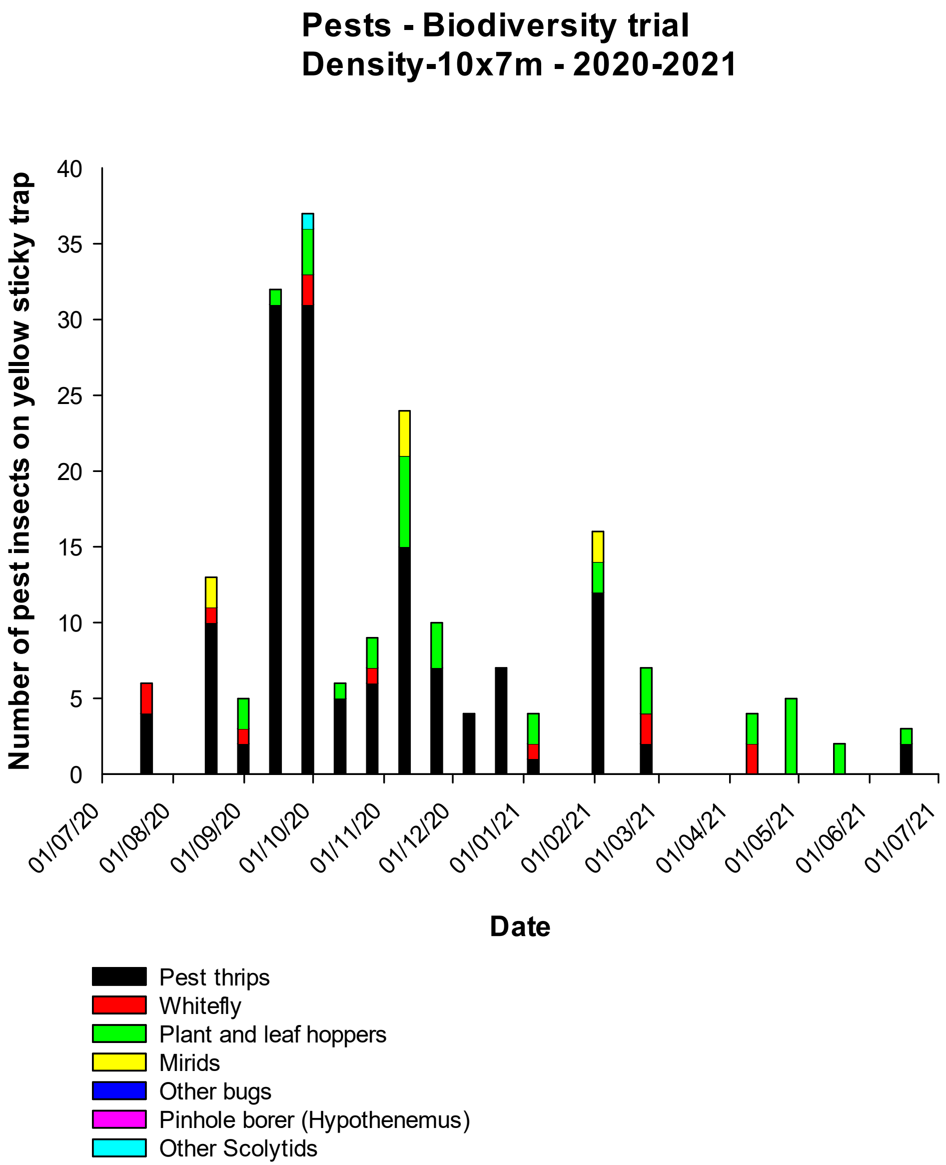
Results for husk and kernel assessment from the crop that was harvested is shown in Table 2.3.2.1.

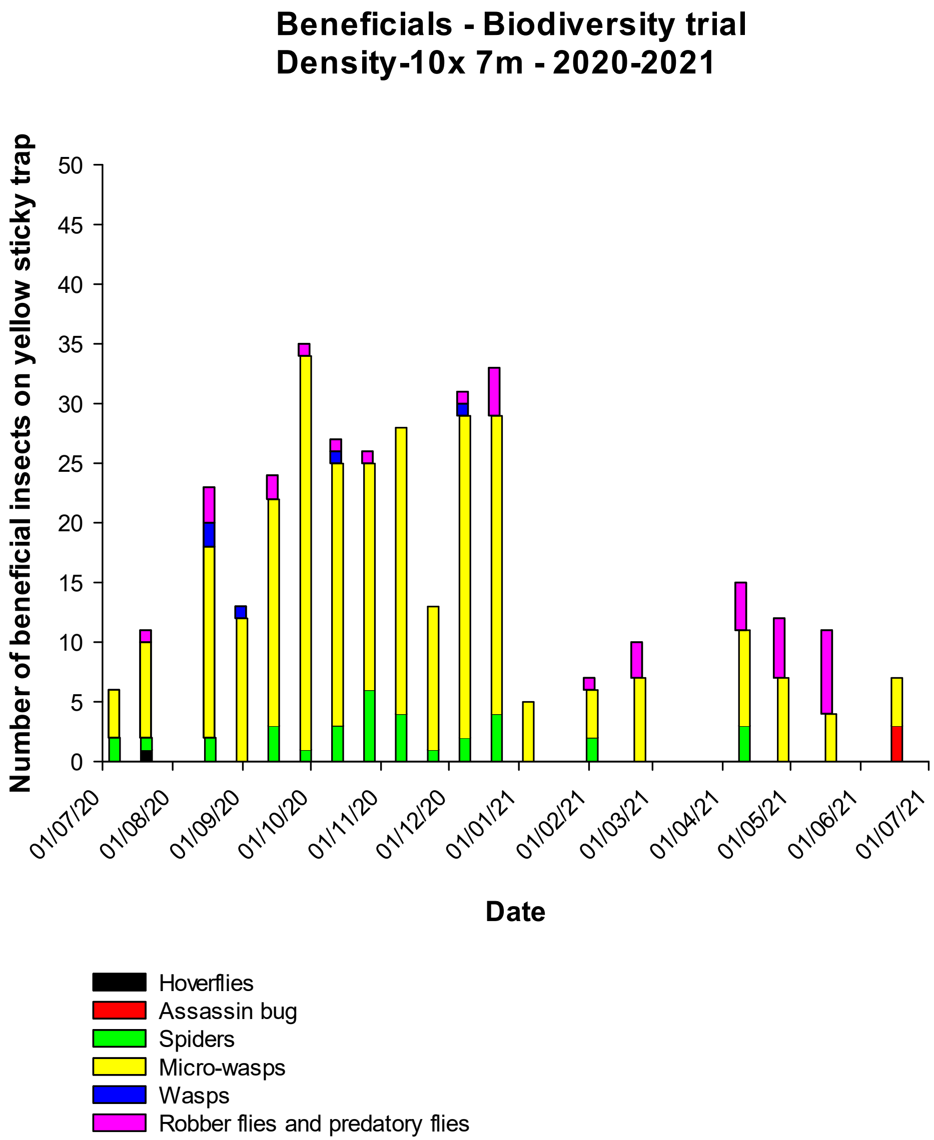
It showed that during the biodiversity trial the yield had tripled from previous year. It also confirmed again that FSB was the main contributor to crop loss. There was certainly much better control of MNB during the inter-row trial than in previous years, as natural enemies including MacTrix had much better conditions to survive. The parasitism of MNB eggs doubled from previous years.



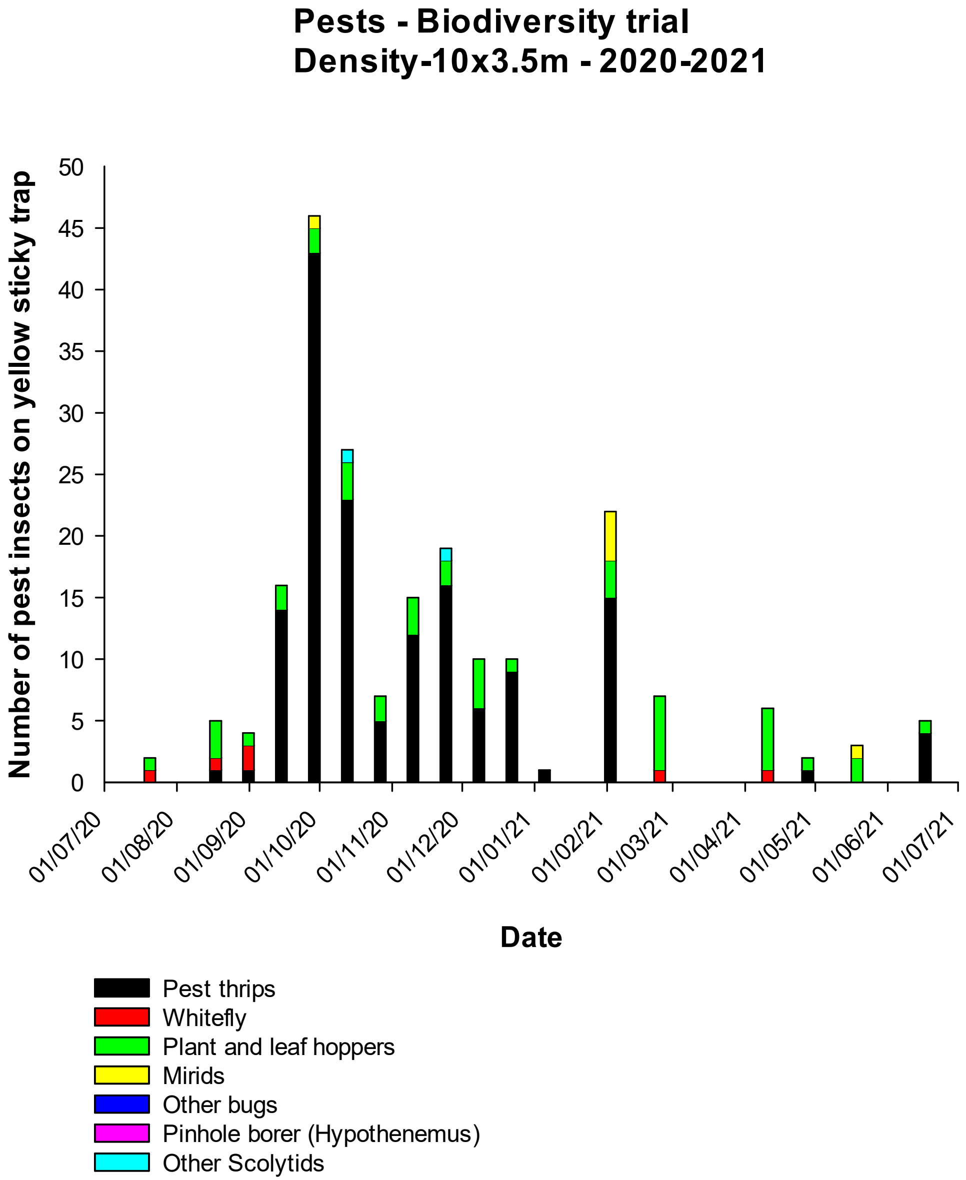


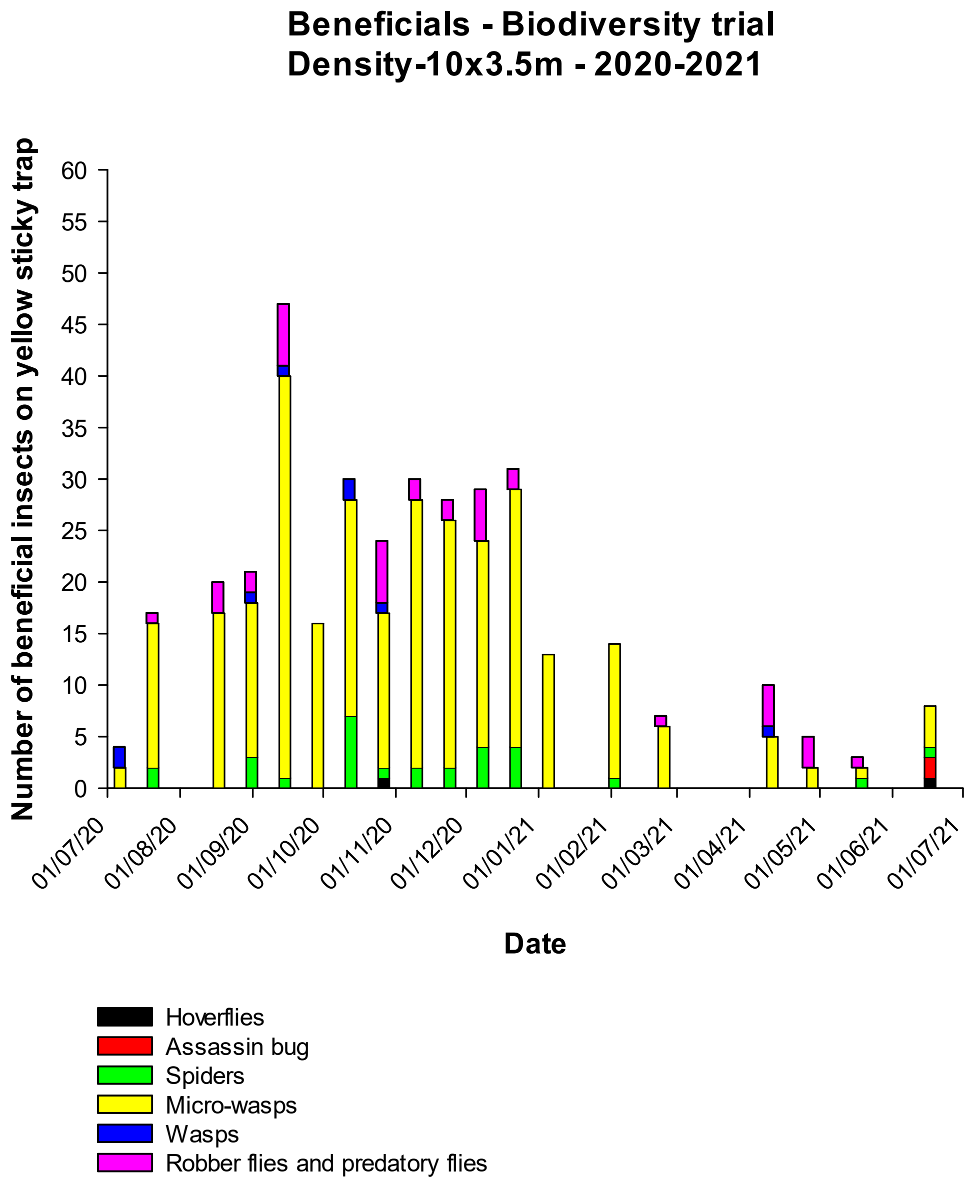
Figures 2.3.2.1.: Pest and beneficials in CTH Biodiversity trial, Density 10x10 meters - 2020–2021





Figures 2.3.2.2.: Pest and beneficials in CTH Biodiversity trial, Density 10x7 meters - 2020–2021





Figures 2.3.2.3.: Pest and beneficials in CTH Biodiversity trial, Density 10x3.5 meters - 2020–2021

Table: 2.3.2.1. Husk and kernel assessment for density block harvests from 2017 to 2021, including biodiversity trial – 2020/2021

	Harvest Year	Treatment	Treatment number	Density	Tree numbers	% Clean husk	Total MNB eggs	% MNB Parasitism	% Husk MNB Tunnels	% Felted Coccid	% Scale	% Thrip	% Pinhole borer	% MSW feeding	% MSW eggs	%Husk spot
Husk assessment	2017	Unsprayed	1	10X3.5	20	17.0	26.9	10.8	29.8	0.0	10.4	24.4		18.2	10.4	1.6
			2	10X7	19	16.9	20.2	16.1	26.0	0.0	10.9	24.7		20.2	14.8	1.1
			3	10X10	17	19.5	22.7	24.6	22.1	0.0	11.5	22.8		23.7	13.0	1.4
	2018	Unsprayed	1	10X3.5	No crop											
			2	10X7												
			3	10X10												
	2019	Unsprayed	1	10X3.5												
			2	10X7												
			3	10X10												
	2020	1 indoxacarb application only	1	10X3.5	23											
			2	10X7	22											
			3	10X10	19											
	2021	Interrows and 1 indoxacarb application	1	10X3.5	22	18.0	40.3	17.5	39.5	0.2	0.0	27.4	0.0	17.0	20.5	0.0
			2	10X7	24	20.6	40.7	26.9	38.8	0.4	0.0	34.1	0.0	18.6	19.0	0.0
			3	10X10	23	27.6	42.1	29.7	33.0	0.5	0.0	20.6	0.0	15.7	11.6	0.2

	Harvest Year	Treatment	Treatment number	Density	Tree numbers	Trees/ha	KR % MNB-kernel	KR% FSB loss	KR% Leptocoris damage	Total-KR % bug damage	KR% Total insect damage	% Immature nut	% Total KR	% Sound KR	Sum of kg DNIS@10%	Average of T/Ha
Kernel assessment	2017	Unsprayed	1	10X3.5	20	285	0.7	3.8	0.0	3.8	4.6	13.6	28.9	19.6	21.1	0.3
			2	10X7	19	143	0.6	3.9	0.0	3.9	4.5	14.5	28.0	18.1	24.0	0.2
			3	10X10	17	100	0.7	2.1	0.0	2.1	2.8	14.7	29.5	21.7	26.0	0.2
	2018	Unsprayed	1	10X3.5	No crop											
			2	10X7												
			3	10X10												
	2019	Unsprayed	1	10X3.5												
			2	10X7												
			3	10X10												
	2020	1 indoxacarb application only	1	10X3.5	23	285	1.9	5.4	0.2	5.6	7.5	27.3	33.6	20.6	26.4	0.3
			2	10X7	22	143	2.8	7.9	0.4	8.3	11.1	27.5	35.6	19.1	80.1	0.5
			3	10X10	19	100	2.6	2.2	0.2	2.4	5.0	29.9	36.1	25.1	101.2	0.5
	2021	Interrows and 1 indoxacarb application	1	10X3.5	22	285	0.1	3.6	0.0	3.6	3.7	27.1	30.7	20.4	93.9	1.2
			2	10X7	24	143	0.1	3.5	0.0	3.5	3.6	29.3	31.2	20.3	284.4	1.7
			3	10X10	23	100	0.1	2.9	0.0	2.9	3.0	25.6	32.2	22.7	344.7	1.5

2.4. Field appraisal of *Beauveria bassiana* spore concentrates- August 2017 to October 2019

Introduction:

Macadamia seed weevil (*Kushelorhychus macadamiae*) had become a serious pest for the crop by 2012 in the northern rivers of NSW after its introduction to the Dunoon area in 2009. The pest was previously known as *Sigastus* weevil from the north Queensland Atherton district in 1992-6 (Harry Fay). The management of the pest had required several broad-spectrum insecticide applications (beta-cyfluthrin, carbaryl, methidathion, acephate have been used until 2017) and vigilant orchard floor hygiene timing to limit its effect on the crop (Jeremy Bright August 2017 NSW DPI fact sheet 1586).

The chance finding of macadamia seed weevil susceptibility to *Beauvaria bassiana* (2014 AMS Bulletin article vol 42 no. 2 p42-43) Figure 2.4.1.) after working with some tea tree beetles on other projects led to the pursuit of enhancing the presence of the spore in the field to effect on the weevil to reduce the adult population where possible. Spores we extracted from dead weevil cadavers and cultivated by the QDPI team led by Diana Leemon and Dalton Baker. A PhD student based at Toowoomba, Khun Kim Khuy was also doing life cycle work on the pest and conducting assays on the compatibility of the product with current management practices (currently used pesticides and fungicides – carbendazim and pyclastrobin especially).

The use of *Beauvaria* and *Metarhizium* suspensions has been found to have beneficial effect on the management of pest insects in high rainfall areas (3-6m annual rainfall- e.g. Brazil, Costa Rica, Columbia). However, there is doubt over the capacity of the spores to remain viable on foliage in higher UV drier environments like Australia and South Africa. Feedback from Simon Newitt pers comm. on Eco BB® and Velifer® use in South African avocado crop under heavy bug pressure this season 2019 was anything but supportive of the product in that environment.

The following is the outcome of the attempts to inoculate the orchard foliage or the understorey to effect on the seed weevil activity as well as other possible target species that cause problems for the macadamia tree. We have been able to find examples of scolytid beetle death in tunnels under macadamia bark from *Beauvaria* sp. certainly *Cryphalus subcompactus , Xyleborus bispinatus, Euwallacea prebrevis* and *Cnestes solidus* all are susceptible in the wet seasons of 2020/2021 and 2021/2022 in Northern NSW and at Peachester in SE Qld. As yet only a few *Hypothenemus* sp have been seen infected and no *Xylosandrus* yet with the infection. Bostrychid and cerambycids are also likely but were not studied.

Figure 2.4.1.: Macadamia seed weevil (*Kuschelorhynchus macadamiae*) is highly susceptible to *Beauvaria bassiana* in a confined space with high humidity (January 2014 NSW DPI). Access to *Beauveria bassiana* infected field collected *Pyrgo* beetles (*Paropsisterna tigrina)* was given to us. The highly infectious strain was first tested at Wollongbar WPII.

Initial laboratory and field trials

Methodology

This initial infected weevil stock maintained in the laboratory at Wollongbar Primary Industries Institute (WPII) was the source of the cultured spores. Simple contact of new live adults with infected weevils in containers would transfer the fungi and perpetuate the fungal organism. Dipping live macadamia seed weevils (MSW) into suspensions of the spores (1-2 crushed cadavers in 1 % Synertrol® and 100ml demineralised water) and monitoring them over 7 days was fatal in a confined space. We could see activity on Banana weevil and Elephant weevil under similar conditions.

Dipping nuts with MSW oviposition markings into similar suspensions and placing them in cell trays for 1 month was also effective in showing the spores could grow into the nutlet and attack the weevil larvae inside the kernel (Huwer et al*.* (2015a). Once the wild spores from the cadavers had been cultured (QDPI) several early attempts at spraying the macadamia foliage (5L/tree) were made. We used spore suspensions (up to 5g/L) in Synertrol®.

In 2019 trialling the pure spore in oil suspensions (spores provided by QDAF) against commercial products and against on *Paropsisterna tigrina* (pyrgo beetle) which does show field death on plant to *Beauvaria*. Dipped melaleuca flushing leaves in ventilated glass jars did not produce the 100% mortality you see in confined spaces (Table 2.4.1.).

Table 2.4.1. Laboratory assay on *Paropsisterna tigrina* (pyrgo beetle) main defoliation pest of melaleuca alternifolia leaf. Assay set on dipped flushing melaleuca leaf 2/1/2019 using refrigerated spore suspensions in summer oil and mixed to 100ml volumes, leaves allowed to dry before addition of adult beetles in glass Acola preserving jar with gauze lids. Mortality recorded after 1,3 and 7 days, feeding rating is amount of flush leaf removed by beetles 1=minor, 2=half, 3 = all.

Chemical	Formulation	Rate ml/ 100L	Rep	24hr dead	72hr dead	7 day dead	Tested pop.	Leaf fed 1-2-3	7 day %mort
Blank	0	0	1	0	0	0	11	3	0.0
Blank	0	0	2	0	0	0	10	3	0.0
Blank	0	0	3	0	0	0	10	3	0.0
Water	0	0	1	0	0	0	10	3	0.0
Water	0	0	2	0	0	0	10	3	0.0
Water	0	0	3	0	0	0	10	3	0.0
Oil 1% (X)	Summer oil	1000	1	0	1	1	10	3	10.0
Oil 1%	Summer oil	1000	2	0	1	3	10	3	30.0
Oil 1%	Summer oil	1000	3	0	0	0	10	3	0.0
Clittoria EXT	Sero X® 400	200	1	0	0	0	11	3	0.0
Clittoria EXT	Sero X® 400	200	2	0	1	1	10	3	10.0
Clittoria EXT	Sero X® 400	200	3	0	0	0	14	3	0.0
Clittoria EXT	Sero X® 400	1000	1	0	0	1	10	3	10.0
Clittoria EXT	Sero X® 400	1000	2	0	0	0	11	3	0.0
Clittoria EXT	Sero X® 400	1000	3	0	0	0	10	3	0.0
TT Beauvaria	Daniels extr +(x)	100	1	2	5	6	10	3	60.0
TT Beauvaria	Daniels extr +(x)	100	2	2	4	5	10	3	50.0
TT Beauvaria	Daniels extr +(x)	100	3	1	4	5	10	3	50.0
MSW Beauvaria	B48 QDPI +(x)	100	1	1	7	10	10	3	100.0
MSW Beauvaria	B48 QDPI +(x)	100	2	2	4	5	10	3	50.0
MSW Beauvaria	B48 QDPI +(x)	100	3	1	7	9	10	3	90.0
Velifer® Beauvaria	Velifer® spore+(x)	100	1	2	3	3	10	3	30.0
Velifer® Beauvaria	Velifer® spore+(x)	100	2	1	5	8	10	3	80.0
Velifer® Beauvaria	Velifer® spore+(x)	100	3	3	7	8	10	3	80.0
MSW Beauvaria	P122 spore +(x)	100	1	2	2	3	10	3	30.0
MSW Beauvaria	P122 spore +(x)	100	2	2	1	1	10	3	10.0
MSW Beauvaria	P122 spore +(x)	100	3	0	0	3	10	3	30.0
QIT Beauvaria ULV	Propar®	500	1	0	3	3	10	3	30.0
QIT Beauvaria ULV	Propar®	500	2	2	4	7	10	3	70.0
QIT Beauvaria ULV	Propar®	500	3	3	7	8	10	3	80.0
Velifer® Beauvaria	Velifer®	500	1	0	0	0	10	3	0.0
Velifer® Beauvaria	Velifer®	500	2	1	1	1	10	3	10.0
Velifer® Beauvaria	Velifer ®	500	3	0	0	0	10	3	0.0
Indoxacarb	Steward® 150	50	1	7	9	9	10	1	90.0
Indoxacarb	Steward® 150	50	2	5	8	8	10	1	80.0
Indoxacarb	Steward® 150	50	3	6	8	8	10	1	80.0

Results

The foliar applications of spore suspensions and Synertrol® showed no reduction in field oviposition or weevil emergence 2015-2016 compared to plain water or the Mycaforce® product at 12g per tree.

Knockdown and oviposition rate reduction was tested in trial 1 in 2017-2018 field trial at CTH, where indoxacarb was found to be effective. *Beauvaria bassiana* suspension performed poorly in trials (see seed weevil section in Appendix 2.5.2. Insecticide screening - field trials). In trial 2 we measured the effect of foliar vs. ground applications of *Beauvaria bassiana* at Tregeagle on the level of seed weevil nut drop. In trial 3 we looked at overwintering of the applied spore mixes applied to the foliage through a Tuff ass sprayer at 10L/tree or adding the mix directly to the ground under canopies with infected nut falling into the area.

The B48 spore was the best of the spore applications, which were better than SeroX® at 200-1000ml/ 100L but well short of the control achieved with indoxacarb (Table 2.4.1.) which is the current field insecticide used for that chrysomelid beetle.

Field trials of *Beauvaria bassiana* spore isolates 2017-2019

The product needed to be suspended into an oil solution first before any tank additions to water were made. Velifer®, a commercial formulation was compared to other strains. In the field trials QDAF extracted the *Beauvaria bassiana* spore out of the Velifer® formulation to compare it gram for gram against the field isolates from seed weevils B27 and B48 (most effective in laboratory trials) provided by DAF.

Macadamia Trial 1

Methodology

The small-scale field trial used the normal field spray equipment (air-blast sprayer) and the biopesticide mixture was prepared in a clean tank prior to synthetic pesticides other sprays into a clean tank (Table 2.4.2.). The sprayer delivered 9-10L per tree. Weevil oviposition and crop loss in comparison with other options were measured.

Table 2.4.2.: Application schedule for CTH Entomology site trial 2017/2018 application volume of 10L per tree was used during the trial (6m + 9m macadamias cv. 246, 741, 849 and A4).

Number	Product formulation	Rate of product per 100L	Dosage A.I. g per 100L	Application timing
1	*Beauvaria* in Synertrol	5g + 1L	5	19/10/17 after nut hygiene and before MSW adult emergence
2	Avatar® 300	30g	9	
3	Lancer® 970	80g	77.6	
4	Supracide® 400	125ml	50	
5	Unsprayed			No hygiene
6	Supracide® 400	125ml	50	No hygiene

Results

CTH entomology 2017/2018 – Indoxacarb stopped MSW egg laying in the field immediately after application 19/10/2017 (Figures 4.7.2. and 4.7.3.), *Beauvaria bassiana* reduced the nut drop with egg marks only marginally better than in the unsprayed area.

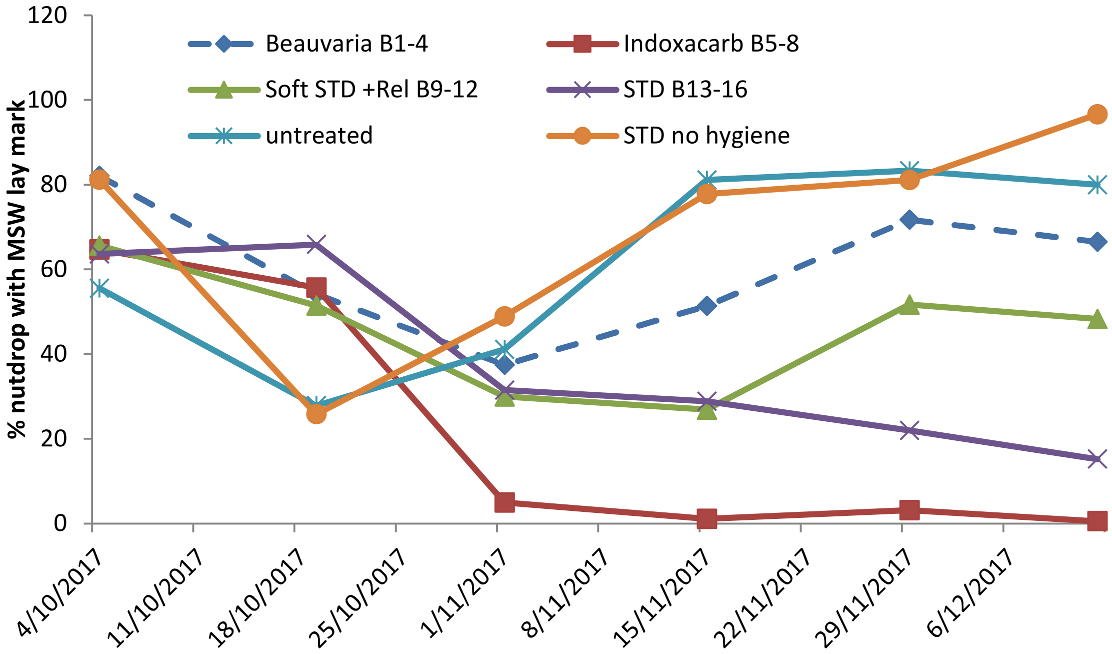


Figure 2.4.2.: Percentage of nutdrop due to MSW oviposition under macadamia trees

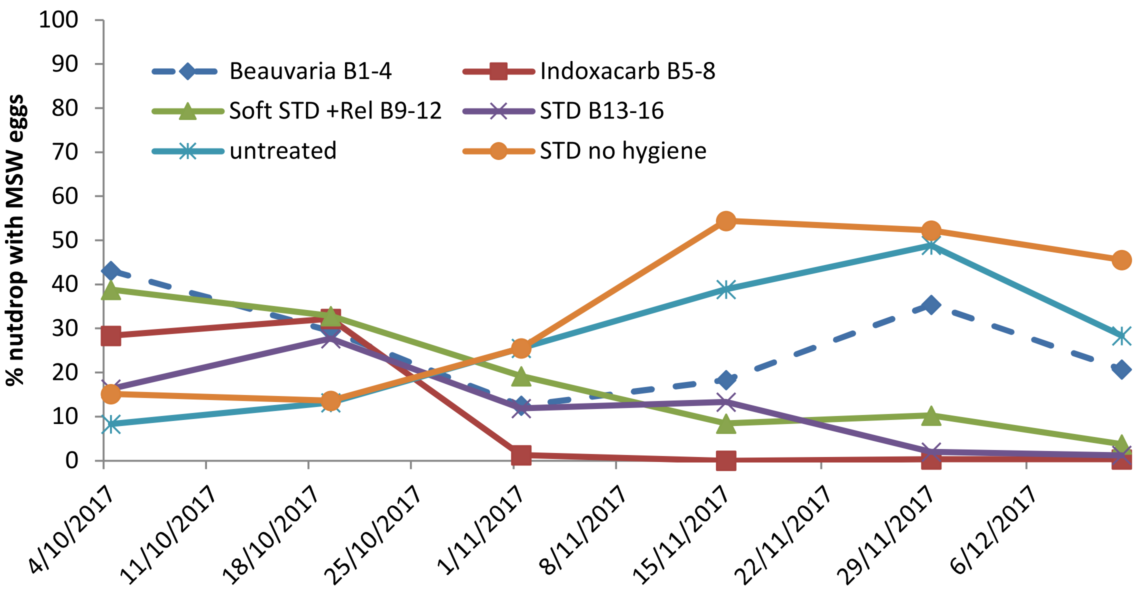


Figure 2.4.3.: Percentage of nutdrop with actual fresh MSW eggs present inside.

Macadamia Trial 2:

Methodology

A small trial on a commercial macadamia orchard at Tregeagle in Northern Rivers region investigated two aspects of the use of *Beauveria bassiana* in managing macadamia seed weevil.

1. What is the effect of adding *Beauvaria bassiana* to the orchard system on MSW survival?
2. Does the *Beauvaria bassiana* spore work better if applied to the bare soil, grass / mulch bed or foliar?

Site was selected because of the high weevil pressure and the western boundary area could be isolated from other treatments being applied to the commercial farm. Tree was also relatively young less than 4m high, with mixed ground cover that could be easily removed from under selected trees to get the bare soil treatment. Six strips of 6 trees were selected along the western boundary to test the 6 treatments in Table 2.4.3.

The site was marked, and ground prepared in September 2017, *Beauvaria bassiana* treatments applied 4/10/17, nut drop collected and assessed fortnightly from there on. Sprays were applied using a utility mounted 5 x multi 70 litre tank pump assisted spray tank.

Each treatment mix was made prior to the arrival on site into the labelled tank. The end tank contained pure water for cleaning between solutions along the treated lines. Weigh spore into oil volume (1L) then added to half the water volume and then topped up to final volume needed. Delivery rates were measured before and after each run (stopwatch and volumetric flask) volumes of 5-10 L per tree or underneath a tree, were used in most trials (see Table2.4.3.).

In October 2017 the trial at Tregeagle compared level of infection inside nut and level of nut drop on trees where *Beauvaria bassiana* has been applied direct to foliage, on bare soil under tree and onto trees where the grass and weed bed is intact. Nut drop due to MSW and incidence of fungal infection were measured fortnightly after the treatments. All nuts with MSW laying marks were collected under each tree, counted and subsamples of 30 labelled and dissected to determine the levels of fungal activity inside the nut.

Table 2.4.3.: Application Schedule for Tregeagle site trial 2017 application volume of 5L per tree was used during the trial.

Treatment code and Target area	5L applied	Rate of product per 100L water	Application timing
1.Bare ground	5L water		1
2.Bare ground +BB	*Beauvaria* in Synertrol®	23.5g + 1L	2
3.Grass floor	5L water		1
4.Grass floor +BB	*Beauvaria* in Synertrol®	23.5g + 1L	2
5.Foliar	5L water		1
6.Foliar + BB	*Beauvaria* in Synertrol®	23.5g + 1L	2

Western boundary Tregeagle site tree treatment map					
Block 1: 325641	Block 2: 162534	Block 3: 236415	Block4: 641352	Block 5: 514263	Block 6. 453126

Results

Levels of fungal detection in the field were very low, and actual best pre-treatment application (Table 2.4.4.). Not more than a 30% reduction in nut drop was observed for treatments where *Beauvaria bassiana* was applied to either foliage or ground beneath trees (Table 2.4.5.). Nut drop was reduced in 3 of the 4 sampling times (Table 2.4.6.). Background infection rates were between 8 and 12 % in the untreated areas and were highest for the foliar treatment 26% (Table 2.4.7.).

Table 2.4.4.: Stages of weevil development observed in the field at each sampling and the levels of *Beauvaria* infection in seed weevil collected at the Tregeagle site trial 2017.

Date	Nuts	Eggs	1st	2nd	3rd	4th	Empty	Incidence of fungal infection
1/9/17 (pre-treat)	30	9	7	0	1	0	2	5
17/10/17	143	96	21	3	8	0	10	1
31/10/17	271	7	23	114	29	7	41	1
14/11/17	144	11	15	8	5	8	79	9

Table 2.4.5.: Levels of nut drop to macadamia seed weevil by treatment pooled by times at the Tregeagle site trial 2017.

Treatment	Trees	Times	Average MSW drop/ tree	(Se) MSW nut drop	Total nut drop due to MSW
Bare ground 1	6	4	19.8	4.2	476
Bare ground + BB 2	6	4	14.2	3.5	340 (-28%)
Grass ground 3	6	4	21.0	5.7	505
Grass ground + BB 4	6	4	15.5	3.2	372 (-26%)
Foliar 5	6	4	19.3	4.8	464
Foliar + BB 6	6	4	17.8	5.1	427 (-8%)
Grand total	**36**	**4**	**17.9**	**1.9**	**2584**

Table 2.4.6.: Levels of nut drop to macadamia seed weevil compared at each sampling time at the Tregeagle site trial 2017.

Untreated	Trees	Average MSW drop/ visit	Se MSW nut drop	Total nut drop due to MSW	% Reduction
17/10/2017	18	35.4	7.7	637	
31/10/2017	18	25.8	5.9	464	
14/11/2017	18	8.5	1.8	153	
28/11/2017	18	10.6	2.2	191	
***Beauvaria* added**					
17/10/2017	18	26.8	6.1	483	24%
31/10/2017	18	20.4	5.4	367	21%
14/11/2017	18	8.7	2.0	156	n/s
28/11/2017	18	7.4	1.7	133	30%

Table 2.4.7.: Levels of *Beauvaria bassiana* (BB) infestation in macadamia seed weevil compared by treatment at each sampling time at the Tregeagle site trial 2017.

Treatment	Trays of field nuts	MSW infected nuts stored	Fungal BB MSW	Total MSW	% BB infested
Bare ground 1	20	201	13	113	11.5
Bare ground + BB 2	20	184	11	62	17.7
Grass ground 3	21	224	15	129	11.6
Grass ground + BB 4	20	190	17	81	21.0
Foliar 5	19	195	9	114	7.9
Foliar + BB 6	18	166	26	98	26.5

Macadamia Trial 3

Methodology

Overwintering of applied spore mixtures at CTH applied March 2019 – *Beauvaria bassiana* infection levels of seed weevil infected nuts under trees compared in September October 2019

Overwintering of *Beauvaria bassiana* spores in macadamia at CTH experiment in 2019. Combined 20g of pure spores in 1L summer oil then mixed to 200L with water on 20/3/2019. Covered 15 trees with 10L/tree normal foliar spray unit in Entomology block row 7 (oil blank), row21 (B27 spore), row 35 (B48 spore) and row 49 (Velifer® spore). Left over 2 by 10 L from each spray were watered under half a tree canopy 8 square meters (watering can) with out of season nut at the flower hedge and continual seed weevil activity on that out of season nut.

Results:

Foliar applications were showing 0-1% infection rates across the board (Table 4.7.8.).

The treatment with applications of *Beauveria* formulations under the tree, to heavily infested seed weevil trees were showing 3.4-4.3% infection rates of the seed weevil larvae in the nuts dropping in September 2019 (Table 2.4.8.).

Table 2.4.8.: Levels of *Beauvaria bassiana* (BB) infestation in macadamia seed weevil compared by treatment at the CTH Entomology block where spores were applied with a foliar sprayer, or hand watered ground applications to shaded heavily infested trees, 20L mixture to $8m^2$ in March 2019.

Treatment	Foliar MSW *Beauvaria* infections	Nut drop sampled 30/10/2019	Under tree MSW *Beauvaria* infections	Nut drop sampled under tree area 12/9/2019
Summer oil	1.0% infection	100	3.4%	59
B27 spore	1.1% infection	90	3.7%	54
B48 spore	1.0% infection	100	4.0%	50
Velifer® spore	0.0 % infection	73	4.3%	93

A 20% reduction in nut drop (Trial 2) and a maybe 1% rise in carryover through winter if applied to heavily infested areas (Trial3) are not effective treatment options compared to a 100% reduction in oviposition from the indoxacarb application (Trial 1).

***Melaleuca alternifolia* Field Trial 4:**

Introduction

After the initial success in the laboratory with *Beauvaria bassiana* it needed to be investigated, whether the fungal infection had come from the field under the macadamia or the tea tree contamination of the storage containers.

An evaluation was undertaken, comparing the *Beauvaria bassiana* spore to the wild spores found on insects that die in the field. The trial was conducted to investigate if the cultured spore was enhancing field activity or not on a defoliating pest in a more humid environment that is susceptible.

Methodology

Applications as per Table 2.4.9. The leaf samples were taken from three plants within each strip treated, they were not the main terminal growth point but were sprayed. We also collected 10 beetles from each of the sample plots and held them for 2 weeks with foliage from each plot to see how much spore would develop. Dead beetles were examined by the pathologist Dr. Rose Daniel (formerly NSW DPI) for confirmation of the pathogen with the isolate.

It was of further interest, whether the fungal spores are already present on the foliage (i.e. can you grow *Beauveria bassiana* just from the leaf) and whether *Beauveria bassiana* persist in the field over winter?

The field site is shown in Figure 2.4.4., treatments used were as listed below and a wild spore site where infected insects can often be collected exists at the northern end of the plantation, well away from the trial site.

Treatments

- Treatment 1: Standard summer oil 1% plus pulse (4.0ml/100L)
- Treatment 2: 5g B27 spore plus Treatment 1
- Treatment 3: 5g B48 spore plus Treatment 1
- Treatment 4: 5g Velifer® spore plus Treatment 1
- Untreated: from 4 plots neighbouring the treated area but outside by 10meters. Nothing applied.

Figure 2.4.4.: *Melaleuca alternifolia* trial site near Lismore airport , showing the constant feeding on the new regrowth (left) , David Robertson and the measurement of plant height changes during the 3 months (centre), and *Beauvaria bassiana* infections growing up in "pyrgo beetle" brought back from the site after 2 weeks (right).

The use of the spore mixtures on the main defoliator is covered by field trial 4 in the looking at both knockdown and persistence of the spores in the field over winter at a site where we knew that the foliage was carrying active spore and if the additions we going to enhance that activity. Collecting beetles from the trial plots into labelled vials bringing them back to the laboratory, feeding clean leaf from another source, and watching the fungal infections appear in the bodies over time.

Table 2.4.9: Application Schedule for treatments applied at Lismore Airport *Melaleuca alternifolia* plantation 10 L of the mixtures was applied to each 10 m row.

Code	Treatment applied	Rate of product Per 100L water	Timing
1	Summer Oil + pulse		1
2	*Beauvaria* B27 in Summer Oil + pulse	10g + 1L +2ml	2
3	*Beauvaria* B48 in Summer Oil + pulse	10g + 1L +2ml	3
4	Velifer® spore in Summer Oil + pulse	10g + 1L +2ml	4

Eastern boundary Lismore airport site Each strip is a 10m row of plants with 1 row buffers between. Untreated area is outside plot by 20 m and at northern runway end.				
Block	**Treatment**			
1	4	1	2	3
2	2	3	4	1
3	3	4	1	2
4	1	2	3	4

Results:

"Pyrgo beetle" levels were consistent throughout the trial and could be seen during the middle of the day on the foliage in low numbers (Figure 2.4.5.).

The feeding of the beetles on the foliage continued throughout the trial regardless of the treatments applied, to the extent that no growth in any of the plants was observed despite new flush appearing after a major rainfall event in May June only to be consumed (Figure 2.4.6.).

Beauvaria bassiana infection was good initially with a higher level for both the B27 and B48 strains than for the Velifer® spores.

Infection was not detectable after winter in the beetles collected except in the wild spore area (Figure 2.4.7.).

The plain oil leaf also gave a rise in infection which suggests there is a high background level of the wild pathogen strain present.

This suggested that the leaf itself is a source of infection and a better viability of wild spores compared to the spores introduced from the laboratory is questionable (Figure 4.7.7.) because none of the treated areas were showing any level of infection when the late winter population returned.

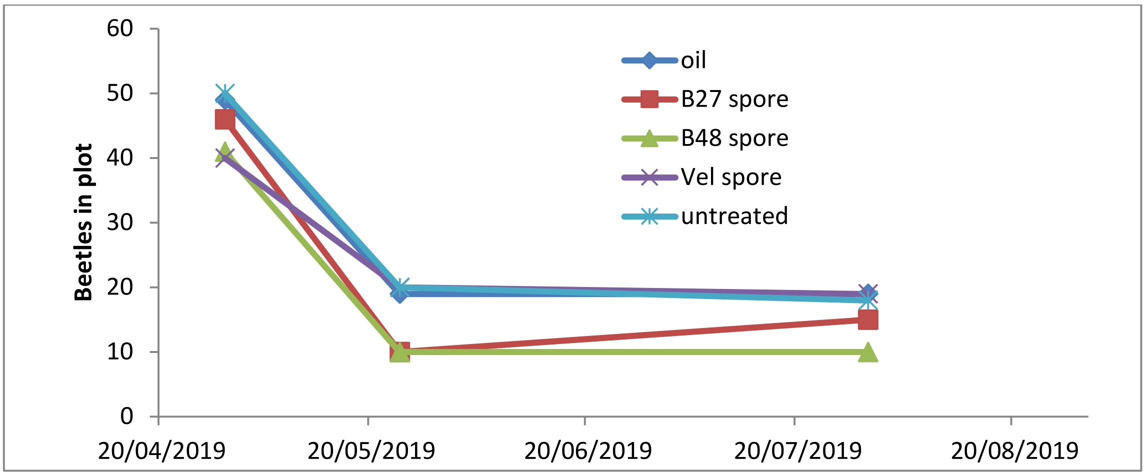


Figure 2.4.5.: Beetles collected in the plots under the different treaments at the Lismore airport *Melaleuca alternifolia* site.

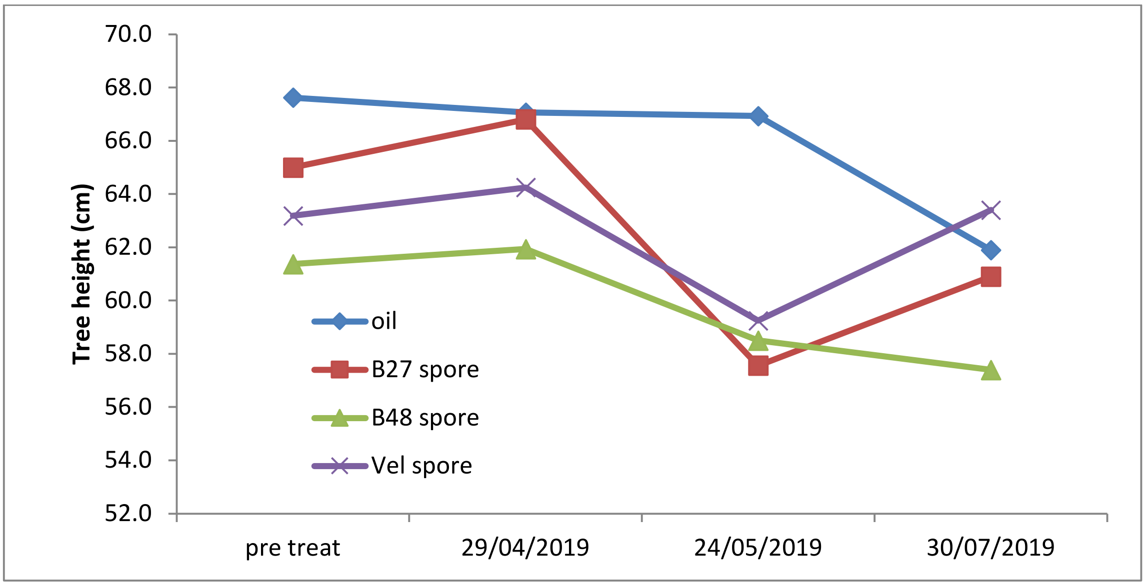


Figure 2.4.6.: Growth of the plants over time showing feeding is occurring all through winter, no plants are increasing in height at the Lismore airport *Melaleuca alternifolia* site.

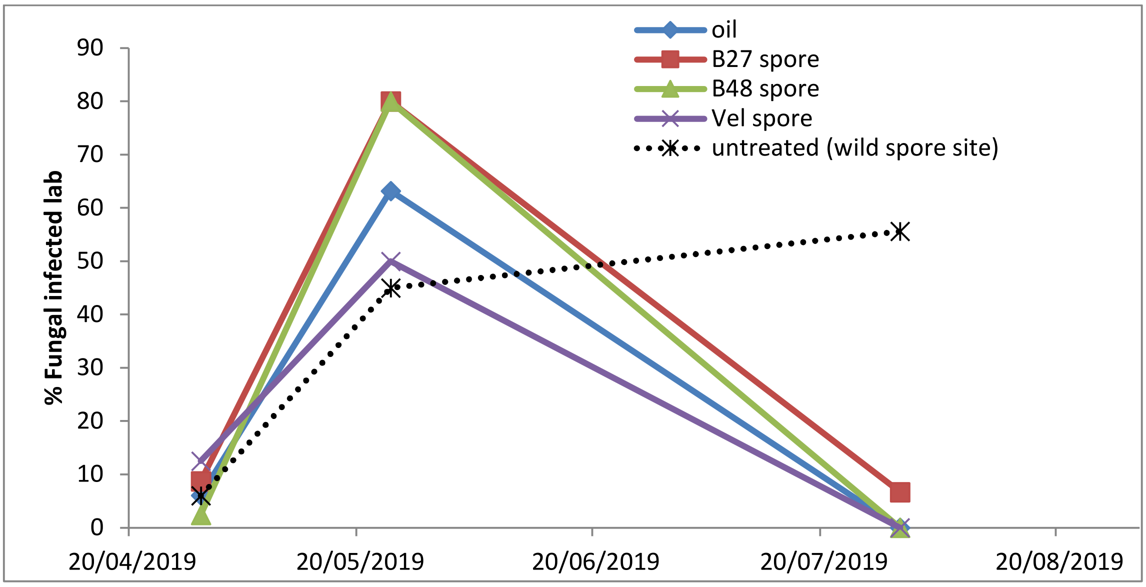


Figure 2.4.7.: Levels of *Beauvaria bassiana* infection inside the "pyrgo beetles" collected from plants sprayed with various spore solutions and the ones collected from the natural infection area at the Lismore airport *Melaleuca alternifolia* site.

2.5. Insecticides screening

Screening of different chemicals including new products was undertaken for key pests initially in the laboratory and usually followed by broader field trials for selected products.

2.5.1. Laboratory screening

1. **Macadamia lace bug**

Methodology

In a laboratory assay 2ml misting of infested racemes in small water vials in glass counted after 24 hours (old techniques)

Live racemes in the field were tagged and treated (2ml mist/ raceme) tagged, collected after 7 days and evaluated under microscope at 12x magnification.

Results are shown in Tables 1

Results and Discussion:

The new experimental compound (SYNFO 121) option may also be of benefit in the future, as it appears to have lepidopteran, coleopteran and hemipteran activity (see MNB, macadamia seed weevil and FSB assays). This compound has been included, as Sivanto® Prime and Transform® options will not be able to manage something as potentially damaging as the combination of both flower caterpillar and macadamia lace bug. There is no information available yet on the effect on bees.

Trials are needed on other flower threats especially *Heliopeltis* sp., (tea mosquito bug is present in QLD and now Brisbane QDPI 2015-2019) and *Leptocoris sp*. (rice bug is attacking macadamia flower in Mackay QLD). The need for 3 sprays to set cashew flowers rotating pyrethroids with Acetamiprid (e.g. Trivor®) for tea mosquito bug management in India (Makawana et al. 2017 and Raviprassad and Vanitha 2020) and cashew nut set is significant. The finding that cyhalothrin use at flowering will allow nut set even though the flower is apparently only bee pollinated is similar to the situation with macadamia lace bug in macadamia and citrus blossom bug in avocados. Fortunately, macadamia lace bug can be managed with a singled well-timed spray on most farms most seasons in NSW.

The other interested finding is that neem trees are a key host for *Heliopeltis* in India and a tested neem product (OCP Azmax® 2000/ml/ 100L-(Table2.5.1.1.) did not appear to be very effective against macadamia lace bug.

Table 2.5.1.1. Laboratory bioassay results 13/03/2012 for macadamia lace bug mortality after 24 hour exposure to a 2ml application of the formulation tested

Highlighted products have been banned since assay was undertaken

Active	Formulation	Lowest effective rate (100% mortality)	Gai applied	Macadamia lace bug Test population	Std Dev. (% mortality)	Seek Possible New Use Permit
Abamectin	Stealth® 18g/L	100ml/ 100L	0.000036	12	0	yes
Acephate	Lancer® 970	50g/ 100L	0.001	20	0	yes
Flupyradifurone	Sivanto® Prime200 SC	50ml/ 100L	0.0002	19	0	yes
Diazinon	Country® 800	75ml/ 100L	0.00012	16	0	yes
Endosulfan	Endosulfan®350 EC	150ml/ 100L	0.0007	19	0	OLD STD
Fenthion	Lebaycid® 550	375ml/ 100L	0.000041	14	0	yes
Cyantraniliprole	Exirel® 100sc	100ml/ 100L	0.00002	20	0	yes
Indoxacarb	Avatar® 300 WP	N/A 200g/ 100L 60%	0.0012	16	34	no
Indoxacarb	Steward® 150 EC	N/A 200ml/ 100L 75%	0.0006	18	43	no
Malathion	Malathon ®500 EC	N/A 150ml/ 100L 97%	0.00015	30	4	If desperate
Sulfoxaflor	Transform® WG	100ml/ 100L	0.00048	20	0	yes
Thiamethoxam	Actara® 250 WP	30g/ 100L	0.00015	30	0	Foliar issues
Trichlorfon	Lepidex® 500	200ml/100L	0.0002	240	0	
	Organic treatments					
Azadarachtin	OCP Azmax® 41ml/L	N/A 2000ml/ 100L 50%	0.0016	18	16	no
	Leaf Coat	N/A 3000ml/ 100L 69%	?	18	30	no
Paraffinic Oil	Biopest® oil 815g/L	N/A 2000ml/ 100L 27%	0.0016	29	20	no
Pyrethrin	Pyganic® 13g/L+	200ml/ 100L	0.000005	23	0	Yes
Demineralised water		Background mortality 1.9%	2.0	398	3.8	

+ only organic treatment showing any effect

Table 2.5.1.2.: Macadamia lace bug (*Cercotingis decoris*) field trial results CTH Alstonville Germplasm area, mist spraying infected racemes (2ml/raceme), tagging them then collecting them 7 days later into labelled paper bags for examination under 12x magnification. Treated 18/08/2017, collected, counted 25/08/2017. Current standard treatment and untreated controls highlighted in yellow for comparison.

Treatment	Rate ml/ 100L	Racemes examined	Raceme with cast skins	Total number of lace bug	Dead lace bug	Live adults	Lace bug per raceme	Std err	Live lace bugs per raceme
Pre treat		26	22	198	6	8	7.6	1.6	7.4
Untreated		10	10	57	3	1	5.7	1.5	5.4
Transform®	40ml/ 100L	20	15	11	10	1	0.6	0.2	0.1
Diazinon	125ml/ 100L	20	17	19	15	4	1.0	0.3	0.2
Lepidex®	200ml/ 100L	20	18	18	0	4	0.9	0.2	0.9
Sero X®	100ml/ 100L	20	19	162	4	10	8.1	2.1	7.9
Sero X®	200ml/ 100L	20	19	147	5	15	7.4	2.2	7.1
Sero X®	400ml/ 100L	20	19	56	5	9	2.8	0.4	2.6
Sero X®	800ml/ 100L	20	17	122	8	16	6.1	1.1	5.7

Table 2.5.1.3.: Macadamia lace bug (*Cercotingis decoris*) field trial results CTH Alstonville Germplasm area, mist spraying infected racemes (2ml/raceme), tagging them then collecting them 7 days later into labelled paper bags for examination under 12x magnification. Treated 29/08/2018, collected, counted 5/09/2018.

Treatment	Racemes	Raceme with lace bug damage	Lace bug cast skins	Total lace bug	Dead lace bug	Live lace bug/ raceme	Live adults	Ave lace bug/ raceme	Se lace bug/ raceme
Pre treat	40	40	39	171	2	4.23	28	4.28	1.02
Water	40	39	34	171	10	4.03	27	4.28	0.51
Untreated	50	47	49	180	15	3.30	20	3.60	0.42
Wetcit®@ 200ml/ 100L	40	39	31	121	18	2.58	14	3.03	0.53
Wetcit®@ 400ml/ 100L	40	39	32	115	29	2.15	9	2.88	0.52
Wetcit®@ 600ml/ 100L	40	38	33	135	15	3.00	7	3.38	0.52
Wetcit®@ 800ml/ 100L	40	39	31	140	13	3.18	12	3.50	0.47
DC163 @ 15ml/ 100L	40	37	28	34	7	0.68	6	0.85	0.27
DC163 @ 30ml/ 100L	40	39	31	38	11	0.68	12	0.95	0.25
SeroX® @ 200ml/ 100L	39	37	29	156	5	3.87	17	4.00	1.00
SeroX® @1000ml/ 100L	40	38	25	49	7	1.05	12	1.23	0.24
Imidan® @100ml/ 100L	39	39	35	48	4	1.13	5	1.23	0.29
Imidan® @500ml/ 100L	30	29	28	54	22	1.07	3	1.80	0.46
Venerate® @100ml/ 100L	40	35	32	128	14	2.85	25	3.20	0.48
Venerate® @200ml/ 100L	40	36	21	33	5	0.70	5	0.83	0.15
Grandevo® @ 100g/ 100L	40	38	21	57	13	1.10	6	1.43	0.47
Grandevo® @ 200g/ 100L	40	35	21	55	14	1.03	14	1.38	0.60
Diazinon @ 125ml/ 100L	40	32	21	23	15	0.20	4	0.58	0.19
Sivanto® Prime @ 50ml/ 100L	40	25	12	9	4	0.13	2	0.23	0.08
Transform® @ 40ml/ 100L	40	27	17	4	2	0.05	1	0.10	0.05
Lepidex® @ 200ml/ 100L	40	24	16	7	1	0.15	0	0.18	0.11
Plot totals	838	752	586	1728	226	1.79	229	2.06	0.11

Table 2.5.1.4.: Macadamia lace bug (*Cercotingis decoris*) field trial results CTH Alstonville Germplasm area, mist spraying infected racemes (2ml/raceme), tagging them then collecting them 7 days later into labelled paper bags for examination under 12x magnification. Treated 19/08/2019, collected, counted 280/8/2019.

Treatment	Rate as ml/ 100L	Racemes	Raceme with lace bug damage	Cast skins	Live lace bug	Live adult	Live nymphs	Total lace bugs	Average live lace bug/ raceme	Std dev lace bug / raceme	Std err lace bug/ raceme
Pre-treat		32	26	22	48	5	43	48	1.50	1.89	0.33
Unsprayed		30	29	28	76	16	60	78	2.53	3.34	0.61
Agral® *	10	30	29	27	79	18	61	86	2.63	2.37	0.43
Synfo121	10	30	30	18	6	2	4	7	0.20	0.54	0.10
Synfo121 + Agral®	10	30	30	18	14	1	13	20	0.47	1.02	0.19
Synfo121 + Designer®	10	40	40	27	5	0	5	10	0.13	0.64	0.10
Synfo121 + Agral®	30	30	28	19	3	0	3	8	0.10	0.40	0.07
Synfo121 + Agral®	60	30	26	23	1	0	1	4	0.03	0.18	0.03
Diazinon	125	40	35	19	2	0	2	4	0.05	0.22	0.03
Tea tree b 18%	100	30	26	17	15	2	13	19	0.50	1.12	0.20
Tea tree b 18%	25	30	26	17	21	3	18	27	0.70	1.10	0.20
Nufarm 3445	300	30	26	19	8	0	8	13	0.27	0.63	0.11
Nufarm 3445	150	30	30	28	28	6	22	36	0.93	1.46	0.27
Transform®	40	30	26	18	3	3	0	19	0.10	0.30	0.05
Sivanto® Prime	50	40	35	23	2	2	0	21	0.05	0.22	0.03
OCP oil	160	30	26	9	8	1	7	11	0.27	0.96	0.18
Tea tree a 23%	100	30	29	18	34	3	31	39	1.13	1.50	0.27
Tea tree a 23%	25	30	27	23	34	2	32	34	1.13	1.52	0.28
Nufarm 3145	500	30	23	16	34	1	33	36	1.13	1.75	0.32
Wettable sulfur	500	30	22	9	47	1	46	50	1.57	2.81	0.51
Wettable sulfur	200	30	27	21	40	4	36	44	1.33	1.72	0.31
Copper sulfur	1500	30	30	22	31	5	26	39	1.03	1.43	0.26
Overall totals		692	626	441	539	75	464	653	0.78	1.64	0.06
Post treatment	10/09/2019	30	29	24	145	28	117	150	4.83	5.82	1.06

2. Macadamia Felted Coccid (MFC)

A trial undertaken in August 2019 (Tables 2.5.1.5. and 2.5.1.6.) showed that DC092 (Sivanto® Prime) at both the 100ml/100L and 50ml/100L rate and Transform®40ml/100L rate have been effective at controlling MFC. The follow up trial in August 2020 showed that a similar result was obtained with Transform®40ml/100L plus oil @ 0.25% and 0.5% but the Movento®40ml/100L application did not control MFC expansion on racemes (Tables 2.5.1.7. and 2.5.1.8.).

Table 2.5.1.5.: Summary of the pre-treatment *Acanthacoccus ironsidei* (macadamia felted coccid MFC) incidence levels 22/08/2019 based on field assessment of kinked flowers per 20 racemes, Steve and Brooke Mclean farm, Whites Lane Alstonville NSW.

Treatment	**Rate**	**Trees**	**Average % FC infested**	**Standard Error % FC infested**
Control	untreated	4	23.8	4.8
Sivanto® Prime	100ml/ 100L	6	31.7	2.9
Sivanto® Prime	50ml/ 100L	7	22.9	2.1
Diazinon	125ml/ 100L	7	26.1	2.0
Transform®	40ml/ 100L	7	31.1	2.6
Overall		31	27.3	1.3

Table 2.5.1.6.: Treatment comparisons of *Acanthacoccus ironsidei* (macadamia felted coccid MFC) based on live insect assessment 20 days post spraying. Each tree had 10 racemes examined. Dead MFC were determined by desiccation status and lack of leg movement under 12-50x magnification. The trial was conducted at Steve and Brooke Mclean's farm, Whites Lane Alstonville NSW August 2019 (* significantly higher level using the Z-test P <0.05).

Treatment	**Rate**	**Racemes**	**Total FC**	**Live FC**	**Live Female adults**	**Live crawlers**	**FC +Eggs**	**Live FC/ raceme**	**Standard error Live FC/raceme**
Control	untreated	50	116	80	30	49	24	1.6 a*	0.4
Sivanto® Prime	100ml/ 100L	50	58	4	4	0	16	0.1	0.0
Sivanto® Prime	50ml/ 100L	50	70	9	4	5	19	0.2	0.1
Diazinon	125ml/ 100L	50	85	23	5	18	14	0.5	0.2
Transform®	40ml/ 100L	50	104	24	1	23	9	0.5	0.2
Overall		250	433	140	44	95	82	0.6	0.1

Table 2.5.1.7: Site 2 comparisons of *Acanthacoccus ironsidei* (macadamia felted coccid, MFC) treatments based on live insect assessment 20 days post spraying. Based on 4 replicate samples of 20-25 infested racemes collected from within each treated area and examined. Dead MFC were determined by desiccation status and lack of leg movement under 12-50 X magnification NSW DPI Wollongbar, NSW. Pre-treatment assessment and collection count 19/08/2020, sprayed 25/08/2020 Diazinon plus 0.5% summer oil mix, 26/08/2020 Transform plus 0.5% summer oil mix, and 27/8/2020 Transform plus 0.25% summer oil mix, all @ 7L / tree applied spray volume. The post treatment collected 14/09/2020 and counted 15/9/2020. Dead MFC were determined by desiccation status and lack of leg movement under 12-50x magnification NSW DPI Wollongbar, NSW.

Treatment	**Rate**	**Raceme number**	**Total FC**	**Live FC**	**Live Female adults**	**Live FC crawlers**	**Female FC + Eggs**	**Live FC/ raceme**	**Standard error Live FC/ raceme**
Pre treatment		36	83	74	33	31	10	2.1	0.3
Control		97	293	232	108	107	54	2.4**	0.4
Transform®	40ml/ 100L +0.25% oil	96	259	63	36	26	38	0.7	0.1
Transform®	40ml/ 100L +0.5% oil	46	139	34	27	6	21	0.7	0.2
Diazinon	125ml/ 100L +0.5%oil	99	377	53	24	29	52	0.5	0.2

** Significantly higher level using the Z-test *P*<0.05.

Table 2.5.1.8.: Site 1 comparisons of *Acanthacoccus ironsidei* (macadamia Felted Coccid MFC) treatments based on live insect assessment 20 days post spraying. Based on 5 replicate samples with at least 20 infested racemes collected and examined. Dead MFC were determined by desiccation status and lack of leg movement under 12-50x magnification NSW DPI Wollongbar, NSW. A 1% summer oil spray was applied to block 10-14/08/2020, pre-treatment assessment and collection count 17/08/2020, sprayed 20/08/2020 @ 7L / tree applies spray volume without oil, post treatment collected 8/9/2020 and counted 09/09/2020.

Treatment	**Rate**	**Raceme number**	**Total FC**	**Live FC**	**Live Fem AD**	**Live FC crawlers**	**Female FC + Eggs**	**Live FC/ raceme**	**Standard error Live FC/ raceme**
Pre treatment		43	74	53	32	16	18	1.2	0.2
Control	untreated	102	421	354	115	220	55	3.5**	0.6
Diazinon	125ml/ 100L	106	361	91	11	77	48	0.9	0.3
Movento®	40ml/ 100L	108	471	256	61	179	79	2.4**	0.5
Transform®	40ml/ 100L	104	298	91	17	74	44	0.9	0.3

** Significantly higher level using the Z-test *P*<0.05.

Table 2.5.1.9.: *Trichogrammatoidea cryptophlebiae* wasp emergence rates from pesticide dipped *Cryptophlebia ombrodelta* eggs. 3 card replicates for each dose listed, averages for the 1st generation (G1) to emerge, numbers of parasitised eggs for the second generation of wasps to emerge from and the rate of emergence G2.

Parasitised egg age	Chemical	Rates ml/ 100L	Target eggs	G1 %emerged	G2 eggs	G2 %emerged
Day 1	Control	0	88	89.3	44	86.1
	Lancer®970 + Designer®	80	79	94.0	24	64.2
	Avatar® + Designer®	25	59	85.6	29	56.5
	Steward® + Designer®	50	69	93.1	30	89.9
	Agral®	10	76	92.8	34	91.8
	Syn 0121	10	98	87.6	39	77.4
	Syn 0121 +Agral®	10	89	88.6	36	79.7
	Syn 0121 +Agral®	30	61	91.1	30	86.9
	Syn 0121 +Agral®	60	58	89.9	28	91.7
	Syn 0121 + Designer®	10	83	93.5	29	95.8
Day 4	Control	0	124	83.3	24	87.8
	Lancer®970 + Designer®	80	73	70.5	8	100.0
	Avatar® + Designer®	25	78	77.4	12	100.0
	Steward® + Designer®	50	80	81.5	3	100.0
	Agral®	10	129	88.7	10	100.0
	Syn 0121	10	113	69.4	3	100.0
	Syn 0121 +Agral®	10	64	66.0	12	90.0
	Syn 0121 +Agral®	30	140	79.5		
	Syn 0121 +Agral®	60	103	73.4	6	100.0
	Syn 0121 + Designer®	10	144	84.7	6	100.0
Day 7	Control	0	95	86.6	97	88.8
	Lancer®970 + Designer®	80	88	82.7	38	89.4
	Avatar® + Designer®	25	91	89.7	72	76.3
	Steward® + Designer®	50	98	90.2	115	88.0
	Agral®	10	90	93.0	84	88.4
	Syn 0121	10	83	82.7	41	91.2
	Syn 0121 +Agral®	10	79	94.9	57	90.7
	Syn 0121 +Agral®	30	78	93.9	55	90.0
	Syn 0121 +Agral®	60	74	87.8	58	75.3
	Syn 0121 + Designer®	10	65	86.1	33	81.5

A

B

C

D

E

F

Figure 2.5.1.1.: Showing assay techniques for 1 day old macadamia nut borer larvae feeding on synthetic cell tray diets (A and B), the parasitised nut borer eggs being dipped and dried before going into vials to measure parasite emergence and sterility issues (C), the macadamia seed weevil assays using dipped nuts (D) and the spotting bug assays (E) using topical application with a Hamilton precision syringe and cryolisers to immobilise the bugs, and using dipped *Murraya paniculata* berries for feeding on a treated surface (F).

Table 2.5.1.10.: One day old larval bioassay for macadamia nut borer (*Cryptophlebia ombrodelta* MNB) at Wollongbar Entomology laboratory NSW DPI as part of the efficacy testing of the Syngenta product supplied by Lauren O'Conner in 2019.

Macadamia Nut borer Bioassays

Assay Type 1: 20ul Dose applied to egg cluster on diet surface (Egg Assay)

Assay Type 2: 20ul Dose applied to diet surface and 1 day old MNB larvae added (Larvae Assay)

Scoring: Set 07/02/2019 checked 14/02/2019 (7days at 25^{o}C for Assay 2) for each dose combination: three replicate trays of 12 larvae on treated diets

Serial dilutions made from SYNFO 121 sample

Source MNB population: NSW DPI MNB colony Wollongbar

Type 2 Assay	**Concentration (ml/100L)**										
SYNFO121		**25**	**10**	**10**	**10**	**30**	**60**	**STD**	**STD**	**STD**	**CTL**
Agral®	**10**			**10**		**10**	**10**	**Bulldock®**	**Prodigy®**	**Lancer®**	
Designer®					**10**			**10**	**10**	**10**	
Rate for standards								**50**	**40**	**80**	
Sum of Larvae	36	36	36	36	36	36	36	36	36	36	36
Sum of Dead	11	27	31	35	33	32	33	35	36	35	4
Sum of Live	25	8	5	0	2	3	1	0	0	0	31
Sum of Missing	0	1	0	1	1	1	2	1	0	1	1
% live MNB larvae remaining	69	22	14	0	6	8	3	0	0	0	86

Table 2.5.1.11.: One day old larval bioassay for macadamia nut borer (*Cryptophlebia ombrodelta* MNB) at Wollongbar Entomology laboratory NSW DPI as part of the efficacy testing of the Bayer DC143 sample supplied February 2016, assays done up end of April 2016

Serial dilutions made from Bayer sample DC143 (Vayego ®) concentration in ml/L
Source MNB population: NSW DPI MNB colony Wollongbar

Type 2 Assay

	Vayego®													STD	CTL
ml/ 100L	**1500**	**1250**	**1000**	**750**	**500**	**100**	**50**	**10**	**0.05**	**1.0**	**0.5**	**0.1**	**0.05**	**Bulldock®**	**water**
Sum of Larvae	24	24	24	24	48	24	24	24	24	24	48	24	24	96	108
Sum of dead larvae	24	23	24	23	48	23	23	22	16	19	35	14	9	94	19
Sum of live larvae	0	0	0	0	0	1	0	0	6	5	13	10	14	0	86
Sum of missing larvae	0	1	0	1	1	1	2	1	0	0	0	0	1	2	3
% live MNB larvae remaining	0	0	0	0	0	4	0	0	25	21	27	42	58	0	80

Type 2 Assay

Pesticide	Abamectin	Acephate	Diazinon	Acetamiprid + pyriproxyfen	Methidathion	Methomyl	Pymetrazine	Spinetoram	Sulfoxaflor		
Product	**Stealth®**	**Lancer®**	**Country®**	**Trivor®**	**Supracide®**	**Lannate®**	**Chess®**	**Success neo®**	**Transform®**		
Rate ml/ 100L	**200**	**80**	**125**	**80**	**125**	**200**	**40**	**200**	**40**	**80**	**100**
Sum of larvae	24	24	12	24	24	12	24	24	24	24	24
Sum of dead larvae	24	23	12	21	24	11	3	17	4	20	18
Sum of live larvae	0	0	0	2	0	1	19	0	14	4	1
Sum of missing larvae	0	1	0	1	0	1	2	8	8	0	0
%live MNB larvae remaining	0	0	0	8	0	8	79	0	58	17	4

Table 2.5.1.12.: Dipped macadamia nuts bioassay for macadamia seed weevil (*Kuschelorhynchus macadamiae* MSW) at Wollongbar Entomology laboratory NSW DPI. Nuts dipped on 02/11/2018 survivorship recorded day 1, 2, 3 and finally day 7.

Chemical	**Formulation**	**Rate ml/ 100L**	**Replica te**	**24hr dead**	**48hr dead**	**72hr dead**	**Feeding 123**	**Tested population**	**7 day dead**	**3day %mortality**	**7 day %mortality**
Water	0	0	1	0	0	0	3	10	1	0.0	10.0
Water	0	0	2	0	0	0	3	10	3	0.0	30.0
Water	0	0	3	0	0	0	3	10	1	0.0	10.0
Indoxacarb	Avatar® 300 +10 wks field	25	1	0	1	2	2	10	3	20.0	30.0
Indoxacarb	Avatar® 300 +10 wks field	25	2	0	0	0	2	10	2	0.0	20.0
Indoxacarb	Avatar® 300 +10 wks field	25	3	0	0	0	3	10	2	0.0	20.0
Dc163	Dc 163	12.5	1	2	6	6	0	10	8	60.0	80.0
Dc163	Dc 163	12.5	2	1	3	3	1	10	2	30.0	20.0
Dc163	Dc 163	12.5	3	1	6	6	0	10	7	60.0	70.0
Beta cyfluthrin	Bulldock® 25EC	50	1	2	3	6	0	10	6	60.0	60.0
Beta cyfluthrin	Bulldock® 25EC	50	2	0	3	3	1	10	5	30.0	50.0
Beta cyfluthrin	Bulldock® 25EC	50	3	0	3	5	1	10	7	50.0	70.0
Burkholderia spp. strain A396	Venerate®	200	1	2	2	2	3	10	2	20.0	20.0
Burkholderia spp. strain A396	Venerate®	200	2	0	1	2	3	10	2	20.0	20.0
Burkholderia spp. strain A396	Venerate®	200	3	1	1	2	3	10	2	20.0	20.0
Chromobacterium subtsugae	Grandevo®	200	1	0	2	1	3	10	2	10.0	20.0
Chromobacterium subtsugae	Grandivo®	200	2	0	1	2	3	10	3	20.0	30.0
Chromobacterium subtsugae	Grandivo®	200	3	0	1	1	2	10	7	10.0	70.0
Indoxacarb	Avaunt® evo 300	25	1	4	8	6	0	10	4	60.0	40.0
Indoxacarb	Avaunt® evo 300	25	2	5	6	8	0	10	5	80.0	50.0
Indoxacarb	Avaunt® evo 300	25	3	6	2	7	1	10	9	70.0	90.0
Flupyrafurone	Sivanto® Prime 200EC	100	1	2	2	2	1	10	4	20.0	40.0
Flupyrafurone	Sivanto® Prime 200EC	100	2	0	4	5	2	10	5	50.0	50.0
Flupyrafurone	Sivanto® Prime 200EC	100	3	6	6	6	1	10	4	60.0	40.0
Acetamiprid + Pyriproxyfen	Trivor®	80	1	4	6	6	0	10	9	60.0	90.0
Acetamiprid + Pyriproxyfen	Trivor®	80	2	4	5	8	1	10	8	80.0	80.0
Acetamiprid + Pyriproxyfen	Trivor®	80	3	3	7	7	1	10	7	70.0	70.0
Acephate	Lancer® 970	80	1	6	7	9	1	10	9	90.0	90.0
Acephate	Lancer® 970	80	2	3	6	7	2	10	8	70.0	80.0
Acephate	Lancer® 970	80	3	2	6	7	1	10	8	70.0	80.0

Table 2.5.1.13.: Two replicates dipped macadamia nuts bioassay and 1 replicate of 1ul topical application for macadamia seed weevil (*Kuschelorhynchus macadamiae* MSW) at Wollongbar Entomology laboratory NSW DPI. Nuts dipped and doses applied on 18/01/2019, survivorship recorded day 1,2,3 and finally day 7.

Chemical	Formulation	Rate ml/ 100L	Replicate	24hr Dead	48hr Dead	72hr Dead	Tested population	7 day dead	3day %mortality	7 day %mortality
Water	0	0	1	0	0	0	10	0	0.0	0.0
Water	0	0	2	0	0	0	5	0	0.0	0.0
Water	0	0	TA	0	0	0	5	0	0.0	0.0
Indoxacarb + Designer®	Avatar® 300	25	1	2	3	3	8	5	37.5	62.5
Indoxacarb + Designer®	Avatar® 300	25	2	0	0	0	5	2	0.0	40.0
Indoxacarb + Designer®	Avatar® 300	25	TA	0	0	0	5	0	0.0	0.0
Acephate + Designer®	Lancer® 970	80	1	4	6	6	8	8	75.0	100.0
Acephate + Designer®	Lancer® 970	80	2	2	5	5	5	5	100.0	100.0
Acephate + Designer®	Lancer 970	80	TA	0	0	0	5	0	0.0	0.0
Nonyl phenol	Agral®	10	1	0	0	0	8	0	0.0	0.0
Nonyl phenol	Agral®	10	2	0	0	0	5	0	0.0	0.0
Nonyl phenol	Agral®	10	TA	0	0	0	5	0	0.0	0.0
Synfo121	Syn	10	1	2	2	4	8	4	50.0	50.0
Synfo121	Syn	10	2	0	0	0	5	0	0.0	0.0
Synfo121	Syn	10	TA	0	0	0	5	0	0.0	0.0
SYNFO121+ Agral®	Syn	10	1	0	1	1	8	0	12.5	0.0
SYNFO121+ Agral®	Syn	10	2	0	0	1	5	3	20.0	60.0
SYNFO121+ Agral®	Syn	10	TA	0	0	0	5	0	0.0	0.0
SYNFO121+ Agral®	Syn	30	1	1	2	4	8	8	50.0	100.0
SYNFO121+ Agral®	Syn	30	2	2	4	5	5	5	100.0	100.0
SYNFO121+ Agral®	Syn	30	TA	0	0	0	5	1	0.0	20.0
SYNFO121+ Agral®	Syn	60	1	4	5	6	8	6	75.0	75.0
SYNFO121+ Agral®	Syn	60	2	2	3	5	5	5	100.0	100.0
SYNFO121+ Agral®	Syn	60	TA	0	0	0	5	0	0.0	0.0
SYNFO121+ Designer® 0.1	Syn	10	1	2	2	5	10	8	50.0	80.0
SYNFO121+ Designer® 0.1	Syn	10	2	0	0	3	5	5	60.0	100.0
SYNFO121+ Designer® 0.1	Syn	10	TA	1	1	1	5	1	20.0	20.0

3. **Fruit spotting Bug (FSB)**

Methodology

Fruit spotting bug (*Amblypelta nitida*, FSB) and banana spotting bug (*A. lutescens lutescens*) assays have been performed at CTH Alstonville and Wollongbar laboratories since late 1990's (Campbell et al. 1996, Maddox et al. 2002b). The technique uses the dipped *Murraya paniculata* berries (Figure 2.5.1.2.) and then releasing adult or nymph populations into jars containing the berries and monitoring the survival rate over 1, 2 ,3, and 7 days.

Figure 2.5.1.2.: Dipped *Murraya paniculata* berries and ventilated Acola preserving jars for FSB and *Leptocoris* sp. assays

Result and comments

Imtrade products were compared with similar Bayer formulations in 2017 and the other registered FSB control options for nymphs and adult survivorship (Table 2.5.1.14.). All products were effective on FSB nymphs (Table 2.5.1.14.). The FSB adults were not as well controlled, (Tables 2.5.1.15. and 2.5.1.16.) and *A. lutescens* appears to be controlled better with cypermethrin and bifenthrin than beta-cyfluthrin (Table 2.5.1.17.). Naphthalene based rather than Xylene based beta-cyfluthrin was equally effective and may meet the necessity to change from the mutagenic solvent if that becomes an issue for product use.

Screening an experimental compound (BAS) and SeroX® against *A. lutescens* nymphs did not show any significant activity (Table 2.5.1.18.).

4. ***Leptocoris* spp. (soap berry bugs, *L. rufomargta* and *L. tagalica* Rhopalididae)**

Methodology

These assays were done originally using field collected bugs from the Gympie district mainly around Amamoor and Dagun QLD as there was suspected failure of Bulldock® treatment on a commercial farm in the Gympie area to achieve control.

We had trailed Sivanto® Prime and Transform® as alternate FSB options on this farm and this did suggest then that both those products were not working on *Leptocoris* sp.

An initial assay had Bulldock® only killing 30%, acephate 100% and trichlorfon over 80% (Figure 7.1.8; Field pesticide chapter).

The assay was done by exposing *Leptocoris* sp. to nuts dipped pesticide mixture. Two populations of bugs were screened which were collected in 2018 and 2019 (Tables 2.5.1.19 and 2.5.1.20.).

In the latest laboratory screening dipped *Murraya paniculata* berries were used (same as FSB) because the bugs were recorded feeding in the monitoring hedges at CTH as well as on the nuts (Tables 2.5.1.21. and 2.5.1.22.).

Result summary

The control offered by the pyrethroids is variable and likely that it is not working in the Gympie or Bundaberg area.

The Trivor® results are not consistent across the populations tested,

The new Group 4 compounds are not effective. Certainly Vayego® and many other bug control options are not showing high enough mortality. In the screening trials bugs may indeed be getting back up after knockdown of 24-48 hours and flying away.

A new experimental compound that proved successful against FSB is yet to be screened against *Leptocoris* spp.

Table 2.5.1.14.: The comparison of *Amblypelta nitida* daily survivorship rates for Imtrade bifenthrin, alpha-cypermethrin and beta-cyfluthrin formulations at the same dose (10% of registered beta-cyfluthrin rate) with the products registered for use in macadamia. This is based on bioassays of nymphs (at least 3rd instar set 23/05/2017). Three replicates of 5 individuals placed into breathable containers using feeding on dipped *Murraya paniculata* berries as the delivered dose.

Active Ingredient	**Formulation**	**Rate ml/ 100L**	**Gai/100 ml**	**Nymphs**	**24 hr live**	**48 hr live**	**72 hr live**	**7 day live**
Water		0		15	15	15	13	13
Bifenthrin	Imtrade Bifenthrin 300	0.43	0.00013	15	2	1	1	0
Bifenthrin	Zeus® 100	1.25	0.00013	15	3	1	0	0
Alpha-cypermethrin	Imtrade Dictate duo® 100g/L	1.25	0.00013	15	1	0	0	0
Beta-cyfluthrin	25 Naphlalene Imtrade	5	0.00013	15	2	1	0	0
Beta-cyfluthrin	25 Xylene Imtrade	5	0.00013	15	6	5	1	0
Beta-cyfluthrin	Bulldock® 25 EC	5	0.00013	15	2	2	1	0
Beta-cyfluthrin	Bulldock® 25 EC	50	0.00125	15	1	0	0	0
Trichlorfon	Lepidex® 500 EC	200	0.1	15	0	0	0	0
Acephate	Lancer® 970 WP	80	0.776	15	2	0	0	0
Sulfoxaflor	Transform® 240 EC	40	0.0096	15	5	2	1	0

Table 2.5.1.15: The comparison of *Amblypelta nitida* Day 7 mortality rates for Imtrade beta- cyfluthrin formulations with Bulldock® 25 EC based on bioassays of nymphs (2nd -3rd instar set 26/04/2017) and adults (set 03/05/2017). Three replicates of 5 individuals placed into breathable containers using feeding on dipped *Murraya paniculata* berries as the delivered dose. Survivorship checked at 24, 48 and 72 hours and emptied out at 7 days to record eggs laid as well as final numbers.

Formulation	Rate ml/ 100L	Nymphs tested	%Mortality nymphs	SD %Mort. nymphs	Adults tested	Females	Eggs laid	Day7 live females	%Mortality adults	SD %Mort adults
Water control	0	15	6.7	9.4	15	9	29	9	13.3	9.4
25 Naphlalene Imtrade	12.5	15	100	0	15	8	3	2	80.0	16.3
	25	15	100	0	15	7			100.0	0.0
	50	15	100	0	15	7		2	86.7	9.4
	100	15	100	0						
25 Xylene Imtrade	12.5	15	100	0	15	6	11	2	80.0	16.3
	25	15	100	0	15	7		1	86.7	9.4
	50	15	100	0	15	8		1	93.3	9.4
	100	15	100	0						
Bulldock® 25 EC	12.5	15	100	0						
	25	15	100	0						
	50	15	100	0	15	8		1	93.3	9.4
	100	15	100	0						

Table 2.5.1.16.: The comparison of *Amblypelta nitida* daily survivorship rates for Imtrade beta- cyfluthrin formulations with the Bulldock® 25 EC based on bioassays of nymphs (2nd -3rd instar set 26/04/2017) and adults (set 03/05/2017). Three replicates of 5 individuals placed into breathable containers using feeding on dipped *Murraya paniculata* berries as the delivered dose.

Active Ingredient	Formulation	Rate ml/ 100L	Nymphs tested	24 hr live	48 hr live	72 hr live	Adults tested	24 hr live	48 hr live	72 hr live
Water	Water control	0	15	15	14	14	15	14	14	14
Beta-cyfluthrin	25 Naphlalene Imtrade	12.5	15	5	0	0	15	13	11	8
		25	15	4	3	1	15	12	10	5
		50	15	5	2	1	15	12	6	5
		100	15	2	2	1				
Beta-cyfluthrin	25 Xylene Imtrade	12.5	15	5	0	0	15	11	6	5
		25	15	4	3	1	15	13	8	3
		50	15	5	2	1	15	14	6	3
		100	15	2	2	1				
Beta-cyfluthrin	Bulldock® 25 EC	12.5	15	5	0	0				
		25	15	4	3	1				
		50	15	5	2	1	15	12	6	3
		100	15	2	2	1				

Table 2.5.1.17.: The comparison of *Amblypelta lutescens* Day 7 mortality rates for Imtrade bifenthrin 300 and Dictate duo formulations with the Bulldock® 25 EC. This is based on bioassays of nymphs (at least 3rd instar set 10/5/17). Three replicates of 5 individuals placed into breathable containers using feeding on dipped *Murraya paniculata* berries as the delivered dose. Survivorship checked at 24, 48 and 72 hours and emptied out at 7 days to record final numbers.

Active Ingredient	Formulation	Rate ml/ 100L	Nymphs tested	%Mortality nymphs	SD %Mortality nymphs
Water		0	15	20.0	0.0
Bifenthrin	Imtrade Bifenthrin 300®	16.7	15	100.0	0.0
Beta-cyfluthrin	Zeus 100®	50	15	100.0	0.0
Alpha-cypermethrin	Imtrade Dictate duo® 100g/L	10	15	100.0	0.0
		100	15	100.0	0.0
Beta-cyfluthrin	Bulldock® 25 EC	50	15	86.7	9.4

Table 2.5.1.18.: The comparison of *Amblypelta lutescens* Day 7 mortality rates for Imtrade bifenthrin 300 and Dictate duo formulations with the Bulldock® 25 EC. This is based on dipped *Murraya paniculata* berry bioassays of nymphs (at least 3rd instar set 10/05/2017). Three replicates of 5 nymphs, BAS formulations and SeroX® also supplied and tested at suggested rates.

Rep	Chemical	Formulation	Rate ml/ 100L	24hr Live nymph	7 day live nymph	Tested nymph population	Dead nymphs	% mortality nymphs
1	Water	0	0	5	4	5	1	20.0
2	Water	0	0	5	4	5	1	20.0
3	Water	0	0	4	4	5	1	20.0
1	Beta-cyfluthrin	Bulldock® 25 EC	50	3	1	5	4	80.0
2	Beta-cyfluthrin	Bulldock® 25 EC	50	4	1	5	4	80.0
3	Beta-cyfluthrin	Bulldock® 25 EC	50	4	0	5	5	100.0
1	Clittoria Extract	SeroX®	2000	4	4	5	1	20.0
2	Clittoria Extract	SeroX®	2000	4	3	5	2	40.0
3	Clittoria Extract	SeroX®	2000	5	3	5	2	40.0
1	Clittoria Extract	SeroX®	500	5	4	5	1	20.0
2	Clittoria Extract	SeroX®	500	4	3	5	2	40.0
3	Clittoria Extract	SeroX®	500	5	5	5	0	0.0
1	Cypermethrin	Imtrade Dictate® 100	100	2	0	5	5	100.0
2	Cypermethrin	Imtrade Dictate® 100	100	3	0	5	5	100.0
3	Cypermethrin	Imtrade Dictate® 100	100	2	0	5	5	100.0
1	Cypermethrin	Imtrade Dictate® 100	10	1	0	5	5	100.0
2	Cypermethrin	Imtrade Dictate® 100	10	2	0	5	5	100.0
3	Cypermethrin	Imtrade Dictate® 100	10	2	0	5	5	100.0
1		BAS 440	31	5	4	5	1	20.0
2		BAS 440	31	5	3	5	2	40.0
3		BAS 440	31	5	4	5	1	20.0
1		BAS 440	6.3	5	3	5	2	40.0
2		BAS 440	6.3	5	2	5	3	60.0
3		BAS 440	6.3	5	5	5	0	0.0
1		BAS 550	100	4	2	5	3	60.0
2		BAS 550	100	3	2	5	3	60.0
3		BAS 550	100	5	4	5	1	20.0
1		BAS 550	50	5	5	5	0	0.0
2		BAS 550	50	5	3	5	2	40.0
3		BAS 550	50	5	4	5	1	20.0
1	Bifenthrin	Imtrade Bifenthrin 300	16.7	1	0	5	5	100.0
2	Bifenthrin	Imtrade Bifenthrin 300	16.7	0	0	5	5	100.0
3	Bifenthrin	Imtrade Bifenthrin 300	16.7	2	0	5	5	100.0
1	Bifenthrin	Zeus® 100	50	1	0	5	5	100.0
2	Bifenthrin	Zeus® 100	50	2	0	5	5	100.0
3	Bifenthrin	Zeus® 100	50	2	0	5	5	100.0

Table 2.5.1.19: The comparison of *Leptocoris* Day 7 mortality rates from Gympie QLD sites when exposed to nuts dipped in various pesticides (set 02/11/2018).

Chemical	Formulation	Rate ml/ 100L	Rep	24hr dead	72hr dead	Tested population	7 day dead	3day % mortality	7 day % mortality
Fipronil	Regent® 200	40	1	2	7	10	10	70.0	100.0
Fipronil	Regent® 200	40	2	6	10	10	10	100.0	100.0
Fipronil	Regent® 200	40	3	4	8	10	10	80.0	100.0
Clittoria EXT	SeroX® 400	1000	1	0	0	10	0	0.0	0.0
Clittoria EXT	SeroX® 400	1000	2	0	0	10	0	0.0	0.0
Clittoria EXT	SeroX® 400	1000	3	1	1	10	2	10.0	20.0
Sulfoxaflor	Transform® 240 SC	80	1	1	1	10	2	10.0	20.0
Sulfoxaflor	Transform® 240 SC	80	2	1	1	10	2	10.0	20.0
Sulfoxaflor	Transform® 240 SC	80	3	2	1	10	3	10.0	30.0
Sulfoxaflor	Transform® 240 SC	40	1	0	0	10	1	0.0	10.0
Sulfoxaflor	Transform® 240 SC	40	2	0	1	10	1	10.0	10.0
Sulfoxaflor	Transform® 240 SC	40	3	0	0	10	1	0.0	10.0
Flupyrafurone	Sivanto® Prime 200 EC	100	1	0	0	10	0	0.0	0.0
Flupyrafurone	Sivanto® Prime 200 EC	100	2	0	1	10	0	10.0	0.0
Flupyrafurone	Sivanto® Prime 200 EC	100	3	0	2	10	1	20.0	10.0
Flupyrafurone	Sivanto® Prime 200 EC	50	1	0	0	10	2	0.0	20.0
Flupyrafurone	Sivanto® Prime 200 EC	50	2	0	2	10	0	20.0	0.0
Flupyrafurone	Sivanto® Prime 200 EC	50	3	1	1	10	2	10.0	20.0
Cyanitraniprolle	Exirel® 100 EC	100	1	3	1	10	1	10.0	10.0
Cyanitraniprolle	Exirel® 100 EC	100	2	2	3	10	3	30.0	30.0
Cyanitraniprolle	Exirel® 100 EC	100	3	0	0	10	3	0.0	30.0
Acephate	Lancer® 970	80	1	6	10	10	10	100.0	100.0
Acephate	Lancer®970	80	2	7	9	10	10	90.0	100.0
Acephate	Lancer® 970	80	3	8	8	10	9	80.0	90.0
Acetamiprid + pyripoxifen	Trivor®	80	1	8	8	10	9	80.0	90.0
Acetamiprid + pyripoxifen	Trivor®	80	2	6	8	10	8	80.0	80.0
Acetamiprid + pyripoxifen	Trivor®	80	3	5	6	10	8	60.0	80.0
Trichlorfon	Lepidex® 500	200	1	5	8	10	10	80.0	100.0
Trichlorfon	Lepidex® 500	200	2	5	8	10	9	80.0	90.0
Trichlorfon	Lepidex® 500	200	3	5	8	10	10	80.0	100.0
Spirotetramat	Movento®	40	1	0	1	10	2	10.0	20.0
Spirotetramat	Movento®	40	2	1	1	10	2	10.0	20.0
Spirotetramat	Movento®	40	3	1	2	10	4	20.0	40.0
Beta-cyfluthrin	Bulldock® 25 EC	50	1	1	1	10	2	10.0	20.0
Beta-cyfluthrin	Bulldock® 25 EC	50	2	2	2	10	3	20.0	30.0
Beta-cyfluthrin	Bulldock® 25 EC	50	3	1	2	10	5	20.0	50.0
Water	0	0	1	0	0	10	0	0.0	0.0
Water	0	0	2	0	0	10	0	0.0	0.0
Water	0	0	3	0	0	10	0	0.0	0.0

Table 2.5.1.20.: The comparison of *Leptocoris* Day 7 mortality rates from Gympie QLD sites when exposed to nuts dipped in various pesticides (set 24/07/2019).

Chemical	Rate ml/ 100L	Rep	24hr dead	72hr dead	Tested population	7 day dead	3day % mortality	7 day % mortality	Parasites
Water	0	1	0	0	10	0	0.0	0.0	
Water	0	2	1	1	10	1	10.0	10.0	
Water	0	3	0	0	10	1	0.0	10.0	1
Trichlorfon	200	1	8	9	10	10	90.0	100.0	
Trichlorfon	200	2	8	10	10	10	100.0	100.0	
Trichlorfon	200	3	10	10	10	10	100.0	100.0	
Acephate	80	1	4	8	10	10	80.0	100.0	
Acephate	80	2	6	9	10	10	90.0	100.0	
Acephate	80	3	3	10	10	10	100.0	100.0	
Pymetrozine 500	40	1	0	1	10	1	10.0	10.0	
Pymetrozine 500	40	2	0	1	10	1	10.0	10.0	1
Pymetrozine 500	40	3	2	2	10	3	20.0	30.0	
Nu 3445	10	1	1	1	10	2	10.0	20.0	
Nu 3445	10	2	3	3	10	4	30.0	40.0	
Nu 3445	10	3	4	5	10	6	50.0	60.0	
Nu 3445	50	1	3	5	10	7	50.0	70.0	2
Nu 3445	50	2	4	4	10	4	40.0	40.0	
Nu 3445	50	3	3	3	10	3	30.0	30.0	
Nu 3445	100	1	3	4	10	6	40.0	60.0	1
Nu 3445	100	2	2	6	10	6	60.0	60.0	
Nu 3445	100	3	3	4	10	4	40.0	40.0	
SYNFO121+ Agral®	10	1	2	7	10	8	70.0	80.0	
SYNFO121+ Agral®	10	2	1	6	10	7	60.0	70.0	1
SYNFO121+ Agral®	10	3	2	5	10	7	50.0	70.0	
SYNFO121+ Agral®	30	1	3	7	10	9	70.0	90.0	
SYNFO121+ Agral®	30	2	2	6	10	8	60.0	80.0	
SYNFO121+ Agral®	30	3	3	4	10	7	40.0	70.0	1
SYNFO121+ Agral®	60	1	7	10	10	10	100.0	100.0	
SYNFO121+ Agral®	60	2	5	8	10	9	80.0	90.0	
SYNFO121+ Agral®	60	3	7	7	10	10	70.0	100.0	
SYNFO121+ Designer® 0.1	10	1	3	8	10	9	80.0	90.0	
SYNFO121+ Designer® 0.1	10	2	3	3	10	6	30.0	60.0	
SYNFO121+ Designer® 0.1	10	3	3	4	10	8	40.0	80.0	
Nonyl phenol	10	1	1	1	10	1	10.0	10.0	
Nonyl phenol	10	2	0	0	10	0	0.0	0.0	
Nonyl phenol	10	3	0	1	10	2	10.0	20.0	

Table 2.5.1.21.: The comparison of *Leptocoris* Day 7 mortality rates collected from Alstonville CTH sites when exposed to nuts dipped in various pesticides (set 09/01/2020). The spreader Designer® was used in each mixture at the 10ml/100L rate.

Chemical	Rate ml/ 100L	Rep	24hr dead	48hr dead	72hr dead	Tested population	7day dead	3day % mortality	7 day %mortality
Water	0	1	0	0	0	10	0	0.0	0.0
Water	0	2	0	0	0	10	0	0.0	0.0
Water	0	3	0	0	0	10	0	0.0	0.0
Designer®	10	1	0	0	0	10	0	0.0	0.0
Designer®	10	2	0	0	0	10	0	0.0	0.0
Designer®	10	3	0	0	0	10	0	0.0	0.0
Beta-cyfluthrin	50	1	2	2	0	10	0	0.0	0.0
Beta-cyfluthrin	50	2	0	1	0	10	1	0.0	10.0
Beta-cyfluthrin	50	3	0	0	0	10	0	0.0	0.0
Trichlorfon	200	1	0	0	0	10	1	0.0	10.0
Trichlorfon	200	2	0	0	1	10	3	10.0	30.0
Trichlorfon	200	3	0	7	7	10	8	70.0	80.0
Acephate	80	1	0	0	2	10	9	20.0	90.0
Acephate	80	2	0	0	2	10	8	20.0	80.0
Acephate	80	3	3	6	7	10	10	70.0	100.0
Acetamiprid + pyriproxyfen (Trivor®)	20	1	0	0	1	10	1	10.0	10.0
Acetamiprid + pyriproxyfen (Trivor®)	20	2	0	0	0	10	0	0.0	0.0
Acetamiprid + pyriproxyfen (Trivor®)	20	3	0	0	0	10	0	0.0	0.0
Acetamiprid + pyriproxyfen (Trivor®)	40	1	0	0	1	10	2	10.0	20.0
Acetamiprid + pyriproxyfen (Trivor®)	40	2	0	0	0	10	1	0.0	10.0
Acetamiprid + pyriproxyfen (Trivor®)	40	3	0	0	0	10	0	0.0	0.0
Acetamiprid + pyriproxyfen (Trivor®)	80	1	2	3	3	10	3	30.0	30.0
Acetamiprid + pyriproxyfen (Trivor®)	80	2	0	0	0	10	0	0.0	0.0
Acetamiprid + pyriproxyfen (Trivor®)	80	3	0	0	0	10	1	0.0	10.0
Synfo121	30	1	1	2	2	10	10	20.0	100.0
Synfo121	30	2	0	1	1	10	5	10.0	50.0
Synfo121	30	3	0	2	2	10	6	20.0	60.0
Synfo121	60	1	0	0	3	10	8	30.0	80.0
Synfo121	60	2	0	0	2	10	9	20.0	90.0
Synfo121	60	3	0	1	2	10	5	20.0	50.0

D= Designer®

Table2.5.1. 22.: The comparison of adult *Leptocoris* (from Goonellabah site) and *A. nitida* Day 7 mortality rates when exposed various pesticides (set 30/03/2021). Replicates of 5 individuals placed into breathable containers using feeding on dipped *Murraya paniculata* berries as the delivered dose. Survivorship checked at 24, 48 and 72 hours and emptied out at 7 days to record final numbers. The spreader Designer® was used in each mixture at the 10ml/ 100L rate.

Chemical	Rep	Rate ml/ 100L	Species	24hr live	72hr live	7 day live	Tested population	3Day %mortality	7Day %mortality
Acetamiprid + pyriproxyfen (Trivor®) + D.	1	20	*Leptocoris*	4	4	3	5	20.0	40.0
Acetamiprid + pyriproxyfen (Trivor®) + D.	2	20	*Leptocoris*	5	4	3	5	20.0	40.0
Acetamiprid + pyriproxyfen (Trivor®) + D.	1	40	*Leptocoris*	3	1	1	5	80.0	80.0
Acetamiprid + pyriproxyfen (Trivor®) + D.	2	40	*Leptocoris*	4	5	3	5	0.0	40.0
Cyborg® Plus 100	1	12.5	*Leptocoris*	1	3	4	5	40.0	20.0
Cyborg® Plus 100	2	12.5	*Leptocoris*	1	2	2	5	60.0	60.0
Beta-cyfluthrin + D.	1	50	*Leptocoris*	3	3	3	5	40.0	40.0
Beta-cyfluthrin + D.	2	50	*Leptocoris*	2	3	2	5	40.0	60.0
Nu Farm 3445 +D.	1	120	*Leptocoris*	5	4	3	5	20.0	40.0
Nu Farm 3445 +D.	2	120	*Leptocoris*	5	5	3	5	0.0	40.0
Syn 121 + D.	1	20	*Leptocoris*	5	3	1	5	40.0	80.0
Syn 121 + D.	2	20	*Leptocoris*	5	4	2	5	20.0	60.0
Syn 121 + D.	1	30	*Leptocoris*	4	3	2	5	40.0	60.0
Syn 121 + D.	2	30	*Leptocoris*	5	3	0	5	40.0	100.0
Acephate +D.	1	80	*Leptocoris*	5	1	0	5	80.0	100.0
Acephate +D.	2	80	*Leptocoris*	5	5	0	5	0.0	100.0
Designer® (D.)	1	10	*Leptocoris*	5	5	4	5	0.0	20.0
Designer® (D.)	2	10	*Leptocoris*	5	5	5	5	0.0	0.0
Nu Farm 3445 + D.	1	120	*A. nitida*	5	5	3	5	0.0	40.0
Nu Farm 3445 + D.	2	120	*A. nitida*	5	4	3	5	20.0	40.0
Syn 121 + D.	1	20	*A. nitida*	5	2	0	5	60.0	100.0
Syn 121 + D.	2	20	*A. nitida*	5	5	1	5	0.0	80.0
Designer® (D.)	1	10	*A. nitida*	5	5	4	5	0.0	20.0
Designer® (D.)	2	10	*A. nitida*	5	5	4	5	0.0	20.0

D= Designer®

Introduction

To determine how long an insecticide would be able to control bugs migrating into the orchard, assays determining the residual activity of a range of products was compared for *Amblypelta nitida* (FSB) 2020 and *Leptocoris* sp. 2021.

Earlier field results led to a need to investigate the residual times of different pesticides, the actual time span of protection provided by the various pesticides options available to the growers now. If the weather conditions are conducive to FSB activity it means it is very important to have the crop protected the end of January early February, otherwise the FSB are likely to return to damaged fruit (Huwer et al. 2015b). The 2020 crop result for the case study IPM and conventional farms not only showed that damage is increasing in the early winter period on the crop still hanging on tree and products with very limited residual activity, may not be useful at all if the flights are continual late in the season.

Methodology

Major residual activity testing was investigated using tagged berries on *Murraya paniculata* hedges at CTH Alstonville in July 2020 for FSB and again in June 2021 for *Leptocoris* sp. Berry laden branches on the southern side of a *Murraya* hedge containing 25 plants were selected for application of pesticides. Each treatment area was tagged and spaced at least 1.5m away from the next branch on the next tree. A volume of 1L of the screened pesticide mixture was applied to run off over the berries, using a 1 L hand mister. The mister was triple rinsed between treatments. Pesticide mixtures were made up at Wollongbar in 1L volumetric flasks labelled, sealed and transported to CTH Alstonville for application.

In 2020 treated berries were picked at day 1, day 7, day 14, day 21 and fed to FSB in the clean Acola preserving jars and the mortality rate scored over the week (field trial section this report). Numbers of available bugs always limit the replication options and the life stages tested. For FSB we used a replicate of 5 nymphs (3^{rd}-5^{th} instar) and a replicate of 5 adults for each test compound at each time period (total of 50 for each compound).

In 2021 the process was repeated when *Leptocoris* sp. were collected from a pecan orchard at Tatham NSW giving us access to live bugs for over 6 weeks to do the trial. The berry laden branches were treated 17/6/21 in the same way and tagged up the same and berries were picked at day 1, day 7, day 14, day 21. This time we used 2 replicates of 5 *Leptocoris* adults and a replicate of 5 FSB for comparison to the previous season for each chemical mixture at each time.

Results in 2020

Mortality rate after feeding on berries for 7 days is reported in Table 2.5.1.23. for day 1 treated berries, Table 2.5.1.24. for day 7 treated berries, Table 2.5.1.25. for day 14 treated berries, and Table 2.5.1.26. for day 21 treated berries. Beta-cyfluthrin as Bulldock® is the most residual option and most products work a lot better on nymphs than adults (as we found before Maddox et al. 2002b) and are not really effective for more than a week. The new experimental compound appears to be the next most residual depending on rate applied.

Results in 20221

Mortality rate after feeding on berries for 7 days is reported in Table 2.5.1.27. for day 1 treated berries, Table 2.5.1.28. for day 7 treated berries, Table 2.5.1.29. for day 14 treated berries, and Table 2.5.1.30. for day 21 treated berries. In this case the pyrethroids Cyborg® Plus and Bulldock® were compared directly, and the new Nufarm product 3445 was included and lower rates for the new experimental product. This time both the pyrethroids were effective on the bugs for the full 21 days, very different to the bugs from Gympie, the activity on *Leptocoris* is very much population dependent.

Table 2.5.1.23.: The comparison of *A. nitida* Day 7 mortality rates from Alstonville CTH sites when exposed various pesticides (set 17/6/2021). Replicates of 5 individuals placed into breathable containers using feeding on **1 day** post spraying *Murraya paniculata* berries as the delivered dose. Survivorship checked at 24, 72 hours and emptied out at 7 days to record final numbers. The spreader Designer® was used in each mixture at the 10ml/ 100L rate.

Chemical	Rep	Rate ml/ 100L	Life Stage	24hr live	72hr live	7 day live	Tested population	3Day % Mortality	7Day % Mortality
Water	1		Nymph	4	3	3	5	40.0	40.0
Water	2		Adult	5	5	2	5	0.0	60.0
Designer® (D.)	1	10	Nymph	5	4	4	5	20.0	20.0
Designer® (D.)	2	10	Adult	5	4	4	5	20.0	20.0
Vayego® + Bond®	1	15	Nymph	2	2	1	5	60.0	80.0
Vayego® + Bond®	2	15	Adult	2	2	1	5	60.0	80.0
Vayego®	1	15	Nymph	3	0	0	5	100.0	100.0
Vayego®	2	15	Adult	2	1	0	5	80.0	100.0
Trichlorfon +D.	1	200	Nymph	0	0	0	5	100.0	100.0
Trichlorfon +D.	2	200	Adult	0	0	0	5	100.0	100.0
Syn 121 + D.	1	60	Nymph	2	0	0	5	100.0	100.0
Syn 121 + D.	2	60	Adult	4	1	0	5	75.0	100.0
Syn 121 + D.	1	30	Nymph	2	0	0	5	100.0	100.0
Syn 121 + D.	2	30	Adult	4	0	0	5	100.0	100.0
Sulfoxaflor + D.	1	40	Nymph	3	2	1	5	60.0	80.0
Sulfoxaflor + D.	2	40	Adult	3	3	1	5	40.0	80.0
Acetamiprid + pyriproxyfen (Trivor®) + D.	1	40	Nymph	0	0	0	5	100.0	100.0
Acetamiprid + pyriproxyfen (Trivor®) + D.	2	40	Adult	2	1	0	5	80.0	100.0
Beta-cyfluthrin + D.	1	50	Nymph	1	0	0	5	100.0	100.0
Beta-cyfluthrin + D.	2	50	Adult	0	0	0	5	100.0	100.0
DC154 + D.	1	100	Nymph	2	2	2	5	60.0	60.0
DC154 + D.	2	100	Adult	2	2	1	5	60.0	80.0
Methoxyfenozide + D.	1	100	Nymph	3	3	3	5	40.0	40.0
Methoxyfenozide + D.	2	100	Adult	5	5	3	5	0.0	40.0

D= Designer®

Table 2.5.1.24: The comparison of *A. nitida* Day 7 mortality rates from Alstonville CTH sites when exposed various pesticides (set 17/6/2021). Replicates of 5 individuals placed into breathable containers using feeding on **7 days** post spraying *Murraya paniculata* berries as the delivered dose. Survivorship checked at 24, 72 hours and emptied out at 7 days to record final numbers. The spreader Designer® was used in each mixture at the 10ml/ 100L rate.

Chemical	Rep	Rate ml/ 100L	Life Stage	24hr live	72hr live	7 day live	Tested population	3day % Mortality	7day % Mortality
Water	1		Nymph	5	4	4	5	20.0	20.0
Water	2		Adult	5	5	4	5	0.0	20.0
Designer® (D.)	1	10	Nymph	5	5	5	5	0.0	0.0
Designer® (D.)	2	10	Adult	5	5	5	5	0.0	0.0
Vayego® + Bond®	1	15	Nymph	4	3	1	5	40.0	80.0
Vayego® + Bond®	2	15	Adult	5	5	5	5	0.0	0.0
Vayego®	1	15	Nymph	5	5	5	5	0.0	0.0
Vayego®	2	15	Adult	5	4	3	5	20.0	40.0
Trichlorfon + D.	1	200	Nymph	5	5	4	5	0.0	20.0
Trichlorfon + D.	2	200	Adult	5	4	3	5	20.0	40.0
Syn 121 + D.	1	60	Nymph	4	0	0	5	100.0	100.0
Syn 121 + D.	2	60	Adult	5	2	0	5	60.0	100.0
Syn 121 + D.	1	30	Nymph	5	4	1	5	20.0	80.0
Syn 121 + D.	2	30	Adult	5	5	2	5	0.0	60.0
Sulfoxaflor + D.	1	40	Nymph	5	3	2	5	40.0	60.0
Sulfoxaflor + D.	2	40	Adult	5	5	4	5	0.0	20.0
Acetamiprid + pyriproxyfen (Trivor®) + D.	1	40	Nymph	5	4	2	5	20.0	60.0
Acetamiprid + pyriproxyfen (Trivor®) + D.	2	40	Adult	4	3	3	5	40.0	40.0
Beta-cyfluthrin + D.	1	50	Nymph	0	0	0	5	100.0	100.0
Beta-cyfluthrin + D.	2	50	Adult	0	0	0	5	100.0	100.0
DC154 + D.	1	100	Nymph	5	4	3	5	20.0	40.0
DC154 + D.	2	100	Adult	4	4	4	5	20.0	20.0
Methoxyfenozide + D.	1	100	Nymph	5	5	4	5	0.0	20.0
Methoxyfenozide + D.	2	100	Adult	5	5	4	5	0.0	20.0

D= Designer®

Table 2.5.1.25.: The comparison of *A. nitida* Day 7 mortality rates from Alstonville CTH sites when exposed various pesticides (set 17/6/2021). Replicates of 5 individuals placed into breathable containers using feeding on **14 days** post spraying *Murraya paniculata* berries as the delivered dose. Survivorship checked at 24, 72 hours and emptied out at 7 days to record final numbers. The spreader Designer® was used in each mixture at the 10ml/ 100L rate.

Chemical	Rep	Rate ml/ 100L	Life Stage	24hr live	72hr live	7 day live	Tested population	3day % Mortality	7day % Mortality
Water	1		Nymph	5	5	5	5	0.0	0.0
Water	2		Adult	5	5	5	5	0.0	0.0
Designer® (D.)	1	10	Nymph	5	4	4	5	20.0	20.0
Designer® (D.)	2	10	Adult	5	5	5	5	0.0	0.0
Vayego® + Bond®	1	15	Nymph	5	4	3	5	20.0	40.0
Vayego® + Bond®	2	15	Adult	4	4	4	5	20.0	20.0
Vayego®	1	15	Nymph	5	4	4	5	20.0	20.0
Vayego®	2	15	Adult	5	5	5	5	0.0	0.0
Trichlorfon + D.	1	200	Nymph	5	5	4	5	0.0	20.0
Trichlorfon + D.	2	200	Adult	5	5	5	5	0.0	0.0
Syn 121 + D.	1	60	Nymph	5	1	0	5	80.0	100.0
Syn 121 + D.	2	60	Adult	5	5	1	5	0.0	80.0
Syn 121 + D.	1	30	Nymph	4	1	1	5	80.0	80.0
Syn 121 + D.	2	30	Adult	5	5	3	5	0.0	40.0
Sulfoxaflor + D.	1	40	Nymph	5	5	4	5	0.0	20.0
Sulfoxaflor + D.	2	40	Adult	5	5	5	5	0.0	0.0
Acetamiprid + pyriproxyfen (Trivor®) + D.	1	40	Nymph	5	4	3	5	20.0	40.0
Acetamiprid + pyriproxyfen (Trivor®) + D.	2	40	Adult	4	4	4	5	20.0	20.0
Beta-cyfluthrin + D.	1	50	Nymph	1	0	0	5	100.0	100.0
Beta-cyfluthrin + D.	2	50	Adult	1	0	1	5	100.0	80.0
DC154 + D.	1	100	Nymph	5	5	4	5	0.0	20.0
DC154 + D.	2	100	Adult	5	5	4	5	0.0	20.0
Methoxyfenozide + D.	1	100	Nymph	5	5	5	5	0.0	0.0
Methoxyfenozide + D.	2	100	Adult	5	4	4	5	20.0	20.0

D= Designer®

Table 2.5.1.26.: The comparison of *A. nitida* Day 7 mortality rates from Alstonville CTH sites when exposed various pesticides (set 17/6/2021). Replicates of 5 individuals placed into breathable containers using feeding on **21 days** post spraying *Murraya paniculata* berries as the delivered dose. Survivorship checked at 24, 72 hours and emptied out at 7 days to record final numbers. The spreader Designer® was used in each mixture at the 10ml/ 100L rate.

Chemical	Rep	Rate ml/ 100L	Life Stage	24hr live	72hr live	7 day live	Tested population	3day % Mortality	7day % Mortality
Water	1		Nymph	5	5	5	5	0.0	0.0
Water	2		Adult	5	5	5	5	0.0	0.0
Designer® (D.)	1	10	Nymph	4	4	4	5	20.0	20.0
Designer® (D.)	2	10	Adult	5	5	4	5	0.0	20.0
Vayego® + Bond®	1	15	Nymph	5	4	3	5	20.0	40.0
Vayego® + Bond®	2	15	Adult	5	5	5	5	0.0	0.0
Vayego®	1	15	Nymph	5	4	3	5	20.0	40.0
Vayego®	2	15	Adult	5	5	5	5	0.0	0.0
Trichlorfon + D.	1	200	Nymph	5	3	3	5	40.0	40.0
Trichlorfon + D.	2	200	Adult	5	5	5	5	0.0	0.0
Syn 121 + D.	1	60	Nymph	5	5	3	5	0.0	40.0
Syn 121 + D.	2	60	Adult	4	4	4	5	20.0	20.0
Syn 121 + D.	1	30	Nymph	4	2	1	5	60.0	80.0
Syn 121 + D.	2	30	Adult	5	5	5	5	0.0	0.0
Sulfoxaflor + D.	1	40	Nymph	4	4	4	5	20.0	20.0
Sulfoxaflor + D.	2	40	Adult	5	5	5	5	0.0	0.0
Acetamiprid + pyriproxyfen (Trivor®) + D.	1	40	Nymph	3	2	1	5	60.0	80.0
Acetamiprid + pyriproxyfen (Trivor®) + D.	2	40	Adult	5	5	5	5	0.0	0.0
Beta-cyfluthrin + D.	1	50	Nymph	2	2	1	5	60.0	80.0
Beta-cyfluthrin + D.	2	50	Adult	1	4	4	5	20.0	20.0
DC154 +D.	1	100	Nymph	4	4	2	5	20.0	60.0
DC154 +D.	2	100	Adult	5	5	5	5	0.0	0.0
Methoxyfenozide + D.	1	100	Nymph	4	4	4	5	20.0	20.0
Methoxyfenozide + D.	2	100	Adult	5	5	5	5	0.0	0.0

D= Designer®

Table 2.5.1.27: The comparison of adult *Leptocoris* and *A. nitida* Day 7 mortality rates from Alstonville CTH sites when exposed various pesticides (set 17/06/2021). Replicates of 5 individuals placed into breathable containers using feeding on **1 day** post spraying *Murraya paniculata* berries as the delivered dose. Survivorship checked at 24, 72 hours and emptied out at 7 days to record final numbers. The spreader Designer® was used in each mixture at the 10ml/ 100L rate.

Chemical	**Rep**	**Rate ml/ 100L**	***Species***	**24hr live**	**72hr live**	**7 day live**	**Tested population**	**3day % Mortality**	**7day % Mortality**
Untreated	1	0	*Leptocoris*	5	5	5	5	0.0	0.0
Untreated	2	0	*Leptocoris*	5	5	5	5	0.0	0.0
Designer® (D)	1	10	*Leptocoris*	5	5	5	5	0.0	0.0
Designer® (D)	2	10	*Leptocoris*	5	5	5	5	0.0	0.0
Nu Farm 3445 + D.	1	120	*Leptocoris*	5	5	4	5	0.0	20.0
Nu Farm 3445 + D.	2	120	*Leptocoris*	5	5	5	5	0.0	0.0
DC 143 (Vayego®) + D.	1	12.5	*Leptocoris*	5	5	5	5	0.0	0.0
DC 143 (Vayego®) + D.	2	12.5	*Leptocoris*	5	5	5	5	0.0	0.0
Acetamiprid + pyriproxyfen (Trivor®) + D.	1	20	*Leptocoris*	1	3	0	5	40.0	100.0
Acetamiprid + pyriproxyfen (Trivor®) + D.	2	20	*Leptocoris*	2	1	0	5	80.0	100.0
Acetamiprid + pyriproxyfen (Trivor®) + D.	1	40	*Leptocoris*	2	2	0	5	60.0	100.0
Acetamiprid + pyriproxyfen (Trivor®) + D.	2	40	*Leptocoris*	1	2	0	5	60.0	100.0
Cyborg® Plus 100 + D.	1	12.5	*Leptocoris*	1	1	0	5	80.0	100.0
Cyborg® Plus 100 + D.	2	12.5	*Leptocoris*	0	1	0	5	80.0	100.0
Acephate + D.	1	80	*Leptocoris*	5	1	0	5	80.0	100.0
Acephate + D.	2	80	*Leptocoris*	1	0	0	5	100.0	100.0
Syn 121 + D.	1	20	*Leptocoris*	5	5	4	5	0.0	20.0
Syn 121 + D.	2	20	*Leptocoris*	5	2	1	5	60.0	80.0
Trichlorfon + D.	1	200	*Leptocoris*	4	1	0	5	80.0	100.0
Trichlorfon + D.	2	200	*Leptocoris*	5	5	5	5	0.0	0.0
Syn 121 + D.	1	30	*Leptocoris*	5	1	0	5	80.0	100.0
Syn 121 + D.	2	30	*Leptocoris*	5	1	0	5	80.0	100.0
Beta-cyfluthrin + D.	1	50	*Leptocoris*	0	2	0	5	60.0	100.0
Beta-cyfluthrin + D.	2	50	*Leptocoris*	0	1	0	5	80.0	100.0
Untreated	3	0	*A. nitida*	5	5	5	5	0.0	0.0
Designer® (D)	3	10	*A. nitida*	5	4	4	5	20.0	20.0
Nu farm 3445 + D.	3	120	*A. nitida*	5	5	5	5	0.0	0.0
DC 143 (Vayego®) + D.	3	12.5	*A. nitida*	5	5	4	5	0.0	20.0
Acetamiprid + pyriproxyfen (Trivor®) + D.	3	20	*A. nitida*	5	4	2	5	20.0	60.0
Acetamiprid + pyriproxyfen (Trivor®) + D.	3	40	*A. nitida*	3	3	2	5	40.0	60.0
Cyborg® Plus 100 + D.	3	12.5	*A. nitida*	0	0	0	5	100.0	100.0
Acephate + D.	3	80	*A. nitida*	2	0	0	5	100.0	100.0
Syn 121 + D.	3	20	*A. nitida*	4	3	1	5	40.0	80.0

D= Designer®

Table 2.5.1.28.: The comparison of adult *Leptocoris* and *A. nitida* Day 7 mortality rates from Alstonville CTH sites when exposed various pesticides (set 17/06/2021). Replicates of 5 individuals placed into breathable containers using feeding on **7 days** post spraying (24/06/2021) *Murraya paniculata* berries as the delivered dose. Survivorship checked at 24, 72 hours and emptied out at 7 days to record final numbers. The spreader Designer® was used in each mixture at the 10ml/ 100L rate.

Chemical	Rep	Rate ml/ 100L	*Species*	24hr live	72hr live	7 day live	Tested population	3day % Mortality	7day % Mortality
Untreated	1	0	*Leptocoris*	5	5	5	5	0.0	0.0
Untreated	2	0	*Leptocoris*	5	5	5	5	0.0	0.0
Designer® (D.)	1	10	*Leptocoris*	5	5	5	5	0.0	0.0
Designer® (D.)	2	10	*Leptocoris*	5	5	5	5	0.0	0.0
Nu Farm 3445 + D.	1	120	*Leptocoris*	5	5	4	5	0.0	20.0
Nu Farm 3445 + D.	2	120	*Leptocoris*	5	5	5	5	0.0	0.0
DC 143 (Vayego®) + D.	1	12.5	*Leptocoris*	5	5	5	5	0.0	0.0
DC 143 (Vayego®) + D.	2	12.5	*Leptocoris*	5	5	5	5	0.0	0.0
Acetamiprid + pyriproxyfen (Trivor®) + D.	1	20	*Leptocoris*	5	5	5	5	0.0	0.0
Acetamiprid + pyriproxyfen (Trivor®) + D.	2	20	*Leptocoris*	5	5	5	5	0.0	0.0
Acetamiprid + pyriproxyfen (Trivor®) + D.	1	40	*Leptocoris*	5	4	1	5	20.0	80.0
Acetamiprid + pyriproxyfen (Trivor®) + D.	2	40	*Leptocoris*	5	4	2	5	20.0	60.0
Cyborg® Plus 100 + D.	1	12.5	*Leptocoris*	3	3	0	5	40.0	100.0
Cyborg® Plus 100 + D.	2	12.5	*Leptocoris*	3	2	1	5	60.0	80.0
Acephate + D.	1	80	*Leptocoris*	5	5	5	5	0.0	0.0
Acephate + D.	2	80	*Leptocoris*	5	5	5	5	0.0	0.0
Syn 121 + D.	1	20	*Leptocoris*	5	5	5	5	0.0	0.0
Syn 121 + D.	2	20	*Leptocoris*	5	5	4	5	0.0	20.0
Trichlorfon + D.	1	200	*Leptocoris*	5	5	5	5	0.0	0.0
Trichlorfon + D.	2	200	*Leptocoris*	5	5	5	5	0.0	0.0
Syn 121 + D.	1	30	*Leptocoris*	5	3	0	5	40.0	100.0
Syn 121 + D.	2	30	*Leptocoris*	5	5	2	5	0.0	60.0
Beta-cyfluthrin + D.	1	50	*Leptocoris*	1	3	0	5	40.0	100.0
Beta-cyfluthrin + D.	2	50	*Leptocoris*	2	3	0	5	40.0	100.0
Untreated	3	0	*A. nitida*	5	5	5	5	0.0	0.0
Designer® (D.)	3	10	*A. nitida*	5	4	4	5	20.0	20.0
Nu Farm 3445 + D.	3	120	*A. nitida*	5	5	5	5	0.0	0.0
DC 143 (Vayego®) + D.	3	12.5	*A. nitida*	5	5	4	5	0.0	20.0
Acetamiprid + pyriproxyfen (Trivor®) + D.	3	20	*A. nitida*	4	3	3	5	40.0	40.0
Acetamiprid + pyriproxyfen (Trivor®) + D.	3	40	*A. nitida*	4	4	3	5	20.0	40.0
Cyborg® Plus 100 + D.	3	12.5	*A. nitida*	3	3	4	5	40.0	20.0
Acephate + D.	3	80	*A. nitida*	5	3	0	5	40.0	100.0
Syn 121 + D.	3	20	*A. nitida*	5	5	4	5	0.0	20.0

D= Designer®

Table 2.5.1.29.: The comparison of adult *Leptocoris* and *A. nitida* Day 7 mortality rates from Alstonville CTH sites when exposed various pesticides (set 17/06/2021). Replicates of 5 individuals placed into breathable containers using feeding on **14 days** post spraying (01/07/2021) *Murraya paniculata* berries as the delivered dose. Survivorship checked at 24, 72 hours and emptied out at 7 days to record final numbers. The spreader Designer® was used in each mixture at the 10ml/ 100L rate.

Chemical	Rep	Rate ml/ 100L	Species	24hr live	72hr live	7 day live	Tested population	3day % Mortality	7day % Mortality
Untreated	1	0	*Leptocoris*	5	5	5	5	0.0	0.0
Untreated	2	0	*Leptocoris*	5	5	5	5	0.0	0.0
Designer® (D.)	1	10	*Leptocoris*	5	5	5	5	0.0	0.0
Designer® (D.)	2	10	*Leptocoris*	5	5	5	5	0.0	0.0
Acetamiprid + pyriproxyfen (Trivor®) + D.	1	20	*Leptocoris*	5	5	5	5	0.0	0.0
Acetamiprid + pyriproxyfen (Trivor®) + D.	2	20	*Leptocoris*	5	5	5	5	0.0	0.0
Acetamiprid + pyriproxyfen (Trivor®) + D.	1	40	*Leptocoris*	5	5	5	5	0.0	0.0
Acetamiprid + pyriproxyfen (Trivor®) + D.	2	40	*Leptocoris*	4	4	2	5	20.0	60.0
Cyborg® Plus 100 + D.	1	12.5	*Leptocoris*	3	2	0	5	60.0	100.0
Cyborg® Plus 100 + D.	2	12.5	*Leptocoris*	3	1	0	5	80.0	100.0
Acephate + D.	1	80	*Leptocoris*	5	3	3	5	40.0	40.0
Acephate + D.	2	80	*Leptocoris*	5	5	5	5	0.0	0.0
Syn 121 + D.	1	20	*Leptocoris*	5	5	5	5	0.0	0.0
Syn 121 + D.	2	20	*Leptocoris*	4	4	3	5	20.0	40.0
Syn 121 + D.	1	30	*Leptocoris*	5	5	5	5	0.0	0.0
Syn 121 + D.	2	30	*Leptocoris*	5	5	5	5	0.0	0.0
Beta-cyfluthrin + D.	1	50	*Leptocoris*	0	0	0	5	100.0	100.0
Beta-cyfluthrin + D.	2	50	*Leptocoris*	2	0	0	5	100.0	100.0
Untreated	3	0	*A. nitida*	5	5	5	5	0.0	0.0
Designer® (D.)	3	10	*A. nitida*	5	5	4	5	0.0	20.0
Acetamiprid + pyriproxyfen (Trivor®) + D.	3	20	*A. nitida*	5	5	4	5	0.0	20.0
Acetamiprid + pyriproxyfen (Trivor®) + D.	3	40	*A. nitida*	5	5	3	5	0.0	40.0
Cyborg® Plus 100 + D.	3	12.5	*A. nitida*	3	3	3	5	40.0	40.0
Acephate + D.	3	80	*A. nitida*	5	4	4	5	20.0	20.0
Syn 121 + D.	3	20	*A. nitida*	5	5	5	5	0.0	0.0
Syn 121 + D.	3	30	*A. nitida*	5	5	5	5	0.0	0.0
Beta-cyfluthrin + D.	3	50	*A. nitida*	0	1	1	5	80.0	80.0

D= Designer®

Table 2.5.1.30: The comparison of adult *Leptocoris* and *A. nitida* Day 7 mortality rates from Alstonville CTH sites when exposed various pesticides (set 17/06/2021). Replicates of 5 individuals placed into breathable containers using feeding on **21 days** post spraying (08/07/2021) *Murraya paniculata* berries as the delivered dose. Survivorship checked at 24, 72 hours and emptied out at 7 days to record final numbers. The spreader Designer® was used in each mixture at the 10ml/ 100L rate.

Chemical	Rep	Rate ml/ 100L	Species	24hr live	72hr live	7 day live	Tested population	3day % Mortality	7day % Mortality
Untreated	1	0	*Leptocoris*	5	5	5	5	0.0	0.0
Untreated	2	0	*Leptocoris*	5	5	4	5	0.0	20.0
Designer® (D.)	1	10	*Leptocoris*	5	5	5	5	0.0	0.0
Designer® (D.)	2	10	*Leptocoris*	5	4	3	5	20.0	40.0
Acetamiprid + pyriproxyfen (Trivor®) + D.	1	40	*Leptocoris*	5	5	5	5	0.0	0.0
Acetamiprid + pyriproxyfen (Trivor®) + D.	2	40	*Leptocoris*	5	5	3	5	0.0	40.0
Cyborg® Plus 100 + D.	1	12.5	*Leptocoris*	4	3	1	5	40.0	80.0
Cyborg® Plus 100 + D.	2	12.5	*Leptocoris*	3	3	0	5	40.0	100.0
Acephate + D.	1	80	*Leptocoris*	5	5	4	5	0.0	20.0
Acephate + D.	2	80	*Leptocoris*	4	5	5	5	0.0	0.0
Syn 121 + D.	1	30	*Leptocoris*	5	5	4	5	0.0	20.0
Syn 121 + D.	2	30	*Leptocoris*	5	5	4	5	0.0	20.0
Beta-cyfluthrin + D.	1	50	*Leptocoris*	2	2	0	5	60.0	100.0
Beta-cyfluthrin + D.	2	50	*Leptocoris*	2	1	0	5	80.0	100.0
Untreated	3	0	*A. nitida*	5	5	5	5	0.0	0.0
Designer® (D.)	3	10	*A. nitida*	5	5	5	5	0.0	0.0
Acetamiprid + pyriproxyfen (Trivor®) + D.	3	40	*A. nitida*	5	5	4	5	0.0	20.0
Cyborg® Plus 100 + D.	3	12.5	*A. nitida*	2	2	1	5	60.0	80.0
Acephate +D.	3	80	*A. nitida*	5	5	5	5	0.0	0.0
Syn 121 +D.	3	30	*A. nitida*	5	4	4	5	20.0	20.0
Beta-cyfluthrin +D.	3	50	*A. nitida*	4	4	4	5	20.0	20.0

D= Designer®

2.5.2. Insecticide screening-field trials

Overview

Pesticide screening for the pest complex in Australian macadamia during as part of the program MC16004 (2016-2021) and pest monitoring evaluations in extreme dry and wet seasons 2020 and 2021 crops.

2016-2017

Fruit spotting bug (Amblypelta nitida) management

Experiment to show the importance of coverage with 9 m verses 6 m canopy height pruned centre rows of each plot to show need for coverage in tree tops.

Screening of alternate chemistries.

2017-2018

Macadamia lace bug assays (*Ulonemia decoris = Cercotingis decoris*) on live tagged racemes
Macadamia seed weevil (*Sigastus = Kuschelorhynchus macadamiae)* assays - alternate chemistry
Soap berry bugs *(Leptocoris* sp.) population collected for assays-alternate chemistry

2018–2019

Macadamia lace bug assays on live tagged racemes germplasm area – alternate chemistry
Leptocoris bug assays – alternate chemistry
Felted coccid assays- alternate chemistry
Field residual control of seed weevil sprays

2019-2020

Macadamia ace bug assays on live tagged racemes germplasm area- alternate chemistry
Leptocoris bug assays – alternate chemistry
Felted coccid assays- alternate chemistry
Fruit spotting bug residual control assays on Murraya berries
Field residual control of seed weevil sprays
Macadamia nut borer assays – alternate chemistry
Trichogrammatoidea cryptophlebiae effect – alternate chemistry

2020–2021

Leptocoris bug assays and residual control assays on Murraya berries
Felted coccid assays
Fruit spotting Bug residual control assays on Murraya berries
Field residual control of seed weevil sprays
Field residual control of Fruit spotting bug
Field residual control nut borer- alternate chemistries
Field FSB egg parasitism in density block assessment

All key options suggested by July 2020 macadamia SARP report (Hort Innovation MT19008) were investigated in 2020–2021 Physiology block trial at CTH Alstonville.
In the Regional Variety Trial (RVT) 3 at CTH Alstonville pest evaluation was undertaken during the period 2015-2021. FSB monitored flight timing was used as an action point for spray applications rather than calendar sprays. Within this block, two new early dropping varieties that are felted coccid and thrip and mite resistant were identified.

1. Summary

Significant management gains for the local macadamia growers have been achieved since 2016, as demonstrated by the individual seasonal results.

2016-2017

Good spray coverage above 6m is critical for successful management of Fruit spotting bugs (*Amblypelta* spp.) (FSB) in macadamia at CTH Alstonville especially the late maturing, thinner shelled varieties (849 and A4). Even the industry standard beta cyfluthrin (i.e. Bulldock®) treatments were failing to protect the crop in 9m trees (>40% FSB damage) compared with 6m trees (<9% FSB damage for all varieties).

Smaller tree size is necessary to reduce spray drift issues for the crop. New sprayer arrived PTO mounted 2000L trailer Tuffass single sided air-blast sprayer to the tops of 9m high macadamia trees at the rate of 3000L/ha (10-15L per tree).

2017-2018

Macadamia lace bug treatments were examined, SeroX® (Butterfly pea extract) at the recommended rate of 2L/Ha was tested, but control proved not to be sufficient. Sulfoxaflor (i.e. Transform® 40ml/100L) was equally controlling macadamia lace bug as standard diazinon and trichlorfon treatments in the field assay.

Indoxacarb field efficacy on seed weevil oviposition were noted 1/11/2017, registration of product achieved by mid-August 2018. It was noted that indoxacarb stopped weevil oviposition for 13 weeks in dry season, which is a major improvement.

2018–2019

Macadamia lace bug assay testing flupyradifurone (i.e. Sivanto® Prime) at 50ml/100L also equivalent to the standard treatments, SeroX® (Butterfly pea extract) rates of 1000ml/ 100L were starting to show some activity against macadamia lace bug but not economic to use in the field at that rate according to the manufacturer.

The adoption of the indoxacarb (i.e. Avatar®) treatment for managing MSW in northern rivers was close to 100% with good results.

The December / January *Macadamia ternifolia* FSB flight time was adopted for the spray schedule of the RVT3 trial block, the Entomology block (main IPM trial) and Physiology blocks at the Centre for Tropical Horticulture (CTH) at Alstonville.

2019-2020

Field assays on felted coccid, flupyradifurone (i.e. Sivanto® Prime) at 50ml/100L and sulfoxaflor (i.e. Transform®) at 40ml/100L were compared to diazinon 125ml/100L. Sivanto® Prime and Transform® gave comparable control.

A further assay with macadamia lace bug assays showed that a new compound (Syngenta SYNFO121) gave good control at low doses. Effects on bees are still unknown, but wider examination of its profile showed activity against macadamia nut borer and FSB and *Leptocoris* bugs. Tests showed some compatibility with the egg parasitoid for MNB.

2020–2021

In July 2020 SARP recommendations for macadamia key pests were evaluated. Tetraniliprole (i.e. Vayego®) at 12.5ml/100L and Syngenta SYNFO121 applied at 30ml/100L did give some control of Fruit spotting bug *Amblypelta nitida* (FSB) and macadamia seed weevil *Kuschelorhnychus macadamiae* (MSW) when applied through spring and summer (3 applications October, November and January) compared to the untreated plots.

Applications of Vayego® and the new compound significantly reduced the levels of MSW laying and oviposition by November 18th compared to the untreated areas but was not as effective as indoxacarb, which had reached that point by November 4th. Indoxacarb remained effective for 12 weeks in a much wetter season than the previous year.

Syngenta SYNFO121 and Vayego® were applied at the determined FSB flight times at CTH Alstonville and were

effective at controlling FSB under high pressure. Untreated plots were averaging above 50% FSB losses in this area in the early harvests and to be equivalent to beta-cyfluthrin is impressive (15% damage). The trial also clearly showed just how selective FSB feeding can be. By sampling the neighbouring cv. 246 rows in the untreated and standard spray areas (April harvest only) damage was 50% reduced compared to the cv. 849 trees in both treatments.

Syngenta SYNFO121 and Vayego® were also successfully suppressing macadamia nut borer *Cryptophlebia ombrodelta* (MNB) oviposition. There were few MNB tunnels detected in February then only 11% of nuts in the first harvest in March. This compared well to the standard beta-cyfluthrin (15% tunnels at first harvest) treatments and (22% tunnels at first harvest) in the untreated plots.

Introduction

Figure 2.5.2.1.: NSW DPI Centre for Tropical Horticulture (CTH) Alstonville site from above taken in 2010. All the main macadamia plots are visible:

1. Sink plot planted 2007 – testing pest risks "out of season flowering" cropping in autumn.
2. Front Block planted 2004- cv. 816/ 246 some A4 canopy management limiting tree height.
3. Physiology planted 1998 –cv. 849 / 246 cincturing hedging and for spray trials
4. Entomology planted 1998 – cv. 741,246,849, A4 with 246 pollinator buffers for spray trials
5. RVT 3 planted 2007- new varieties vs. industry standards under best management practice.
6. Density plot planted 2007 – cv. 246 testing pest risks of "planting density" on production.
7. Wild germplasm and Progeny block planted 2000– Reference specimens from all known wild plants.
8. Accession planted mid 1970's – Paired plants of all major cultivars reference specimens.
9. Sustainability block cv. 849 planted 2000- originally a soil erosion plot and regrowth pruning.
10. Arboretum planted from 1963- Original wild *Macadamia tetraphylla* seedlings on site and reference fruit trees globally sourced.

Centre for Tropical Horticulture (CTH) Alstonville - background and pest pressure for season summaries

The site is unique in Australia in terms of the array of macadamia germplasm available to assess production and management issues for the local macadamia industry. The two seasons 2019/2020 and 2020/2021 have been complete opposites in terms of extremes of moisture stress on trees and the management required and as such the need to measure the pest pressure and treatment response were important.

The main management trials were conducted in Block 4 (Entomology block), and Block 3 (Physiology block) where the macadamia variety 849 is one of the most prone to FSB and MNB attack on the entire site. At CTH Alstonville we monitor *Cryptophlebia ombrodelta* (macadamia nut borer) (MNB) with pheromone flight traps in the Entomology (4), Arboretum (10), Accession (8), and Germplasm (7- highest elevation on farm) areas, and use of the laboratory reared egg parasitoids for control. The FSB monitoring hedges are located above the arboretum (10) area, next to the Bruxner highway, and between the wild Germplasm and Sink blocks (1). The Arboretum and rainforest area around the creek below the packing shed are major host breeding areas for a range of key macadamia pests but in recent time the expansion of the foam bark plantings in there has led to more *Leptocoris* sp. being on site as well. *Amblypelta nitida* (FSB), *Kuschelorhynchus macadamiae* (MSW) and several macadamia lace bug species (mainly *Cercotingis decoris previously Ulonemia decoris*) and *Acanthococcus ironseidei* macadamia felted coccid (MFC) are plentiful on site so reliable pressure to conduct experimental work on their management is very feasible. Flush leaf and growing point pests are also common Scirtothrips (*Scirtothrips albomaculatus*), broad mite (*Polyphagotarsonemus* sp.) and Eriophyiid mites (*Diptilomiopus davisi* on cv. A4s). Taxonomists suggested that there are new species involved here as well (Danuta Knihinicki, pers. Comm.).

We have collaborated on a range of biological control agents and the site has many sought after parasitoids naturally present (eg. flies:*Trichopoda giacomelli,(GVB) T. pennipes, Apocephalid sp. (*ex-FSB*) Gymnoclytia* sp. (ex-*Leptocoris* sp.)*,* wasps: *Centrodora darwinii (ex-FSB), Gryon sp (ex FSB)., a local Anastatus* sp*.* and *Metaphychus macadamiae* (Polaszek et al. 2020) the newly named felted coccid parasite). Phygastrid mites which do feed on macadamia seed weevil lava in the field and various entomopathogenic fungi like *Beauvaria bassiana* and *Metarhyizium* sp. are also present. We still culture some of these when necessary in the laboratories at Wollongbar Primary Industries Institute (WPII).

Laboratory colonies of *Cryptophlebia ombrodelta* and its egg parasitoid *Trichogrammatoidea cryptophlebiae*, *Amblypelta nitida, Amblypelta lutescens*, *Nezara viridula*, and recently *Kuschelorhynchus macadamiae*, *Leptocoris* sp. and a range of scolytid trunk borers are kept at Wollongbar WPII for research purposes.

Monitoring schedules used at CTH Alstonville in all trial areas

The total crop loss due to insect pest activity has been studied for many years (Ironside, 1981; 1982; 1983; 1987; 1988). To determine the effect of specific pests you need to be monitoring the crucial periods where that pest population is expanding and how certain conditions effect on that pest and the beneficials that may regulate it.

Macadamia lace bugs (Tingiidae) are a cumulative pest that builds up between seasons when the trees begin to flower. The pest is usually worse in the more elevated areas and thrives in closed poorly ventilated canopies, and the adults remain on the trunks and branches to feed between the flowering events which is when they enter the breeding cycle (approximatly16 days @ 25°C) (Huwer et al. 2011). Eggs are laid into the florets all 5 nymph stages and adults feed on the racemes and some young leaf, each raceme can generate more than 20 macadamia lace bugs and the saliva is toxic to the floret causing dieback (Figure 2.5.2.2.) (Huwer and Maddox, 2007). Flooding rain can wash them off the trunks and reduce the carry over if it falls before the main flowering.

For macadamia lace bug species, the monitoring of the flowering in the untreated macadamia sites at CTH Alstonville (CTH blocks 1, 6, 7 and 10 (Figure 2.5.2.1.) between June and the main flowering in September each season, is very important. Knowing how the macadamia lace bug population builds up on the out of season crop that could be present is important. Monitoring includes checking for breeding areas of burnt flower, cast skins and live nymph and adult populations, to determine when the population will fly (Huwer and Maddox, 2007; Maddox, 2009; 2010; Huwer et al. 2011) and the opening time for the florets of the main crop, are all key considerations.

Once macadamia lace bugs have become established on a farm the decision for most growers is whether to use a broader durable treatment like diazinon before the florets open to eliminate the threat to nut set and reduce the effect on the bees. The alternative has been to use trichlorfon during flowering to get control of about one week during this period, if macadamia lace bugs have migrated into the orchard when flowering has commenced. Organic growers are using pyrethrin at fortnightly intervals from early July to stop the population build up.

Wider tree spacing and improved ventilation do reduce the damage caused by macadamia lace bug which attacks the flowers from the bottom of the tree up usually.

This research investigated the effectiveness of the butterfly pea extract SeroX®, inter-rows and larger biodiversity. In a previous study we found that releases of green lace wings without the support. of pyrethrin sprays were not effective (Huwer, 2011) and SeroX® needed to be at much higher rate than recommended (at least 1000-2000ml/ 100L) to control bugs (Huwer et al. 2015b).

Figure 2.5.2.2.: Left: The macadamia lace bug (*Cercotingis decoris)* damage to florets with nymphs on the raceme and seed weevil oviposition marks on the green husk are distinctive in the out of season crop that set in April/May. Rright: Macadamia lace bug damage and breeding happening on the early flower (cv. 344) ready to move into the main flowering months behind in development.

Monitoring of early nut drop was undertaken to determine what has caused the crop loss after nut set and natural thinning of set nut, which requires experience with the various key pests (see Figures 2.5.2.3. and 2.5.2.4.). The 10 freshest fallen nuts are collected from under each tree and examined for the MSW laying mark and MNB oviposition. The nuts are dissected below the mark with a pocket knife to see what MSW life stage is present (egg, larvae, pupae or adult or missing or even fungal infected) and these numbers were recorded. The cut kernel was also examined for evidence of FSB feeding within the husk and shell, which is also recorded. The usual season monitoring intervals are shown in Table 2.5.2.1., based on determining the effectiveness of experimental sprays in comparison with conventional options applied at the same time and the seasonal conditions.

After December the nut drop has normally ceased and cannot be used for monitoring. Therefore, a sample of 10 green nuts is collected from the canopy of each of the trial areas (at about 8m height, using an elevated working platform (i.e. Hydralada®). The nut sample is placed into labelled onion bags and kept in a cool room 5^{o}C until they were assessed for presence of MSW, MNB and FSB feeding or MSW and MNB oviposition. Monitoring was done fortnightly until harvest in early March.

Figure 2.5.2.3.: The macadamia seed weevil oviposition marks on the green husk are distinctive and life stages can be determined by cutting open the nut and examining the kernel and inner shell lining.

Figure 2.5.2.4.: The cause of dropped nuts under trees can be visually sorted as macadamia seed weevil (MSW) activity top left, *Cryptophlebia ombrodelta* (MNB) activity top right, and *Amblypelta nitida* (FSB) below. After shell hardening the FSB damaged kernel is picked up at harvest when nuts are dried, cracked and assessed.

Table 2.5.2.1.: The timing of treatment evaluations for CTH trial sites during 2020/21 season but have been very close to this for many seasons (+/- 2 weeks usually 2017-2021).

Date	Evaluation/ Application	Target	Evaluation Description
July/August	Pre treat EV flowers weekly	Lace bug	Nut set critical option
Aug/Sep	Macadamia lace bug spray		7 days post spray for re infestation sample Assess mortality levels under microscope
22/9/20	EV1 10 nuts per tree	MSW/ FSB activity	Pre treatment
7/10/20	EV2 10 nuts per tree	MSW/ FSB activity	Pre treatment
	MSW/ FSB spray		
21/10/20	EV 3 10 nuts pre tree	MSW/ FSB/ MNB activity	7 days post spray1
4/11/20	EV 4 10 nuts pre tree	MSW/ FSB/ MNB activity	22 days post spray1
	MSW/ FSB spray		
18/11/20	EV 5 10 nuts pre tree	MSW/ FSB/ MNB activity	12 days post spray 2
1/12/20	EV 6 10 nuts pre tree	MSW/ FSB/ MNB activity	25 days post spray 2
	FSB/MNB spray		
16/12/20	EV 7 10 nuts per tree	MSW/ FSB/ MNB activity	11 days post spray 3
8/1/21	EV8 10 nuts canopy	FSB/ MNB activity	34 days post spray 3
	FSB/MNB spray		
29/1/21	EV9 10 nuts canopy	FSB/ MNB activity	7 days post spray 4
10/2/21	EV 10 10 nuts canopy	FSB/ MNB activity	19 days post spray 4
March 2021	EV 11 1st harvest 30 nuts pre tree	Thrips/ MFC/ MNB FSB nut quality	Husk examination Kernel recovery
April 2021	2nd Harvest 30nut/tree	FSB/ MNB nut quality	Kernel recovery
May 2021	3rd Harvest 30nut/tree	FSB/ MNB nut quality	Kernel recovery
June 2021	4th Harvest 30nut/tree	FSB/ MNB nut quality	Kernel recovery
July 2021	5th Harvest 30nut/tree	FSB/ MNB nut quality	Kernel recovery
August 2021	6th Harvest 30nut/tree	FSB/ MNB nut quality	Kernel recovery

At harvest a sample of 30 nuts was taken from under the tree. Harvest was undertaken monthly between March and August. The nuts collected were freshly dropped nuts with green husks if possible, to allow for examination. Counted and weighed and total harvest under each tree was also weighed to give a nut estimate. This is always an underestimate of total crop because the fresh green nut is the heaviest, but it gives a reasonable guide to likely yields until the dried nut in shell kernel figures are obtained.

The sample nuts were kept in a cool room 5°C until they were assessed for presence of MSW and MNB oviposition or feeding, macadamia felted coccid (MFC) or thrips and mite activity on the husk using headband magnifiers (Optivisor) with 7x magnification in the laboratory examinations.

MFC is an insect that expands across almost every part of the tree and causes major damage to foliage, flowers, branches, and in high enough populations can be lethal. The MFC crawlers will move onto the husk surface each season. The detection of more than 10 live MFC on the nut husk surface is an indication of expansion throughout the tree, the proportion of the nut sample (30 nuts) that has more than 10 live MFC is the unit we express in the data (e.g. 10nuts /30 would be 33% nuts have a mobile MFC population present). Thrips and mite activity is determined by having more than 25% of the nut husk surface showing feeding damage and is scored as number of nuts from the sample like MFC (Table 2.5.2.2.).

After the green nut is examined and the levels of pest activity recorded, the nuts were de-husked then step dried to 1.5% moisture and cracked for kernel quality assessment (as per industry guidelines). In most cases the FSB damage is not visible until shell removal. Proportions of nut lost to FSB are described as the number of kernels damaged over the total number of kernels assessed for each sample. Process was repeated for each subsequent harvest.

Table 2.5.2.2.: Management changes and drought effects on the pest insect fauna populations in RVT3 at CTH Alstonville planted 2007. Each tree is sampled mid harvest (May -30 nuts from each canopy). In the drought season* (2020 crop) produced nuts that were on average 21.4% smaller and had 17.6% more kernel inside. Bug damage in 2020 is over 75% *Leptocoris* sp. (*264 seen on *Macadamia ternifolia* trap trees) the rest was *Amblypelta nitida* (FSB) which is the primary cause in the other seasons. (from Macadamia Pest Management Guide 2021-22)

RVT 3 management changes (170 trees)	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**
Total rain in mm (1800 mm 40 year mean)	1939	1489	1970	1397	787	2299	2022
August-December (534 mm 40 year mean)	632	448	663	466	213	645	670
Diazinon for Lace bug	none	yes	yes	yes	yes	yes	yes
Trichogrammatoidea releases for MNB	yes	yes	yes	yes	yes	yes	yes
Acephate/ beta-cyfluthrin (MSW/ FSB)	none	yes	yes	yes			
Hedge/ *M. ternifolia* FSB flight spray timing	none			yes	yes	yes	yes
Indoxacarb (MSW)	none				yes	yes	yes
RVT3 crop changes (block averages)							
nutsize (g) @1.5% moisture DNIS	7.8	7.9	7.0	7.5	7.0	5.9	7.7
%TKR @1.5% moisture DNIS	38.2	37.2	38.8	40.0	39.7	45.6	39.1
RVT3 Insect activity							
% bugloss in kernel per tree	4.9	1.2	4.1	0.3	0.8	0.8	0.6
FSB seen on *M. ternifolia* (Oct-March)		274	521		189	103*	339
% nut fed on by seed weevil (MSW)	0.4	1.3	19.7	6.3	0.5	0.1	1.7
Male MNB moth catch rate Nov-March	9.3	3.9	26.0	35.8	18.7	54.7	50.8
MNB eggs per 100 nuts	15.7	13.3	64.9	14.4	21.7	13.1	31.1
MNB tunnels per 100 nuts	3.6	3.5	19.5	2.0	1.6	0.4	2.2
% Thrip/Mite damage on husk	7.2	6.3	30.5	40.8	43.4	75.1	34.8
% Nut with felted coccid (>10 live)	0.3	1.4	1.4	6.0	23.6	38.4	34.8
Variety A538 % nut with felted coccid	0.0	0.0	1.3	0.0	3.4	0.0	0.0
Variety A447 % nut with felted coccid	0.0	0.0	0.0	0.0	0.6	0.0	1.1

Individual tree yields were usually measured. Total nut in husk collection was weighed (+/-0.05kg), up to 30 nut sub-sample were gathered for each tree sampled (weighed +/-0.05 kg). From this, total nut number was calculated and when the kernel quality data was done, the dry weight was calculated as dry nut in shell weight @ 10 % moisture for each tree. The total crop was usually expressed as kg dry nut in shell (DNIS) @ 10% moisture / tree and converted to tons of nut/ hectare or tons of kernel per hectare.

The labelled samples allowed us to combine the yields for the sample tree and the quality results to show the effect the treatments had on the pest. Data was analysed and presented as graphed averages over time for the season evaluations and each harvest period. Significant differences were generated using t test. Comparisons between treatments and seasons across varieties were made (Table 2.5.2.3).

Strategic spray timing is developed by knowing when crop loss to the various pest matters

Crop loss to MSW is rarely detected at harvest time, yet it can be 100% crop failure by Christmas. From 2012-up to season 2018 in the Northern Rivers district the weevil imposed major losses. The Sink block at CTH has not produced any nut for over 4 seasons when untreated, which was mostly due to damage by macadamia lace bug and MSW (Maddox et al. in Bright 2021). Crop loss due to macadamia lace bug can also approach 100% if unmanaged (Huwer et al. 2011; Bright, 2021).

Losses to FSB in dry seasons are usually around 10% but can be far higher as shown in a wet season and over 80% on some varieties in high pressure areas is common (Huwer et al. 201b,; MT10049 p.145, see data 2016-2017 data, SARP 2020 trial this volume, and previous work in germplasm blocks where *M. ternifolia* were >85% FSB damaged at the CTH site 2013-2015, Maddox et al. 2015, in Topp, MC 09021, 2015, pp.140-167, Huwer et al. 2015b, MT10049 p. 202). Old damage in November/December is also attractive for later season activity (February-May) in most crops they attack (Huwer et al. 2015b, MT 10049 p. 223) so that needs to be minimised.

Crop loss to MNB and husk spot disease can both be seen as immature kernel in some seasons and also cause almost total crop failure if unmanaged, so some form of green husk assessment at harvest is needed to partition that crop loss correctly.

The effect of felted coccid, thrips and mites is more the build up phase between seasons, whenever we see high levels on green nuts the likelihood of high populations on trunk and leaves points to effect on the flower health in the following season. Too many mites/ thrips no bud formation, too much felted coccid significant flower dieback and regrowth wilting, and these are major nursery issue worldwide for macadamia (Figure 2.5.2.5.). The current best practice spray program used on the regional variety trial 3 at CTH has advanced (Table 2.5.2.2.) from the 6 monthly Bulldock® applications of the 1990's (CSIRO Cameron McConchie request), it was down to 2 FSB targeted applications in 2002-2006 with little need to treat for MNB, organic controls were being reviewed by the DPI on a larger scale (Treverrow, 2003), but macadamia lace bug and macadamia seed weevil changed all that for NSW growers from 2007 (O'Hare et al. 2004).

The weather extremes generate very different pest pressures (Table 2.5.2.2). One group of pests that do not show in the harvest data but are limiting the orchard lifespan are the trunk boring beetles. The very dry season for a rainforest tree, and the enhancing of the trunk borers and the associated tree death where water has become limiting, brought home that care is needed with products like Ethephon® and how those beetles can be managed is debatable.

Figure 2.5.2.5.: CTH Alstonville macadamia flush leaf and growing point pests are also common Scirtothrips (*Scirtothrips albourmaculatus*), Broad mite (*Polyphagotarsonemus* sp.) and Eriophyiid mites (*Diptilomiopus davisi*on cv. A4s) Danuta Knihinicki suggested that there are new species involved here as well.

Addressing the coverage issue for CTH spray trials: 2016/2017

Real FSB damage estimations cannot be accurate if the old spray equipment at CTH is not covering the upper canopy (see Table 2.5.2.3. and Figure 2.5.2.6.). The lessons learnt from earlier trials were that FSB damage increases as trees get bigger, later maturing thinner shelled varieties are prone (Figure 2.5.2.6.). Large numbers of untreated macadamia tree buffers between the single treatment trees leads to heavy build up of macadamia lace bug over a few seasons. This trial (Table 2.5.2.3.) led to the NSW DPI purchasing the new Tuffass sprayer (Figure which was instrumental in the macadamia seed weevil application success (2017-2018).

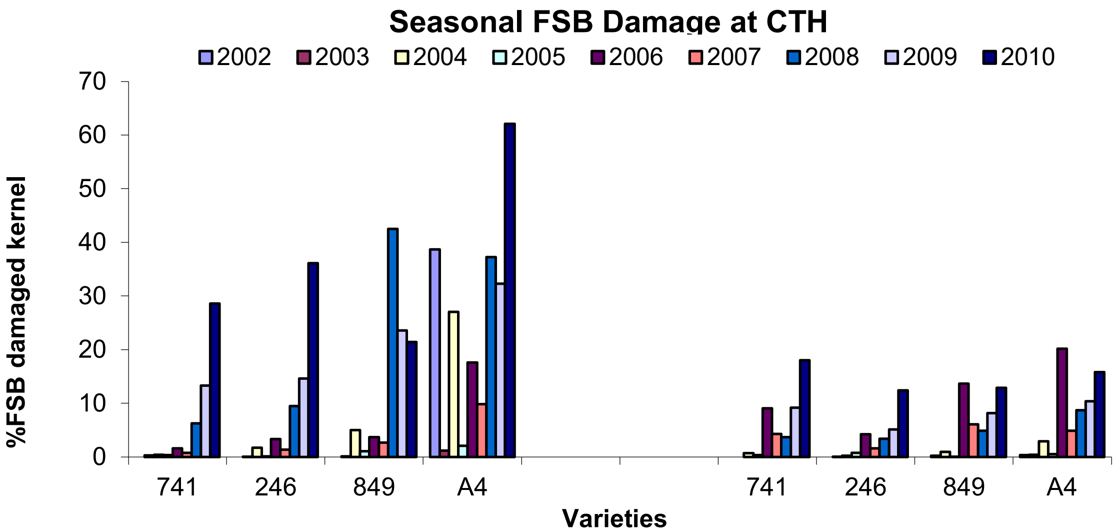
The centre row of each treatment strip was pruned to 6m to compare sprayer efficacy with surrounding 9m rows. Two to four fold feeding preference by the bugs for the later varieties cv. 849 and cv. A4, required better equipment, if we were going to use this block to measure differences in chemical efficacy.

Untreated cv. 246 or cv. 741 has FSB damage levels of 10-15% loss usually, effective spraying will halve that, but for the later varieties loses can be well over 50% and spraying is important (Figure 2.5.2.6.).

The Entomology block is well situated to test FSB treatments because of the rainforest source proximity, finding clean nut on those later varieties shows efficacy. Bulldock® is clearly still effective at 50ml/100L on 6 m trees but not at 9m same block, same spray equipment (Table 2.5.2.3.).

Table 2.5.2.3.: Season 2016-2017 Comparison of %FSB damage to macadamia kernel (standard error) from the different varieties treated December and January with Tornado air-blast sprayer 8L/tree at the CTH Entomology block.

FSB treat	**Variety**	**246**	**333**	**344**	**741**	**849**	**A4**
9m Bulldock® 50ml/ 100L	trees %FSB (se)	7 11.2 (3.9)	4 8.8 (0.6)	4 1.8 (1.9)	3 26.6 (1.2)	3 43.4 (1.4)	3 15.6 (2.8)
9m Untreated	trees %FSB (se)	3 11.1 (0.5)			3 11.3 (1.8)	3 46.7 (10.8)	4 53.4 (9.7)
9m Bulldock® 50ml/ 100L B20	trees %FSB (se)	9 12.6 (2.6)					
9m Untreated B19	trees %FSB (se)	9 12.4 (3.1)					
6m pruned Bulldock® 50ml/ 100L	trees %FSB (se)	12 8.3 (2.7)			12 5.9 (0.9)#	12 6.2 (1.8)#	11 7.2 (1.7)#



Wasps only standard sprays (2x endosulfan 2x Bulldock®)

Figure 2.5.2.6.: Increasing FSB activity in the entomology plot at CTH Alstonville as trees age (planted 1998) 9 tree means over seasons harvest for each variety either sprayed or unsprayed and using wasps *Centrodora darwinii* releases for FSB and *Trichogrammatoidea cryptophlebia* releases for MNB from 2002-2010. Canopy size is an increasing risk, making coverage critical and smaller tree size desirable.

Figure 2.5.2.7.: NSW DPI 2000L trailer mounted Tuffass® spray unit details, and canon nozzle structure, and manufacturing plate.

Macadamia lace bug management

SeroX® was tested at 2L/Ha applications, as recommended and also at the dose range from 100ml/ 100L- 800ml/ 100L in 2017 for macadamia lace bug management.

Our assay for macadamia lace bug, was done on tree because the pest requires live florets every 2-3 days to survive (Huwer et al. 2011). Populations in flowers were monitored in July/ August each season and different pesticides were screened in the germplasm block area (Block 7, Figure 2.5.2.1.). Pesticide mixtures were applied to infested racemes. Treated racemes were tagged and collected 7 days later, put into labelled paper bags. In the laboratory at WPII, macadamia lace bug mortality was examining under microscopes at 12x magnification. This accounts for re-infestation and presence of live young nymphs emergence which can be missed at day 3.

Table 2.5.2.4.: Major findings of the macadamia lace bug assays conducted on tagged racemes in CTH Alstonville germplasm area in years 2017, 2018 and 2019. Each mixture was applied by a small hand mister at the rate of 2ml per raceme. A group of 10 tagged racemes showing damage were treated on 3-4 trees when the live nymph population has reached the build up phase. Racemes were collected into labelled paper bags after 7 days and scored under a stereo microscope 12x magnification back at Wollongbar WPII. Standard registered treatment is Diazinon or Lepidex® shown in yellow, the survival rate (*) per raceme is not different to the standard for that year and (**) is better than the untreated control (shown in blue) in that year.

Treatment applied		Racemes examined	Raceme with cast skins	Total LB	Live adults	Live LB per raceme	std err
Pre Treat	18/8/17	26	22	198	8	7.4	1.6
Untreated	25/8/17	10	10	57	1	5.4	1.5
Transform®	40ml/ 100L	20	15	11	1	0.1*	0.2
Diazinon	125ml/ 100L	20	17	19	4	0.2	0.3
Lepidex®	200ml/ 100L	20	18	18	4	0.9	0.2
SeroX®	100ml/ 100L	20	19	162	10	7.9	2.1
SeroX®	200ml/ 100L	20	19	147	15	7.1	2.2
SeroX®	400ml/100L	20	19	56	9	2.6	0.4
SeroX®	800ml/ 100L	20	17	122	16	5.7	1.1
Pre Treat	28/8/18	40	38	171	28	4.3	1.0
Untreated	5/9/18	50	49	180	20	3.6	0.4
Transform®	40ml/ 100L	40	17	4	1	0.05*	0.05
Diazinon	125ml/ 100L	40	21	23	4	0.2	0.2
Lepidex®	200ml/ 100L	40	16	7	1	0.2	0.1
Sivanto® Prime	50ml/ 100L	40	12	9	2	0.1*	0.08
Wetcit®	800ml/ 100L	40	31	140	12	3.5	0.5
SeroX®	200ml/ 100L	39	29	156	17	4.0	1.0
SeroX®	1000ml/ 100L	40	25	49	12	1.2**	0.2
Pre Treat	19/8/19	32	22	48	5	1.5	0.3
Untreated	28/8/19	30	28	78	16	2.5	0.6
Diazinon	125ml/ 100L	40	19	4	0	0.05	0.03
Sivanto® Prime	50ml/ 100L	40	23	21	2	0.05*	0.03
Transform	40ml/ 100L	30	18	19	3	0.1*	0.05
Wettable sulfur	500g/ 100L	30	10	50	1	1.6	0.5
Synfo121	10ml/ 100L	40	27	10	0	0.13*	0.1
Nuf 3445	300ml/ 100L	30	19	13	0	0.3**	0.1
OCP Oil	160ml/ 100L	30	9	11	1	0.3**	0.2

The results of the 2017 trials for the control of MLB showed that only Transform® applied at 40ml/100L was offering control similar to the normal Diazinon treatment. The SeroX® applications were no different to the untreated control even at 800ml/ 100L which is 8x the recommended rate. In 2018 we continued the applications showing that the Bayer product Sivanto® Prime at 50ml/100L will also be effective against macadamia lace bug, and that the SeroX® when applied at 1000ml/ 100L was beginning to give some control, but not as effective as other tested products.

The 2019 assays were testing two new options the Syngenta Synfo121 which was effective at the 10ml/100L rate, the Nufarm experimental 3445 product was effective at 30ml/100L but wettable sulfur failed to suppress lace bug activity at 500g/ 100L rate. The organic pyrethrum oil OCP applied at 160 ml/ 100L also gave activity.

Re-infection of macadamia lace bug from neighbouring untreated farms or unsprayed macadamia trees nearby is possible within a week is possible with products with a short residual time (Table 2.5.2.5. and Figures 2.5.2.7. and 2.5.2.8.). Well timed spraying is very effective and the Entomology trial block at CTH Alstonville has had significant pressure since 2007 and was used to show Diazinon is the chemical with the longest residual time option in 2012 (and 2.5.2.8.).

Macadamia lace bug will fly onto sticky shiny flight cards (i.e. yellow sticky traps) or reflective surfaces and adult numbers can be measured simply by placing flight cards in the lower canopy of trees within a treatment block. The last 3 seasons have had monitoring cards and plates checked monthly looking for lace bug presence (Figure 2.5.2.7. adult per plate per month) and the beneficials that may be associated with them. The Entomology blocks have been using the results from the CTH assays in 2017-2019 (Table 2.5.2.5.) to make the comparisons with yields over the full season. Assay results were repeated in the field trial with only 3 macadamia lace bugs in November total over 3 years after nut set being found, compared to all year activity in untreated areas at CTH (sink block and density block, blocks 1 and 6, Figure 2.5.2.1. site map).

Block 1 2019 – Sivanto® Prime 50ml/ 100L, 2020- Sivanto® Prime 50ml/100L, 2021- Sivanto® Prime 50ml/ 100L
Block 2 2019 – Lepidex® 200ml/ 100L 2020 – Sivanto® Prime 50ml/ 100L, 2021 - Synfo 121 (confidential)
Block 3 2019 – Transform® 40ml/ 100L, 2020 – Diazinon 1.25 ml/ 100L, 2021- Diazinon 125ml/ 100L
Block 4 2019 – Diazinon 125ml/ 100L, 2020- Diazinon 125ml/ 100L, 2021- Diazinon 125ml/ 100L

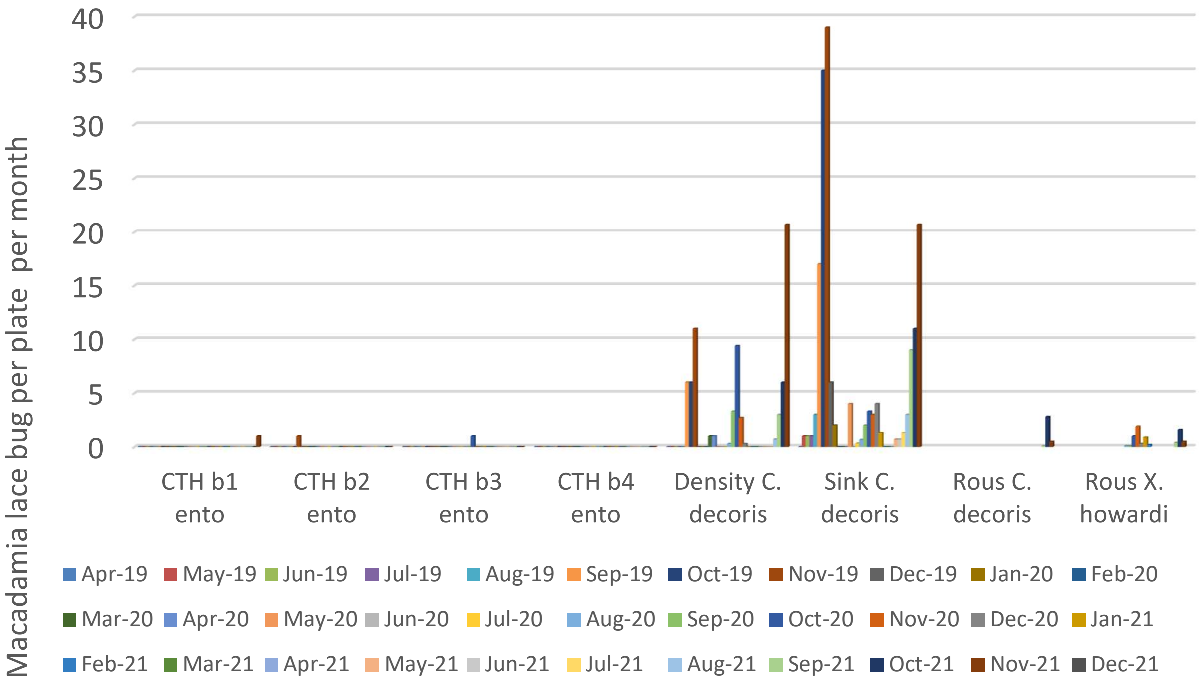


Figure 2.5.2.7.: Adult macadamia lace bug monthly incidence in the main trial blocks at CTH Alstonville and monthly yellow flight card trapping from May 2020 at the Rous site which mainly has the other species.

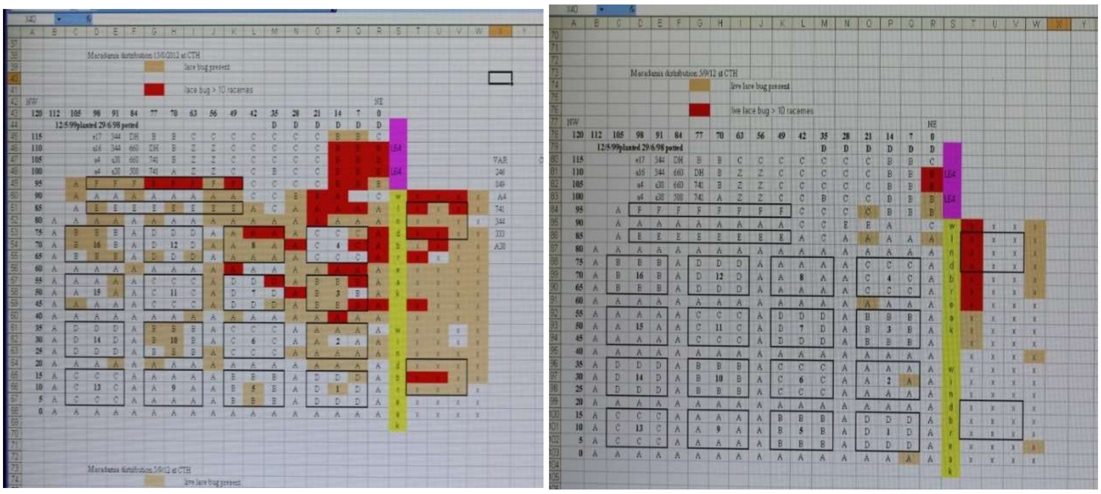


Figure 2.5.2.8.: Spatial distribution of macadamia lace bug on flowers in trees in the Entomology block 2012 CTH Alstonville. Each individual square is a tree in the block (Left) 15/8/2012 trees with more than 10 racemes carrying live nymphs in red, live bugs present in pink, clear without shading. Block spraying on 21/8/2012, two strips of 5 trees next to blue and lower yellow end of windbreak left untreated, samples collected 23/8/2012 and assessed for survivorship under microscopes at Wollongbar WPII. (Right) Spatial distribution of live macadamia lace bug on florets on 5/9/2012, only untreated areas are carrying heavy populations (red shading) 2 weeks after spraying and evidence of 20-70m spread from the remaining lace bug source.

It is different when the unsprayed Sink block, with cultivars that like to flower often and give macadamia lace bug unrestricted opportunity to breed and have adult bugs present all the time. This results in expanding numbers after flowering. The macadamia lace bug population remains on the bark between the floral events. The result was that the Sink block hardly a nut left in the middle of the block for the last 4 years (Figure 2.5.2.7.). This data shows how well the macadamia lace bugs did in 2019 and 2021 but were somewhat restricted by the heavy rain in 2020 (rainfall patterns in Appendix 2.5.4.

The Rous site is ideally situated between a larget organic orchard and the block monitored is 100m away, across the road in a managed farm area. The levels of macadamia lace bugs migrating each season from the organic farm into the managed orchard was effectively monitored. It was trapped from May 2020 onwards showing it was not usually invaded by *C. decoris* but other species of lace bug in this period, and that his spraying has been effective despite the constant invasion (Figure 2.5.2.7.).

The Density block has the inter-row in place from 2020 and has not shown significant differences compared to the Sink block since then (Figure 2.5.2.7.). The influence of the inter-row (Density block 6, Figure 2.5.2.1.) as opposed to actual tree density is still unresolved. The Density block was showing reduced production by 2012-2013 (year 6) in the tighter spaced trees, but normal cropping on those at 10 x10m spacing when unsprayed mainly due to macadamia lace bug activity (Huwer, et al. 2016). With the advent of indoxacarb applications for seed weevil (2018 this project) it became possible to revisit that effect and look at FSB parasitism and damage by tree spacing at the individual tree level along with inter-row diversity.

Summary for Macadamia lace bug

Macadamia lace bug has been controlled in all areas treated with the new chemical options in the Entomology block. The block remained macadamia lace bug free April 2019- December 2021.

The project was initiated after a recommendation to test SeroX® at of 2L/ hectare, which is the registered rate in cotton. Previous work (Huwer et al. 2011, 2016) showed that SeroX® was effective at rates around the 1000ml/ 100L for macadamia lace bug (Table 2.5.2.4.) and for FSB rates around 2000ml/ 100L were required.

Field assays were conducted to test SeroX® being used and a wide range of organic suitable pesticide options. Efficacy data is included in Table 2.5.2.4.

Alternate options to Diazinon needed to be investigated. Trials showed that macadamia lace bug control using Transform®, and Sivanto® Prime were equivalent to diazinon in controlling macadamia lace bug and ensuring nut set each year. These two products also controlled felted coccid effectively. These new products give protection against the sucking pests only . Further pesticides applicications are needed for management of caterpillar and beetle pests as well as flower diseases during a similar time.

Trichlorfon is still an available option but its use pattern is prioritised for review. Out of the new products coming the SYNFO121 is looking the most promising, but bee safety is still to be determined by manifacturer (Table 2.5.2.4.).

Residue work for both Synfo121 and Sivanto® Prime as pre flower application is on the way in collaboration with manufacturer.

To date, multiple applications of natural pyrethrin are the option for organic growers (*Huwer,* et al. 2011), but re-infestation of macadamia lace bug after a week remains likely.

From a cultural control perspective it was already known that wider tree spacings reduce the activity of lace bug, improved light and ventilation in and through the trees is important (Huwer et al. 2011). In blocks badly affected by macadamia lace bug nut set occurs only at the ends of the row. In the Density block, areas with 10 x 10 m cv. 246 spaced trees were producing around 17kg DNIS at 10 % moisture per tree with only a single indoxacarb application in the last two seasons.

The biodiversity trial with flowering inter-rows needs a few more seasons of data to draw conclusions and judge whether the biodiversity inter-rows reduce the pest populations, specifically macadamia lace bug. It is not clear yet whether open canopy or wider tree spacings is even more effective.

We know that the heavy winter rain can remove the overwintering adult population on the trunks in some seasons explaining why they just take longer to start up some years.

Diagnostically, Ryan Schoffner and Gerry Cassis (UNSW) have been re-labelling the entire Australian Tingid group, using genetic markers for all of the macadamia species collected to date. There are believed to be at least 5 species commonly attacking macadamia and that many again found occasionally on close Proteaceae hosts like *Grevillia* sp., and *Hicksbeachia* sp. (Schoffner et al 2018).

At this stage the two main pest species found in NSW and south east Queensland are *Cercotingis decoris (*previously *Ulonemia decoris* Drake*)* and *Proteatingis howardii*. The original *Ulonemia concava* (Ironside 1981, 1983, Figure 2.5.2.9.) has not been collected at all and this will mean a re-labelling of the type specimens in USA (Figure 2.5.2.9., Schoffner et al. 2018).

The search for beneficials that will keep them at bay in winter is continuing with a PhD study at Southern Cross University. Kirsten Ellis (SCU) has preliminary data showing that *Orius* sp. (pirate bugs) could be a potential biological control agent for macadamia lace bug.

Ulonemia concava *Ulonemia leai* *Ulonemia decoris* *Proteatingis howardii*

*(*Smithsonian lace bug images – 1942 Carl Drake type specimens, source- Jennifer Kirton Wollongbar WPII library from Thomas J. Henry: Systematic Entomology Laboratory ARS, USDA, MRC-168 c/o National Museum of Natural History, P.O. Box 37012, Smithsonian Institution Washington, DC 20013-7012

Figure 2.5.2.9.: The type specimen photos we received from Thomas Henry during 2010 (above) including the original damaged *Ulonemia concava* (Ironside, 1983) and the main CTH Alstonville lace bug issue *Cercotingis decoris = Ulonemia decoris*. *Ulonemia leai* is present in NSW and Queensland and the other main pest species found in Northern NSW macadamia crops is *Proteatingis howardii* collected from cv. 849 at Sustainability and Accession Blocks (Blocks 8 and 9 CTH site map).

Fruit spotting bug monitoring at CTH Alstonville

FSB can feed through the macadamia shell as late as May for most varieties. The bugs will return to fruit that is carrying early season damage and hanging (correlation between fresh and old damage is at least a factor of 2 in intensity R^2 >0.75 for 3 seasons on avocado trials at Bundaberg 2012-2015 (Huwer et al. 2015b; MT10049 p. 223).

FSB damage in macadamia can be just as high in totally unsprayed trees as it is in trees only sprayed up to Christmas. Late damage is the key problem, varietal characters are immportant which needs to be considered as part of cultural control. FSB will revisit out of season flowering (A4 are prone to this in December /January and March-May when they have not set properly).

Flowers with high benzaldehyde volatile emissions apprear to be attractive to FSB. *Murraya paniculata* and *Macadamia* sp. share this floral component only it is 100-times stronger in *M. paniculata*. A natural floral source of benzaldehyde is probably a good strategy to keep a steady stream drawing the bugs to where we want them to go.

FSB mostly occupy the upper canopy in a macadamia tree and need some foliage cover to protect them from birds. In a custard apple orchard near Alstonville we observed that trellising not only stopped the wind damage it had major improvements in FSB management, as the trellises also allowed for more effective spray coverage.

The relationship between FSB activity and rainfall has long been known but now we can show it in the numbers of visible bugs on the various monitoring host plants we use, and when they will fly (Figures 2.5.2.10. and 2.5.2.11. and Table 2.5.2.5.). The sensitivity of the FSB population to weather is being displayed in the numbers of bugs present and breeding on the monitoring hedges.

The ability to monitor the FSB on alternate hosts across the whole season has made a major difference to the timing of spray decisions after nuts stop falling in late December each season (Tables 2.5.2.1. and 2.5.2.2. and 2.5.2.5.). This was achieved in the previous research (Huwer et al. 2016). Adopting the timing based on those flights at CTH reduced damage by half at least in the managed blocks at CTH Alstonville (Tables 2.5.2.1. and 2.5.2.2.).

We have shown that this is also transferable to other areas. The late season FSB damage increases were measured at the IPM case study site 7 at the Mid North Coast Region and Arapala, another farm in Nambucca (Maddox et al. 2021; Appendix 5.14.) (Table 2.5.2.5.).

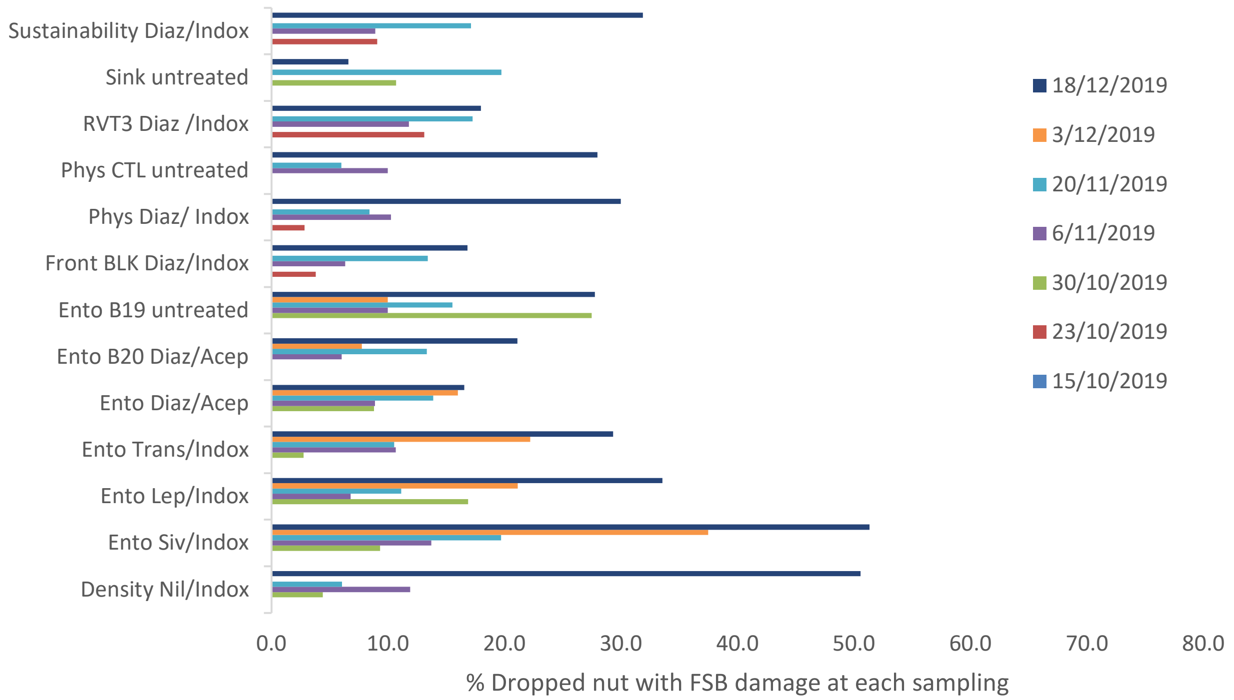
An increase in FSB population after rainfall events on *Murraya paniculata*, and the difference in fortnightly activity translates to the percentage of nut drop due to FSB in various macadamia blocks (see Figure 2.5.2.1.) during the drought season 2019, compared to the wet season of 2020 clearly (Figure 2.5.2.10. above compared to below).

Macadamia ternifolia has proven to be a good monitoring crop. The reliability of the nut set on the *Macadamia ternifolia* crop in the germplasm plot at CTH is limited by macadamia lace bug and macadamia seed weevil activity (Maddox et al. 2015, in Topp, 2015) and can be augmented with appropriate spraying. Once that crop has set it is far easier to see the bugs on that fruit at that time of year on that crop than the other options in that period.

Other options for monitoring FSB activity are also custard apples (the Victoria Park Site has been used in this study). A further tool that has been used was a *Murraya paniculata* bush with corky passion vines growing amongst it and fruiting during summer.

The host plant list for FSB is by no means exhausted with regards to alternative hosts for monitoring. Only the species that are already known to be attractive hosts have been used. Other plants like native fruiting *Pittosporum* sp. *Cupaniosis*, *Micromelum minutum* (Matt Weinert, pers. comm.), *Neolitsia, Murrogun* might be suitable if they reliably produce fruit like *Murraya paniculata.* Some of these hosts plants have been planted for future investigations.

Tools for monitoring *Leptocoris* sp. were investigated and *Macadamia ternifolia* proved to be an option, which became important in 2019 (Figure 2.5.2.11.). It is well known that the primary sources of this pest are golden rain trees and foam bark trees (Carroll et al. 2005) which have been commonly used for rainforest regeneration on farms. Wet weather is restricting the nymph survival, but the pest can occasionally be found on *Murraya paniculata*.



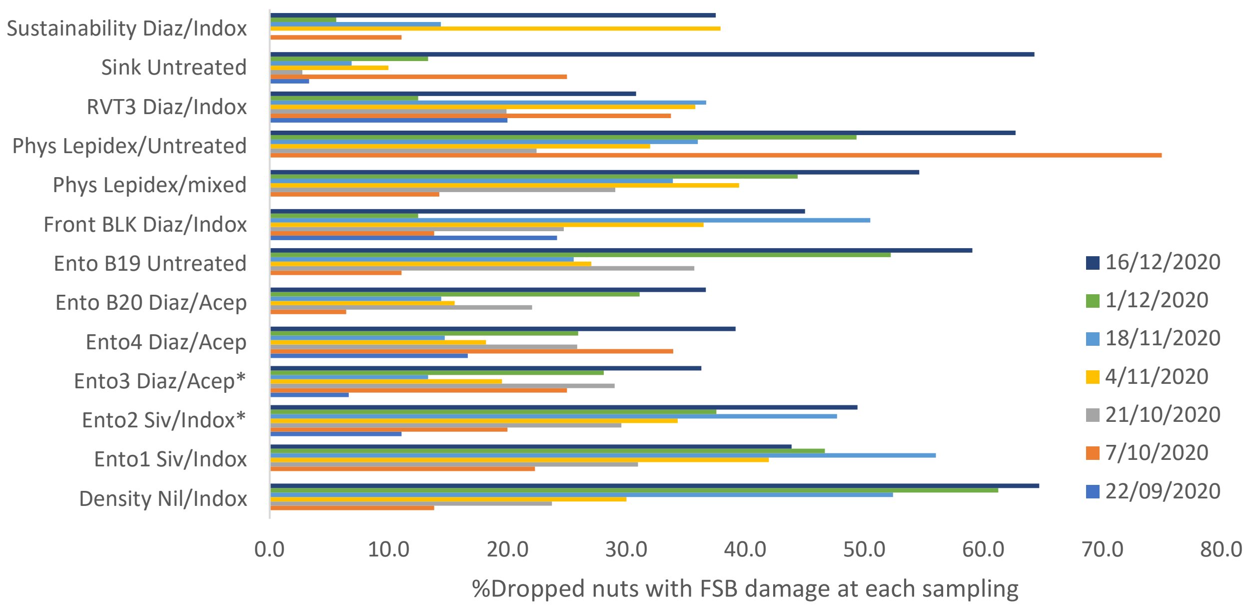


Figure 2.5.2.10.: Comparison of the % FSB damage in the nut sampling in each trial block at CTH Alstonville during the extreme dry season 2019–2020 (above) as compared to the wet season 2020–2021 (below). Every block shows far more FSB activity with the wetter conditions prevailling in 2020, nut drop in December 2019 was the only time in the nut development stages when FSB damage was over 40% for that season.

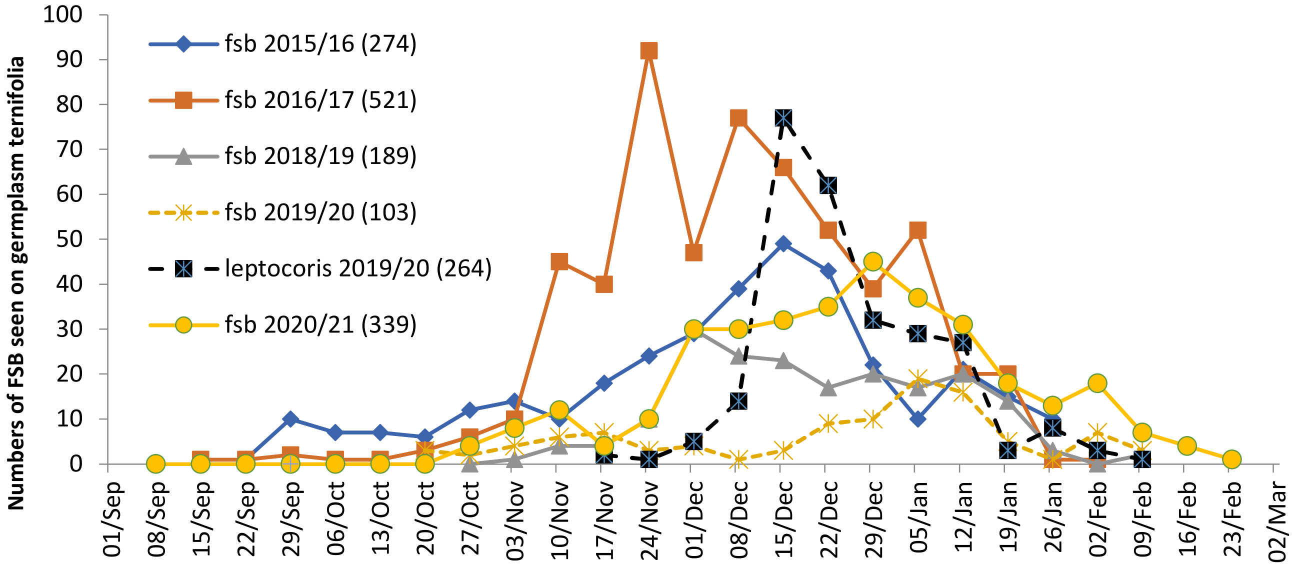


Figure 2.5.2.11.: *Amblypelta nitida* (FSB) activity on *Macadamia ternifolia* plants in the macadamia germplasm area in each season shows how the 2018/2019 and 2019/2020 is very low compared to seasons with average rainfall. FSB invasion and activity is linked to performance on other hosts in the winter and rainfall during spring and summer. *Leptocoris sp*. invasion occurred in 2019/2020 at the peak of the dry conditions (first time for CTH Alstonville), and was visible on the same trees. The only season we were unable to monitor FSB in the block was 2017/2018 when macadamia lace bug removed the nut set.

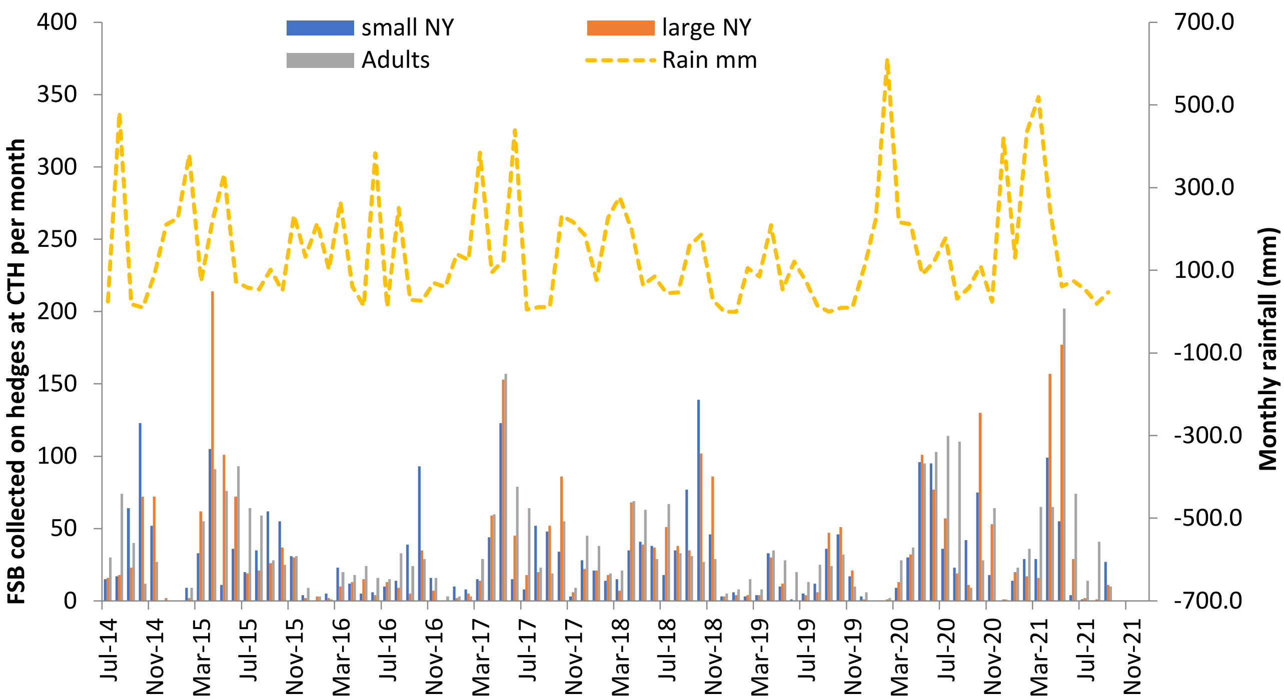


Figure 2.5.2.12.: *Amblypelta nitida* (FSB) activity on *Murraya paniculata* hedges at CTH showing monthly capture rates by instar size or adult against the rainfall (mm), breeding on the hedge is low in year 2019. The FSB are breeding throughout the winter months in some seasons with young nymphs present when ever there is food. This means microclimate, and suitable food can over ride shorter daylength limitations predicted by Waite (2000).

Table 2.5.2.5.: Effective spraying benefit to the macadamia crop quality showing average crop loss to fruit spotting bug expressed as % of kernel fed on by *Amblypelta nitida* (FSB) based on the 2nd harvest, 30 nut samples from each of 9 trees for each macadamia variety (standard error). Those averages followed by ** are significantly lower using the z test at *P* <0.05. Drier season 2019/2020 showing lower FSB damage regardless of applied chemistry, and later maturing thinner shelled varieties (849 and A4) most prone to damage. The Nambucca site values (+) are from 300 nut samples and the varieties are different from CTH with mainly A16 / A4 but the lower dry season damage values and late season activity are apparent. Predicted FSB flight times each season are based on the local populations of FSB collected from the *Murraya paniculata* hedges, and *Macadamia ternifolia* trees at CTH Alstonville NSW.

CTH Alstonville plots	**2017/18 crop**		**2018/19 crop**		**2019/20 crop**		**Nambucca 2018/19+**		**Nambucca 2019/20+**	
Variety	STD spray	IPM compatible spray	STD spray	IPM compatible spray	STD spray	IPM compatible spray	STD spray	IPM	STD spray	IPM
741	1.5** (0.5)	6.5 (1.9)	2.6** (0.8)	7.0 (2.8)	3.1 (1.1)	4.5 (1.0)	3/04/2019	300 nuts	28/04/2020	300 nuts
246	1.9**(1.5)	17.1 (2.2)	2.2** (0.8)	10.5 (2.2)	2.4 (0.8)	2.8 (0.9)	0.5	4.7	0.3	10.1
849	10.3**(3.8)	36.8 (7.7)	8.4** (1.7)	30.6 (3.8)	4.5**(1.1)	16.1 (3.6)	29/07/2019	300 nuts	21/06/2020	300 nuts
A4	6.4** (2.0)	25.2 (8.2)	15.4** (3.1)	39.8 (5.0)	8 (3.2)	13.9 (3.1)	3.2	19.9	1.3	14.6
2nd harvest date	28/03/2018		04/04/2019		10/04/2020					
FSB flights on counts	4		4		4					
predicted by CTH hedges		action		action		action				
FSB flight 1	04/12/2017	sprayed	21/12/2018	sprayed	23/12/2019	sprayed		sprayed		sprayed
FSB flight 2	08/01/2018	sprayed	04/02/2019	sprayed	27/01/2020	sprayed		sprayed		sprayed
FSB flight 3	12/03/2018	left	25/03/2019	left	23/03/2020	left		left		left
FSB flight 4	30/04/2018	left	6/05/2019	left	11/05/2020	left		left	treated in Arapala trial	

FSB monitoring summary

The relationship between FSB activity and rainfall has long been known but now we can show it in the numbers of visible bugs on the various monitoring host plants we use, and when they will fly (Figure 2.5.2.12., 2.5.2.11., Table 2.5.2.5.).

The ability to monitor the FSB on alternate hosts across the whole season has made a major difference to the timing of spray decisions after nuts stop falling in late December each season (Tables 2.5.2.1. ,2.5.2.2. and Table 2.5.2.5.). This was achieved in previous studies (Huwer et al. 2016) and adopting the timing based on those flights at CTH reduced damage at least by 50% in the managed blocks at CTH Alstonville (Tables 2.5.2.1. ,2.5.2.2. and Table 2.5.2.5.).

It was shown that monitoring hedge data can be transferable to other districts. The hedge data from CTH was used to detect late season FSB damage on farms in the Mid North Coast region in 2020 (Maddox et al. 2021, Appendix 5.14.) (Table 2.5.2.5).

FSB breeding depends on rain events surges after rainfall events, which is shown in a comparison from monitoring during the drought season (2019) and a wet season (2020) (Figure 2.5.2.10.).

Leptocoris can be monitored on the *Macadamia ternifolia* but also on the *Murraya paniculata*so definitely waiting for dry conditions to re surface.

Possible hosts suistable for FSB Monitoring are native fruiting *Pittosporum* sp., corky passion vines, *Cupaniosis* , *Micromelum minutum, Neolitsia* and *Murrogun* new options will be tested as part of a monitoring hedge at CTH Alstonville.

Fruit spotting bug (*Amblypelta nitida*) management:

Methodology for the spray trials is contained in the following Tables 2.5.2.6., 2.5.2.7. 2.5.2.8. and 2.5.2.9. where the key information about product application rates, weather conditions and spray gear setting are recorded. The trail designs are unique to each plot on the site but generally follow a randomised block designs (for Front block and Physiology blocks Figure 2.5.2.1.). For entomology block (site 4 Figure 2.5.2.1. and 2.5.2.8.) those designs have been agreed upon to test specific treatment combinations for the last 4 seasons, generally neighbouring treatment strips over the 4 different varieties. A dose rate of 10L/Tree and 100 tree areas being treated at each spray application has been used for the crop yield and damage numbers since 2018. The density plot (site 6 Figure 2.5.2.1.) has only been sprayed from the road side since 2019 with indoxacarb for macadamia seed weevil, no crop was produced in that area since 2013 until that happened. Daily rainfall data is presented in Appendix 2.5.4. and most applications are containing a spreading sticker agent (Designer® @10ml/100L) which is rainfast within 3 hours.

Table 2.5.2.6.: The following treatments were used during the nut development and maturation period in Physiology plot at CTH Alstonville.

Product Number	Product formulation	Rate of product (ml per 100L)	Doseage (a.i.g per 100L)	Application timing
1	DC 143 200 (Vayego®)	12.5	2.5	13/10/2020 MSW laying, 06/11/2020, FSB 1 05/12/2020, FSB 2, MNB 22/01/2021, FSB 3
2	Bulldock® 25	50	1.25	
3	Trivor® 186+	40	7.4	
4	Steward® 150	50	7.5	
5	EXP C	confidential	confidential	
6	EXP A	confidential	confidential	

Table 2.5.2.7.: Weather conditions during application details for Physiology Block trial at CTH Alstonville.

Application number	1	2	3	4
Date	13/10/2020	6/11/2020	5/12/2020	22/1/2021
Days between treatments		24	29	48
Time of day	7-11 am	9-11.30 am	8.30-12am	9-12.30
Temperature 9am	21° C	22° C 11am	27° C 11am	29° C 11.30am
Relative Humidity % 9am	65%	56%	76%	62%
Cloud cover	10%	10%		5%
Wind (speed and direction)	1.5 km/hr ESE	5 km/hr E	calm	2.2km/hr NW
Crop growth stage	Nut development	Nut development	Nut development	Nut Maturation
Standard block	Steward	Trivor	Bulldock	Bulldock
Experimental blocks	Experimentals	Experimentals	Bulldock	Experimentals
Mixing Observations	Nil	Nil	Nil	Nil

Table 2.5.2.8.: Treatment method and application schedule, all rinsed between applications in Entomology block at CTH Alstonville.

Equipment *photos App 9.3	ATR2000 air-blast spray unit Tuffass® machinery
Method	Rear mounted to tractor PTO side pass each side
Nozzles	Canon for upper canopy, standard misting cones for rest
Tractor speed	5-5.5 Km/Hr
Pressure	20 bar on gauge is needed to give optimum emission
Application volumes	100 trees per 1000L mix 10L/tree (2000L capacity) Entomology
Residual volumes	Spray treatment area until empty.

Table 2.5.2.9.: Treatment method and application schedule, all rinsed between applications residual volumes collected at the changes for Physiology block spray trial at CTH Alstonville. These applications are targeted for macadamia seed weevil 13/10/2020, and Fruit spotting bug 13/11/2020 and on 05/12/2020 and both Fruit spotting bug and macadamia nut borer in 22/01/2021.

Equipment *photos App 9.3	ATR2000 air-blast spray unit Tuffass® machinery		
Method	Rear mounted to tractor PTO side pass each side		
Nozzles	Canon for upper canopy, standard misting cones for rest		
Tractor speed	3.5-4.5 Km/Hr		
Pressure	20 bar on gauge is needed to give optimum emission		
Application volumes	300L mix		
Tank mixing 2000L capacity	sprayed out into 5 plots of 3 treatment trees plus 0.5 buffer each end as per map. Buffer rows 246 were not sprayed standard area every row was sprayed.		
Residual volumes	0-50L remaining in tank after spraying		
Order applied	**Tank mix**	**RESIDUE(l)**	**Vol/tree (L)**
13/10/2020	**150ml Spin®+30ml Designer**		
7.10am Steward® 50ml/100L	150mls +tank mix		10.0
9.40am DC143 (Vayego®) 12.5ml/100L	37.5mls + tank mix	0	13.6
10.30am Experimental C	X + tank mix	50	11.9
11.00am Experimental A	Y + tank mix	0	13.6
6/11/2020	**120ml Choice coup + 30ml D**		
9.15am Trivor® 40ml/100L	120ml +tank mix		10.0
10.45am DC143 (Vayego®) 12.5ml/100L	37.5mls + tank mix	5	13.4
11.15am Experimental C	X + tank mix	3	14.1
11.35am Experimental A	Y + tank mix	5	14.0
05/12/2020	**+ 30 ml Designer**		
8.30am Bulldock® 50ml/100L	150ml +tank mix		10.0
22/1/2021	**+ 30 ml Designer**		
9.15am Bulldock® 50ml/100L	150ml +tank mix		10.0
10.50am DC143 (Vayego®) 12.5ml/100L	37.5mls + tank mix	3.5	14.9
11.30am Experimental A	Y + tank mix	35	16.5
12.10pm Experimental C	X + tank mix	30	15.9

Table 2.5.2.10.: Comparison of mean % FSB damage in macadamia nut sampled from cv. 849 trees in Physiology block trials at CTH Alstonville. No difference in dry 2019–2020 dose response trial for Trivor® all applied with designer 10ml/100L and 10L / tree 29/12/2019 and 30/01/2020. Data is % of kernel showing FSB damage and (nut number sampled). In wet 2020–2021 season trial on same trees overall harvest data March – August 2021 (5 plots for each treatment, 30 nuts per plot, 6 harvests n=30). Means followed by the same letter are not significantly different at pr<0.05 using z test. * Entomology block neighbouring cv. 849 FSB damage level (from Table 2.5.2.5.).

2019–2020 trial Date sampled	**(7 rep) Trivor® 20ml/100L**	**(7rep) Trivor® 40ml/100L**	**(5rep) Trivor® 80ml/100L**	**(5 rep) Untreated**	**Bulldock® 50ml/100L***
07/01/2020 canopy	2.1 (70)	1.4 (70)	2.0 (50)	2.0 (50)	
12/02/2020 canopy	8.6 (70)	1.4 (70)	0.0 (50)	10.0 (50)	
05/03/2020 harvest 1	10.6a (213)	7.7a (209)	9.3a (151)	11.7a (153)	
07/04/2020 harvest 2	13.1a (180)	11.8a (182)	11.0a (131)	11.9a (147)	4.5 (270)*
2020–2021 trial					
Pesticide	**DC 143 (Vayego)**	**Bulldock®**	**Exp A**	**Exp C**	**Untreated**
# samples	30	28	30	30	29
Mean % FSB	15.4a	13.2a	27.8b	15.6a	41.8c
Std error	2.1	1.7	2.6	2.1	2.5

Trial designs are presented in the Appendix 2.5.5. and the monitoring and evaluations for the key pests schedules shown in Table 2.5.2.1. and results in Table 2.5.2.10. and at each harvest in Figure 2.5.2.12. The FSB activity in season 2019–2020 was late, we could only show a dose response for Trivor® 2 weeks after the second spray in the canopy samples 12/02/2020, and by harvest no difference between any of the treatments (Table 2.5.2.10.). In contrast far more FSB activity in season 2020–2021 (Figure 2.5.2.10). The two new compounds DC143 (Vayego®) and Experimental C are showing similar efficacy for FSB control compared to beta-cyfluthrin (Bulldock®).

Understanding your site risk from FSB is important. The bug has co evolved with macadamia and has many other hosts (Waite and Huwer, 1998). It is an elusive canopy dweller, can fly reasonable distances (>1KM) to re infest an orchard, and a tendency to form "hotspots" within the orchard which it will return to.

To minimise the damage from a growers perspective, has three distinct phases. In spring , preventing a large build up of the population arising within your orchard. Adults are laying eggs and feeding on young nutlets from flowering each season, nuts will fall as part of the natural thinning of the crop, a lot more will be under the trees where the FSB are breeding. In early summer, nuts stop dropping when fed on by the bug and become part of the reject crop that is hanging on the tree, growers are normally spraying monthly to reduce this hanging damage. By late summer early autumn it was assumed that the shell will protect the crop from feeding, not so for the later maturing thinned shelled and higher value varieties like cv. A4 or 849 if poorly managed (Figure 2.5.2.13, Table 2.5.2.3. page 12, Figure2.5.2.13.).

The usual drop patterns of the damaged nuts are shown (Figure 2.5.2.13.) where the first harvests (March and April) normally carry the bulk of the damaged nut and get progressively cleaner, regardless of treatment. Beta cyfluthrin (i.e. Bulldock®) is the current standard treatment to control FSB damage, season 2020–2021 was a particularly heavy year for FSB activity and this is data from the pesticide evaluation trial done in the Physiology block (site 3, Figure 2.5.2.1.) next to the IPM trial at CTH.

What is clear is that FSB can be very selective in where they feed, by sampling of the cv. 246 replicates from the neighbouring trees in the trial rows you can see they are carrying half the damage in April sprayed or not. This shows variety is a big factor for late feeding. We originally showed this in 2004 with the trials that showed FSB damage after Decemeber on cv. A4 was equal to completely unsprayed A4 (Huwer et al. 2006; Topp et al. 2015) and in the Fruit spotting bug Management Guide (Huwer et al. 2016). If something works on cv. 849 it is going to be beneficial to the industry because that is a high risk crop (Table 2.5.2.10.).

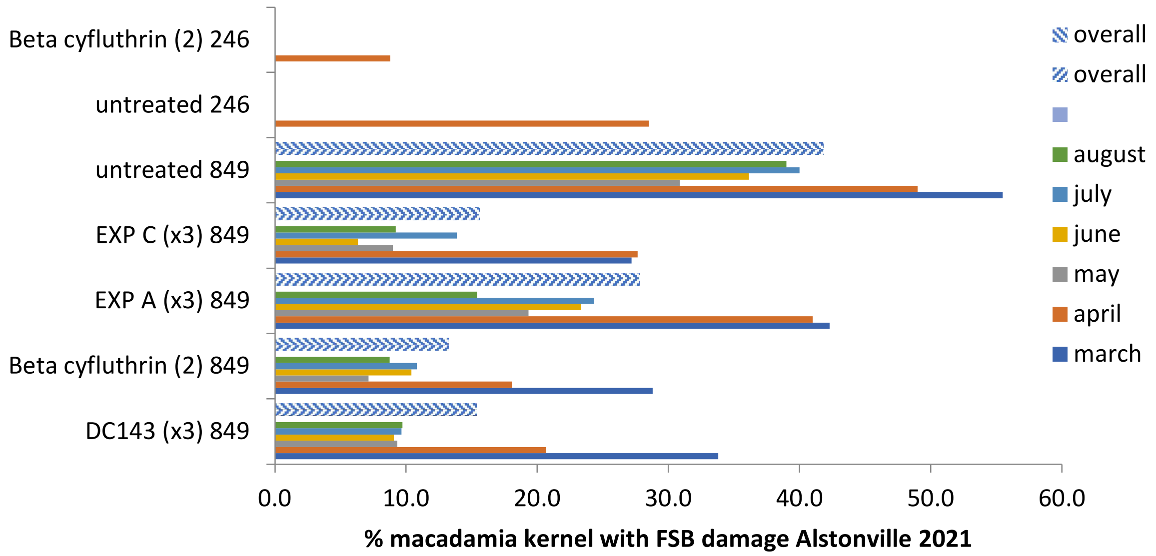


Figure 2.5.2.13.: Comparison of the cv. 849 macadamia nut harvest samples (30 nuts per plot, 5 plots per treatment) in the physiology spray trial at CTH Alstonville (site 3, Figure 2.5.2.1.) 2020 showing mean % FSB damage in the kernel each month harvested and combined overall.

This selectivity the FSB exhibits has been instrumental in revealing the tree species that can be used for monitoring field populations.

Seasonal activity is shown in Figures 2.5.2.11. and 2.5.2.12.), and linked strongly to the preceding rainfall, basically the severe drought in NSW delivered conditions that favored *Leptocoris* attack in 2019/20 the rest of the time it was FSB and we could tell when they were flying at CTH at least. We use the flight times from the monitoring to time the sprays when the adults are in the orchards (10-14 days after 30% of the nymphs we see are 5th instar (Huwer et al. 2015b) and Fruit spotting bug Management Guide (Huwer et al. 2016).

We know FSB pressure in the Nambucca region is higher by the Benchmarking studies which have consistently shown 1-2% more damage by weight (this is roughly 3-6% by kernel number) compared to other regions 2009-2020 (QDPI macadamia Benchmarking report 2021). The normal reasons were more bush surrounding farms, poorer spray coverage on later maturing varieties and not as much control being attempted generally. The sharp increase in damage shown in the current project trial site (Figure 2.5.2.14. IPM case study site 7 in the Mid North Coast region 2019-2021) has happened during harvest. There was a need to investigate whether FSB are able to continue to invade that late in the season and more than triple the damage. After checking the caged nut on tree trials at CTH Alstonville where we released FSB and *Leptocoris* to compare the visual characteristics of the feeding on the CTH varieties between February and May 2020 we knew it was possible (Figure 2.5.2.13. AMS Bulletin article 2020).

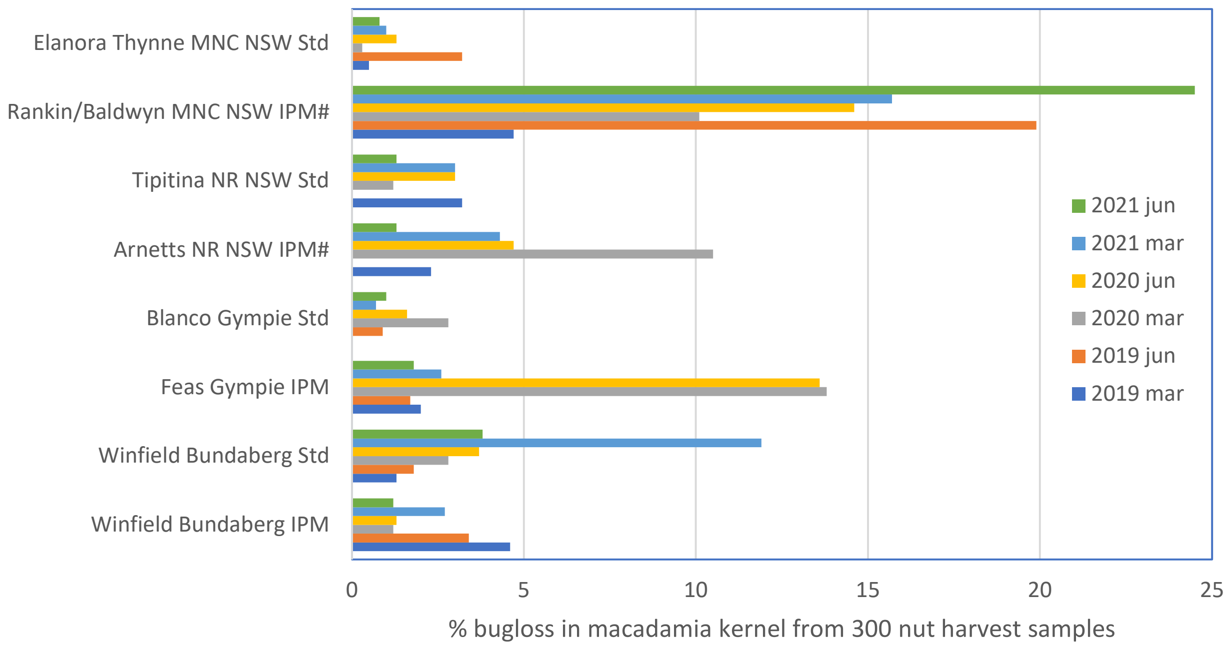


Figure 2.5.2.14.: The % bugloss in kernel samples from the regional IPM and standard spraying macadamia trial sites between 2019 and 2021. (#)are sites where the inter-rows are established within orchard rows. *Anastatus sp* is released to reduce the FSB breeding at all the IPM sites.

The activity of *Leptocoris* sp. is not affected by the *Anastatus* sp. parasite and is responsible for the bulk of the damage that has occurred at the IPM case studysites 3 in the Gympie-Glasshouse Mt. region and IPM case study site 5 in the Northern Rivers region in 2020. Case study site 3 is now sprayed when *Leptocoris* is present after the loss that year. case studysite 5 is widely spaced smaller trees with a low FSB pressure and has also sprayed to control *Leptocoris.*

The inter-row effect on MLB is the most interesting at this stage (Figure 2.5.2.14.). The Central Queensland region case studysites 1 and 2 near Bundaberg (both sites are part of one farm) do not have inter-row plantings established and are not really all that different except that the case studysite 2 was virtually nutless with Abnormal Vertical Growth rampant throughout (this compomised the productivity ofand potential of case studysite 2). Both case studysites used Trivor® to combat felted coccid, which also gives some control of spotting bugs (FSB and banana spotting bug (BSB)). The control of felted coccid has been a major success for the site.

The collaborating consultant Eddy Dunn made the observation that the bulk of the pheromone traps for BSB, catch bugs until the nuts are on trees then the adults move to the fruit not the trap is important in the pursuit of a no spray lure and kill approach for both spottingbug species.

The main site, where majour factors are in play (i.e. inter-row present, high FSB pressure on the crop, and parasitoid releases to reduce the late season FSB population in the orchard) is case studysite 7 in the Mid North Coast region. The grower is still using at least two pyrethrin sprays to control macadamia lace bug and is not just relying on the inter-row. The crop yield is good at this site (> 3T/ha) but is relying on pyrethrin sprays. The FSB damage is increasing later in the season each year suggesting the egg parasitoids released are not stopping the bugs flying into the orchard after March. The resulting 20-25% crop loss to FSB is a very significant in a high pressure wet year (Figure 2.5.2.14.). The matching case study site in the region, case study site 8 highlights the benefits of well timed and effective spraying with the result achieved in particular for 2020/2021, outstanding under very high FSB pressure and extremely wet seasonal conditions.

To test if the damage was occurring at even the best managed sites in the Nambucca area and investigate whether this late FSB damage can be prevented, the collaborating pest consultant for the Mid North Coast region, Bob Maier and manager of the Arapala farm, Chris Cook were consulted for collaboration in a further trial. This trial investigated whether any increase in FSB damage to the crop could be shown by canopy sampling before and well after the last flight. Samples from 8 different blocks on the Arapala farm were provided with suspected late bug damage in early May 2020. After the May 2020 flight was detected at CTH Alstonville on the trap hedges, an 8-tree section of each trial block at Arapala farm was sprayed with Lepidex® (200 ml/100 L) to see if treatment would be effective. Samples were then supplied back to NSW DPI to assess the damage levels taken from nuts in the canopy in mid June 2020. The process was repeated in 2021 with samples supplied in late April and mid July from the same sites at Arapala farm. Severe flooding in the region made it impossible to put on the spray between the two samples this year but the results and effect on the damage were the same. It proved that FSB are still feeding within the plots in May/June and causing crop damage (Table 2.5.2.11.).

Residue trials were undertaken during the past two seasons for a range of insecticide, in different sections of a *Murraya paniculata* hedge at CTH Alstonville, when the berries and FSB are plentiful (from autumn onwards). A hand mister 1L capacity was used for chemical mixture. This area of treated berries was tagged and labelled for feeding trials. At intervals of 1 day, 7 days, 14 days and 21 days after application, a collection of the berries was labelled and returned to the Wollongbar WPII laboratories. Depending on the pest insect availability, a series of 2 or 3 replicate Acola preserving jars with either 5 or 10 pest insects were introduced to a treated berry sprig in water and covered with gauze lid to prevent sweating (Figure 2.5.2.15.). The mortality of the bugs after feeding on the treated berries was monitored for the next 7 days to determine the residual effect of the mixture. Mortality rates were averaged and presented in Tables 2.5.2.13. and 2.5.2.14. and Figure 2.5.2.15. This was repeated for each time period collected in 2020 focusing on FSB. In 2021 we have tried to include the *Leptocoris* bug with the same range as it is clear that different populations of this bug are showing quite different pesticide susceptibility (Figure 2.5.2.16.).

Comments Bob Maier and Chris Cook:

"This is a good news IPM story for growers who now have a tool to detect late FSB activity levels and decide whether a control spray may be warranted. At the Dymocks sites 6 trees in each of 8 known 'hot spot' rows from the 8 blocks were permanently tagged by me for future sampling. I collected 150 tree sampled nuts from each of these 8 rows and sent off for analysis, before and after treatment to gauge changes in FSB activity. If growers wanted to do their own checking next season it would be important to contact the lab and ask if they can give the percentage breakdown of the different kinds of insect damage and in particular FSB, GVB and Leptocoris sp. Regarding the existing hedges at Valla, Macksville (Macvest –Macksville) and Yarrahapinni (Dymocks), NSW DPI suggested boosting existing hedge planting density for reliability. This boosting in numbers has taken place. Weekly hedge data ideally from local hedges will inform growers in real-time of any local increases in activity and the timing of such sprays is well documented in the DPI Plant Protection Guide. We owe a great deal of thanks to the DPI team for past and ongoing work on macadamia pests and of course the timely local support to growers and consultants." "I wanted to communicate to growers that we will use our hedges for our late FSB spray. And I will also talk to other growers with a hedge to time my late sprays. I will definitely be spraying later in the future."

Table 2.5.2.11.: Winter pest activity shown in well managed macadamia orchards by increases in *Amblypelta nitida* damage found in macadamia nut sampled from canopies at blocks of late maturing high kernel recovery (thin shelled varieties) on the Arapala farm in the Nambucca district NSW for seasons 2019–2020 and 2020–2021. Trichlorfon was applied at 200 ml/ 100L but was ineffective at reducing the damage (100-150 nuts from tagged tree canopies each time 8 different blocks)

Arapala Farm Block name	varieties	%bugloss May 2020	%bugloss June 2020	season 2020 %TKR	%bugloss April 2021	%bugloss July 2021	season 2021 %TKR
GS	A203	0.05	2.0	39.9	0.0	0.0	36.9
Jindilli A		0.05	2.0	42.9	0.0	0.0	42.8
Jindilli D		2.3	8.4	47.9	0.7	0.0	45.5
Nook	741	0.05	2.3	42.9	0.3	3.7	39.5
Old house	a4/a16	0.05	2.4	45.2	4.3	3.1	45.6
Plateau West	a16	0.6	1.0	42.9	3.2	0.0	40.7
Shed Block		0.6	0.6	48.6	1.3	12.7	47.1
SW	a4/a16	1.4	2.4	46.3	1.2	9.3	45.7
			with spray			no spray	

Figure 2.5.2.15.: CTH Alstonville caged nut experiments on varieties 741, 344, A4 and 849 from February 2020-June 2020. Far more extensive tissue damage around the *Amblypelta nitida* (Lower left) vs. *Leptocoris tagalica* (Lower right) feeding damage. Both species can feed through the shell cv. 849 and A4 in March, April and May.

Table 2.5.2.12.: Residual toxicity of various pesticides to *Amblypelta nitida* (FSB). Seven day mortality rate comparison across a range of pesticides held in clean glass Acola preserving jars with gauze lids. Standard 1 ul droplet test in centre of thorax when immobilized by short term exposure to -18 C and allowed to feed on clean *Murraya paniculata* berries. Field aged residues on *Murraya paniculata* berries collected and assayed 1 day, 7 days, 14 days, and 21 days after treatment presented to *Amblypelta nitida* nymphs or adults to feed on in the jars. Pesticide solutions were mixed with a grade volumetric glassware at Wollongbar WPII laboratories and applied with hand misting guns at the rate of 1L per section of tagged berry laden *Murraya paniculata* hedge trees at CTH Alstonville NSW between June- August 2020.

					1ul topical app	**DAY1**	**DAY7**	**DAY14**	**DAY21**
Chemical	**Rate ml/ 100L**	**Life Stage**	**Replicates at each time**	**Total bugs screened**	**7D%mortality**	**7D%mortality**	**7D%mortality**	**7D%mortality**	**7D%mortality**
Water		Nymph	2 x 5bugs	50	40	40	20	0	0
Water		Adult	2 x 5bugs	50	0	40	20	0	0
Designer® (D.)	10	Nymph	2 x 5bugs	50	40	20	0	20	20
Designer® (D.)	10	Adult	2 x 5bugs	50	40	20	0	0	20
Tetraniliprole + Bond®	15	Nymph	2 x 5bugs	50	40	80	80	40	40
Tetraniliprole + Bond®	15	Adult	2 x 5bugs	50	40	80	0	20	0
Tetraniliprole	15	Nymph	2 x 5bugs	50	0	100	0	20	40
Tetraniliprole	15	Adult	2 x 5bugs	50	0	100	40	0	0
Trichlorfon +D.	200	Nymph	2 x 5bugs	50	100	100	20	20	40
Trichlorfon +D.	200	Adult	2 x 5bugs	50	80	100	40	0	0
Expc +D.	60	Nymph	2 x 5bugs	50	100	100	100	100	40
Expc +D.	60	Adult	2 x 5bugs	50	80	100	100	80	20
Expc +D.	30	Nymph	2 x 5bugs	50	80	100	80	80	80
Expc +D.	30	Adult	2 x 5bugs	50	80	100	60	40	0
Sulfluxaflor +D.	40	Nymph	2 x 5bugs	50	100	80	60	20	20
Sulfluxaflor +D.	40	Adult	2 x 5bugs	50	80	80	20	0	0
Acetamiprid + pyripoxyfen+D.	40	Nymph	2 x 5bugs	50	80	100	60	40	80
Acetamiprid + pyripoxyfen+D.	40	Adult	2 x 5bugs	50	80	100	40	20	0
Beta Cyfluthrin +D.	50	Nymph	2 x 5bugs	50	100	100	100	100	80
Beta Cyfluthrin +D.	50	Adult	2 x 5bugs	50	100	100	100	80	20
Flupyradifurone +D.	100	Nymph	2 x 5bugs	50	60	60	40	20	60
Flupyradifurone +D.	100	Adult	2 x 5bugs	50	80	80	20	20	0
Methoxyfenozide+D.	100	Nymph	2 x 5bugs	50	80	40	20	0	20
Methoxyfenozide+D.	100	Adult	2 x 5bugs	50	20	40	20	20	0

D.= Designer®

Table 2.5.2.13.: Residual toxicity of various pesticides to *Amblypelta nitida* and *Leptocoris* spp. (Both *L. rufomarginata* and *L. tagalica* have been found coming from the foam bark and golden rain tree hosts on to macadamia). Seven day mortality rate comparison across a range of pesticides held in clean glass Acola preserving jars with gauze lids. Field aged residues on *Murraya paniculata* berries collected and assayed 1 day, 7 days, 14 days, and 21 days after treatment presented to *Leptocoris* nymphs or adults to feed on in the jars. Pesticide solutions were mixed with a grade volumetric glassware at Wollongbar WPII laboratories and applied with hand misting guns at the rate of 1L per section of tagged berry laden *Murraya paniculata* hedge trees at CTH Alstonville NSW between June- August 2021.

Chemical	**Rate ml/ 100L**	**Species**	**30/3/21 Goonellabah *Leptocoris***	**17/6/21 Pecan *Leptocoris* population Tatham NSW**			
			DAY1	**DAY1**	**DAY7**	**DAY14**	**DAY21**
			7D%mortality	**7D%mortality**	**7D%mortality**	**7D%mortality**	**7D%mortality**
Untreated	0	*Leptocoris*		0	0	0	10
Untreated	0	*Amblypelta*		0	0	0	0
Designer® (D)	10	*Leptocoris*	20	0	0	0	20
Designer® (D)	10	*Amblypelta*	20	20	20	20	0
Nu Farm 3445 +D.	120	*Leptocoris*	40	10	10		
Nu Farm 3445 +D.	120	*Amblypelta*	40	0	0		
Tetraniliprole +D.	12.5	*Leptocoris*		0	0		
Tetraniliprole +D.	12.5	*Amblypelta*		20	20		
Acetamiprid + pyripoxifen+D.	20	*Leptocoris*	40	100	0	0	
Acetamiprid + pyripoxifen+D.	20	*Amblypelta*		60	40	20	
Acetamiprid + pyripoxifen+D.	40	*Leptocoris*	60	100	70	30	20
Acetamiprid + pyripoxifen+D.	40	*Amblypelta*		60	40	40	20
Beta Cyfluthrin 100+D.	12.5	*Leptocoris*	40	100	90	100	90
Beta Cyfluthrin 100 +D.	12.5	*Amblypelta*		100	20	60	80
Acephate +D.	80	*Leptocoris*	100	100	0	20	10
Acephate +D.	80	*Amblypelta*		100	100	20	0
Exp C +D.	20	*Leptocoris*	70	100	10	20	
Exp C +D.	20	*Amblypelta*	90	80	20	0	
Exp C +D.	30	*Leptocoris*	80	100	80	0	20
Exp C +D.	30	*Amblypelta*				0	20
Trichlorfon +D.	2	*Leptocoris*		50	0		
Beta-cyfluthrin 25+D.	50	*Leptocoris*	50	100	100	100	100
Beta-cyfluthrin25+D.	50	*Amblypelta*				80	20

D.= Designer®

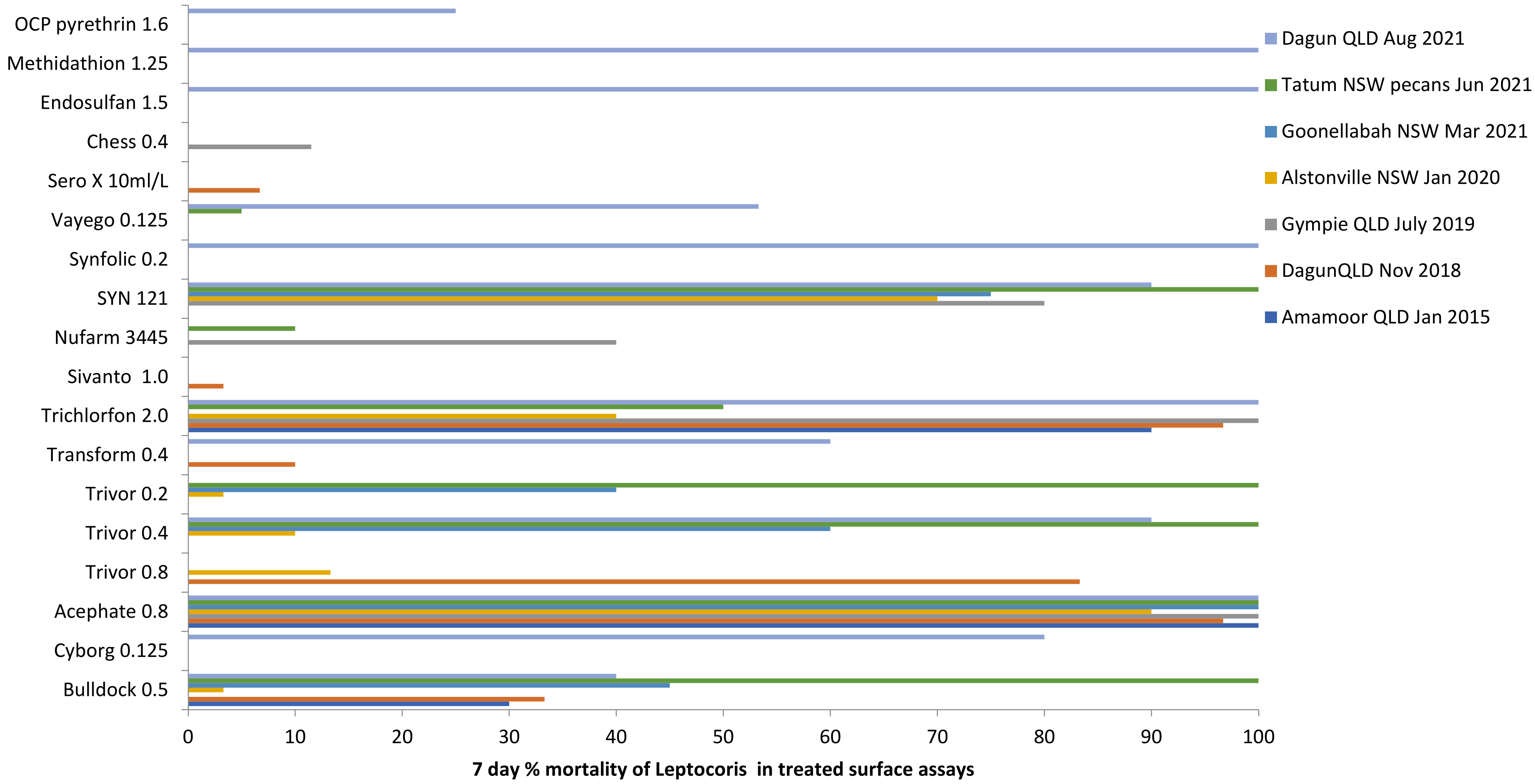


Figure 2.5.2.17.: Mortality rates after 7 days exposure for different *Leptocoris* sp. populations when fed on dipped *Murraya paniculata* berries. An average of 2 replicates of 5-10 individuals in clean glass Acola preserving jar with gauze lids. Pesticides were applied by dipping berries in the mixture and allowing to dry (5 mins). Only the new Syngenta product is more reliable than Trivor® if the organophosphate products are removed from sale (i.e. acephate and trichlorfon).

Table 2.5.2.14.: Density block at CTH Alstonville showing *Amblypelta nitida* (FSB) damage as a percentage of the kernel inspected at the individual tree level for season 2020 . Interow planted in December 2019. Trees in positions 1-4 and 16-19 are 10 x 3.5m, trees 5-7 and 15-13 are 10 x 7m rest at 10 x 10m. Same trees below in 2021 season with *Anastatus* releases aswell. FSB egg trap sited at tree 17 row 3, *Anastatus* releases split across whole block tree 18 row 3, tree 14 row 2, tree 11 row 3 , tree 6 row 3 and tree 2 row 2.

*Number per tree = % FSB damage to kernel halves; [yellow box] = biochar tree; Leptocoris was present in 2020 but not in 2021

2020	Tree #																		# Stung kernel per row#
Row #	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	
1		*5.3	1.1	6.4	1.3	13.1	17.8	0.5	2.9	3.1	0.0	9.6		12.1	13.1	7.1	16.3	13.5	9.9	292
2	4.9	6.1	27.3	23.9	13.1	26.9		5.2	1.7	2.1	7.6	2.5	7.3	8.0	0.0		10.8	7.0	3.9	296
3	6.8	28.6	45.1	27.5	12.5		7.6	8.2	3.0	2.5			7.6	20.0	11.8	19.9	9.0	8.6	10.4	507
4	23.7	34.8	33.3	44.8	44.8	23.4		5.0	1.7	2.9		12.8	43.8	23.2	6.0	8.3			11.7	633
Total # stings	83	105	160	240	167	143	60	44	22	25	18	52	112	147	73	76	58	58	85	1728

- Total number kernel halves withFSB stings: 1,728
- Total number of kernel halves sampled: 13,978
- % of kernel halves with FSB damage: 12.4%

2021	Tree #																		# Stung kernel per row#
Row #	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	
1		15.8	8.3	19.2	15.3	11.2	11.7	8.3	16.7	4.2	0.0	3.3	10.0	9.2	4.3	10.3	13.4	10.8	10.9	192
2	7.5	12.5	20.0	17.5	28.3	12.5		19.2	13.3	4.2	10.0	8.3	6.7	0.8	5.0		9.4	10.8	5.8	225
3	13.3	10.0	18.3	30.8	20.0		17.5	8.3	25.8	10.8			6.7	5.2	4.2	15.3	5.8	14.2	7.5	256
4	16.7	17.9	22.8	6.7	18.3	5.0	12.5	11.7	4.2	10.8		5.0	10.8	4.2	17.5	14.2			8.1	221
Total # stings	45	66	77	89	98	34	50	57	72	36	12	20	31	23	37	47	28	41	31	894

- over 32000 *Anastatus* released December to April
- Total number kernel halves withFSB stings: 894
- at least 11000 emerged wasps in plot
- Total number of kernel halves sampled: 7,664
- % of kernel halves with FSB damage: 11.7%

Table 2.5.2.15.: Density block at CTH Alstonville showing macadamia yield as kgs DNIS @ 10% moisture per tree and the standard deviation of that figure (sd), and the level of *Amblypelta nitida* (FSB) damage as a percentage of the kernel inspected and the standard deviation of that figure, for the season 2020 and 2021. Data is split by planting density (significant effect) and presence of biochar underneath (no effect) and combined.

CTH Density plot

Spacing	2020 combined harvest						2021combined harvest					
	Trees	**Sum kg DNIS**	**Sd**	**kg/tree**	**% FSB damage**	**Sd %FSB loss**	**Trees**	**Sum Kg DNIS**	**Sd**	**kg/tree**	**%FSB damage**	**Sd %FSB loss**
Biochar 10 x 10	2	36.7	3.5	18.3	5.8	5.8	2	44.8	1.8	22.4	6.3	3.7
	3	40.4	7.6	13.5	7.4	5.1	3	51.1	3.4	17.0	14.2	10.8
	15	260.8	10.0	17.4	5.8	5.6	15	224.4	4.6	15.0	9.9	6.5
10 x 10 Total		**337.9**	**9.1**	**16.9**	**6.1**	**5.3**	**20**	**320.4**	**4.4**	**16.0**	**10.2**	**7.2**
Biochar 10 x 3.5	3	7.1	2.1	2.4	27.1	16.4	3	15.3	1.7	5.1	15.7	7.1
	3	2.2	0.5	0.7	30.9	20.3	3	9.3	0.8	3.1	14.0	7.0
	16	77.4	3.5	4.8	11.7	8.3	16	59.3	1.9	3.7	12.0	6.0
10 x 3 Total		**86.7**	**3.4**	**3.9**	**16.4**	**13.3**	**22**	**83.9**	**1.7**	**3.8**	**12.9**	**6.3**
Biochar 10 x 7	3	27.0	4.2	9.0	26.5	24.4	3	26.1	2.2	8.7	13.7	8.4
	4	48.1	6.8	12.0	19.3	7.5	4	56.6	4.6	14.2	8.3	10.2
	16	193.2	5.1	12.1	18.1	15.2	16	180.8	2.9	11.3	12.3	9.2
10 x 7 Total		**268.3**	**5.1**	**11.7**	**19.4**	**15.1**	**23**	**263.5**	**3.2**	**11.5**	**11.8**	**9.2**
Grand Total		**692.9**	**8.1**	**10.7**	**14.3**	**13.3**	**65**	**667.8**	**4.0**	**10.3**	**11.6**	**7.8**

Table 2.5.2.16.: Parasitoid capture rates for *Amblypelta nitida* (FSB) egg trap cards used on the entire CTH Alstonville station and in the unsprayed Density block at CTH Alstonville from April 2020 onwards. *Murraya paniculata* trap hedges and Germplasm *Macadamia ternifolia* and the entomology refuge area sites were carrying significant FSB populations during this period.

2020	Target FSB eggs	*Gryon* Parasite	Eaten eggs	*average % FSB Hatch*	Density Blk target FSB	*Anastatus* released	*Anastatus* emerged	# captured
Apr	55	0	15	*55.6*				0
May	80		5	*62.5*				0
Jun	80		5	*85.0*				0
Jul	80	3	10	*67.5*				0
Aug	140		15	*67.3*				0
Sep	85	5		*87.1*				0
Oct	85	4		*79.5*				0
Nov	100	1		*91.0*	5			0
Dec	60		10	*76.7*	15	5300	1680	0
2020 total	765	13	60	*75.1*	20			0
Jan	80			*91.3*	20	11000	3410	0
Feb	80	12	5	*71.3*	20	11000	3410	0
Mar	100		5	*76.0*	25	5300	1960	0
Apr	60			*100.0*	15	5400	1710	0
May	100		5	*90.0*	25			0
Jun	80		10	*76.3*	20			0
Jul	72		17	*69.5*	20			0
Aug	80			*90.0*	20			0
2021 total	652	12	42	*82.5*	165			0
overall totals	1417	25	102	*78.7*	185	38000	11700	0

Figure 2.5.2.18.*: Gryon* sp. (Hymenoptera: Scelionidae) parasitoid that was emerging from fresh *Amblypelta nitida* eggs placed at various breeding areas on the CTH Alstonville site April 2020-August 2021 – (Left: photo: Maxine Dawes SCU). Target *Amblypelta nitida* eggs placed weekly in Density block (Centre). One of the 5 release points for *Anastatus* within the density plot at CTH Alstonville (Right).

Summary for *Amblypelta nitida* (FSB) management

The data from the pesticide assays (Figure 2.5.2.16.) and field trials still suggests it is very important to keep the hanging FSB damage in the macadamia crop to a minimum in January and from then on the FSB tend to choose other targets to feed upon. At CTH Alstonville the next two generations (emerging in March and May usually, Table 7.1) are consumed with feeding and breeding on *Murraya paniculata* from that point on unless we have left the crop unprotected. Fortunately the positive feedback loop that seems to drive FSB activity can be used to manipulate their behaviour. The Sink block area at CTH was set up with that precisely in mind but it was over run with seed weevil. Now that weevil problem is somewhat solved, that could be re visited, just as the density plot is being used to look at macadamia lace bug and FSB again.

The FSB problem remains difficult to solve without effective spraying in NSW. Varietal selection and weather conditions are the key factors driving FSB population and pressure (Huwer et al. 2015b, MT10049 p.145 cultivar vs. damage). What actually constitutes an effective spray is a bit limited by how long you want to maintain control. For a knockdown product we have several new options like the group 4 products (Trivor®, Transform® and Sivanto® Prime) which do appear to have little residual activity after a week (Table 2.5.2.11. and 2.5.2.12.). The appearance of *Leptocoris* sp. during the summer on macadamia is a major complication because of the relative ineffectiveness of the pyrethroids (Table 2.5.2.12. and Figure 2.5.2.14.) has revealed the group 4 products are less effective on nut borer larvae that were covered by the pyrethroid applications (section 9 this chapter, Table 9.2). Acephate has been the back up compound for seed weevil, FSB and MNB control (Table 2.5.2.12 and Figure 2.5.2.14.) and it is slated for review by the APVMA. It does appear that the new Syngenta product and the Bayer DC143 (Vayego®) will be important to give growers more rotation options that have both bug and lepidoperan activity in the future (Figure 2.5.2.12.and Tables 2.5.2.9., 2.5.2.11. and 2.5.2.12.). Knowing which bugs are in the orchard in January is becoming more important.

The CTH Alstonville density plot (all 246, Tables 2.5.2.13., 2.5.2.14. and 2.5.2.15.) has been altered to include a flowering inter-row plant mix and the effect of the *Anastatus* parasitoid was measured in the field at an individual tree level on the damage done by FSB to the crop. Counts were made when the inter-row was planted (late December 2019 early January 2020). The 2020 crop has more damage on certain trees than the 2021 crop. The distribution of damage in 2021 is far more even, suggesting damage from adults flying in rather than concentrated damage of nymphs feeding. It suggests that the parasitoids released may have reduced the breeding of nymphs in one tree. This is a similar result to that found in 2016 at CTH with no difference in damage levels being detected for plots with *Anastatus* releases compared to the untreated control for cv. 849 (Huwer et al. 2015b, MT10049 p 145).

Most of the 246 blocks untreated at CTH will have FSB damage levels in the 10-20% mark as shown earlier and in the canopy coverage trial (Table 2.5.2.3. and Table 2.5.2.10.) and field data for the new chemistries trialled 2021 (Figure 2.5.2.12. and Table 2.5.2.9.). The field activity is far more lined up with the weather. The inter-rows were planted when the drought broke and the FSB levels were far higher from February 2020 than what they had been from December 2018 up until then (Figure 2.5.2.12 and 2.5.2.13.).

There was no significant difference in the per tree yield betweeen the seasons (Table 2.5.2.14.) . The planting density of 10 X 10 m showing the highest production levels of 16-16.9 kgs/tree DNIS @ 10 % moisture, and the tightly spaced 10X3.5 m trees only producing 3.8-3.9 kgs / tree in each season (Table 2.5.2.14.) same as what was shown in 2013-2014 (Huwer, 2016).

Parasitised egg cards >30,000 eggs were placed in density plot between mid December 2020 and April 2021, of those, over 11,700 hatched (active *Anastatus* in the block). Out of the 1400 target FSB eggs between April 2020 and August 2021 only 25 were parasitised and of those all were *Gryon* sp. (Table 2.5.2.1. and Figure 2.5.2.18.).

Similar results is what we have seen at the Mid North Coast IPM case study site 7 (Figure 2.5.2.11.), highlighting risk of late FSB on even the best managed blocks occurrring in May/ June 2020 and again in winter 2021. The activity of FSB detected in the orchards around Nambucca is going to be hard to protect against because it is occuring mid- harvest. Adopting the clean crop in February approach and maybe using trap cropps to protect against FSB is another possibility being explored in that region to limit the loss. An efficent adult FSB parasitoids or predators would be helpful.

What is an acceptable loss in a season is a valid question for the industry to consider.

Spraying from above and around with no drift, low noise effect on neighbours on smaller trees does appear to be one solution and that does bring the option of a trellase variety into play.

Macadamia Seed Weevil (*Kuschelorhynchus macadamiae*) management

Macadamia seed weevil (*Kushelorhychus macadamiae*) (Oberprieler et al. 2019) had become a serious pest for the crop by 2012 in the Northern Rivers region in NSW after its detection in the Dunoon area in 2009. The pest was previously known as *Sigastus* weevil from the north Queensland Atherton district in 1992-1998 (Fay, 1998). The management of the pest had required several broad spectrum insecticide applications (beta cyfluthrin, carbaryl, methidathion, acephate have been used until 2017) and vigilant orchard floor hygiene timing to limit its effect on the crop (Jeremy Bright August 2017 NSW DPI Fact sheet 1586).

The *Beauvaria bassiana* options were only working well under laboratory conditions (confined space high humidity) (Maddox et al. 2014, Huwer et al. 2015c; Figure2.4.1.) and were only showing a 20% reduction in field activity during the early nut drop period. A commercial product (Velifer®) was tested in the field but only as the pure isolated spores, and the wild field collected spores that were cultivated by QDPI (B27 and B48) were not showing any carry over between seasons at CTH and really required much wetter conditions to be effective.

The use of *Beauvaria* and *Metarhizium* suspensions has been found to have beneficial effect on the management of pest insects in high rainfall areas (3-6m annual rainfall-e.g. Brazil, Costa Rica, Columbia). There is doubt over the capacity of the spores to remain viable on foliage in higher UV drier environments like Australia and South Africa.

The original field indoxacarb application in the CTH Alstonville Entomology plot trial during October 2017 and the subsequent monitoring data of the plot is shown in Table 2.5.2.17. The way the female weevils chew out a piece of the husk, which allows it to oviposit into the husk shell boundary area actually, gives it option for control with pesticides ingested during that process.

Trials with indoxacarb showed that macadamia seed weevil oviposition stops within a fortnight of the spray and appears last for 13 weeks with a single application. This basically led to the adoption of indoxacarb as the primary treatment for macadamia seed weevil in 2018. Comparing macadamia seed weevil treatments, the total yields were not higher than the standard acephate sprayed plots in all the years except 2020 crop which did have very low levels of FSB and MNB compared to normal (Table 2.5.2.17.).

Indoxacarb is very specific for macadamia seed weevil management. What was a series of mulching exercises before the adult weevils emerge from infested dropped nut, and 2-3 organophosphate / pyrethroid sprays to protect the nut, became a strategically timed single spray when the grower begins to see drop nut with seed weevil oviposition (Macadamia Pest Management Guide, Bright, 2016; 2018; 2019; 2020; 2021).

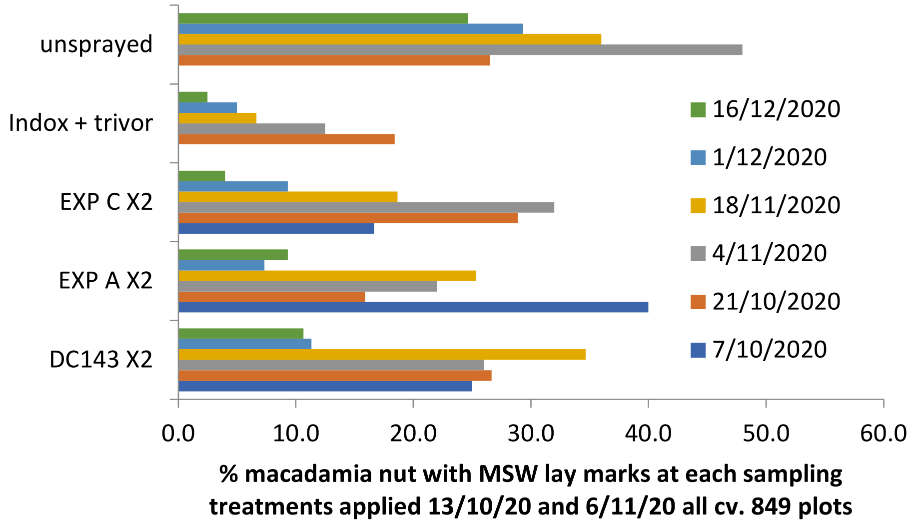
Other pesticides tested for management of the weevil were not as successful as indoxacarb (Figures 2.5.2.20., 2.5.2.21. and 2.5.2.22.). Double applications of Vayego® (DC143) and a new experimental product do have some effect on the weevil activity similar to acephate in the action and response (SARP review 2020).

The seasons swung in January 2020 from record dry to wet and the comparative seasonal efficacy of the indoxacarb application was examined in several blocks at CTH Alstonville. The blocks are labelled as shown in the map in Figure 2.5.2.1. and with the macadamia lace bug spray/ seed weevil spray code and the corresponding weevil infection levels at each fortnightly monitoring. We left some blocks unsprayed and some were sprayed with products so that the seed weevil activity could be compared between the dry/ wet seasons as lay marks on dropped nut (Figures 2.5.2.20. and 2.5.2.21.), or as actual eggs laid (Figures 2.5.2.20. and 2.5.2.22.).These show that virtually from 8mm nut size, when the nuts are targeted for laying by the weevils (early October) to January seed weevil oviposition remains absent regardless of the weather if indoxacarb and designer are used to make sure the compound is spread and stuck to the husk surface.

Grower feedback this season (2021-2022) suggested trying Vayego® to get a combined activity against macadamia weevil and FSB with the one spray. This needed a follow application up with indoxacarb to restrict the weevil expansion (Steve Mclean, pers. comm. 2021).

Table 2.5.2.17.: Comparison of the average percentage of nut drop due to macadamia seed weevil (MSW) oviposition and (standard error) under each tree before and after the main MSW spray applications in October and November 2017. MSW oviposition rates with same letter are not significantly different using Genstat unbalanced ANOVA followed by LSD determination. Data was analysed as arcsine transformed %. The untreated (19) and standard (20) without hygiene blocks are neighbouring the main plot but serve to show the importance of picking up infested nuts before the key emergence periods (early September and late October in 2017). (+) Only central 9 trees down each treatment used for monitoring counts on these dates, all 36 trees for the rest. Indoxacarb application in yellow.

Date	IPM 2 Block 1-4 Hygiene (36 trees)	IPM 1 Block 5-8 Hygiene (36 trees)	STD + Bio B9-12 Hygiene (36 trees)	STD B13-16 Hygiene (36 trees)	UNTREATED B 19 no hygiene (9 trees)	STD B 20 no hygiene (9 trees)	F-value	LSD
04/10/2017	82.4 (8.9)a	66.9 (8.1)a	72.2 (8.1)a	66.7 (10.1)a	65.7 (14.4)a	81.9 (19.2)a	0.333	30.7
17/10/2017	60.0 (5.8)a	59.3 (5.4)a	54.4 (5.1)a	64.7 (5.5)a	26.8 (8.5)b	24.8 (8.5)b	0.679	16.8
19/10/17 sprays	Hygiene done *Beauvaria* spore	Hygiene done Avatar® 300®	Hygiene done Lancer® 970®	Hygiene done Supracide® 400®		Supracide® 400®		
01/11/2017(+)	37.5 (7.6)b	7.2 (7.5)c	61.8 (8.7)a	31.3 (7.2)b	40.1 (7.5)b	47.9 (7.5)b	<0.001	20.3
15/11/2017(+)	52.4 (7.3)b	2.1 (7.3)d	39.9 (7.3)bc	29.9 (7.3)c	83.3 (7.8)a	80.0 (7.8)a	<0.001	19.5
13/11/17 sprays	SeroX®	Exirel® 100®	Lepidex® 500®	Lancer® 970®		Lancer® 970®		
29/11/2017	72.1 (3.9)a	3.6 (3.9)d	52.5 (3.9)b	23.8 (3.9)cd	83.5 (7.6)a	81.2 (7.6)a	<0.001	13.4
12/12/2017	67.2 (3.3)b	1.5 (3.3)d	46.9 (3.4)bc	15.1 (3.4)d	80.0 (6.5)ab	96.7 (6.5)a	<0.001	11.5
(June 2018 yield) Nuts / per 9m tree	316 (24)c	1326 (77)b	1279 (48)b	1674 (75)a	21 (2)d	15 (2)d		



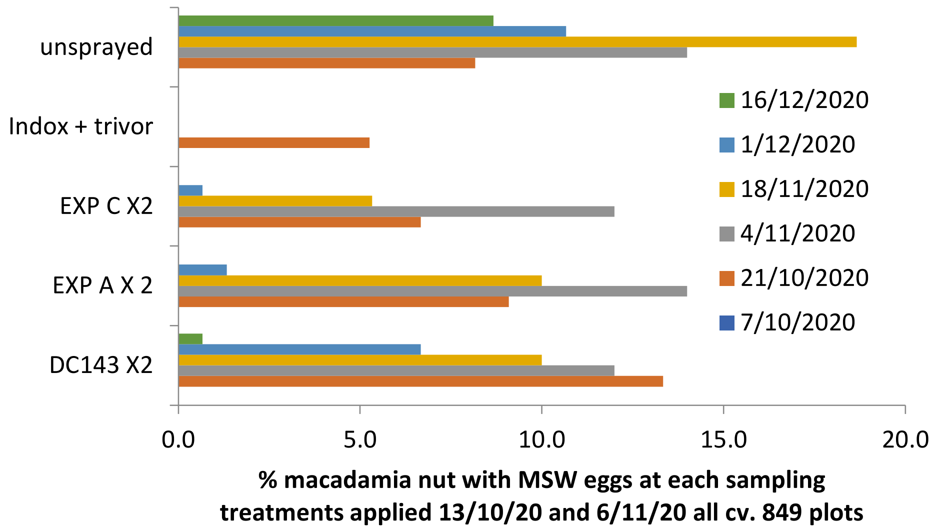
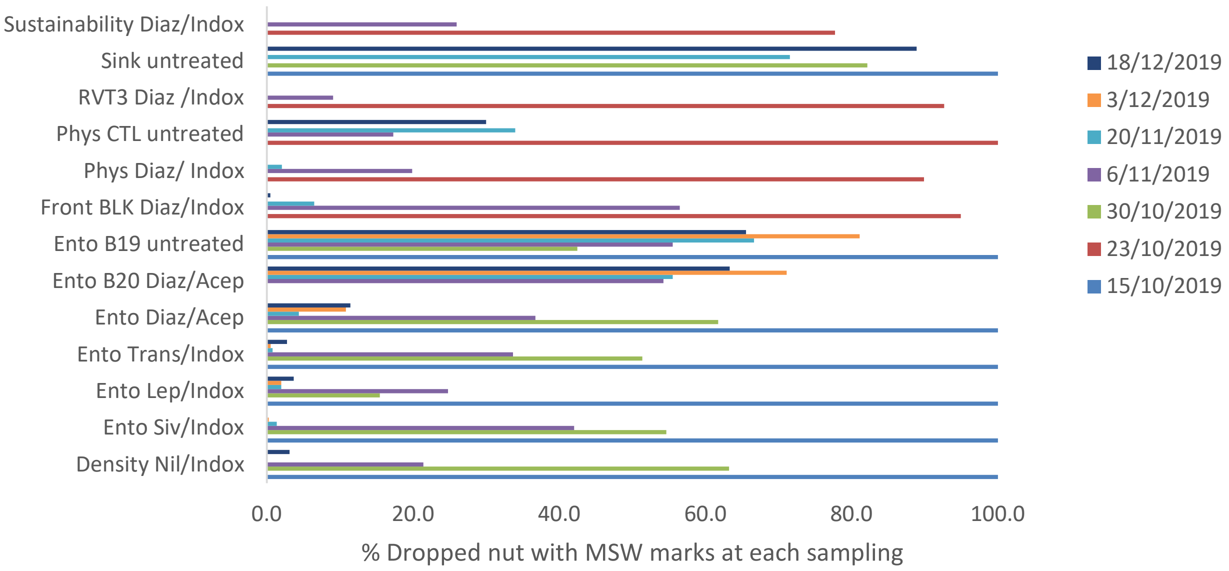


Figure 2.5.2.20.: Comparison of fortnightly macadamia seed weevil activity in the physiology plot trial at CTH Alstonville 2020 showing proportion of nuts with lay marks (top) and actual eggs (bottom graph) if unsprayed or treated. This shows the current Indoxacarb treatment is stopping seed weevil oviposition more effectively than the three new experimental products including (DC143=Vayego®) (SARP July 2020 seed weevil registration suggestions). Trivor® is not effective against macadamia seed weevil and was applied for the *Amblypelta* activity that was beginning to damage the crop in November 2020.



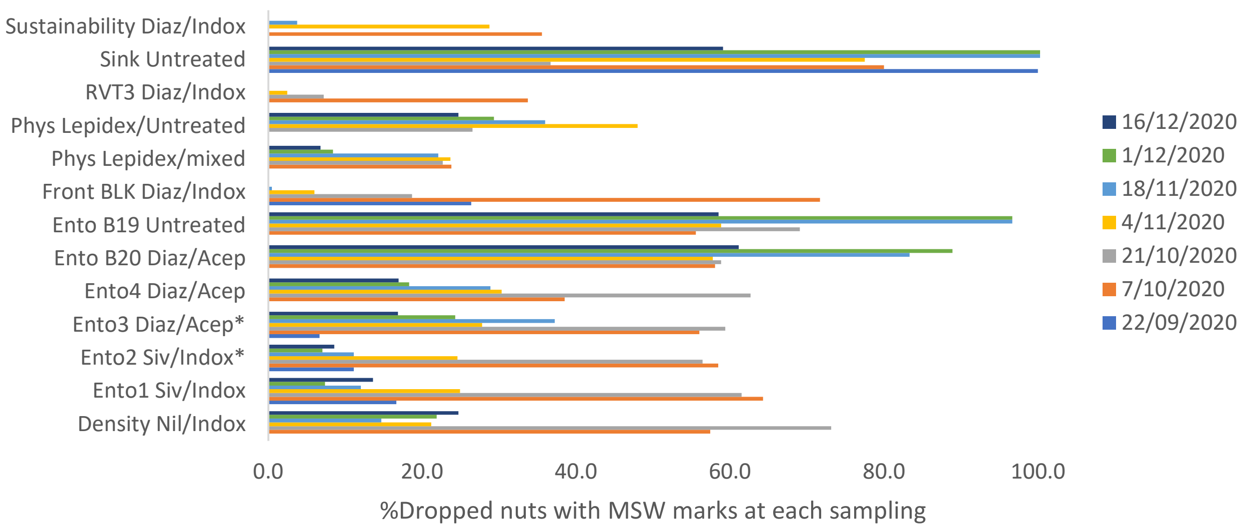
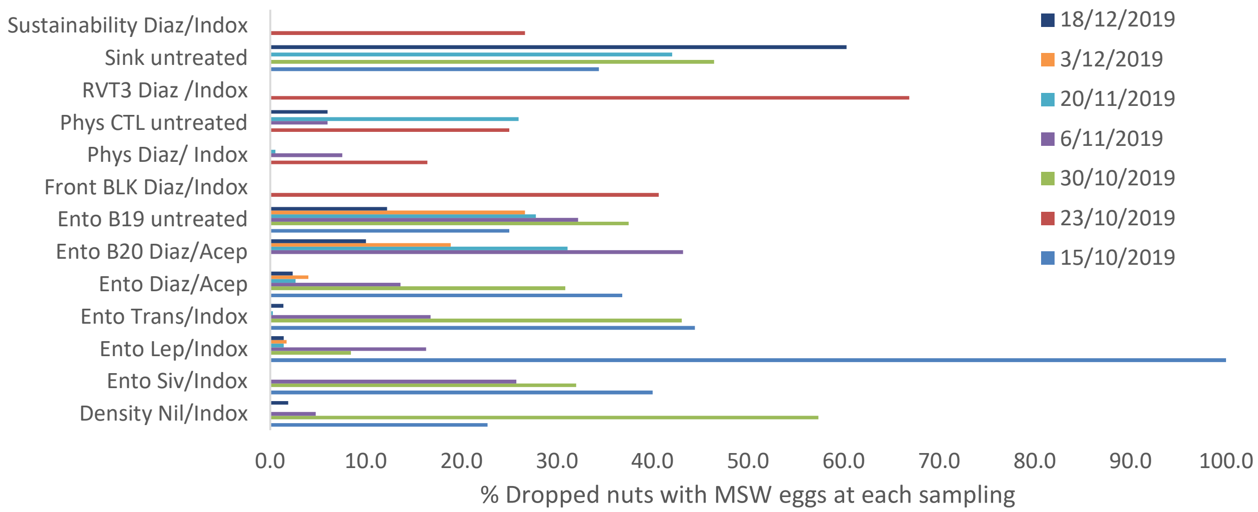


Figure 2.5.2.21.: Comparison of the % macaddamia seed weevil (MSW) marks in the dropped nut sampling in each trial block at CTH Alstonville during the extreme dry season 2019–2020 (above) as compared to the wet season 2020-21(below). Blocks treated with Indoxacarb were far less damaged under dry conditions. Complete nut removal is normally seen by late December in untreated areas, almost 100% of nuts are showing attack for the last 3 samplings in these blocks (Sink block and the unsprayed Block 19 next to the Entomology orchard). Blocks where the whole block was treated with indoxacarb and they don't border an untreated area (RVT3 and Front Block) are not showing continual low level re infestation. Indoxacarb did last the entire infestation period in the wet season in both RVT3 and Front block no laying detected after application.



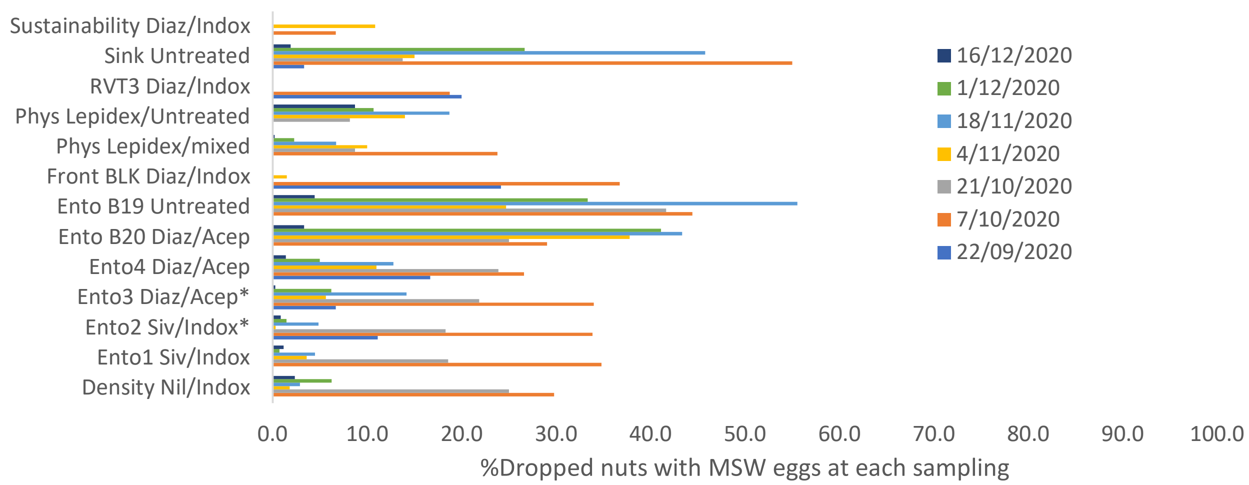


Figure 2.5.2.22.: Comparison of the % macadamia seed weevil (MSW) eggs laids in the nut sampling in each trial block at CTH Alstonville during the extreme dry season 2019–2020 (above) as compared to the wet season 2020–2021 (below). Blocks treated with indoxacarb had far fewer eggs present after the application mid October. In blocks where an indoxacarb treatment had not been applied through November and December, new oviposition levels are over 20% of the nut drop (Sink block and the unsprayed Block 19 next to the Entomology orchard). Blocks where the whole block was treated with indoxacarb and which don't border an untreated areas (RVT3 and Front Block) are not showing continual low level re-infestation. Indoxacarb did last the entire infestation period in the wet season in both RVT3 and Front block no laying detected after application.

Macadamia Nut borer (MNB *Cryptophlebia ombrodelta*) management.

The threat to the macadamia crop from nut borer has been a major concern since the 1970's and MNB was the perceived main threat, just as they had found in South Africa (the wasps origin – Waite, 1994). In time it became evident, that the MNB egg parasitoid mainly saved the last pesticide applicatioin on early varieties (Maddox et al. 2002, Huwer et al. 2006), and critical to keep FSB damage in January to a minimum and to augment that area with parasitoids to allow them to build up and prevent the overwintering of MNB in your orchard. That approach is still used successfully today (Figures 2.5.2.23. and 2.5.2.29. and Table 2.5.2.20.).

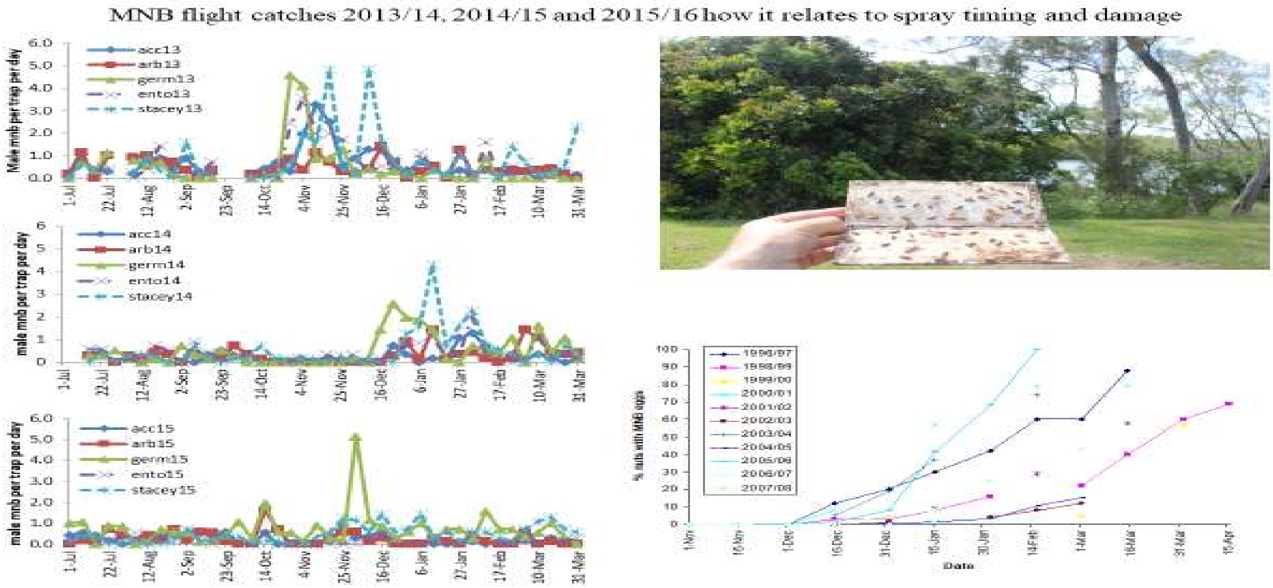


Figure 2.5.2.23.: The use of pheromone lures and delta traps to monitor male moth flights into macadamia orchards at CTH Alstonville (seasons 2013-2015 shown here) and in the mangrove areas where the overwintering populations exist is half of the monitoring for macadamia nut borer(MNB). Levels spike in the traps (around 5 - 6 moths/trap/day) and egg parasitiods are normally released when that starts. The other important task is to check for MNB oviposition on the nuts (lower right graph), if the crop is already mature and laying on nuts has not started before early March, MNB is not going to be an issue that season. Laying can commence when the nuts reach 20mm diameter if the conditions are right , surges in egg laying are checked for, spray thresholds were 1 live egg/ 100 nuts sampled in December (Ironside, 1983).

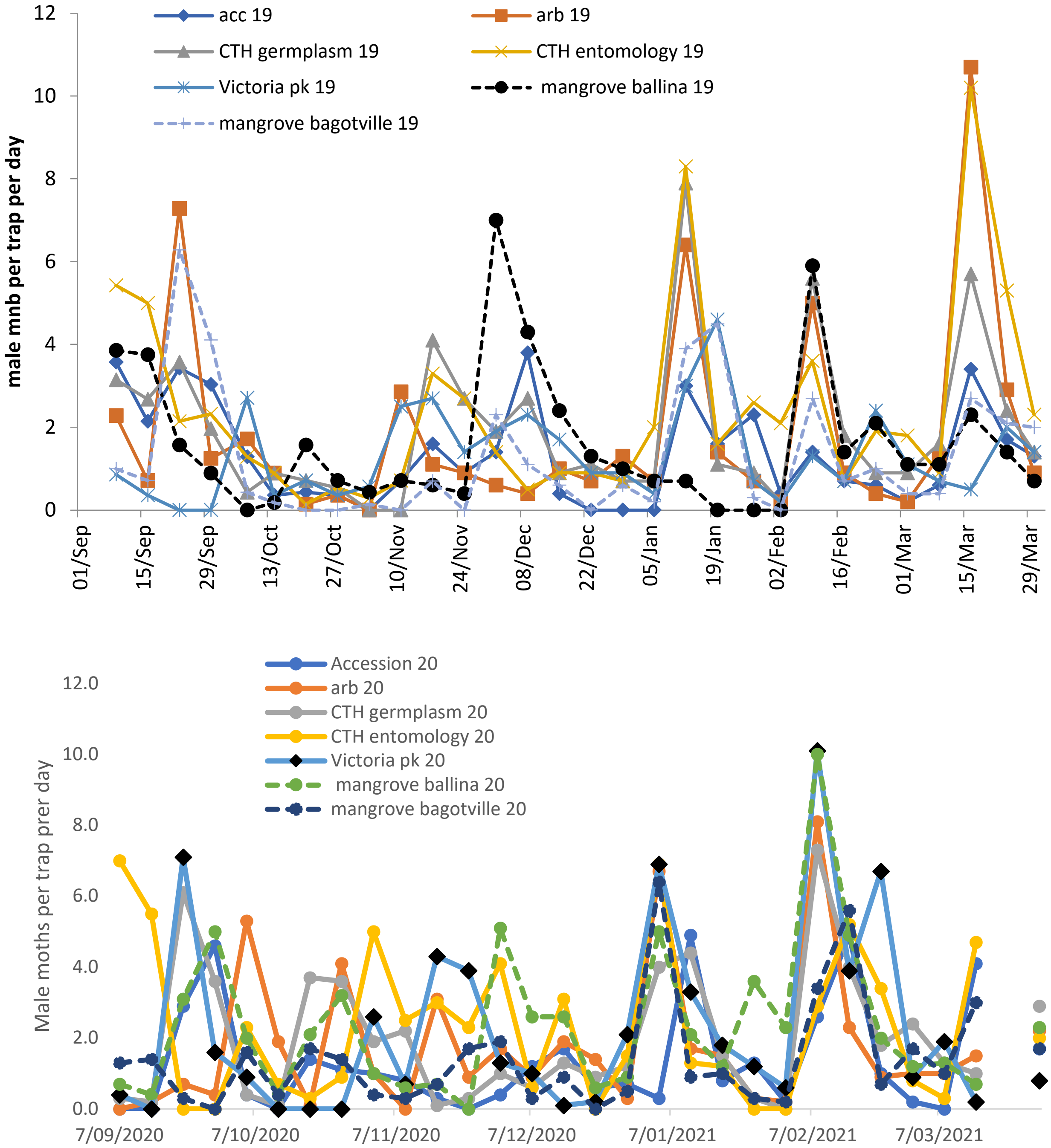
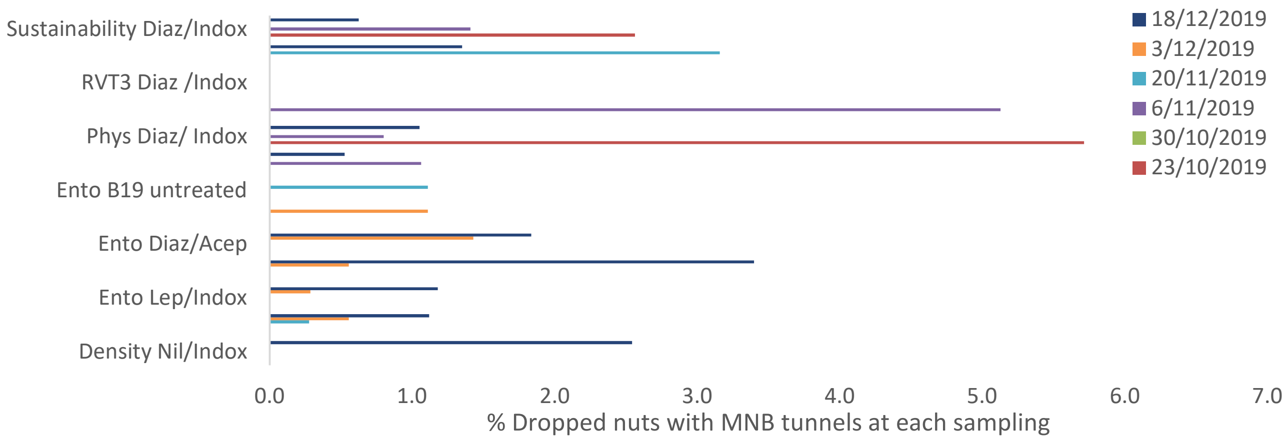
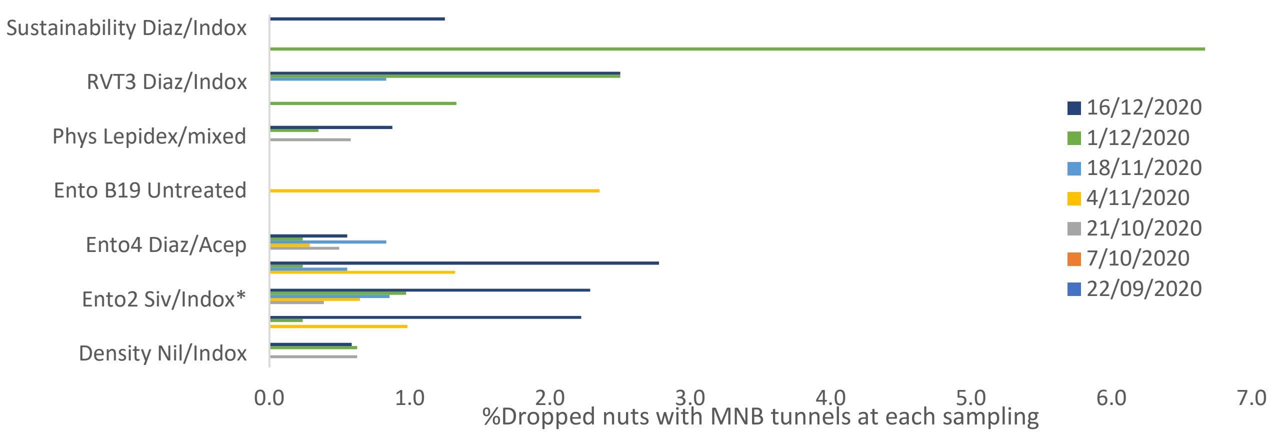


Figure 2.5.2.24.: Comparison of the daily male *Cryptophlebia ombrodelta* (MNB) catches in pheromone traps on the Alstonville plateau in Northern NSW. Delta traps placed in trees at CTH Alstonville in macadamia orchards, in mangroves on estuaries at Ballina and Bagotville and at Victoria Park Nature Researve on the southern edge of the escarpment during the extreme dry season 2019–2020 as compared to the wet and MNB damaging season 2020–2021. Macadamia nuts are susceptible to MNB attack from about 20mm diameter up until nut maturity. Peak moth catches are now double what they were in 2013-2015 period.





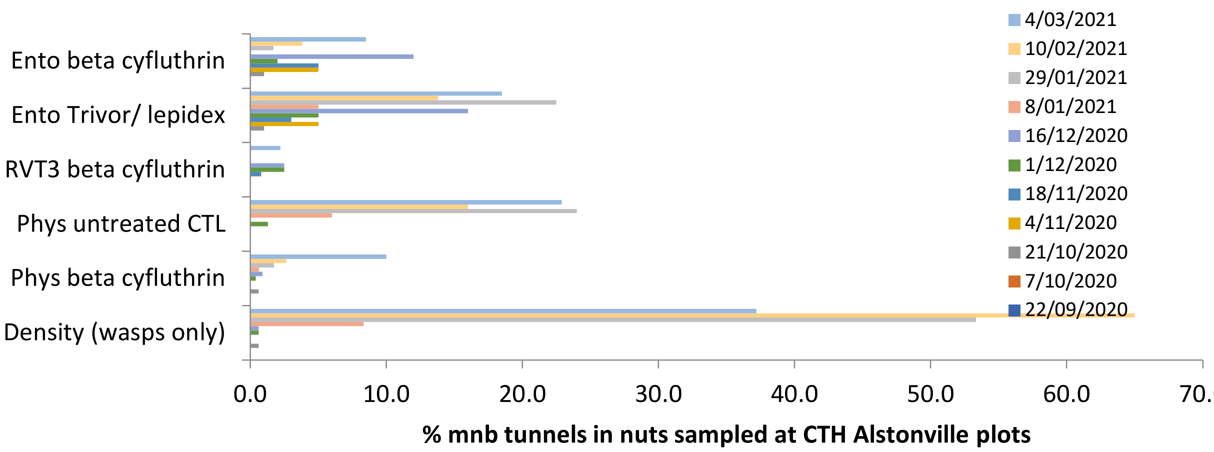


Figure 2.5.2.25.: Comparison of the % MNB tunneling in the nut sampling in each trial block at CTH Alstonville during the extreme dry season 2019–2020 as compared to the wet season 2020–2021. There was no real difference in the trial blocks at CTH Alstonville up to December each season only 3-4 % nuts with larvae dropped (top and middle graphs). MNB larval survivorship is enhanced with higher humidity. The flood events in December 2020 rather than the January and February of 2020 had higher effect on the crop. Parasitic wasp activity is hampered by continuous heavy rain and very high temperatures (lower graph, T>35° C for 3-4 days; Maddox et al. 2002). Blocks treated with beta-cyfluthrin in December had far fewer tunnels in the canopy samples from January up to the first harvest in March 2021 (lower graph). Blocks without spraying (e.g. Density block) had high levels of MNB damage in husk from 08/01/2021 (>20%) and even the Lepidex sprayed areas had 15-20% damage in husk and high levels of immaturity was found in the kernel recovery of the crop.

Figure 2.5.2.26.: Female *Cryptophlebia ombrodelta* (MNB macadamia nut borer) can lay > 150 eggs in a week and this shows the way they lay on damaged surfaces and grooves (a grazed poinciana pod in this case).

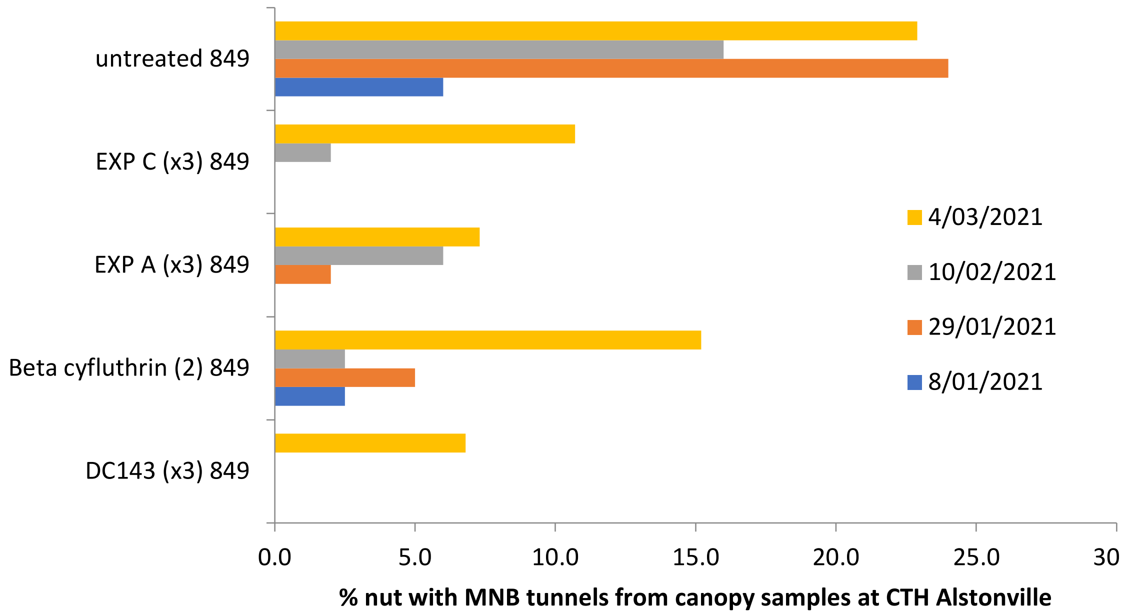


Figure 2.5.2.27.: Comparison of the canopy macadamia nut samples (10 nuts per replicate, 5 replicates per treatment) in the Physiology block at CTH Alstonville showing mean macadamia nut borer tunneling (% nut with tunnels) compared with the first harvest in March 2021, pesticide applied 22/1/2021.

Table 2.5.2.18.: Comparison of the total nut drop due to macadamia nut borer (MNB) oviposition and tunneling across the Entomology block for season 2019/2020 and 2020/2021 up until December 17Th from under each tree sampling (10 nuts per tree, 9 trees per replicate). The wet season effect of MNB is shown at harvest between January and March. A lot of nut can drop tunneled and immature. At harvest in March 2021 the husk levels of MNB tunneling (30 nuts per tree, 9 trees per replicate), show a preference for cv. 246, A4 and 849 over cv. 741 (roughly twice the damage). Two applications of beta cyfluthrin as (i.e. Bulldock®) at 50ml/100L in December and January was used in the standard treatment and reduced the level of MNB damage to the husk over 50% to trichlorfon (i.e. Lepidex®) at 200ml/100L as MNB treatment.

Nut drop		**Oct 22**	**Nov 5**	**Nov 19**	**Dec 2**	**Dec 17**	
2019/20 Nuts		271	1783	2463	1600	2448	Dry season
MNB Tunnel/ 100 nuts		1.1	0.3	0.2	0.7	1.3	
2020/21 Nuts		1781	2367	3049	3225	2977	Wet season
MNB Tunnel/ 100 nuts		0.2	0.5	0.3	0.5	1.3	
2021 March harvest				**2021 March harvest**			
MNB treatment /variety	**plot**	**nuts**	**tunnels/ 100nut**	**MNB treatment /variety**	**plot**	**nuts**	**tunnels/ 100nut**
Lepidex®/ 741	1	269	19.7	Bulldock®/ 246	9	263	24.0
Lepidex®/ 246	2	268	40.7	Bulldock®/ 849	10	260	16.5
Lepidex®/ 849	3	269	44.6	Bulldock®/ A4	11	261	22.2
Lepidex®/ A4	4	270	38.9	Bulldock®/ 741	12	269	10.4
Lepidex®/ 849	5	256	37.5	Bulldock®/ A4	13	264	25.8
Lepidex/A4	6	263	44.9	Bulldock/741	14	270	5.6
Lepidex/741	7	240	18.3	Bulldock/246	15	208	21.2
Lepidex/246	8	266	53.8	Bulldock/849	16	266	13.9

Table 2.5.2.19.: Comparison of the green husk on the harvested crop in March 2021 after two applications (18/12/2020, 26/01/2021) of the various products for FSB control in Front block at CTH Alstonville. Thirty nuts were collected from each of the four trees examined under 10x magnification for macadamia nut borer (MNB) oviposition, thrip feeding (>25% surface) and presence of live felted coccid. MNB egg laying and larval tunnel levels are far lower for the Bulldock® treatment (*) but thrip damage and felted coccid levels are enhanced (**).

Treatment	**Number of trees**	**Green nuts**	**MNB eggs**	**MNB tunnels**	**%live MNB eggs**	**Thrip damage**	**Nuts > 10 felted coccid**
Transform ® @ 40ml/ 100L	4	120	58	58	3.3	43	1
Sivanto® Prime @ 100ml/ 100L	4	120	41	39	0.0	27	3
Trivor® @ 40ml/ 100L	4	120	56	54	0.0	40	3
Bulldock® @ 50ml/ 100L	4	120	13*	14*	0.0	53**	10**
Sivanto® Prime @ 75ml/ 100L	4	120	34	56	0.0	24	3

MNB summary

The weather conditions in 2020–2021 favoured MNB larval emergence from early January and heavy rainfall **f**or extended periods limited the capacity of the parasitoid to work the orchards in northern NSW. The variability in seasonal flight times is shown in Figures 2.5.2.23., 2.5.2.24. and 2.5.2.28. The wasp release timings are shown in Figure 2.5.2.29. Egg parasitoid releases have the optimal efficiency at host densities of around 10-12 MNB eggs/100 nuts and releases had only really failed in 2017 (Table 2.5.2.20.) with the right spray timing.

Only the blocks that had been treated with beta cyfluthrin showed reduced MNB tunneling at harvest (Tables 2.5.2.18., 2.5.2.19. and 2.5.2.20. and Figure 2.5.2.25.). New products tested in a small scale trial (Figure 2.5.2.27.) gave better results than beta cyfluthrin in keeping the MNB oviposition and tunneling lower for longer under very wet conditions. Certainly, the Vayego® (DC143) and the Syngenta product are performing well and have some FSB activity.

The compatibility studies with the egg parasitoid showed that both new products were not reducing wasp emergence or fertility of the next generation of wasps.

Table 2.5.2.20.: Management changes and drought effects on the pest insect fauna populations in RVT3 at CTH Alstonville planted in 2007. Each tree is sampled mid harvest (May -30 nuts from each canopy). The drought season (2020 crop) produced nuts that were on average 21.4% smaller and had 17.6% more kernel inside.

RVT 3 management changes (170 trees)	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**
Total rain in mm (1800 mm 40 yr mean)	1939	1489	1970	1397	787	2299	2022
August-December (534 mm 40 yr mean)	632	448	663	466	213	645	670
Diazinon for macadamia lace bug	none	yes	yes	yes	yes	yes	yes
Trichogrammatoidea releases for MNB	yes	yes	yes	yes	yes	yes	yes
Acephate / beta-cyfluthrin (MSW/FSB)	none	yes	yes	yes			
Hedge/*M.ternifolia* FSB flight spray timing	none			yes	yes	yes	yes
Indoxacarb (MSW)	none				yes	yes	yes
RVT3 crop changes (block averages)							
nutsize (g) @1.5% moisture DNIS	7.8	7.9	7.0	7.5	7.0	5.9	7.7
%TKR @1.5% moisture DNIS	38.2	37.2	38.8	40.0	39.7	45.6	39.1
RVT3 Insect activity							
% bugloss in kernel per tree	4.9	1.2	4.1	0.3	0.8	0.8	0.6
FSB seen on *M.ternifolia* (Oct-March)		274	521		189	103*	339
% nut fed on by seed weevil (MSW)	0.4	1.3	19.7	6.3	0.5	0.1	1.7
Male MNB moth catch rate Nov-March	9.3	3.9	26.0	35.8	18.7	54.7	50.8
MNB eggs per 100 nuts	15.7	13.3	64.9	14.4	21.7	13.1	31.1
MNB tunnels per 100 nuts	3.6	3.5	19.5	2.0	1.6	0.4	2.2
% Thrip/Mite damage on husk	7.2	6.3	30.5	40.8	43.4	75.1	34.8
% Nut with felted coccid (>10 live)	0.3	1.4	1.4	6.0	23.6	38.4	34.8
Variety A538 % nut with Felted coccid	0.0	0.0	1.3	0.0	3.4	0.0	0.0
Variety A447 % nut with Felted coccid	0.0	0.0	0.0	0.0	0.6	0.0	1.1

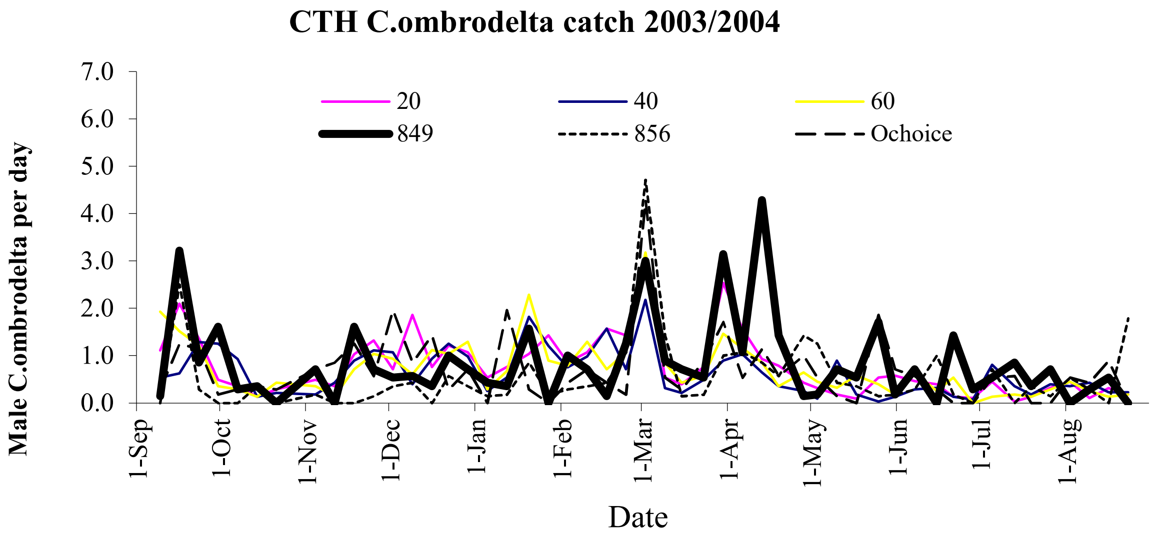


Figure 2.5.2.28.: Male *Cryptophlebia ombrodelta* (MNB) catch per day over the year 01/09/2003-01/09/2004 across the Entomology trial site. The 2004 crop in northern rivers was one of the best recorded and its apparent that the main MNB flights detected (spikes in moth catch on farm) did not happen until after the nuts were mature in March.

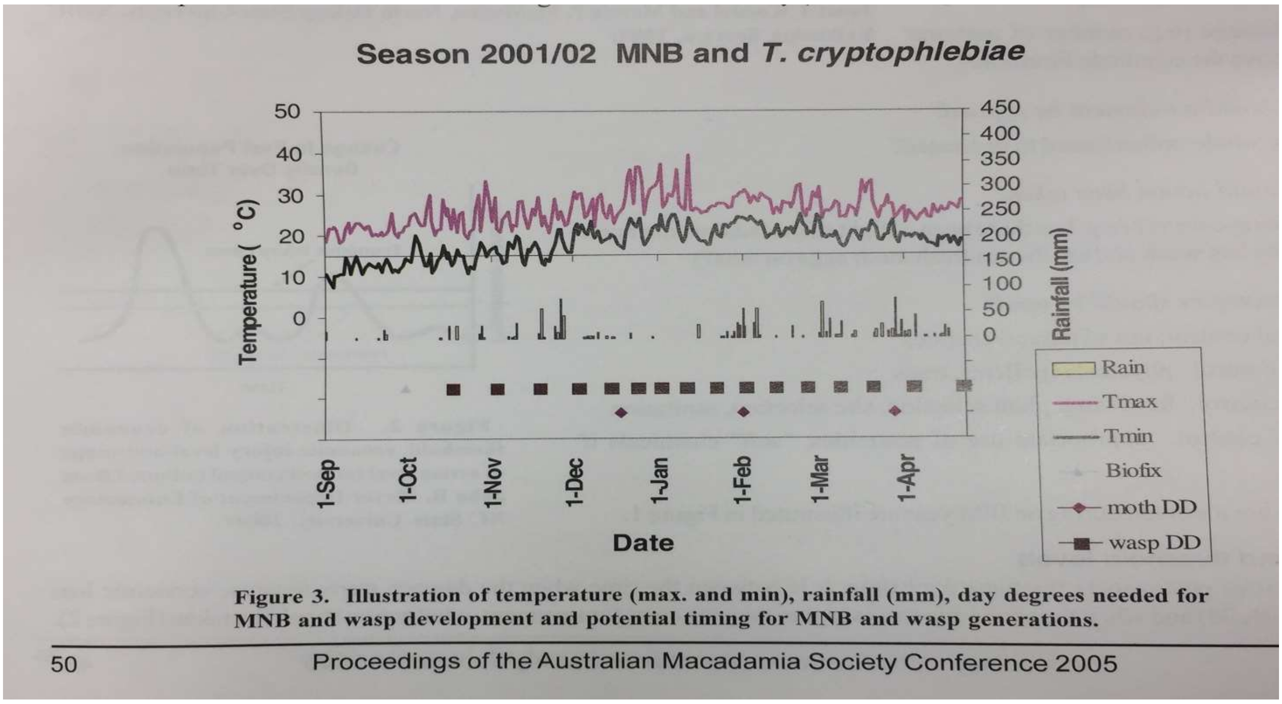


Figure 2.5.2.29.: Modelling *Cryptophlebia ombrodelta* (MNB) 3 generations (♦) based on the degree day summations from biofix (night minumums above Dz, 408 DD above 13.8° C) and *Trichogrammatoidea cryptophlebia* (TC) 15 generations (■) based on 165 DD above 9.5°C originally from Maddox et al 2002.

Conclusion and recommendations

Appraisal of a new experimental product

The experimental product SYNFO 121 formulation (EXP C in the graphics) applied at 30ml/100L controlled populations of FSB and MSW when applied through spring and summer (3 applications October, November and January). SYNFO 121 applications had significantly reduced the levels of MSW laying and oviposition (Figure 2.5.2.20) by November 18th compared to the untreated areas, this however was not as effective as the indoxacarb standard which had reached that point by November 4th (Figure 2.5.2.20 and Appendix 2.5.6) within two weeks of application and remained that way until the end of December. SYNFO 121 when applied on the determined FSB flight times at CTH Alstonville is effective at controlling FSB under high pressure (Table 2.5.2.5. and Figure 2.5.2.13. and Appendix 2.5.6.). Untreated blocks were averaging above 50% FSB losses in this area in the early harvests.

The new product appears to give equivalent control to beta-cyfluthrin (Table 5.1.1 and Figure 5.1.2). SYNFO 121 was also a suppressive treatment of the MNB oviposition compared to the standard beta-cyfluthrin (15% tunnels at first harvest) treatments and 22% tunnels in the untreated plots (Figure 2.5.2.27.) There were less MNB tunnels detected during February then only 11% of nuts in the first harvest in March.

The trial also shows just how selective FSB are in there feeding preference by sampling the neighbouring cv. 246 row in the untreated and standard spray areas (April harvest only). This variety shows about 50% less FSB compared to the cv. 849 trees (Figure 2.5.2.13.).

Crop residues are currently unknown, but the product needs to be deemed safe to be considered for use on macadamia farms.

Bee toxicity is also unknown and required for use around flowering time for endorsement of the product.

2.5.3. Comments from AMS pest consultant meetings

Where were we at in 2016?

IPDM in macadamia at the start of the project- Notes (Maddox CD NSW DPI) from 8/6/2017 pest consultants meeting regional roundup. Pest problems from previous season 2016-17 from the people who advise the top growers.

Steve Mclean NR NSW: "Macadamia lace bug down, 10% *botrytis* on flower, low incidence of dry flower, felted coccid low, Seed weevil earlier and more widespread heavy pressure. FSB consistent, higher late MNB, thrips and mites higher in 344, RATS significant issue, pin hole borer going through shell."

Matt Kunde Gympie QLD: "Flower caterpillar and macadamia lace bug down, FSB high pressure, heavy and late MNB, hail issues and RATS."

Phil McCarthy NR NSW: "*Botrytis* higher, dry conditions for nut development then FSB took off late, Seed weevil right through, MNB higher, more rat damage."

Mick Matthews Emerald QLD: "Felted coccid and FSB light, MNB none, Mealy bugs released *Cryptolaemus*, post rainfall pests exploded thrips rampant."

Paul Mooseburger NR NSW: "Rats feeding on green nut in tree baiting very important, Seed weevil from pea size nut onwards."

Bob Maier Nambucca NSW: "Macadamia lace bug down except in organic areas, flower caterpillar medium pressure, FSB average year and MNB low, pin hole borer (*Hypothenemus* sp.) increasing in nut in shell, felted coccid, thrips and broad mite. Diseases *botrytis* late in flowering yes and dry flower in A268, husk spot very low, A38 immature and reduced nut diameters in the dry."

Chris Fuller Gympie QLD: "High flower caterpillar, macadamia lace bug expansion in glasshouse mountains area, Gympie macadamia lace bug less, less thrip FSB normal, MNB higher in both Gympie and Glasshouse Mt. regions."

Jade King Gympie QLD: "Macadamia lace bug new concern, Trunk borers in block dead trees showing 10-12 common per plot."

Alan Coates Gympie QLD: "Rats higher, macadamia lace bug lower, flower caterpillar higher, FSB usual, MNB higher."

Megan Boote Gympie QLD: "Cockatoos, pigs and hail early in season, and MNB."

Graham Wessling NR NSW: Cane land coastal macadamia- no Seed weevil there yet, losses to the flood, rats higher, pin hole borers higher."

Scott Hill NR NSW: "Macadamia seed weevil expanding, mulchers leaving a lot behind, maybe Monchero harvesters are collecting the infected nut better."

Clayton Mattiazzi Hinkler park Bundaberg QLD: "Coverage/resistance issue Bundaberg is over spraying and FSB damage is still rising? Mites are increasing and pin hole borers as well. Need to maintain natural resilience in the orchard if sprays are not working."

Rob Hobbson Bundaberg QLD: "Pin Hole borer in A16 nuts and bark beetles killing the branches."

Les Gain Amamoor QLD: "No lace bug issues, flower caterpillar late and heavy, low husk spot, early FSB, MNB late and heavy, *Leptocoris* required 3 sprays (Lancer best) population building under foam bark leaves on ground, PIGS and Cockatoos and hail damage early."

Chris Searle Glasshouse/ Bundaberg QLD: "Glasshouse Lace bug causing big losses , Bundaberg dry flower, *Hypothenemus* sp. and bark beetle into nut and petioles of a16, 816 and a4, brown centres are back and weather related."

Eddy Dunn Bundaberg QLD: "Banana fruit caterpillar was usual levels, FSB coverage gave control though not everywhere, Flower caterpillar up, Pin hole borer and bark beetle up, heavy branch dieback in both avocado and macadamia. No macadamia lace bug or seed weevil in Bundaberg yet."

Jarrah Coates NR NSW: "Heat affected late flowers in area, low lace bug, FSB picked up late, MNB had a January spike, Seed weevil major concern."

Kim Wilson NR NSW: "Seed weevil need better coverage, better timing, Rats on rise again, Mackay QLD – dry flower in a203, cockatoos horrendous."

Andrew Pearce Bundaberg QLD: "Poor nut size in the un-irrigated blocks, some SeroX® uptake in Bundaberg and new sprayers being used."

Mark Duncan NSW: "Macadamia lace bug lowest in 6 years, MNB lowest in 10 years, FSB very low, treating for seed weevil (formerly *Sigastus*) has stopped them. MSW back in April need to fix the stuff on the ground and still hanging to fix it. Rotating the chemistries dry weather meant good coverage but Broad mites, thrips and Rats all up on usual."

John Pretorius:"*Sigastus* (now, macadamia seed weevil) infected nut collected by harvester in February worked better than by mulching."

Mark Whitten MPC NSW: "Seed weevil main issue, people trying *Anastatus* as a biological, how are we going with the semiochemistry for MSW in the shape of a lure."

Bill Johnstone NR NSW:" Questions about the timing of chemical rotation for seed weevil, abamectin working well for thrips and mites, some farms are importing husk need to watch out if MSW in that."

Ray Norris Bundaberg Alloway QLD: "FSB issues with resistance? Bulldock® too often in Bundaberg?"

Neil Innes Bundaberg QLD: "Thrips big problem on out of season A38"

Mary Burton NR NSW: "Macadamia lace bug a non issue avoided using diazinon, dry flower blight and some flower caterpillar. cockatoos! Seed weevil consistent damage and high nut shedding across the area, FSB also consistent, Has husk spot reduced? MNB up after Christmas and into new year. Rats were higher, 3-4 sprays for seed weevil is reducing the beneficials."

Kevin Quinlan MPC NSW:" Heavy leaf shed in January with the dry, insect damage levels 1/3 what they were the previous season in the consignments received. Need to ID exactly what insect is actually doing the damage. Rats were a problem using the CO mower modified unit for the main ground nest sites with some success. Need to address the late season FSB Monitoring."

Ross Burgess Mac Direct NSW: "GVB causing damage on the cane lands near soybean rats still a big problem, we need softer options for seed weevil."

Alan Coates NR NSW and Gympie QLD: "Poor spray calibration leading to poor coverage."

Matt Burns Bundaberg and Rockhampton QLD:"Thrip and mites big issue up in Rockhampton and the mistletoe removal worse than Bundaberg."

Scott Herd Norco NR NSW: "Getting unmanaged farms back into action with improved soil health and reducing phytophthora in the dry periods especially. More narrow option chemistry needed, IPM is difficult when NIS prices are so high, any word on carbendazim removal for husk spot have heard it might be out soon?"

Alwynn du Preez Sth African crop consultant special guest for the conference meeting 2016-2017:" In South Africa we are normally applying 5-7 insecticide in a growing season some areas over 10 (thrips, various moths and various bugs feeding through the shell like FSB). We do also have trouble with monkeys, pigs, and theft from the locals, which also requires security and razor wire around the orchards. No we don't want seed weevil or macadamia lace bug, felted coccid is giving enough trouble already".

Where are we now 2020–2021?

IPDM in macadamia at the end of the project- Notes (Maddox CD NSW DPI) from 17/11/2020 pest consultants meeting regional roundup. Pest problems from previous season 2019-20 and what was happening 2020–2021.

Bob Maier Nambucca NSW: "Macadamia lace bug higher, Flower caterpillar and loopers low, citrus blossom bug and broken back bug around in flowers too. Weather variable, good bee numbers, cockatoo's high #, plenty of silver eyes and honeyeaters. Grey mould was up, Husk spot had little effect on the crop, *Phomopsis* (husk rot) occurred on a high temperature event on 344's. *Hypothenemus* sp. around FSB low until the rain events then late activity in April May. MNB very low, Rats low, KR higher and yields good, Yarrahappini Euangai had smaller nuts.

2020-21- Flowering good lighter in the A16, macadamia lace bug low but prevalent in the organic block, flower caterpillar, loopers and leaf miner all higher this year. Nut set effected by fungal diseases and *Phytophthora* showing in some areas. Husk spot treatments going on, FSB active already in blocks.

Mark Duncan Yamba / Coastal Clarence NSW: "Macadamia lace bug non existent, flower caterpillar lower, high felted coccid and GVB not FSB in the nuts later. Did see Seed weevil at Ashby but not in Yamba yet. Good nut set."

Paul Mooseburger Coastal Clarence NSW: "Very thin shells last season a lot failed to go through the de husker at processing without damage. Nut set this year is very good."

Jarrah Coates NR NSW: "2019–2020 – Good flowering macadamia lace bug higher, no rainfall affected trees, heavy leaf drop, MSW treatment very effective, FSB levels low generally, quality good KR higher than expected, some smaller nut, MNB egg laying low, *Leptocoris* was prevalent for the first time.

2020-21- Stress continuing high leaf flush and higher leaf miner with it. Lace bug lower generally but higher in Dunoon and Whian Whian. Higher FSB, variable nut set, A16 poor blight after rain, MSW treatments look not quite as good this year re treatment needed on some places with poorer coverage. Felted coccid hitting leaf and flower, scarab, *Leptocoris* not seen yet."

Chris Fuller Gympie Glasshouse SE QLD: "2019–2020 – Good flowering no rain high immaturity and crop failure. Heavy *Leptocoris* activity, Thrips and mites were heavy, FSB very low, stung nut drop was not working because it doesn't fall 0.6% damage levels. Glasshouse area had higher rainfall and Hail damage in some spots took a lot of crop some around 30% down. 2020–2021 – macadamia lace bug higher this year and spreading, flowering went OK, caterpillar was being controlled by prodigy, thrips were lower (wet weather) FSB back to normal levels, little MNB, but high catch in MNB traps, Felted coccid rising heaviest around Gympie on Daddows, taking out half the bunches of nuts. *Botrytis* was serious on rainfall event during flowering (Merivon®) did appear to work. Lots of trunk borers *Hypothenemus* sp. and bark beetle through all old wood and husks. No seed weevil to date. Landsborough the 741 flowers are browning off and appear to die."

Megan Boote Gympie QLD: "2019-20 – only 1% immaturity but lots of small nuts and internal discolouration, insect damage much higher this season. Did have brown centres and Hail issues on farms. *Leptocoris* was heavy with both shell and kernel damage visible. 2020–2021- Macadamia lace bug more prevalent worse on a couple of known spots, felted coccid heavy attacking flower/ flush rain saved the flower bronzing this year. *Botryspheria* leaf spot on some leaf oil spots with brown centre (Brett Newell)" causes the young leaf to wither and drop. Insect damage was later in the season so was maturity, adult FSB kept coming. Thrip damage was high toughened up the husk and made de-husking an issue for some growers."

Andrew Pearce Bundaberg QLD: "2019-20-Lots of late *Carpophilus* beetle and kernel grub getting into nut being sent to processors. At Rockhampton tree shaking removed the carry over nut populations maybe adding to number in shipments. Brown centres were high and *Leptocoris* was higher in Bundaberg. 2020–2021- Flowering lower in 741, thrips very heavy (Trivor® is helping) FSB has been higher and *Leptocoris* has been seen swarming on the local foambark trees again. Poor nut size in the un-irrigated blocks, some SeroX® uptake in Bundaberg and new sprayers being used."

Eddy Dunn Bundaberg QLD: "*Pestaliopsis* on the A203's, Spherical mealy bug, and felted coccid both far more active. 2019-20 high but heavier now. High dry flower pressure (fungicides not working?) What is happening as the innoculum is building on site poor 741 flowering basically all varieties later than 816. Early FSB been drop sheeting since June sprayed 10% of what is there lots of aphids, influx of lacewings tree health did decline in the A-series, Hawaiian varieties not so. 2019 more banana fruit caterpillar and big ones earlier activity, 2020 only small ones around easier to treat and leaf litter dependent.”

Alan Coates Bundaberg QLD: “Felted coccid on trunks – did not move to new flush and flowers, higher parasitism rates. Pollination very disappointing 3 days of fog hit them then rain on open flower A16 secondary thrip problems becoming very heavy. Cockatoos becoming difficult to manage along the western side of the Bundaberg growing region.”

Mick Matthews Emerald and Mackay district QLD: “very high pressure from flower caterpillar controlled well by Prodigy®, high levels of *Leptocoris* and FSB on the crop, no MNB.”

Table 2.5.3.1.: Summary of the changes in macadamia pest issues emphasised by the consultants from the various crop regions (+++Likely new pest records). *Phytophthora*, husk spot (trees shaking has changed this), and flower diseases are still constant issues if conditions are right in all regions.

Growing region	**2016 issues**	**2021 issues**
Mackay FNQ	MSW BSB/FSB, MLB, felted coccid, Cockatoos, flower caterpillars other bugs+++	BSB/FSB, MLB, felted coccid, cockatoos flower caterpillar, other bugs/ moths+++ pigs, rats
Bundaberg Qld	BSB/FSB MNB pin hole BFC thrips, felted coccid, flower cat.	Pin hole beetle/*Botyrspheria, Leptocoris* MNB, C*arpophilus* sp., other borer, BFC, cockatoos
Gympie SE Qld	*Leptocoris,* pin hole borer, FSB/BSB felted coccid	*Leptocoris*, pin hole borer, FSB/BSB MNB rats, pigs
Northern Rivers NSW	MSW FSB MLB felted coccid Rats	*Leptocoris,* FSB, MLB, felted coccid, trunk beetles, scarab beetles? rats
Mid north coast NSW	FSB, MLB, flower caterpillars, rats	FSB, MLB, flower caterpillars, pin hole borer, cockatoos, rats
Coastal Cane Land	Rats, pin hole borers no seed weevil yet	Water logging / drought issues felted coccid, auger beetles, GVB, MSW, scarab beetles, rats, pigs

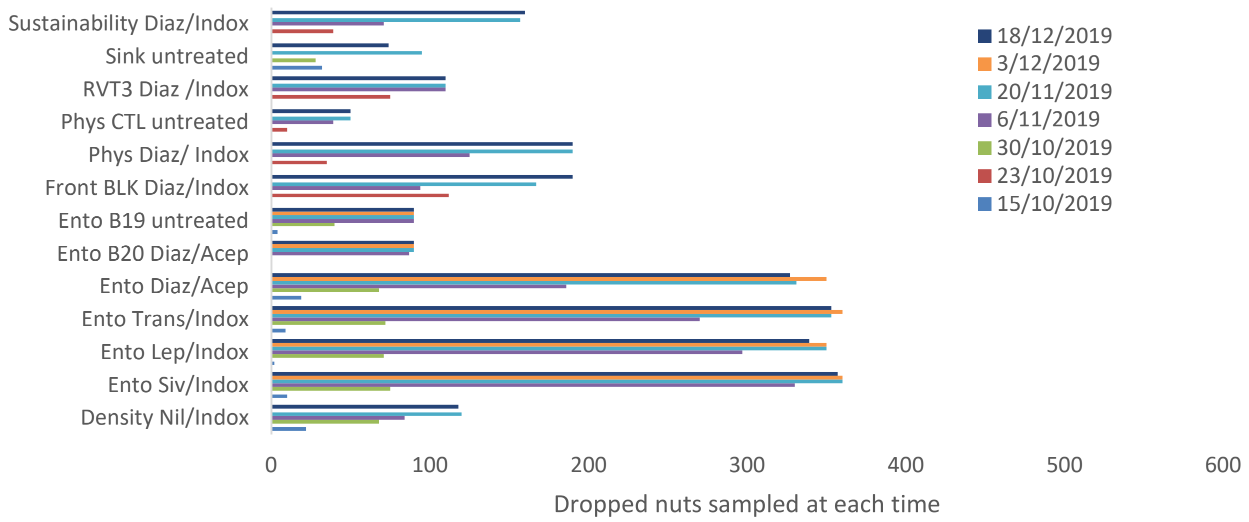
2.5.4. Rain data and samples sizes for 2019/2020 and 2020/2021

Table 2.5.4.1.: Daily rainfall (mm) from CTH Alstonville manual weather station 1/7/19-30/06/2020 Entomology plot spray dates are shaded. Average annual rainfall is 1800mm based on data from 1963-2007. The 2019–2020 season had 1638.3 mm, which is unusually low. The calendar year rainfall for 2019 was 787mm only. From mid January to the end of June 1.5m of rain fell, break the drought and produced significant macadamia shell and size changes.

							Month					
Date	**Jul-19**	**Aug-19**	**Sep-19**	**Oct-19**	**Nov-19**	**Dec-19**	**Jan-20**	**Feb-20**	**Mar-20**	**Apr-20**	**May-20**	**Jun-20**
1	12	12.2				44						3
2	5.5					17						
3	0.3			4	3			31				
4	1.3				2				15	7.5		2
5	29	2						16			20	
6								168.4				
7								20	21	27.6		
8	22							95.2	1			1.4
9						8.4		10	9		9	20
10				2				10	0.5			35.8
11							14	2	1	1		
12							3.4	79.2	1	17	2.3	
13							1.8	35	1			1.4
14				3			3.2	1	8			9.8
15							1					
16						2.5	1	0.5	1.3		12.8	
17							1	13			56	1.5
18							172.6					12
19							1.3				7.3	9
20			13				1					4.8
21				15							3	
22								12.5				
23						0.8			13			
24						0.5		59	1.3		0.5	
25	4					31	25	1.5				
26								0.5	13.7			
27							1	54	111	10.2		
28								4.5	21	37		0.5
29								2		0.5		18.3
30					5.6				0.3		3	
31		0.3									3	
Totals	74.1	14.5	13	24	10.6	104.2	226.3	615.3	219.1	100.8	116.9	119.5

Table 2.5.4.2.: Daily rainfall (mm) from CTH Alstonville manual weather station 01/07/20-30/06/2021 Spray dates shaded. Average annual rainfall is 1800mm based on data from 1963-2007. The 2020–2021 season had 2296.5 mm which is well above average. Entomology and Physiology block spray applications days are highlighted in yellow.

	Month											
Date	**Jul-20**	**Aug-20**	**Sep-20**	**Oct-20**	**Nov-20**	**Dec-20**	**Jan-21**	**Feb-21**	**Mar-21**	**Apr-21**	**May-21**	**Jun-21**
1						1.9	17.5	2	11.5	13.5		
2							1.5	12.4	4			
3							0.3	1	47.5	4.5	5	
4										20		
5						3		1			12	
6			1			4	17		12	48		
7		17.2			22		33			65.5		
8	16						14		15	38		
9				1.4	0.4		4.2		17	5		
10	1		47.5				1.6	4.3	28			6.5
11									11		4.2	
12						204						
13	3		6.4			32						
14						104		33.8				
15		11				27	8.2	2.4	33			1
16						17		25	15.5			
17						4		22	37	11		
18								58			13.5	
19				29			17	22	22			
20			1.5	4		5	8	9	2			3
21							9		24			1.4
22						1.5		3	177			
23	32	4						19	40		3	4.5
24	52				2			17			23	
25				19.1					2		1	1
26	74			6								2
27			1	6								
28				9.2								11
29				50		151			20			24
30	7			31		1.3			3	42		19
31						6.8			12			
Totals	185	32.2	57.4	155.7	24.4	562.5	131.3	231.9	533.5	247.5	61.7	73.4



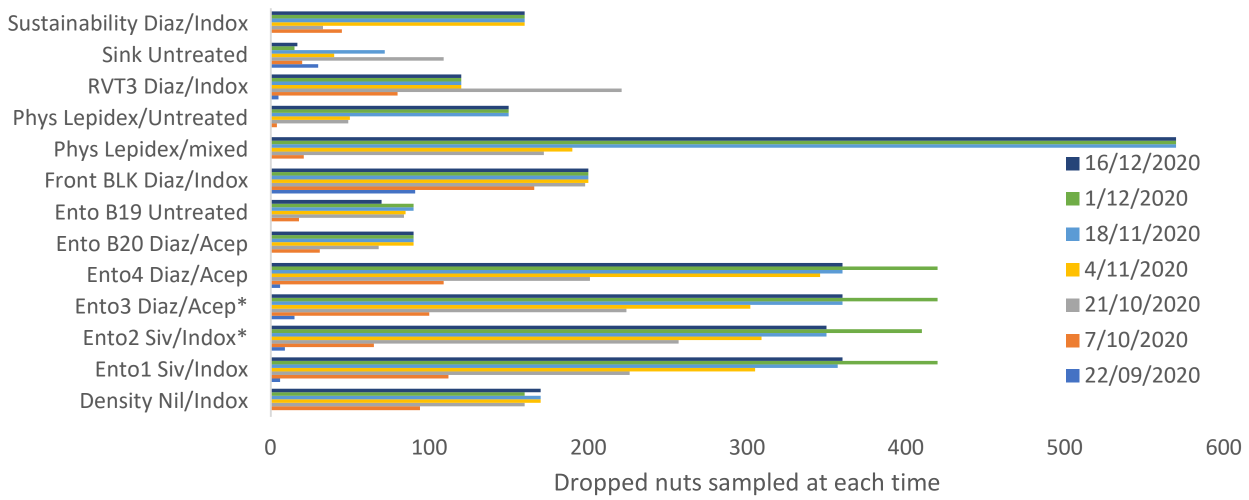


Figure 2.5.4.1.: Nut sampling in each trial block at CTH Alstonville during the extreme dry season 2019–2020 as compared to the wet season 2020–2021. Macadamia lace bug and seed weevil treatments are used to show the sampling comparisons examined in each plot. * Identical treatment profiles except the flower sprays align for the varieties with different flowering times (did A4 and 849 later).

2.5.5. Trial designs for CTH Alstonville physiology block trial and Front block trial

Physiology Block

– The design for the trial in the Physiology Block is shown in Figure 2.5.5.1.

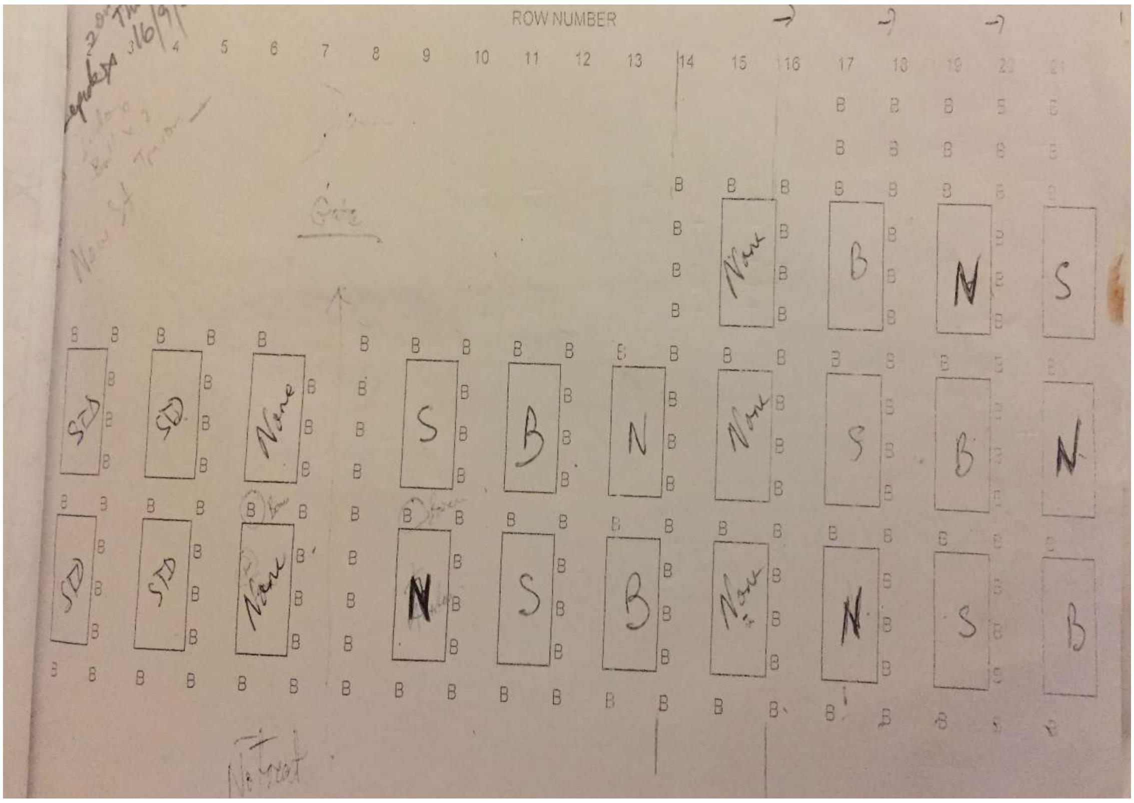


Figure: 2.5.5.1.: Physiology block design

Treatment trees: 5 replicates of 3 trees 849 cv. and 246 buffers.

Treatments: (also see Table 2.5.2.9.)

- All trees treated with Lepidex® (200ml/100L) 16/9/2020 for macadamia lace bug to ensure nut set.
- All trees except "None" treatment (untreated after nut set) areas received Bulldock® application on MNB flight 6/12/2020.
    - None = no insecticide applied after nut set
    - B = DC143 (Vayego®) 12.5ml/100L,
    - N= Experimental A,
    - S= SYNFO 121 30ml/100L= Experimental C,
    - Std = Standard practice is:
        - Indoxacarb (MSW) in October
        - Trivor® (FSB) in November
        - Bulldock® December
        - Bulldock® (MNB and FSB) in January

Under drought conditions heavy *Leptocoris* sp. activity rather than FSB would result in changing Bulldock® to acephate or Trivor® at this stage.

<u>Front Block:</u>

– The design in for the trial in the front block is shown in Figure 2.5.5.2.

		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Tree Number	**1**	T1	**2 Red**	816	**1 Blue**	T1	**5 Orange**	246	X
	2	816		816		246		246	**4 White**
	3	816	1	816	6	246	11	246	16
	4	816	816	816	816	246	246	246	246
	5	T2	**4 White**	816	**5 Orange**	T2	**3 Yellow**	246	**1 Blue**
	6	816		816		246		246	
	7	816	2	816	7	246	12	246	17
	8	816	816	816	816	246	246	246	246
	9	P1	**1 Blue**	246	**2 Red**	P1	**2 Red**	816	**3 Yellow**
	10	246		246		816		816	
	11	246	3	246	8	816	13	816	18
	12	246	246	246	246	816	816	816	816
	13	P2	**5 Orange**	246	**3 Yellow**	P2	**1 Blue**	816	**5 Orange**
	14	246		246		816		816	
	15	246	4	246	9	X	14	816	19
	16	246	246	246	246	816	816	816	816
	17	T5	**3 Yellow**	816	**4 White**	P3	**4 White**	246	**2 Red**
	18	816		816		246		246	
	19	816	5	816	10	?	15	246	20
	20	816	816	816	816	246	246	246	246
	21	A4	A4	A4	A4	A4	A4	A4	A4

TREATMENTS		**Treatment tag colour**	**Plots**
1	Transform® @40ml/ 100L	Blue	3 6 14 17
2	Trivor® @40ml/ 100L	Red	1 8 13 20
3	Sivanto® Prime @75ml/100L	Yellow	5 9 12 18
5	Sivanto ® Prime @100ml/ 100L	Orange	4 7 11 19
4	Control Bulldock®@50ml/ 100L	White	2 10 15 16

Figure 2.5.5.2.: CTH Alstonville front block trial design season 2020–2021, yield measured on tagged tree in each plot.

2.5.6. Evaluation of SARP 2020 recommendations

Early season indicators of the efficacy of the various compounds on the two main target pests, FSB and seed weevil, showing only the Bayer product and Syngenta product had been significantly better than the untreated control prior to the application of the whole block Bulldock® treatment (05/12/2020) for FSB damage in the main pre mature nut drop. This was only for 1 week each and neither were better than the Bulldock® standard in the kernel quality once harvest began. Shows the fickleness of FSB activity and why it is important to address the whole season activity especially with late maturing varieties.

Initial nut drop was collected from all 3 trees in each plot (n=5) until 2nd spray application, then as the nut drop intensified every tree in each plot was sampled 10 nuts/ tree (n=15) until the Bulldock® spray 05/12/2020 across all plots bar untreated to restart the FSB part of the trial for late season damage that will occur in January, February and March 2021.

For seed weevil the indoxacarb application (current standard) was superior in terms of laying mark presence or fresh egg presence but all were significantly better than the untreated control.

Field monitoring results for each fortnightly nut sample during the trial showing

The level of FSB damage (Table 2.5.6.1) and the level of significance relative to the untreated control

Nut drop determined using t-tests and critical t values listed below.

Similar (Table 2.5.6.2.) only using the seed weevil lay marks.

The actual fresh egg laying on the nuts by seed weevil is shown in Table 2.5.6.3.

Appraisal of a new experimental product

The experimental product SYNFO 121 formulation (EXP C in the graphics) applied at 30ml/100L controlled populations of FSB and MSW when applied through spring and summer (3 applications October, November and January). SYNFO 121 applications had significantly reduced the levels of MSW laying and oviposition (Figure 2.5.2.20.) by November 18th compared to the untreated areas, this however was not as effective as the indoxacarb standard which had reached that point by November 4th (Figure 2.5.2.20 and Appendix 2.5.6) within two weeks of application and remained that way until the end of December. SYNFO 121 when applied on the determined FSB flight times at CTH Alstonville is effective at controlling FSB under high pressure (Table 2.5.2.5. and Figure 2.5.2.13. and Appendix 2.5.6.). Untreated blocks were averaging above 50% FSB losses in this area in the early harvests.

The new product appears to give equivalent control to beta-cyfluthrin (Table 5.1.1 and Figure 5.1.2). SYNFO 121 was also a suppressive treatment of the MNB oviposition compared to the standard beta-cyfluthrin (15% tunnels at first harvest) treatments and 22% tunnels in the untreated plots (Figure 2.5.2.27.). There were less MNB tunnels detected during February then only 11% of nuts in the first harvest in March.

The trial also shows just how selective FSB are in there feeding preference by sampling the neighbouring cv. 246 row in the untreated and standard spray areas (April harvest only). This variety shows about 50% less FSB compared to the cv. 849 trees (Figure 2.5.2.13.).

Table 2.5.6.1.: Treatment comparison of SARP (2020) new chemical options for % FSB damage in nut drop by T-test at CTH Physiology block

CTH cv. 849 Treated MSW 13/10/20 Treated FSB 6/11/20

Date	**Treatment**	**Plots**	**Nuts**	**Husk FSB**	**Average /10 nut plot**	**Sd /10 nut**	**Se / 10 nut**	**Average %FSB damage**			**t values**
21/10/2020	Lepidex® + Bay@ 12.5ml/ 100L	5	45	11	2.8	0.5	0.2	23.5			-1.123
	Lepidex® + EXP A	5	44	13	2.6	1.3	0.6	28.9			-0.816
	Lepidex® + Syn@ 30ml/ 100L	5	45	16	3.2	1.6	0.7	36.0			-2.041
	Lepidex® + Indoxacarb	4	38	10	3.3	1.5	0.8	28.1			-2.313
	Unsprayed	5	49	11	2.2	1.1	0.5	22.7			
21/10/2020 total		24	221	61	2.8	1.2	0.3	27.8			t values
4/11/2020	Lepidex® + Bay@ 12.5ml/ 100L	5	50	21	4.2	0.8	0.4	42.0			-0.806
	Lepidex® + EXP A	5	50	17	3.4	2.3	1.0	34.0			-0.161
	Lepidex® + Syn@ 30ml/ 100L	5	50	17	3.4	1.1	0.5	34.0			-0.161
	Lepidex® + Indoxacarb	4	40	20	5.0	2.7	1.4	50.0			-1.450
	Unsprayed	5	50	16	3.2	2.8	1.2	32.0			
4/11/2020 total		24	240	91	3.8	2.0	0.4	37.9			t values
18/11/2020	Lepidex® + Bay @ 12.5ml/ 100L x2	15	150	38	2.5	1.1	0.3	25.3	*P* <0.05		2.341
	Lepidex® + EXP A	15	150	53	3.5	1.6	0.4	35.3			0.146
	Lepidex® + Syn@ 30ml/ 100L x2	15	150	48	3.2	1.9	0.5	32.0			0.878
	Lepidex® + Indox+ Trivor®@ 40ml/ 100L	12	120	54	4.5	1.4	0.4	45.0			-1.975
	Unsprayed	15	150	54	3.6	1.8	0.5	36.0			
18/11/2020 total		72	720	247	3.4	1.7	0.2	34.3			t values
1/12/2020	Lepidex® + Bay @ 12.5ml/ 100L x2	15	150	70	4.7	1.0	0.3	46.7		B	0.512
	Lepidex® + EXP A	15	150	73	4.9	2.1	0.5	48.7		B	0.128
	Lepidex® + Syn@ 30ml/ 100L x2	15	150	45	3.0**	1.4	0.4	30.0**	*P* <0.01	A	3.713
	Lepidex® + Indox+ Trivor®@ 40ml/ 100L	12	120	65	5.4	1.9	0.5	54.2		B	-0.928
	Unsprayed	15	150	74	4.9	2.0	0.5	49.3		B	
1/12/2020 Total		72	720	327	4.5	1.9	0.2	45.4			
Grand Total		192	1901	726	3.8	1.8	0.1	38.1			

** significantly lower t test pr<0.05

t 15 d/f =2.131 *P* <0.05
t 15 d/f =2.947 *P* <0.01

t 12 d/f =4.318
pr<0.001t15d/f=4.073pr<0.001

Table 2.5.6.2.: Treatment comparison of SARP (2020) new chemical options for % MSW egg laying marks in nut drop by T-test at CTH Physiology block

CTH cv. 849 MSW Treatment 13/10/20 FSB treated 6/11/20

Date	Treatment	Plots	Nuts	MSW mark	Average /10 nut plot	Sd /10 nut	Se / 10 nut	Average % mark			t values
21/10/2020	Lepidex® + Bay@ 12.5ml/ 100L	5	45	12	2.4	1.5	0.7	26.7			0.392
	Lepidex® + EXP A	5	44	7	1.4	2.2	1.0	14.0	*P* <0.05		2.353
	Lepidex® + Syn@ 30ml/ 100L	5	45	13	2.6	2.4	1.1	26.0			0.000
	Lepidex® + Indoxacarb	4	38	7	1.8	1.0	0.5	18.1			1.667
	Unsprayed	5	49	13	2.6	1.1	0.5	26.2			
21/10/2020 total		24	221	52	2.2	1.7	0.3	22.4			t values
4/11/2020	Lepidex® + Bay@ 12.5ml/ 100L	5	50	13	3.3	2.6	1.2	26.0			1.339
	Lepidex® + EXP A	5	50	11	2.2	1.3	0.6	22.0	*P* <0.05		2.246
	Lepidex® + Syn@ 30ml/ 100L	5	50	16	4.0	1.6	0.7	32.0			0.691
	Lepidex® + Indoxacarb	4	40	5	1.7	0.6	0.3	12.5	*P* <0.05		2.707
	Unsprayed	5	50	24	4.8	2.6	1.2	48.0			
4/11/2020 total		24	240	69	3.3	2.1	0.4	28.8			t values
18/11/2020	Lepidex® + Bay @ 12.5ml/ 100L x2	15	150	52	3.5	2.1	0.5	34.7			0.232
	Lepidex® + EXP A	15	150	38	2.5	1.8	0.5	25.3			1.853
	Lepidex® + Syn@ 30ml/ 100L x2	15	150	28	1.9	1.8	0.5	18.7	*P* <0.01		3.011
	Lepidex® + Indox+ Trivor®@ 40ml/ 100L	12	120	8	0.7	0.9	0.3	6.7	*P* <0.001		5.095
	Unsprayed	15	150	54	3.6	2.2	0.6	36.0			
18/11/2020 total		72	720	180	2.5	2.1	0.2	25.0			t values
1/12/2020	Lepidex® + Bay @ 12.5ml/ 100L x2	15	150	17	1.7	0.9	0.2	11.3	*P* <0.001	AB	4.324
	Lepidex® + EXP A	15	150	11	1.6	0.8	0.2	7.3	*P* <0.001	AB	4.709
	Lepidex® + Syn@ 30ml/ 100L x2	15	150	14	1.8	0.9	0.2	9.3	*P* <0.001	AB	4.174
	Lepidex® + Indox+ Trivor®@ 40ml/ 100L	12	120	6	2.0	0.0	0.0	5.0	*P* <0.01	B	3.425
	Unsprayed	15	150	44	3.1	1.3	0.3	29.3		C	
1/12/2020 total		72	720	92	2.2	1.2	0.1	12.8			
Grand Total		192	1901	393	2.5	1.9	0.1	20.6			

* significantly lower t test *P* <0.05

than untreated CTL

Table 2.5.6.3.: Treatment comparison of SARP (2020) new chemical options for % nuts with MSW egg in nut drop by T-test at CTH Physiology block

CTH	cv. 849	MSW Treatment 13/10/20									
Date	**Treatment**	**Plots**	**Nuts**	**MSW eggs**	**Average/10 nut plot**	**Sd /10 nut**	**Se / 10 nut**	**Average % with eggs**			**t values**
21/10/2020	Lepidex® + Bay@ 12.5ml/ 100L	5	45	6	1.2	0.4	0.2	14.2			0.516
	Lepidex® + EXP A	5	44	4	2.0	0.0	0.0	8.0			-2.582
	Lepidex® + Syn@ 30ml/ 100L	5	45	3	1.0	0.0	0.0	6.0			1.291
	Lepidex® + Indoxacarb	4	38	2	1.0	0.0	0.0	5.0			1.291
	Unsprayed	5	49	4	1.3	0.6	0.3	8.0			
21/10/2020 total		24	221	19	1.3	0.5	0.1	8.4			t values
4/11/2020	Lepidex® + Bay@ 12.5ml/ 100L	5	50	6	2.0	1.0	0.4	12.0			-0.373
	Lepidex® + EXP A	5	50	7	2.3	1.5	0.7	14.0			-0.870
	Lepidex® + Syn@ 30ml/ 100L	5	50	6	1.5	0.6	0.3	12.0			0.373
	Lepidex® + Indoxacarb	4	40	0	0.0	0.0	0.0	0.0	*P* <0.05		2.609
	Unsprayed	5	50	7	1.8	1.5	0.7	14.0			
04/11/2020 total		24	240	26	1.9	1.1	0.2	10.8			t values
18/11/2020	Lepidex® + Bay @ 12.5ml/ 100L x2	15	150	15	1.5	1.0	0.3	10.0			1.133
	Lepidex® + EXP A	15	150	15	1.7	0.9	0.2	10.0			0.755
	Lepidex® + Syn@ 30ml/ 100L x2	15	150	8	1.3	0.8	0.2	5.3			1.510
	Lepidex® + Indox+ Trivor®@ 40ml/ 100L	12	120	0	0.0	0.0	0.0	0.0	*P* <0.001		4.531
	Unsprayed	15	150	28	2.0	1.7	0.4	18.7			
18/11/2020 total		72	720	66	1.7	1.2	0.1	9.2			t values
01/12/2020	Lepidex® + Bay @ 12.5ml/ 100L x2	15	150	10	1.7	1.0	0.3	6.7		C	-0.267
	Lepidex® + EXP A	15	150	2	1.0	0.0	0.0	1.3	*P* <0.05	B	2.405
	Lepidex® + Syn@ 30ml/ 100L x2	15	150	1	1.0	0.0	0.0	0.7	*P* <0.05	B	2.405
	Lepidex® + Indox+ Trivor®@ 40ml/ 100L	12	120	0	0.0	0.0	0.0	0.0	*P* <0.001	A	6.414
	unsprayed	15	150	16	1.6	1.0	0.2	10.7		C	
01/12/2020 Total		72	720	29	1.5	0.9	0.1	4.0			
Grand Total		192	1901	140	1.6	1.0	0.1	7.3			

*significantly lower t test *P* <0.05 than untreated CTL

2.6. Diagnostics

– Diagnostic results from the samples submitted for identification during the course of the program are listed in Table 2.6.1. Figure 2.6.1. shows examples of new pests that recorded as part of monitoring efforts and diagnostics.

Table 2.6.1. Major diagnostic work done over period from 2015-2021 for macadamia industry

Date	Region	Type	Source	Identification	Authority used	Pest / Beneficial
2014-2018	NSW +SE QLD	Beetles in nut	Macadamia silo and deliveries	*Carpophilus* sp.	HO orange	Secondary pest using MSW and various nut borer
2013-2016	NSW	Black thrips	Steve McClean Phil McCarthy	*Thrips setipennis*	HO orange	New thrip in flowers
April 2014*	Mackay	New nut borer	Kim Wilson	Possibly *Cataremna* sp	HO orange	** could be *Mussidia* sp.
Sep-16	Rous NSW	Whitefly	John Pretorius	*Aleurocanthus* sp.	HO orange	Potential pest
Sep-16	Ewingsdale NSW	Scale	Scott Herd-NORCO	Pink Rossette scale	HO orange	No name
May-17	All regions	Felted coccid	Fuller gympie McClean	Felted coccid	HO orange	Checking parasites
2017	CTH Alstonville	Encyrtid wasp	Maddox and Huwer	*Metaphychus macadamiae*	Polezcek British Museum 2020 naming	Now being reared in Hawaii for MFC control
Oct-17	Mackay QLD	Bug	Mark Duncan	*Leptocorisa acuta*	HO orange	Rice seed bug could be major flower issue here
2018-2020	Caniaba NSW	Scarab larva	Mark Whitten Steve McClean	*Cyclocephala signaticollis*	HO orange	Exotic from argentina black soil area
2019	Dagun QLD	Fly and bug	Les Gain	*Leptocoris tagalica*	HO orange	New bug pest in dry seasons, tachinid fly
2018	Tregeagle NSW	Scolytid	Golden Raintree	*Gymnoclytia* sp Phasiinae fly	Ainsley Segao HO	In nut in shell
2018	Tregeagle NSW	Scolytid	NSW DPI trapping	*Hypothenemus seriatus*	Ainsley Segao HO	In nut in shell
2018	Tregeagle NSW	Scolytid	NSW DPI trapping	*Xylosandrus crassiusculus*	Ainsley Segao HO	In branches
2018	Rous NSW	Scolytid	NSW DPI trapping	*Xyleborus bispinatus*	Ainsley Segao HO	In trunk and branches
2018	Rous NSW	Cerambycid	NSW DPI trapping	*Mesolita lineolata*	Ainsley Segao HO	In flight trap
2018	Rous NSW	Scolytid	NSW DPI trapping	*Ambrosiophilus* nr *restrictus*	Ainsley Segao HO	In flight trap
2018	Rous NSW	Scolytid	NSW DPI trapping	*Xylosandrus crassiusculus*	Ainsley Segao HO	In flight trap
2018	Rous NSW	Scolytid	NSW DPI trapping	*Ambrosiodmus latecompressus*	Ainsley Segao HO	In flight trap
2018	Beerwah QLD	Scolytid	NSW DPI trapping	*Euwallacea* nr *fornicatus*	Ainsley Segao HO	In flight trap branches
2018	Beerwah QLD	Scolytid	NSW DPI trapping	*Xylosandrus crassiusculus*	Ainsley Segao HO	In flight trap branches
2018	Beerwah QLD	Scolytid	NSW DPI trapping	*Hypothenemus seriatus*	Ainsley Segao HO	In flight trap
2018	Bundaberg R/S avocado trellises	Scolytid	NSW DPI trapping	*Hypothenemus seriatus*	Ainsley Segao HO	In branches

Table 2.6.1. Major diagnostic work done over period from 2015-2021 for macadamia industry (cont.)

Date	Region	Type	Source	Identification	Authority used	Pest / Beneficial
2018	Winfield QLD	Scolytid	NSW DPI trapping	*Hypothenemus seriatus*	Ainsley Segao HO	In flight trap
2018	Kin Kin QLD	Scolytid	NSW DPI trapping	*Xylosandrus crassiusculus*	Ainsley Segao HO	In flight trap
2018	Tregeagle NSW	Scolytid	NSW DPI trapping	*Hypothenemus seriatus*	Ainsley Segao HO	In nut in shell
Sep-2019	Nimbin NSW	Mirid	Scott Hill Rutherglen bug suspect	*Nysius vinitor*	HO orange	In flowers Dry year
Nov-2019	Dunoon NSW	Cerambycid	Jarrah Coates	*Tricheops ephippigger*	Ainsley Segao HO	Tree death many under main trunk bark
Nov-2019	Newrybar NSW	Cerambycid	Graham Wessling	*Urocanthus* sp.		Tree death small plants on coastal planting whole trunk bored out maybe nursery infected
Nov-19	Rockhampton	Nut borer	Ross Burgess	*Assara seminivale*?	Better specimens needed. new species	In field nut damage
Nov-19	CTH Alstonville	Bostrychid	NSW DPI trapping	*Xylopsocus gibbicollis*	Ainsley Segao HO	In flight trap
Dec-20	CTH Alstonville	Pentataomid	NSW DPI Trapping	*Oncocoris apicalis*	Ainsley Segao HO	Feeding on nuts in germplasm area
Feb-20	Bangalow NSW	Scolytid	Phil McCarthy	*Cryphalus subcompactus*	Many scolytid species in traps once set trees stressed with drought	In trunks and branches
Feb-20	WollongbarNSW	Elaterid	John Underhill	*Gonocephalum* sp.	Ainsley Segao HO	In factory processing room floors
Mar-20	Peachester QLD	Scolytid	Grant Bignell	*Euwallacea* nr *fornicatus* (*perbrevis*)_	Ainsley Segao HO	In branches and in flight traps
Mar-20	Caniaba NSW	Scarab lv	Steve McClean	*Cyclocephala signaticollis*	HO orange	Exotic from argentina black soil area under mulch
Mar-20	Caniaba NSW	Scarab lv	Steve McClean	*Heteronychus aerator*	HO orange	Larvae under mulch in macadamia
Apr-20	Tregeagle NSW	Scolytid	Paul Chapman	*Cryphalus subcompactus*	Ainsley Segao HO	Tree death branch damage
Apr-20	Bundaberg QLD	Ants	Rob Hobbson	*Pheidole megacephala*	Ainsley Segao HO	Secondary after damage by moth
Apr-20	Bundaberg QLD	Beetle	Rob Hobbson	*Carpophilus maculatus*	Ainsley Segao HO	Secondary after damage by moth
Apr-20	Bundaberg QLD	Kernel grub	Rob Hobbson	*Assara seminivale*	Ainsley Segao HO	Secondary after damage
Apr-20	Bundaberg QLD	Ants	Rob Hobbson	*Pheidole megacephala*	Ainsley Segao HO	Secondary after damage
May-20	Bundaberg QLD	Nut borer	Andrew Pearce	*Mussidia* sp.	Ainsley Segao HO	New pyralid moth pest
May-20	Emerald QLD	Nut borer	Andrew Pearce	*Mussidia* sp.	Ainsley Segao HO	New pyralid moth
May-20	Rockhampton QLD	Nut borer	Andrew Pearce	*Mussidia* sp.	Ainsley Segao HO	New pyralid moth
May-20	CTH Alstonville	Cerambycid	NSW DPI trapping	*Syllitis rectus*	Ainsley Segao HO	Most prolific cerambycid at flowering and young nut set
Jul-20	Wollongbar colony NSW	Nut borer	Virgin specimens reared pinned and sent	*Mussidia* sp.	Marianne Horak**	Describing new species, problem

Table 2.6.1. Major diagnostic work done over period from 2015-2021 for macadamia industry (cont.)

Date	Region	Type	Source	Identification	Authority used	Pest / Beneficial
Aug 2020	Palmers Is. NSW	Bostrychid	Suzie Prosser	*Xylopsocus gibbicollis*		Dead trees heavy trunk infestation (is it coastal mac phytophthora related auger beetle attacking sick trees)
Aug-20	Palmers Is. NSW	Bostrychid	Suzie Prosser	Xylopsocus gibbicollis		Dead trees heavy trunk infestation (is it coastal mac phytophthora related auger beetle attacking sick trees)
Aug-20	CTH Alstonville	Tree death	NSW DPI surveyllance	Suspect philinus type white root disease in front block tree death		See what happens with new tree removal trials in place.
Sep-20	Caniaba NSW	Branch yellows core stains	NSW DPI surveillance	Suspected viral issue	Nerida Donavan	No viral issues known in macs? No real answer to what causes the issue yet
Jun 2021	Gympie Qld	Beetle	Mclean and Stuart Edmonds	*Carpophilus* sp.		Secondary pest in factory receivals
Mar-21	Victoria Park NSW	Whitefly	K Quinlan W Alvery	*Aleurocanthus* sp.		Just oil sprays only will die back naturally
Jun-21	Gympie Qld	Beetle	Megan Boote	*Carpophilus* sp.		Secondary pest in factory receivals
Oct-21	Mackay Qld	Bug	Chris Searle	*Leptocorisa acuta*		Rice seed bug on flowers potential pest
Oct-21	Brisbane Qld	Bug	Grant Bignell	*Heliopeltis sp.*		Potential flower pest already problem in South East Asia
Oct-21	Rous NSW	Macadamia lace bug	Neil Jung	*Cercotingis decoris*		Heavy flower damage
Oct-21	Gympie Qld	Bug	Les Gain	Canteo parentum		Large swarm on a couple of trees never seen before
Dec-21	CTH Alstonville	Pentatomid	NSW DPI Trapping	*Oncocoris apicalis*		Feeding on nuts in germplasm area
Jan-22	Victoria Park NSW	Pentatomid	NSW DPI Trapping	*Bathrus variegatus*		Been on avocado custard apple macadamia when pruned. Branch dieback in avocados reported before

** Marianne Horak is the current authority revising the taxa here and a new species (not yet named) has presented in Central Queensland

***Danuta Knihinicki also said likely to be new eriophyid species present and potentially damaging and the phygastrids were being looked at pre pesticides times for scolytid management in Canadian/ USA forestry 1930's.

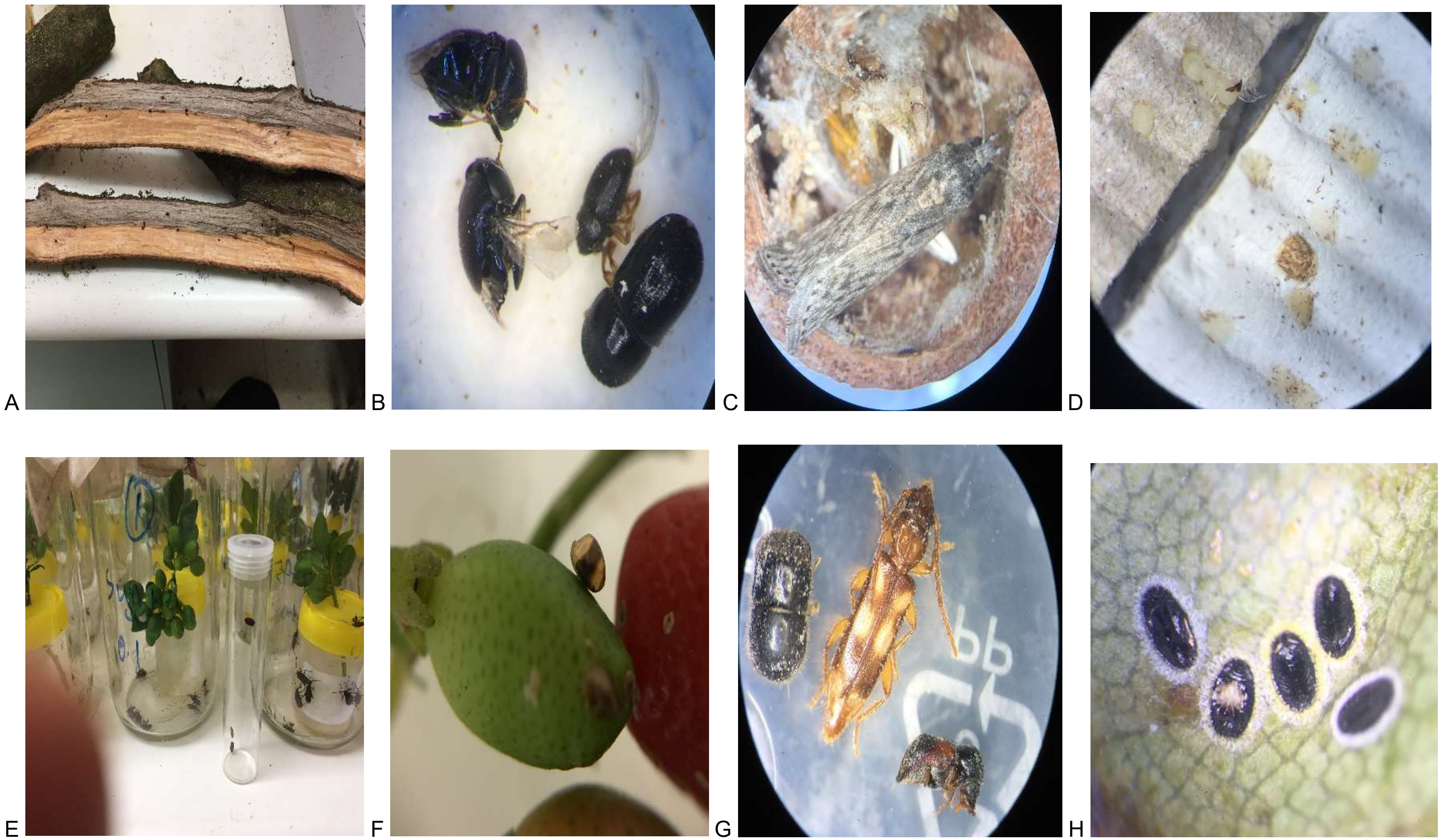


Figure 2.6.1.: Examples from the NSW DPI diagnostics 2016-2021 A) Scolytid attack by *Euwallacea prebrevis* (nr *fornicatus*) in branch death and fungal association at Peachester trial sites, been active in orchards around Beerwah since 2009 and some from NSW since then. B) *Euwallacea prebrevis rt, Cryphalus subcompactus* and white wax scale parasitoid *Scutellista caerulea* found with them in the macadamia tunnels. C) *Mussidia* sp (pyralid) new nut borer species (unnamed yet) can penetrate nuts like MNB in central QLD. D) *Mussidia* sp. eggs left and *Cryptophlebia ombrodelta* eggs right for pest scouts identification. E*) Leptocoris tagalica* assays and the *Gymnoclytia* sp tachinid fly imago emerging from the bodies being collected. F) Tell tale *Amblypelta nitida* egg markings of *Gryon* sp parasite emergence on *Murraya panicalata* berries brought in for assays. G) *Cnestes solidus* (left) common scolytid, *Bethelium* sp cerambycid and *Xylopsocus* sp. Bostrychidae (auger beetle) from new French cerambycid traps at CTH Alstonville during 2020 drought. H) Macadamia whitefly pupae from the leaf ventral surface *Aleurocanthus ceracroceus.*

Appendix 3: "Award for Excellence in Doctoral Research" for Kim Khuy Khun

UNIVERSITY OF SOUTHERN QUEENSLAND AUSTRALIA

AWARD FOR EXCELLENCE IN DOCTORAL RESEARCH

Presented to

Mr Kim Khuy Khun

For achieving the highest possible result for a Higher Degree by Research thesis examination

2021

Professor Peter Terry PhD FAPS FASMF FBASES
Dean (Graduate Research School)
Graduate Research School | Research and Innovation Division

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Appendix 4.: Refereed papers

4.1 Khun, K.K., Ash, G.J., Stevens, M.M., Huwer R. and Wilson, B.A.L. (2020) Response of the macadamia seed weevil Kuschelorhynchus macadamiae (Coleoptera: Curculionidae) to *Metarhizium anisopliae* and *Beauveria bassiana* in laboratory bioassays.

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Response of the macadamia seed weevil *Kuschelorhynchus macadamiae* (Coleoptera: Curculionidae) to *Metarhizium anisopliae* and *Beauveria bassiana* in laboratory bioassays

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ABSTRACT

Macadamia seed weevil, *Kuschelorhynchus macadamiae* Jennings and Oberprieler, is a major pest of macadamia in eastern Australia, causing yield losses of up to 15%. Current control methods involve two applications of acephate per season but more recently have moved to a single application of indoxacarb, combined with the collection and destruction of fallen nuts that contain developing larvae. As a first step towards reducing the dependence of the industry on synthetic insecticides, we tested six isolates of *M. anisopliae*, six isolates of *B. bassiana* and one commercial *B. bassiana* product (Velifer® biological insecticide) against adult macadamia seed weevil under laboratory conditions. All isolates were pathogenic against adult weevils with *M. anisopliae* accession ECS1/BRIP 70272 and *B. bassiana* accession B27/BRIP 70267 causing 97.5% and 92.5% mortality 12 days after being treated at 1 × 10^7 conidia/mL. Isolates ECS1/BRIP 70272 and B27/BRIP 70267 had the shortest LT_{50} values of 5.13 days and 5.37 days respectively. The median lethal concentrations (LC_{50}) for ECS1/BRIP 70272 and B27/BRIP 70267 were 1.48 × 10^5 and 1.65 × 10^5 conidia/mL respectively. Results of this study indicate that *M. anisopliae* accession ECS1/BRIP 70272 and *B. bassiana* accession B27/BRIP 70267 have considerable potential for *K. macadamiae* control, and should be developed into biological insecticides for integration into macadamia pest management programs.

1. Introduction

Macadamias (*Macadamia integrifolia* Maiden and Betche and *M. tetraphylla* L. Johnson) are the second largest nut crop grown in Australia, with 25,000 ha under cultivation and a total farm-gate value of AUD 285 million (ANIC, 2016; AMS, 2018). Australia and South Africa are the largest macadamia producers, and together are responsible for around 48% of global production (INDFC, 2018). In Australia, several important insect pests have been reported to affect macadamias, with macadamia seed weevil being regarded as the greatest threat to the industry (QDAF, 2018). Macadamia seed weevil, *Kuschelorhynchus macadamiae* Jennings and Oberprieler (Coleoptera: Curculionidae), formerly known as 'Sigastus weevil' (Jennings and Oberprieler, 2018), is a native Australian insect, which was initially found in macadamias on the Atherton Tablelands, Queensland in 1994 (Fay et al., 2001) and later in the Northern Rivers region of New South Wales (NSW) (Bright, 2017a, 2017c). The weevil is a major pest of macadamias at the nut setting stage (Bright, 2017a, 2017c) with the female weevil ovipositing inside the nut, inducing premature nut drop (Fay et al., 2001). This premature nut drop has been estimated to lead to crop losses of around 15% (Huwer, 2016). Adults feed on young leaves and can completely remove the bark from seedlings, sometimes killing young plants within a few days (Kim Khuy Khun, personal observations).

The life cycle of the macadamia seed weevil from egg to adult emergence takes around 40 days at 25 °C (Bright, 2017a, 2017c). Adult females lay up to 280 eggs each (Bright, 2017a, 2017c), but only a few eggs are laid each day (Fay et al., 2001). Eggs are laid singly inside individual nuts when they are about 10 mm in diameter, in the tissue between the shell and the husk of the fruit (Fay et al., 2001). The eggs hatch in 6 days under typical ambient temperature and the larvae develop inside the nuts, feeding on the kernel. The larval stage lasts 4

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4.2 Khun, K.K., Ash, G.J., Stevens, M.M., Huwer R. and Wilson, B.A.L. (2020) Compatibility of *Metarhizium anisopliae* and *Beauveria bassiana* with insecticides and fungicides used in macadamia production in Australia.

Research Article

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Compatibility of *Metarhizium anisopliae* and *Beauveria bassiana* with insecticides and fungicides used in macadamia production in Australia

Kim Khuy Khun,[a,b*] Gavin J Ash,[b] Mark M Stevens,[c,d] Ruth K Huwer[e] and Bree AL Wilson[b]

Abstract

Background: Integrating fungal biocontrol agents into crop protection programs dominated by synthetic pesticides is an important first step towards developing an integrated pest management (IPM) program; however, their successful integration relies on an understanding of how their performance may be impacted by the remaining agrochemicals deployed for managing other pests and diseases. In this study we tested 10 formulated pesticides used in macadamia production at different concentrations to determine their effects on the germination, mycelial growth and sporulation of *Metarhizium anisopliae* and *Beauveria bassiana in vitro*. Further tests with laboratory-grade actives of the noncompatible pesticides were conducted to determine whether any antagonistic effects were caused by the active constituent or by formulation additives.

Results: At their registered concentrations, formulated trichlorfon, acephate and indoxacarb were compatible with *M. anisopliae*, whereas *B. bassiana* showed compatibility with formulated trichlorfon, acephate, indoxacarb, sulfoxaflor and spinetoram. Bioassays using laboratory-grade active constituents indicated that the adverse impact of formulated beta-cyfluthrin on both fungal species and that of formulated methidathion on *B. bassiana* is probably due to components of the emulsifiable concentrate formulations rather than their active constituents. Diazinon was the only insecticidal active that showed high toxicity to both fungal species. The two fungicides, carbendazim and pyraclostrobin, were toxic to both fungal species at all tested concentrations.

Conclusion: Our results identify which pesticides used on macadamias in Australia are compatible and incompatible with entomopathogenic fungi. Future studies on pesticide degradation rates will help define the spray intervals required to eliminate these adverse effects.

Keywords: biological index; compatibility; entomopathogenic fungi; fungicides; insecticides

1 INTRODUCTION

Macadamias (*Macadamia integrifolia* Maiden and Betche and *M. tetraphylla* L. Johnson) are the second largest nut crop grown in Australia with a total farm-gate value of AUD 285 million and retail value of more than AUD 850 million.[1,2] The crop is susceptible to various pests and diseases and to control them a number of insecticides and fungicides have been registered.[3] Although these agrochemicals are widely used, the Australian macadamia industry is committed to the development of an integrated pest and disease management (IPDM) program, reducing the use of broad-spectrum chemicals and integrating biological control agents (BCAs) into pest management practices in order to conserve beneficial insects and protect the environment in the macadamia agro-ecosystem.[2]

The entomopathogenic fungi *Metarhizium anisopliae* (Metschn.) Sorokin and *Beauveria bassiana* (Bals.-Criv.) Vuill. are among the main fungal BCAs with cosmopolitan distributions[4,5] and they have shown potential for controlling many economically important insect pests in horticultural crops.[6–8] However, to achieve effective control (>90%) high inoculum rates are required

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4.3 Khun, K. K., Wilson, B. A. L., Stevens, M. M., Huwer, R. K. and Ash, G. J. (2020). Integration of entomopathogenic fungi into IPM programs: Studies involving weevils (Coleoptera: Curculionoidea) affecting horticultural crops.

insects

MDPI

Review

Integration of Entomopathogenic Fungi into IPM Programs: Studies Involving Weevils (Coleoptera: Curculionoidea) Affecting Horticultural Crops

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Simple Summary: Horticultural crops are vulnerable to attack by many different weevil species. Fungal entomopathogens provide an attractive alternative to synthetic insecticides for weevil control because they pose a lesser risk to human health and the environment. This review summarises the available data on the performance of these entomopathogens when used against weevils in horticultural crops. We integrate these data with information on weevil biology, grouping species based on how their developmental stages utilise habitats in or on their hostplants, or in the soil. These patterns of habitat usage can help identify the stages during which pest species are at their most vulnerable, and also help to determine the most effective ways to deploy entomopathogens for their control.

Abstract: Weevils are significant pests of horticultural crops and are largely managed with insecticides. In response to concerns about negative impacts of synthetic insecticides on humans and the environment, entomopathogenic fungi (EPF) have been developed as an alternative method of control, and as such appear to be "ready-made" components of integrated pest management (IPM) programs. As the success of pest control requires a thorough knowledge of the biology of the pests, this review summarises our current knowledge of weevil biology on nut trees, fruit crops, plant storage roots, and palm trees. In addition, three groups of life cycles are defined based on weevil developmental habitats, and together with information from studies of EPF activity on these groups, we discuss the tactics for integrating EPF into IPM programs. Finally, we highlight the gaps in the research required to optimise the performance of EPF and provide recommendations for the improvement of EPF efficacy for the management of key weevils of horticultural crops.

Keywords: attract-and-kill; *Bacillus thuringiensis*; *Beauveria*; endophyte; entomopathogenic nematode; *Metarhizium*; repellent volatile; sterile male; transmission; weevil

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4.4 Khun, K.K., Ash, G.J., Stevens, M.M., Huwer R. and Wilson, B.A.L. (2021) Transmission of *Metarhizium anisopliae* and *Beauveria bassiana* to adults of *Kuschelorhynchus macadamiae* (Coleoptera: Curculionidae) from infected adults and conidiated cadavers.

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Transmission of *Metarhizium anisopliae* and *Beauveria bassiana* to adults of *Kuschelorhynchus macadamiae* (Coleoptera: Curculionidae) from infected adults and conidiated cadavers

Kim Khuy Khun[1,2]✉, Gavin J. Ash[2], Mark M. Stevens[3,4], Ruth K. Huwer[5] & Bree A. L. Wilson[2]

Kuschelorhynchus macadamiae **is a major pest of macadamias in Australia, causing yield losses of up to 15%. Our previous studies have shown the weevil is susceptible to *Beauveria bassiana* and *Metarhizium anisopliae*. The aim of this study was to investigate horizontal transmission of both fungal species to healthy weevils from both infected adults and weevil cadavers. In a confined environment the mortality of healthy adults caused by the transmission of conidia from live fungus-infected adults was < 50%. Under similar experimental conditions, the mortality of healthy adults reached 100% when exposed to conidiated cadavers. However, when conidiated cadavers were used in more spacious environments (insect cages), the mortality of adults was < 80%. Using scanning electron microscopy, it was observed that all healthy adults had conidia attached to all external parts of the body. This suggests that although the conidia were readily transferred to the adults, the lower mortality in the larger insect cages could be the result of an unfavourable environmental factor such as low humidity. The presence of conidia attached to all the adults indicated that they did not show any discriminatory behaviour such as avoidance of conidiated cadavers infected by these two fungal species. The results from this study show that there is potential for enhanced control of adult *K. macadamiae* via transmission from either fungus-infected adults or conidiated cadavers and this could strengthen sustainable pest management in macadamias.**

Macadamia seed weevil, *Kuschelorhynchus macadamiae* Jennings and Oberprieler, formerly known as *Sigastus* weevil[1], is a native Australian insect which was initially found in macadamias (*Macadamia integrifolia* Maiden and Betche and *M. tetraphylla* L.A.S. Johnson) on the Atherton Tablelands, Queensland[2] in 1994 and later in the Northern Rivers, New South Wales (NSW)[3,4]. This weevil is a major pest of macadamias at the nut development stage[3,4] with the female weevil ovipositing inside the husk of the macadamias when they are about 10 mm in diameter, and inducing premature nut drop between the months of September and December each year[2,5]. This premature nut drop has been estimated to lead to approximately AU$ 15 million worth of lost production[6]. Adults also feed on young leaves and completely remove the bark from seedlings, leading to plant death within a few days (K. K. Khun, personal observation).

The entomopathogenic fungi, *Beauveria bassiana* (Bals.-Criv.) Vuill. (Hypocreales: Cordycipitaceae) and *Metarhizium anisopliae* (Metschn.) Sorokin (Hypocreales: Clavicipitaceae) have cosmopolitan distributions[7,8] and

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4.5 Khun, K.K., Ash, G.J., Stevens, M.M., Huwer, R. and Wilson, B.A.L. (2021) Interactions of fungal entomopathogens with synthetic insecticides for the control of *Kuschelorhynchus macadamiae* (Coleoptera: Curculionidae).

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ORIGINAL CONTRIBUTION

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Interactions of fungal entomopathogens with synthetic insecticides for the control of *Kuschelorhynchus macadamiae* (Coleoptera: Curculionidae)

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Abstract

This study investigated the interactions between insecticides (acephate and indoxacarb) and fungal entomopathogens (*Beauveria bassiana* [Bals.-Criv.] Vuill. strain B27, *Metarhizium anisopliae* [Metschn.] Sorokin strain ECS1, and a commercial *B. bassiana* product, Velifer® Biological Insecticide) for controlling the macadamia seed weevil, *Kuschelorhynchus macadamiae* Jennings and Oberprieler, in the laboratory and glasshouse. In the laboratory, additive interactions between insecticides at their full field concentrations (776 mg AI/L of acephate and 75 mg AI/L of indoxacarb) and fungal entomopathogens at 10^7 conidia/ml (ECS1 and B27) or at full field concentration (0.5 ml of Velifer®/L) were seen at 6 days and 12 days post-application. Under the same experimental conditions, synergistic interactions against *K. macadamiae* were observed 6 days post-application when fungal entomopathogens at 2.5×10^6 conidia/ml or at 25% of full field concentration (Velifer®) were co-applied with insecticides at 25% of their full field concentrations, whilst additive interactions were again observed at 12 days post-application. In the glasshouse, additive interactions between insecticides (at full field concentrations) and fungal entomopathogens (at 10^7 conidia/ml, or at full field concentration for Velifer®) were obtained at 6 days and 12 days post-application. The results from this study suggest that acephate and indoxacarb have both synergistic and additive effects against *K. macadamiae* when deployed together with fungal entomopathogens, depending on the initial concentrations of mixture components. Combined application of entomopathogens with compatible insecticides promises to provide more effective management of *K. macadamiae* than individual chemical applications.

KEYWORDS

acephate, *Beauveria bassiana*, combined application, indoxacarb, *Metarhizium anisopliae*, synergy

1 | INTRODUCTION

Macadamia seed weevil, *Kuschelorhynchus macadamiae* Jennings and Oberprieler (Coleoptera: Curculionidae), formerly known as '*Sigastus* weevil' (Jennings & Oberprieler, 2018), is a native Australian insect, which has been categorized as one of the key pests of macadamias (*Macadamia integrifolia* Maiden and Betche and *M. tetraphylla* L.A.S. Johnson) (QDAF, 2019). Adult females lay eggs inside the husk of

4.6 Ellis, K.L. (2021) Confirmation of Candidature - Kirsten Ellis

Confirmation of Candidature Kirsten Ellis

by Kirsten Ellis

Submission date: 10-Feb-2021 08:43PM (UTC+1100)

Submission ID: 1506171583

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Word count: 17869

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4.1. Insect colonies

Methodology and results from colony rearing of macadamia nut borer, *Trichogrammatoidea cryptophlebiae*, Fruit spotting bugs and results of field parasitism of the phorid fly *Apocephalus* sp. are described in the following sections.

4.7.1. Macadamia nut borer

Methodology:

Colony maintenance work in the NSW DPI Wollongbar laboratories has continued since 1998 for *Cryptophlebia ombrodelta* (macadamia nut borer MNB) and its egg parasitoid wasp (*Trichogrammatoidea cryptophlebiae*).

The modified Shorey and Hale diet we have continued to use (Campbell et al. 1999) has been changed slightly in recent times to deal with the toxicity and WHS issues of formaldehyde use. 2-phenylphenol was used as replacement (Wellington, et al. 2017). MNB pupae are extracted twice weekly from diets set 28 days earlier, the numbers of pupae collected and number of wasp release cards are shown in Table 4.7.1.1.

The levels of pupal productions are directly effected by the moth flight and success of mating in the flight cage, which in turn affects the fecundity of the eggs laid on the cards placed in the diets. Pupal survival can also be effected on by desiccation and predatory mite activity in the flight cage which must be cleaned for. During the period 2016-2021 we have maintained the colony at a normal holding level through the autumn /winter period and doubled output of cards from October – March when releases are required in the field blocks. This is achieved by doubling the target cards presented to the wasps and storing the ones parasitised for a few days at below 14 °C to allow a staggered field release around the spray periods at CTH Alstonville

The moth colony production needs to be sufficient to allow target eggs on the cards to be at a suitable density for the wasp activity to be maintained. The main problems we encounter are normally due to low target egg densities leading to super parasitism and poor wasp emergence levels. These are constantly checked across the seasons by taking samples of the parasitised egg cards from the wasp colony at each clean out (twice a week). These egg cards are examined under the microscope to estimate the number of eggs parasitised (black not hatched) and of those, how many emerged (Table 4.7.1.2.). Lots of unparasitised eggs means no wasps are active in the chambers and the MNB larvae can hatch and cannibalise the eggs, or many still born black eggs means the target egg density is too low for the active wasp population, and you will have to rebuild the numbers again. The wasp emergence rate and MNB oviposition do have some links with the colony humidity levels, generally too dry conditions reduce MNB survival in the field and the wasp emergence is better from eggs in the warmer wetter months (Table 4.7.1.2.).

Results

Data from colonies is presented in Tables 4.7.1.1. and 4.7.1.2.

Table 4.7.1.1.: *Cryptophlebia ombrodelta* (MNB) pupal production rates during the project period 2016-2021 from a source of two artificial diet trays per week each month at the Wollongbar DPI entomology laboratories (top table). The number of parasitised egg cards produced each month over the same project period 2016-2021 for release in the river systems (*), and then into the entomology trial areas at CTH Alstonville (**), each card had 6 perforated smaller cards within to spread them further around (lower Table). Wasp colony was last re charged with the flight tube in July 2019.

MNB pupal production

Year	Jan	Feb	March	April	May	June	July	Aug	Sep	Oct	Nov	Dec	Totals
2016	4234	4582	2994	4356	6520	6798	6428	6322	7342	8122	6417	6418	70533
2017	6247	6607	5642	7125	8018	7819	6142	8895	7740	7302	7503	6747	85787
2018	6871	6677	6495	6347	7792	7299	7963	8693	4307	6515	7421	5262	81642
2019	5778	3309	4886	5829	5457	5328	6721	6843	6643	6208	5848	5802	68652
2020	4436	3684	4798	3433	4932	5671	6281	6386	4957	7078	5966	5201	62823
2021	5219	4370	6498	6619	5094	6093	7558	7174					48625
	32785	**29229**	**31313**	**33709**	**37813**	**39008**	**41093**	**44313**	**30989**	**35225**	**33155**	**29430**	**418062**

Wasp release card production for CTH and River systems

	Jan**	Feb**	March**	April	May	June	July	Aug	Sep*	Oct*	Nov**	Dec**	Totals
2016	98	117	68	56	44	36	39	31	48	15	71	112	735
2017	74	83	91	38	38	34	29	27	51	73	36	102	676
2018	98	102	83	64	41	44	54	50	34	51	95	119	835
2019	132	126	111	43	33	31	56#	57	62	41	71	94	801
2020	80	64	47	47	37	53	46	52	47	68	59	100	700
2021	89	63	61	74	55	26	21	40	55	61	63	128	736
	571	**555**	**461**	**322**	**248**	**224**	**256**	**257**	**297**	**309**	**395**	**655**	**4483**

* released to rivers

** released to orchard trial areas

flyers selected

Table 4.7.1.2.: Wasp emergence rates from the parasitised macadamia nut borer egg cards used to seed the field trials and river systems around the Alstonville district each season for MNB control. The *Trichogrammatoidea cryptophlebiae* culture at Wollongbar WPII Entomology laboratories has strips of cards collected twice weekly and counted for emergence holes or still born eggs under 12x magnification. Colony values are presented as target eggs per month summed and the numbers with emergence holes of that total, overall monthly averages are shown below ranging from 48.6% in august to 80.2% in January.

Year	January		Feburary		March		April		May		June	
	sum	emerged	sum	emerged	sum	emerged	sum	emerged	sum	emerged	sum	emerged
2016	682	561	700	592	600	499	600	471	700	395	700	249
2017	990	867	943	835	1014	781	800	568	900	606	950	543
2018	1379	1182	2333	1016	1500	1282	1413	1066	1183	756	1154	692
2019	1084	835	1212	991	1275	956	1300	864	1200	687	1200	812
2020	1134	881	1100	787	1100	873	1023	722	1596	1127	1082	759
2021	1200	859	1384	942	1300	961	1400	1012	1900	1401		
%emerged		80.2		67.3		78.8		72.0		66.5		60.1
Total	**6469**	**5185**	**7672**	**5163**	**6789**	**5352**	**6536**	**4703**	**7479**	**4972**	**5086**	**3055**

Year	July		August		September		October		November		December		Overall	Overall
	Sum	Emerged	Sum	Emerged	Sum	Emerged	Sum	Emerged	Sum	Emerged	Sum	Emerged	Sum	Emerged
2016	700	379	800	395	700	370	700	418	800	593	1034	774	8716	5696
2017	1200	603	1368	529	900	621	900	721	1129	922	1133	991	12227	8587
2018	1422	740	1247	642	1442	1019	1000	782	1179	870	1341	1052	16593	11099
2019	1500	778	1395	682	1100	611	1100	772	1100	794	1000	746	14466	9528
2020	1000	654	1100	623	984	698	1085	720	1052	763	1200	821	13456	9428
2021													7284	5250
% Emerged		54.2		48.6		64.7		71.3		74.9		76.8		68.2
Total	**5822**	**3154**	**5910**	**2871**	**5126**	**3319**	**4785**	**3413**	**5260**	**3942**	**5708**	**4384**	**72742**	**49588**

4.7.2. Phorid fly (*Apocephalus* sp.) in fruit spotting bug colonies

Methodology

The phorid fly (*Apocephalus* sp.) (Figure 4.7.2.1.) has continued to be present within the bodies of the dead *Amblypelta nitida* (FSB) cleaned out of the colony each week (Huwer et al. 2015b MC10049 p 98, 180-181). These bodies are kept in petri dishes dated and examine 3 weeks later to see if any pupae have developed. As we are continually restocking the colonies with wild bugs collected off the *Murraya* hedges at CTH Alstonville each week, it reflects field activity to some extent. The phorid levels were much higher in the beginning of 2016 compared to the other seasons of the project (Table 4.7.2.1.) and did approach the levels seen in the previous project in between 2013-2015 and similar peaks in activity in November and February- May (Huwer et al*.* 2015b, p181, Table 4.7.2.1.). The drought from early 2019 onwards through to early 2020 may have effected on the phorid field activity somewhat here as the FSB numbers were in major decline on the hedges. The sole *Trichopoda* sp (probably *pennipes*) in November 2016 is a rarity to see that fly in Australia (Waterhouse and Norris 1987, p86 as both *T. pennipes* and *T. pilipes* were introduced several times for *Nezara* control from 1940's, 1950's and 1980's, and it really has not been curbing activity of FSB, anything like what the drought did in 2019–2020. *Trichopoda giacomelli* from Argentina has been doing a fine job on *Nezara* sp. since its introduction in 1996-99 (Coombs and Sands, 2001). Yes we could rear *T. giacomelii* through on FSB when live eggs were transplanted on the backs of FSB, but the flies prefer to lay on the broader pentatomid shape not the thin coreid, and we have no found one in the FSB we have collected since 2012 (Huwer et al*.* 2011, 2015b6 and this report).

Figure 4.7.2.1. : *Apocephalus sp*. the Phorid fly associated with field collected *Amblypelta nitida* from *Murraya paniculata* hedges Alstonville CTH 2016-2021. Dead bugs are collected weekly from cages and the fly pupae are allowed to emerge from the corpses and counted after 3 weeks.

Results:

Results for field parasitism of FSB with *Apocephalus* (phorid flies)

Table 4.7.2.1. The phorid fly (*Apocephalidae* sp.) parasitoid emergence from the *Amblypelta nitida* (FSB) bodies in the colonies from the field collections made on the *Murraya* hedges at CTH Alstonville weekly that have died, checked weekly each month during the project period 2016-2021.

Year	Jan	Feb	March	April	May	June	July	Aug	Sep	Oct	Nov	Dec	Totals
2016	25	15	4	53	0	0	0	0	0	0	1*	0	98
2017	4	0	0	0	2	2	0	1	0	0	0	0	9
2018	0	0	3	8	0	0	0	0	0	0	3	1	15
2019	0	0	14	3	0	0	0	1	0	0	0	4	22
2020	0	1	0	0	0	0	1	4	0	1	0	0	7
2021	0	0	0	1	0	0	0	0	0				1
	29	**16**	**21**	**65**	**2**	**2**	**1**	**6**	**0**	**1**	**4**	**5**	**152**

* *Trichopoda* sp.

Appendix 5.: Journal articles

5.1. Maddox, C., Robertson, D., Janetzki, A. (2016) The latest on the Sigastus weevil management project.

THE LATEST ON THE *SIGASTUS* WEEVIL MANAGEMENT PROJECT

Horticulture Innovation Australia

Craig Maddox, David Robertson and Alister Janetzki, NSW DPI Wollongbar/Alstonville CTH

A NSW DPI research team has been examining methods for controlling the macadamia seed weevil *Sigastus* sp., which has become a significant pest of macadamia in the Northern Rivers district of NSW.

The project had several areas of focus, as follows:

- To establish which chemicals are superior to the currently registered products. Two products will be used in field trials in the coming season to provide field data to the APVMA.
- To evaluate the efficacy of various fungal pathogens on the protected immature life stages and adult weevils for field testing, then work out the process to effectively cultivate and deliver such a fungal agent to the field. We have had some success with the local *Beauvaria bassiana* strain but maintaining spore activity in dry periods is still an ongoing issue.
- To determine the life cycle parameters and when might be the best times to control the pest.

During the 2015-16 season we measured crop loss caused by the overwintering and migrating adult weevils (see photos) and quantified the importance of crop hygiene in managing the pest. At the Centre for Tropical Horticulture Alstonville (CTH), using the unsprayed sink block area with 3 m high, 9-year-old trees, we removed all the damaged crop fortnightly from under each tree between June 2015 and January 2016. This damaged nut was examined and scored for *Sigastus* (MSW) oviposition, *Amblypelta nitida* (fruitspotting bug) damage and *Cryptophlebia ombrodelta* (macadamia nutborer) activity within the husk. We compared the losses under 16 trees with multiple crop cycles running (cv L64 and XXX) against ten cv246 trees on a single crop cycle.

(Left) Sigastus weevil (MSW) on young macadamia nut with freshly laid eggs. (Right) MSW pupae and larvae in the nut on the ground waiting for spring to emerge.

We know that the female adults are long lived, migrate well and can lay up to 40 eggs a week when the right age nut is on the tree. The key factor is the amount of out-of-season nut carrying through winter (see figure). Based on this trial result an initial overwintering population estimate of 20 females on these 26 trees can generate 200 extra weevils per tree just before the main crop is vulnerable if there is out-of-season nut present. This determines the impact the pest has on the block yield (see table and figure) and inflates the problem by a factor.

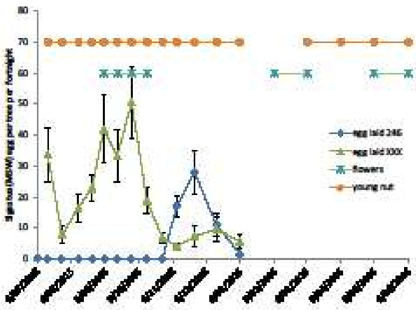


Figure. *Comparison of fortnightly average nut drop per tree to Sigastus weevil (MSW) under 9-year-old macadamia trees with single spring flowering carrying no out-of-season nut (n=10 cv 246) opposed to trees carrying multiple crop cycles (n=16 cv XXX and L64) during 2015-16 unsprayed sink block CTH Alstonville trial site. All F1 potential weevils are removed from the trial presenting nut drop caused by the overwintering and migrating adults only. Breeding cycle will repeat each nut set.*

Limiting the weevil's breeding opportunities is crucial, which comes back to the key question of how do you consistently put nuts on trees in spring and limit that out-of-season flowering, despite the vagaries of climate we have to deal with e.g. 100 mm of rain in September flowering or the very warm May and June we experienced this year (see table).

Field spray timing across the whole Alstonville CTH farm to manage *Sigastus* weevil in late October and November was successful, and we were collecting infected nuts across the farm during October. The management of late season fruitspotting bug was a far

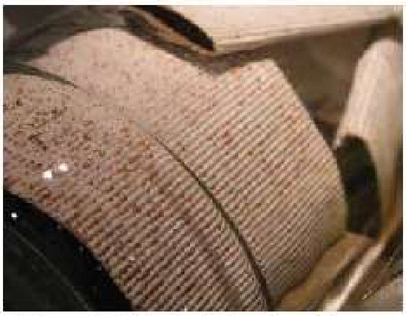
5.2 Bright, J. (2017) Are we dropping the ball on nut borer protection?

ARE WE DROPPING THE BALL ON NUT BORER PROTECTION?

Northern NSW growers are reporting a higher incidence of macadamia nut borer for this season. In fact, it is not that there is more pressure from macadamia nut borer compared to any other year, rather it's the actual incidence of damage that is greater than normal.

One explanation for this is that we could be dropping the ball on nut borer protection. It's been reported that some growers are not setting out wasp cards because they have carried out a late spotting bug spray. Others are relying on the area-wide effect of surrounding orchards placing the cards around them and thereby getting protection from the spill-over effect.

Macadamia nut borer is a serious pest of macadamia and can cause significant damage, particularly in the final stages of crop development.



To help guard against the risk of nut borer damage it is important that growers continue to place parasitoid cards in the orchard.

In the past decade, the industry has put much effort into controlling this pest through the use of wasp cards and insect growths regulators such as Prodigy®. Unfortunately, recently the number of growers using the cards has dropped and this is translating to higher levels of pressure and damage to the crop.

The important message is that macadamia nut borer is a manageable pest and the use of the egg parasitoid cards will support growers through the final development of the crop to harvest. The cards work best on a large scale, i.e. an area-wide approach. Fragmentation in the distribution of the cards will result in the weakest point being affected.

The team at NSW DPI through the new Horticulture Innovation Australia Macadamia IPM Program is communicating with pest consultants on a weekly basis about observations in the district, such as the numbers of bugs in the trap hedges, presence of nut borer eggs, thrips and mite populations and other activities they are seeing in the farms that they check. The system means that both parties are being well informed on the populations of pests and beneficials. This collaboration adds confidence to the grower's decision making process to spray or not spray given the current most up-to-date information.

This project has been funded by Horticulture Innovation Australia Limited using the research and development macadamia levy and funds from the Australian Government.

Note. Photographs courtesy of NSW DPI Entomology.

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5.3 Huwer, R., Maddox, C., Hickey, M. and Bright, J. (2017) IPM Project - A busy year establishing research and case study sites

R & D UPDATE

IPM PROJECT - A BUSY YEAR ESTABLISHING RESEARCH AND CASE STUDY SITES

Ruth Huwer, Craig Maddox, Mark Hickey and Jeremy Bright, NSW DPI, Wollongbar

Project snapshot

Hort Innovation has funded a range of projects to do with integrated pest management (IPM) in the macadamia industry. The objective of the IPM Program is to move from a predominantly spray focus to a more holistic approach to pest management. This holistic approach considers the life cycle and ecology of pests, develops attractants, uses monitoring and develops new control approaches including use of pest pathogens (entomopathogens) and creating beneficial refuges. This approach makes good sense, particularly when you consider the reducing pool of chemical options and long-term sustainability of the industry.

As part of the IPM program, NSW DPI is managing Project MC16004, which started almost a year ago. Since then, research and case study sites have been established in key production regions and the team has been busy communicating the latest management options for key pests using IPM principles to growers and consultants.

In this article, we outline progress to date with the project.

As Paul Horne and the IPM Technologies team conveyed in their regional workshops in mid-2017, the IPM approach uses biological, cultural and chemical options. The challenge for the NSW DPI project team is to integrate these three components into a system optimised for profitable commercial macadamia production. The three focus areas for the team are:

- monitoring (pests and beneficials)
- developing cultural and biological controls
- assessing the impact of chemical treatments on pest and beneficial populations.

Monitoring in full swing in the regions

Dry weather has been a feature of the current season, with the result that most pest species have been active 2 to 3 weeks earlier than normal.

The prevalence of scolytid beetles associated with tree deaths in several districts prompted a series of monitoring trials in several commercial orchards. Three beetle trap/pheromone combinations and sticky traps were trialled to determine the best monitoring method. The three main species of beetle so far identified are *Hypothenemus* sp., *Xyleborus* sp. and *Cryphalus* sp, and the information is helping to understand the spread and extent of the problem. Various control options including pruning have been carried out to reduce beetle populations. All case study sites have scolytid traps in place with three different lures (Ambro, Euwallacea and methanol/ ethanol).

Monitoring of Sigastus weevil emergence rates has started with field activity in early August, and significant loss of out-of-season nut has been recorded. Adult weevils have been supplied to Andrew Hayes (USC) for wind tunnel experiments to look for volatile attractants that can be used in a future pheromone lure.

Trap hedges in the Alstonville district have also been monitored for fruitspotting bug, and monitoring information shared with the Connor Road Area Wide Management pilot group. Hedges have now been established in all growing regions.

5.4 Maddox, C.D.A, Huwer, R., Purdue, I., Robertson, D., Janetzki, A. and Maddox, C. (2018) Late season insect damage not all down to FSB.

R & D UPDATE

LATE SEASON INSECT DAMAGE NOT ALL DOWN TO FSB

Craig Maddox, Ruth Huwer, Ian Purdue, David Robertson, Alister Janetzki and Carly Maddox, NSW DPI Wollongbar

Whenever you see late season bug damage on macadamias, it is down to fruitspotting bug (FSB). Correct?

Maybe not, according to the NSW DPI entomology research team, which has been working on identifying other possible bugs causing damage as part of the IPM research program funded by Hort Innovation through macadamia strategic levy investment.

The team has established that while a lot of the late season bug damage that processors see is caused by FSB (*Amblypelta nitida*), there are other insect pests that are capable of feeding through the macadamia shell (see Table 1).

The team examined methods for determining whether late season bug feeding could be expressed more by cooling the nut in husk during the early harvest rounds between 2015 and 2017. During this period, we were also able to cage other live bug species with mature nut and observe the kernel damage that occurs.

Field and lab tests show FSB not the only bug to feed on mature nuts

The field experiments at CTH and a Victoria Park orchard (for variety A203 only) have shown that:

- FSB adults and nymphs do leave visible feeding traces on the husk immediately after feeding and longer on some varieties (see photos 1 and 2).
- Cooling the nut in husk enhances the occurrence of husk bruising on varieties 246, 849 and A4, but this does not always line up with deeper kernel damage (see photos 3 to 8 and Table 2).

The laboratory feeding experiments with the other bug species showed that all the larger bug species tested were able to feed on mature nuts, along with the already known banana spotting bug (*Amblypelta l. lutescens*), and green vegetable bug.

What do the results mean?

The results point to the fact that being aware of activity of other bugs and the plant species they feed on could be useful to growers with orchards that neighbour these species. As an example, in areas where wild foambark trees grow, soapberry bug activity is likely. We have also observed activity of the lesser horned citrus bug at CTH Alstonville for many years. This is usually closer to the rainforest boundary and at the expense of *Amblypelta* in some trees, as well as on the *Murraya* monitoring hedges from time to time.

The litchi stink bug is a pungent beast not unlike the bronze shield bug that attacks the citrus trees in northern NSW. The exudate they can squirt is to be avoided. They are often in single trees but can cause damage when they arrive *en masse* in autumn.

Having legumes intermingled with macadamia trees can exacerbate the risk posed by green vegetable bug. Historically, the Alstonville research station has had large populations of green vegetable bug when we have been cultivating passionfruit or soybean on the station or when weed management has been left over summer and population levels allowed to build up even under small trees up to 3 m high.

When those plants have been removed, this problem has gone. The vegetable bugs are visible, have a distinctive smell and are slow moving. They are found mainly in the lower third of the canopy, and on nut on the ground, unlike FSB which prefer the upper canopy.

Bugs species	Common name	Family	Nearby alternative host risks to macadamia crops
Nezara viridula	Green vegetable bug	Pentatomidae	Soy bean, passionfruit, many weed species, many garden vegetables
Vitellus antenna	Lesser horned citrus bug	Pentatomidae	Citrus, *Murraya* sp., rainforest fruit
Lyramorpha rosea	Litchi stink bug	Tessaratomidae	Litchi, longan, tuckeroo
Leptocoris sp.	Soapberry bugs	Rhopalidae	Foambark (*Jagera* sp.), particularly post fruiting

Table 1. Other bug species able to feed through macadamia shell after hardening when fed nut in the laboratory at Wollongbar NSW DPI.

PAGE 70 | AUSTRALIAN MACADAMIA SOCIETY LTD | NEWS BULLETIN | AUTUMN 2018

5.5 Bright, J. (2018) Dieback in NSW orchards.

DIEBACK IN NSW ORCHARDS

Jeremy Bright, NSW DPI, Wollongbar

NSW DPI specialists have been called out to properties in the Northern Rivers and mid north coast recently where macadamia trees have displayed symptoms of twig/branch dieback.

Tree showing symptoms of dieback on twigs and branches.

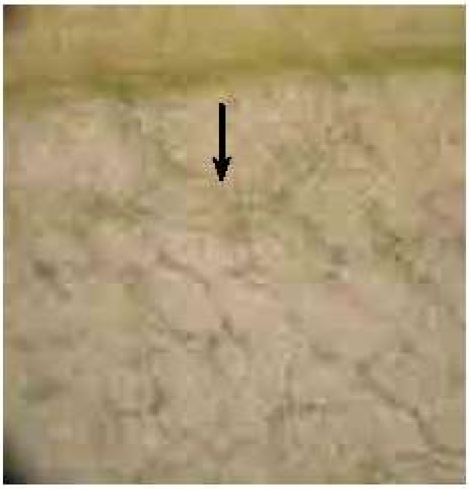
Macadamia twig in the laboratory. You can see mites on the leaf (arrowed) and leaves that have died as a result of mite infestation.

The problem was caused by two mite species: a broad mite pest, *Polyphagotarsonemus latus* (Tarsonemidae) common in many regions, and the rarer but equally damaging *Ditilomiopus davisi* (Eriophyidae) which cannot be seen under 10X lens; it is even difficult to see under 50X lens.

The mites infest buds and young leaves which die over time. The main method of spread is via wind. It appears that these mites are favouring A16 and A4 varieties. Eriophydae may be seasonal as it was reported on in 2003, 2004, 2006 and 2008 by Kevin Quinlan, Craig Maddox and Ruth Huwer. Generally, no spray is warranted unless infestations severe.

The issue does not, however, seem to end with just the mites. There also appears to be a higher prevalence of bark beetle in the regions. Bark beetle *(Cryphalus subcompactus)* tends to favour trees under stress. They enter through lower sap flow pressure and once in the branches they will tend to ring bark the stem and create dieback as a result.

Bark beetles are usually associated with the recognisable bleeding, or gummosis, from the affected limbs. Ideally, control would be to cut out the affected branches, but this may prove too difficult in many orchards. Prevention involves maintaining good sap flow of the plant, i.e. keep the plant healthy. This may prove difficult in dry times for non-irrigated orchards.



An eriophyid mite (arrowed) on a macadamia leaf. The mite is impossible to see with the naked eye and is even hard to see under a 50X lens.

5.6 Huwer, R., Maddox, C., Bright, J. and Hickey, M. (2018) Numbers in for year 1 of CTH IPDM trial.

R & D UPDATE

NUMBERS IN FOR YEAR 1 OF CTH IPDM TRIAL

Dr Ruth Huwer, Craig Maddox, Jeremy Bright and Mark Hickey, NSW DPI, Wollongbar NSW

Project snapshot

The first 12 months of the NSW DPI component of the IPDM project (Hort Innovation sub project MC16004) have mainly been focussed on setting up trials designed to compare "conventional" or standard practice, standard and cultural biological practices and IPDM strategies. These trials are being run at Alstonville's Centre for Tropical Horticulture (CTH) in the Northern Rivers and on farms in the four growing regions (see article on page 30).

This article describes a small-scale research trial which has been established at Alstonville CTH. The treatment plan, discussed with IPM Technologies, includes a broad-spectrum insecticide treatment as a benchmark, a treatment including broad-spectrum insecticide, cultural and biological control, and two different IPDM strategies, including different IPDM compatible insecticides, biological control and biological control alone.

The trial at CTH has been established in the CTH orchard. Trial blocks for each treatment comprise three rows of four variety trees. The four different treatments investigated in this trial are summarised in Table 1.

Some of the trees in each treatment were drastically pruned back to 6 m high.

Monitoring for the season has been completed and harvest was in progress in July, when this article was written. The sites were monitored each week as follows:

- visual observations of pests and beneficials
- setting up and servicing pheromone traps for macadamia nutborer and scolytids (bark beetle, pinhole borer, trunk borer)
- monitoring hedges for both FSB
- installing and servicing yellow sticky traps, intercepting randomly different species of pests and beneficials
- checking fallen nuts for pest damage, i.e. FSB, Sigastus, or macadamia seed weevil (feeding, oviposition, larvae and pupae), and macadamia nutborer.

Spiders, some lacewings, ichneumonoid wasps and ants have been observed in all blocks.

Treatment	Components
Broad-spectrum insecticides + hygiene	Insecticides: organophosphates and synthetic pyrethroids Hygiene: picking up fallen nuts
Broad-spectrum insecticides + hygiene + biological control	Insecticides: organophophates, sulfoxamines, neonicontinoids and insect growth regulator Biological control: Lace wings, Montorensis mite, *Centrodora darwini*, MacTrix Hygiene: picking up fallen nuts
IPDM1	Insecticides: plant extract, oxadiazines, diamide, flonicamid Biological control: Lace wings, Montorensis mite, *Centrodora darwini*, MacTrix Hygiene: picking up fallen nuts
IPM2	Insecticides: pyrethrins, plant extract, diamide, flonicamid Biological control: Lace wings, Montorensis mite, *Centrodora darwini*, MacTrix Hygiene: picking up fallen nuts

Table 1. *The four different treatments implemented at CTH Alstonville.*

The monitoring program for the grower sites in the four growing regions is similar to that for this trial. The case study sites in Queensland also included monitoring for BSB using a combination of pheromone traps within the orchard and monitoring hedges for each region. Queensland sites did not include detailed monitoring of macadamia seed weevil as it is not prevalent in the state. Monitoring data from the season is currently being collated and analysed.

Collection of harvesting data of all trials is still in progress at the time of preparing this article. Preliminary results for the trial at CTH Alstonville are shown in Table 2.

5.7 Maddox, C. and Huwer, R. (2018) Indoxacarb – A new option for macadamia seed weevil management.

R & D UPDATE

INDOXACARB – A NEW OPTION FOR MACADAMIA SEED WEEVIL MANAGEMENT

Craig Maddox and Ruth Huwer, NSW DPI Wollongbar

One of the big pest management news items this season, especially for NSW Northern Rivers growers, has been the approval of an APVMA minor use permit held by Hort Innovation for the use of indoxacarb in macadamias. Indoxacarb is sold by FMC in Australia as Avatar® insecticide or Steward®EC insecticide as a pesticide option to help manage macadamia seed weevil *(Kuschelorhynchus macadamiae)*, formerly known as *Sigastus* weevil.

Timing important

Understanding the life cycle of macadamia seed weevil is critical to getting the right timing for effective control. A lot of plant material is ingested during oviposition (see photo). This is an important observation because it means that there is an indoxacarb treatment window for seed weevil which occurs as the nut is expanding up to the 8 to 10 mm diameter stage when the adults shift into that laying mode that can be so destructive. If successful, this would eliminate the need for a second spray (maximum two sprays per season).

Indoxacarb can be applied in combination with husk spot fungicides. Rural supply stores or crop consultants should be able to advise on product compatibility and best timing for applications.

Applying Indoxacarb

The minor use permit PER86827, states that the first indoxacarb application must be at the beginning of nut set when nuts are pea sized. A second application can be applied 10 to 14 days later **if required.**

Indoxacarb can be applied at the following rates: Avatar 300 g/kg at 25 g/100 L or Steward EC insecticide 150 g/L at 50 mL/100 L with the addition of a non-ionic wetter at label rates.

No more than two applications can be made per season to control macadamia seed weevil.

The permit withholding period states that nuts cannot be harvested for six weeks after application and that livestock cannot be allowed to graze treated macadamia orchards during the season of application. It is also important to avoid spray drift onto adjoining properties or stock areas.

The triangular oviposition marks made by macadamia seed weevil (circled) as opposed to husk damage from recent fruitspotting bug feeding (right hand nut).

5.8 Bright, J. (2019) Incorporating indoxacarb into IPM programs paying dividends for Northern Rivers growers

INCORPORATING INDOXACARB INTO IPM PROGRAMS PAYING DIVIDENDS FOR NORTHERN RIVERS GROWERS

Jeremy Bright, NSW DPI

Macadamia seed weevil (MSW), *Kushchelorhynchus macadamiae*, known until last year as Sigastus weevil, is causing devastating crop losses to macadamia growers, particularly in the Northern Rivers. Funded by Hort Innovation with grower R&D levies and Commonwealth investment, the macadamia IPM project (NSW DPI component project MC16004) is supporting growers looking to reduce these crop losses by investigating options for MSW control.

Integrated pest management (IPM) is about controlling pests to an acceptable economic level using cultural and biological practices as well as chemical control.

Orchard hygiene crucial

Cultural practices, especially good orchard hygiene, are central to controlling MSW numbers at levels where growers can still achieve a profitable income. Infested nuts that the weevils have dropped to the ground must be mulched and destroyed to reduce the next weevil generation. Additionally, all canopies should be structured to allow maximum spray penetration. (See *Macadamia Integrated Orchard Management 2016*, which can be downloaded from the NSW DPI website https://www.dpi.nsw.gov.au/agriculture/horticulture/nuts/growing-guides/macadamia-integrated-orchard-management).

Mulching fallen infested nuts a few weeks after every weevil spray is an important part of orchard hygiene. While this is time consuming and expensive, it is essential as NSW DPI researchers have now shown that spraying without mulching is ineffective, as is mulching on its own. This really highlights the importance of an IPM system; we cannot rely on only one approach to controlling MSW.

Egg laying reduced

Trials in 2017 showed that indoxacarb is effective in reducing MSW numbers on-farm through eliminating weevil egg lay, rather than killing them outright. In November 2018 the APVMA issued a minor use permit for indoxacarb. In the 2018–19 season, most growers using indoxacarb under this minor use permit have seen a significant decrease in MSW egg laying. This has resulted in less nut drop as a result of egg laying.

Orchard hygiene, especially mulching, is crucial to macadamia seed weevil management, as is monitoring fallen nut for signs of activity.

5.9 Bright, J., Maddox, C. and Kojetin, L. (2019) Managing macadamia seed weevil.

PEST AND DISEASE MANAGEMENT

MANAGING MACADAMIA SEED WEEVIL

Jeremy Bright and Craig Maddox (NSW DPI), Leoni Kojetin (AMS)

This article outlines the latest information on an integrated approach for controlling macadamia seed weevil (MSW), a serious pest of macadamia orchards.

An adult macadamia seed weevil chewing a macadamia husk in preparation for egg laying. Photo: Jessica Thurman

Infestations of MSW (previously referred to as *Sigastus* weevil) have been confined to the NSW Northern Rivers and North Queensland, so far. It is important that the pest is managed to reduce populations and the damage it does in these two areas, as well as to stop it spreading to other growing regions.

An integrated approach

The use of insecticides alone is not an effective control for this adaptable native pest, it must be part of an integrated pest management strategy. Understanding the weevil's life cycle, monitoring the orchard regularly to identify critical times for control activities and practising good orchard hygiene are all fundamental elements of a control program.

Life cycle

The MSW life cycle lasts about 40 days at 25°C (see Figure 1). Damage is done by the female who scarifies a 3–4 mm triangular-shaped area on the husk and lays her eggs between the husk and soft, developing shell. After egg laying the female chews on the nut stalk to induce nut drop, although in some cases the nut will remain on the tree. The larvae hatches after about 6 days and feeds on the kernel before pupating and then eating its way out of the nut as an adult.

Figure 1. *The life cycle of the macadamia seed weevil is 40 days. The important period for control using indoxacarb is when nuts are at match-head size. This is well before the weevil will start to lay, at 8–10 mm stage, but ensures adequate protection for 13 weeks which will allow for nuts to develop to maturity. Source: NSW DPI*

Applying indoxacarb

Minor use permits have been issued by APVMA for two insecticides for their use in macadamia: indoxacarb (PER86827) and acephate (PER81463).

Before using either of these insecticides, you must obtain a permit. It is important that you read the labels before applying them and adhere to their requirements, especially in relation to spray timing and conditions, application rates and safety around non-target species.

Indoxacarb, which was approved in 2018, is a newer generation pesticide than acephate and has a different mode of action and a number of benefits over acephate. Importantly, only one application is

Adult macadamia seed weevil laying its egg on chewed patch of husk. Eggs have been exposed for the purpose of highlighting what they look like. Photo: Craig Maddox, NSW DPI

5.10 Maddox, C. (2019) Boring beetles: Depends how you look at it!

BORING BEETLES: DEPENDS HOW YOU LOOK AT IT!

Craig Maddox, NSW DPI

NSW Department of Primary Industries

Australia has many beetles that can exploit drought very effectively. Drought will reduce sap flow and a range of beetles rely on this to enter macadamia trees, and many other tree species, to complete their life cycle. Craig Maddox provides some insight into the types of bark beetle problems DPI have been seeing in macadamia orchards.

The pest pressure that can occur in drought conditions in coastal New South Wales has been well documented (e.g. Greaves 1966–67 *Eucalyptus* plantation deaths in Coffs Harbour forestry areas and cerambycid attack). There are many beetles in Australia that exploit drought conditions, entering the bark, hardwood and branches when sap flow has been reduced. The most common beetles are covered here, but beetles in the Bostrychid and Buprestid families, along with many other weevils are also present.

Longicorns

Recent rainfall in late June has been a welcome relief for our unusually parched soils leading into next year's flowering. However, the damage may have already been done with some areas of macadamia showing extensive branch and tip dieback already, suggesting beetle larvae may be inside the branches. The various longicorn beetles (cerambycids), lay their eggs into bark cracks and terminal growth, and the larvae then bore down the stems to larger branches and eventually pupate and emerge as a longicorn beetle from the classic spiral cuts. We have isolated at least five species from macadamia trees recently.

Some species like Poinciana longicorn (*Agrianome spinicollis*) or larger *Phorocanthus* spp. can live in the trunks of many different trees for several years. For these larger species, the dry season that allowed them in is just the beginning because they will continue to re-establish each spring and summer while the conditions remain favourable – this is when adults emerge to re-infest the trees. Fortunately, the average seasonal wet conditions can keep the infestations isolated to dry areas that miss out on rainfall. Being mindful of when adults are about and fresh pruning with cover sprays, timely burning or mulching of infested branches will help control these pests.

The beginning of the cerambycid life cycle within the tree showing eggs laid under the bark or in cracks.

The beetles cut the branch in a spiral fashion in order to emerge (the example shown here is a Pittosporum longicorn in a lychee branch).

This adult longicorn, which is yet to be identified, emerged from thinner macadamia branches.

The generalist Poinciana longicorn beetle larvae feeding inside pecan trees from Kyogle NSW.

5.11 Maddox, C., Huwer, R., Roberson, D., Janetzki, A. and Purdue, I. (2019) Assessing fresh Fruit spotting bug damage on mature green nut.

ASSESSING FRESH FRUITSPOTTING BUG DAMAGE ON MATURE GREEN NUT

Craig Maddox, Ruth Huwer, David Robertson, Alister Janetski & Ian Purdue
NSW DPI, Wollongbar

NSW Department of Primary Industries

Fruitspotting bug (FSB) is a true canopy bug and late-season damage can result in unmarketable nuts. Given FSB's impact on productivity and yield, any tips and tricks to help identify their presence are welcomed. NSW Department of Primary Industry researchers have discovered a simple but effective way of identifying late-season damage.

FSB fridge test

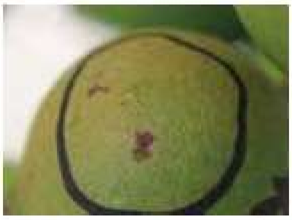
Step 1. Pick nuts off a number of trees and pick them from the top of the tree, not off the ground, in January or February. This test works on varieties 246 and 849. Focus on known FSB hotspots if you know where these are in your orchard.

Step 2. Store nuts in the fridge overnight (at 3°C).

Step 3. Take them out the next morning and let them warm back up to room temperature.

Step 4. Examine the nuts to see if there is any bruising. The bruising indicates FSB damage.

Fruitspotting bug on nut in the canopy during January / February can cause significant crop loss if undetected.



We marked the area of the nut where we saw the bug was feeding.

After cooling the nut overnight, bruises can be seen in the husk which correspond to feeding damage seen inside the nut.

During the last two seasons at Centre for Tropical Horticulture in Alstonville the need to assess fruit from the upper canopy using a hydraladder® at fortnightly intervals to evaluate late season fruitspotting bug (*Amblypelta nitida*) activity has led to an unexpected find. The sampling has been very successful in terms of pinpointing when flights have increased the damage happening on trees and when to treat more effectively to limit that impact. We randomly sampled 10 nuts per plot.

While taking samples of nuts to assess them for FSB and other damage (e.g. thrip feeding or macadamia nut borer egg laying) we labelled the fruit that we saw were actually being fed on by bugs and kept them separately. Then we stored the samples in a fridge overnight (at 3°C) before assessing them. To our surprise, the overnight cooling revealed a bruising on the husk as the nut warmed back up to room temperature.

This bruising effect was apparent for varieties 246 and 849 only at this stage. This simple test may be useful for growers or processors concerned about blocks of these varieties where late activity is suspected and a check is required.

Information
This work had been done as part of project MC16004, funded by Hort Innovation, using the macadamia research and development levy and contributions from the Australian Government.

Hort Innovation | MACADAMIA FUND

5.12 Bright, J. (2020) *Leptocoris* in macadamia.

Hort Innovation MACADAMIA FUND

Leptocoris in macadamia

Jeremy Bright, NSW Department of Primary Industries

Leptocoris species (commonly called soapberry bugs, family Rhopalidiae), are widely distributed throughout New South Wales and Queensland. They will leave their usual host and attack cultivated plants such as macadamia.

Leptocoris spp. adults and nymphs. Photo: Leoni Kojetin.

Risk period

The highest risk period for *Leptocoris* species bugs is from nut set to harvest.

The highest risk period for Leptocoris *species bugs is from nut set to harvest.*

Pest identification

The adult *Leptocoris* spp. is reddish–brown, has a narrow body, is winged and about 12 mm long. Underneath the body is dull red with a dark green area in the middle of the abdomen. Legs and antennae are black. *Leptocoris* spp. nymphs have a bright red abdomen with a brown–black head. There are most likely two species of *Leptocoris: L. rufomarginatus* found in Northern New South Wales; and *L. tagalicus* found in the Amamoor region, Gympie. Both species will feed on macadamia.

Damage

Ideally the native host plants such as the native foam bark tree (*Jagera pseudorhus*) and introduced golden rain tree (*Koelreuteria elegans*) will carry *Leptocoris* spp. while macadamia are susceptible (see pictures opposite). If however, the host has no crop, *Leptocoris* spp. will seek out macadamia. An incursion will generally be a large aggregation of Leptocoris spp. into the macadamia crop.

The damage will appear similar to that caused by fruit spotting bug (FSB) and green vegetable bug but damage to the kernel will be shallower. The damage from all of these pests will render the kernels unsaleable.

NSW DPI entomology staff have produced research that suggests that, through dry weather such as experienced in 2019–2020, fruit spotting bug pressure is low and *Leptocoris* spp. pressure is high. Once rainfall returns, fruit spotting bug pressure increases and *Leptocoris* spp. pressure decreases.

In the 2019–20 season, weekly monitoring picked up flights into macadamia at the Centre for Tropical Horticulture, Alstonville in mid-December and they were coming into selected trees at twice the rate of FSB detection. It is not unusual for *Leptocoris* spp. to come in through drier seasons as was observed in the Gympie area during the 2014–15 season.

Management

Monitoring is the key to controlling this pest. Growers can identify potential pressures by monitoring any surrounding host plants such as golden rain tree or foam bark. It is likely that in a dry year, *Leptocoris* spp. pressure will be high. Pest scouts who perform routine spotting bug checks will also be able to identify *Leptocoris* spp. within the crop. Pest consultants will also have control strategies and as they are working within the region your farm is located, will be able to alert growers of population pressures. As *Leptocoris* spp. populations increase within the orchard, so will the damage to the crop.

5.13 Maddox, C. (2020) To yield or not to yield?

To yield or not to yield?

Craig Maddox, NSW DPI Wollongbar,
E: craig.maddox@dpi.nsw.gov.au

Any recommendation we make about biological, cultural and chemical pest management alternatives only occurs once we know the impact of each option on yield. That means an unbiased assessment of crop loss, under high pest pressure, for each option, for each pest. Yield is the growers' language, and our work has focused on that since the beginning of our research. We measure yield at a single tree level within and importantly, between seasons. We monitor to accurately partition crop loss and understand population expansion triggers. Macadamia is not a staple food crop, it is a premium nut that does not reward growers for inferior product; and it is only recently that growers have stopped being penalised for poor quality deliveries to processors.

Four of the main pest insects that can impact macadamia production are: **macadamia lace bugs** (MLB) (especially *Ulonemia decoris*), **fruit spotting bug** (FSB) (*Amblypelta nitida*), **macadamia seed weevil** (MSW) (*Kuschelorhynchus macadamiae*) and **macadamia nut borer** (MNB) (*Cryptophlebia ombrodelta*).

Each of these species can easily remove over 50% of the crop. MLB, FSB and MSW are all beautifully camouflaged and adapted to exploit our rainforest nut tree. They have co-evolved with macadamias, whereas MNB is a generalist moth pest that moves in from its true all-season host, estuarine mangroves (Figure 1; Komai & Nasu 2003), and lays on a number of hosts with a pod or husk.

Macadamia nut borer moth trap in mangroves
All photos: Craig Maddox DPI

The damage to developing nut caused by fruit spotting bug (Amblypelta nitida) (below), macadamia seed weevil (Kuschelorhynchus macadamiae) (top left) and macadamia nut borer (Cryptophlebia ombrodelta) (top right).

While research is ongoing, of these four pests, only MNB can be reliably managed with releases of biological agents. There are some 'cultural controls' available for the remaining major pests; timely mulching of the infected nut can help control MSW, while the widening of tree spacing to enhance light and ventilation into trees reduces MLB activity. FSB however remains a difficult problem to solve without broad-spectrum insecticides, especially in wet years. Varietal preferences and some trap crop options exist, but that is no guarantee against late damage. Many growers will also be aware of other pest species that are observed in more extreme seasons and localities, which complicates the discussion (e.g. broad mites, assorted Scarab larvae, *Scirtothrips* sp., *Leptocoris* sp., *Assara* sp., *Euwallacea* sp.). In order to protect yield and trees, growers normally choose the most effective option and social licence can become a factor.

Who decides social licence? A blend of the growers, consumers, neighbours, media outlets and the law makers? It needs to be based on key truths to keep an industry viable, new truths may appear that will change that licence, and it can be easily tarnished by misinformation if that becomes gospel.

The 'social licence' to grow the macadamia crop has to include the use of water and impact of chemical inputs on waterways and neighbours. Which pesticides are safe to use? What are acceptable noise levels?

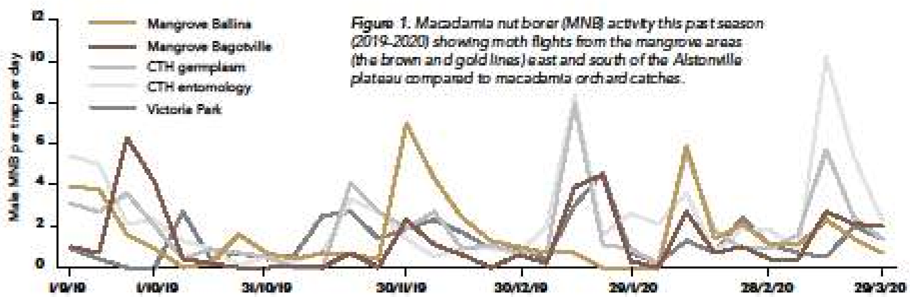


Figure 1. Macadamia nut borer (MNB) activity this past season (2019-2020) showing moth flights from the mangrove areas (the brown and gold lines) east and south of the Alstonville plateau compared to macadamia orchard catches.

5.14 Maddox, C., Cook, C. and Maier, B. (2021) Controlling Fruit spotting bug damage in macadamia: Timing is everything.

Controlling fruitspotting bug damage in macadamia: Timing is everything

Craig Maddox NSW DPI, **Chris Cook** Dymocks farm manager and **Bob Maier** MNC Macadamia pest consultant

Protecting the macadamia crop from insect pests is a complex, ongoing challenge for industry. It requires a deep understanding of the biology/ecology of the various pests that can impact negatively on yield through damage to the nut and/or plant.

Developing this understanding alone is difficult, but when coupled with the responsibility of minimising the impact protection strategies have on the environment and attaining a degree of social licence, the challenge becomes considerably greater. Irrespective of the chemistry that is available for crop protection in macadamia, one thing is for sure: the chances of achieving a satisfactory result are increased considerably when the timing of spray application is optimised.

A lot of our knowledge on fruitspotting bug (FSB) damage and tools to optimise management have been developed through trials set up at the Centre for Tropical Horticulture (CTH) at Alstonville. One of the most effective tools developed in the past is the use of *Murraya paniculata* monitoring hedges to identify the flight times of FSB. This simple but effective tool has enabled targeted, rather than calendar, spray regimes for FSB control.

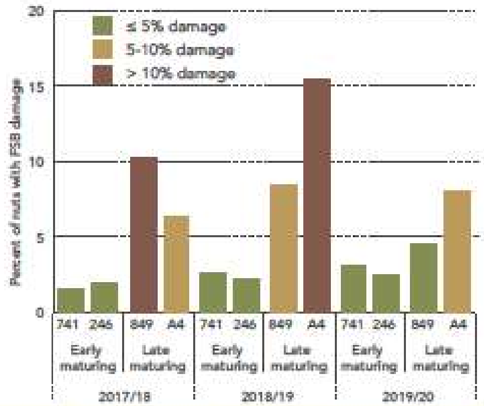
Using this approach has significantly reduced the number of sprays for FSB, from five to six down to two to three per season (see Figure 1). For the CTH site, depending on the timing of the second FSB flight, spray programs to protect the nut until it reaches the shell-hardening phase aren't typically necessary after early February.

Some of our more important observations over the past three seasons when conducting this spray regime are:

- the spray program (depending on chemistry used), when aligned with flight times, is effective at keeping damage levels generally below 5% (see green bars in Figure 1)
- we see higher damage on the later maturing varieties with higher kernel recoveries (Figure 1)
- rainfall events impact on FSB activity and damage risk (i.e. lower risk in drier seasons)
- our worst damage is usually in the first harvest samples of March, and then samples get progressively cleaner until the end of harvest in September.

FSB feeding on Macadamia ternifolia indicates 1st and 2nd flights.

Fruitspotting bug (FSB) feeding on Murraya paniculata monitoring hedge indicates 3rd and 4th flights. Photos: Craig Maddox



FSB flight	Date & action		
1	4/12/17 sprayed	21/12/18 sprayed	23/12/19 sprayed
2	8/1/18 sprayed	4/2/19 sprayed	27/1/20 sprayed
3	12/3/18 no spray	25/3/19 no spray	23/3/20 no spray
4	30/4/18 no spray	6/5/19 no spray	11/5/20 no spray

Figure 1. The effect of season, variety and FSB spray treatment timing on the proportion of nuts with fruitspotting bug damage from the Centre for Tropical Horticulture Alstonville site. Data shown in the table under the chart are the predicted flight dates of FSB based on monitoring of Murraya paniculata hedges and Macadamia ternifolia trees at CTH and the action taken (sprayed or no spray) with regards to FSB control.

5.15 Maddox, C. and Huwer, R. (2021) Understanding the risk of crop loss to macadamia nut borer (*Cryptophlebia ombrodelta*).

Understanding the risk of crop loss to macadamia nut borer (*Cryptophlebia ombrodelta*)

Craig Maddox, Technical Officer Entomology and **Ruth Huwer**, Research Entomologist, NSW DPI, Wollongbar **M:** 0418 318 818 **E:** craig.maddox@dpi.nsw.gov.au

Macadamia nut borer (MNB) was the major source of crop loss in the 1980-2000 period for Australian macadamia growers. The pest has the capacity to drop large numbers of immature nut when it feeds in the husk, as well as physically damage the kernel if it penetrates the shell.

With the development of the pheromone lures, MNB culturing and access to *Trichogrammatoidea cryptophlebiae*, research teams have been able to reduce this problem to a sporadic issue for coastal orchards.

Certain climatic conditions limit the effectiveness of the parasitoid (extended periods > 35⁰ C and continuous heavy rain), but good monitoring and a well-timed beta-cyfluthrin spray normally result in negligible losses. Establishing the egg parasitoid in summer prevents the moth from overwintering within the orchard.

Flight trapping has been a long standing protocol to monitor flights leaving the main breeding areas (mangrove areas - Komai and Nasu 2003), and arriving in the orchards. We change the lures every fortnight and the plates every six weeks.

The further orchards are from the coast, the less of a problem MNB usually is. The most elevated part of an orchard tends to catch more moths, and traps placed higher in trees (6 m > 2 m) receive twice the catch.

There are egg laying and survivorship preferences. Varieties like 344, 246, A4 and 849 are all favoured, less so 741, and others like 333 are almost impervious to the larvae once the husk toughens.

The pheromone trap monitoring is scored as male moths per week and the season begins in September as moths fly into the orchard. We rank seasonal flights by accumulating that moth rate from September to March and then compare this to the egg laying rates and the tunnelling in the nuts to work out how effective the treatments are (Table 1 and 2).

The critical data is when the egg laying appears on the nut, usually in the December – January period, and whether larvae resulting from these eggs are entering the nut. This is why you pay the crop scouts to detect that fresh egg laying. These eggs are normally only on the nut for 2 - 4 days and if the conditions are warm and humid at night, larval penetration is much higher.

Once inside the nut, larvae become difficult to treat and can then emerge within the orchards at an increasing rate. Beta-cyfluthrin is very effective on that flight in the early summer period. The flights we can detect through monitoring with pheromone traps are normally about a week in front of that summer laying so they are a good guide.

The next generation usually emerges around late January and it is on this one the wasp population should be beginning to build up. Egg parasitism will be close to 100% by autumn. If the levels are still high, growers could alternate with a methoxyfenozide (Prodigy®) application which will be wasp compatible. Acephate is effective if both *Leptocoris* sp. and MNB are active, but it will take longer to re- establish the wasps, then if beta cyfluthrin was used.

There is certainly discussion among the ex-South African growers about the use of pheromone pastes for trapping male moths on trees. Our work with Last Call® paste in 2003-2004 found its effectiveness was limited. The key assumption is that the female moths arrive in the

Figures 1 - 3. Tools for macadamia nut borer management include (left) flight traps with a male pheromone lure checked weekly, (centre) checking fallen nut for past oviposition and fresh tunnelling by the moth larva once they are greater than 20mm diameter, and (right) releasing the egg parasitoid around the spray schedule downwind.

5.16 Huwer, R., Maddox, C., Bright, J. and Adkins, M. (2021) IPM in macadamias – Not a strategy but different options.

IPM in macadamias – not one strategy but different options

Dr Ruth Huwer, Research Entomologist, **Craig Maddox,** Technical Officer Entomology, **Jeremy Bright**, Development Officer, Macadamia, and **Matt Adkins**, Leader Northern Horticulture, NSW DPI Wollongbar **E:** ruth.huwer@dpi.nsw.gov.au

The project "IPM Program for the Australian Macadamia Industry - NSW DPI component" is now in its final stages. What have we learned after four years of field trials?

It was important to have case study sites in the main growing regions for macadamias and all sites have adopted some level of IPM through a combination of different management tools. The pest issues of each case study site are different. Therefore, there is not one single recipe for an IPM strategy that suits all farms. However, there are certain components that are key IPM strategies for macadamia farms. These include:

1. Monitoring: Monitoring is a cornerstone of any IPM strategy. It is important to have an understanding about the population dynamics of different pests and beneficials. A monitoring protocol was developed in collaboration with pest consultants overseeing the case study sites in the different regions. The adoption of monitoring of beneficials and pests using yellow sticky traps, macadamia nutborer (MNB) pheromone traps, monitoring of MNB eggs, spotting bug monitoring hedges, banana-spotting bug (BSB) pheromone traps, pheromone traps for different scolytid beetles (bark beetles, branch borers and pinhole borers) was part of the IPM strategy for all case study sites.
2. Cultural control: Cultural control measures as part of the Integrated Orchard Management are most important for increasing orchard health and resilience. This includes tree height and canopy management. Canopy management was applied as it is important to keep the orchard open and ensure good coverage of chemical applications. Further cultural control measures included on our case study sites were hygiene for the management of macadamia seed weevil (i.e. removal of infested nuts on the ground) and growing interrow crops to increase biodiversity and presence of general predators and parasitoids.
3. Biological control: Releases of biological control agents (*Anastatus sp. and/or Trichogrammatoidea cryptophlebiae)* were made on all case study sites. As mentioned above, the encouragement and preservation of natural enemies also plays a part in this.

IPM Options

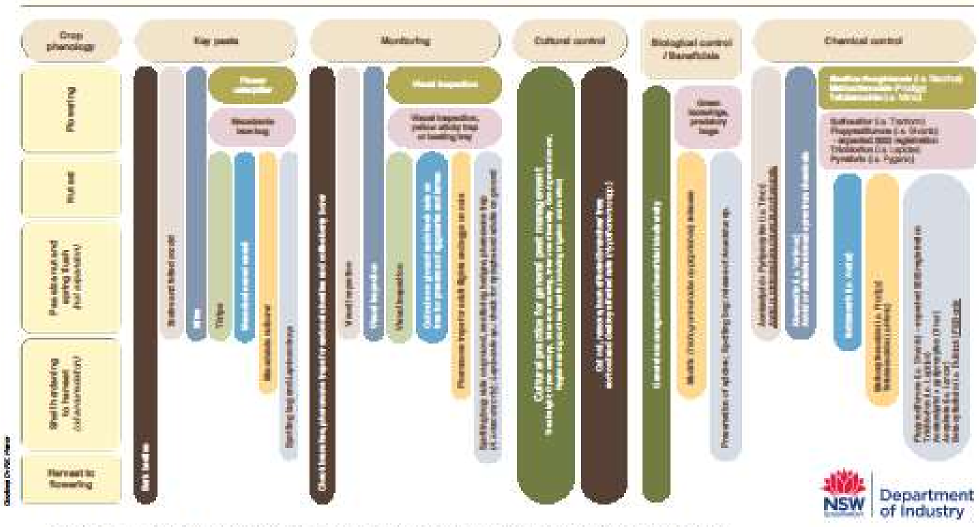


Figure 1. Illustration of IPM options, showing different choices of management tools for key macadamia pests

5.17 Huwer, R., Maddox, C., Bright, J. and Adkins, M. (2021) IPM in macadamia: not a single fix but options.

IPM in macadamias: not a single fix, but options

Ruth Huwer, Craig Maddox, Jeremy Bright and **Matt Adkins***

The project 'IPM Program for the Australian Macadamia Industry NSW component' is now in its final stages. What have we learned after four years of field trials?

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2. Cultural control: Cultural control as part of integrated orchard management is most important for increasing orchard health and resilience. This includes tree height and

canopy management. Canopy management was applied as it is important to keep the orchard open and ensure good coverage of chemical applications. Further cultural control measures including hygiene for management of macadamia seed weevil (i.e. removal of infested nuts on the ground) was applied. Interrow crops to increase biodiversity and therefore presence of general predators and parasitoids was also included in the IPM strategy of our case study sites.

3. Biological control: Releases of biological control agents (*Anastatus* sp. and/or *Trichogrammatoidea cryptophlebiae*) were made on all case study sites. As mentioned above, the encouragement and preservation of natural enemies is also part of this.

4. Chemical control: Strategic use of more specific chemicals, on the basis of monitoring (rather than calendar spraying), compatible with biological control and minimising use of broad-spectrum insecticides, was implemented on all case study sites. It is also included the use of new chemicals

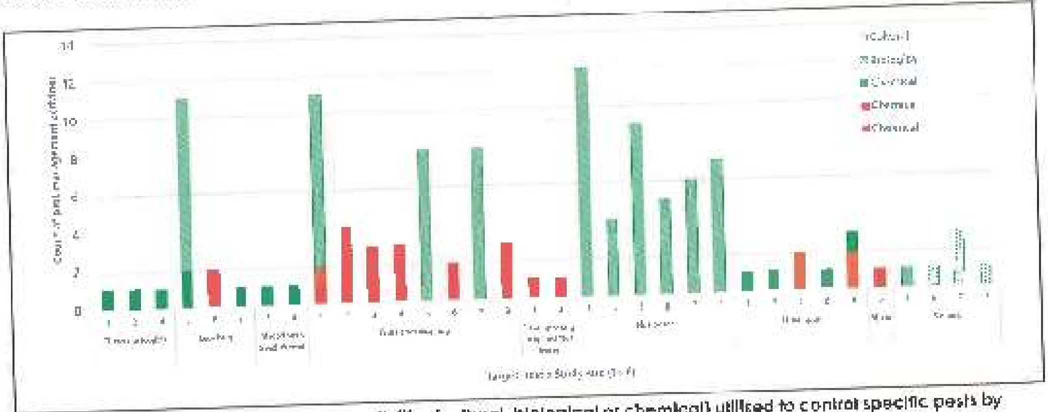

Figure 1: Summary of pest management activities (cultural, biological or chemical) utilised to control specific pests by case study site during the 2019/2020 season. The traffic light colours (green, amber and red) refer to the impact of each activity on beneficial insect populations i.e. green has minimal impact, amber potentially some negative impacts, red significant negative impacts on beneficial populations.

Appendix 6.: Conference presentations

6.1 Huwer, R.K., Maddox, C.D.A., Hickey, M. and Bright, J. (2017) Towards a fully integrated pest management strategy for Australian macadamias.

Towards a fully integrated pest management strategy for Australian macadamias

Ruth K. Huwer, Craig D.A. Maddox, Mark Hickey and Jeremy Bright

There are a number of pests effecting on the productivity of the macadamia industry in Australia, including flower and foliage pests (i.e. macadamia lace bug (*Ulonemia* spp.) and mites and thrips species), kernel and post-harvest pests (such as Fruit spotting bugs (*Amblypelta* spp.) and Sigastus weevil (*Sigastus* sp.)) and pests attacking the branches and trunk (i.e. bark beetles and trunk borers). Pest management strategies in the past have been developed for single pest species. These strategies particularly for Fruit spotting bugs covered a number of approaches, including monitoring tools, chemical and biological control, cultural control and a pilot study of an Area-wide management approach. However, no truly integrated strategy has been developed to date that has taken more than 1 or 2 of the key-pests into account.

Horticulture Innovation tendered a large IPM programme for the Australian macadamia industry. The overall aim of the program is to develop a pest resilient farming system for the macadamia industry.

Specifically, it aims to:

- Identify and address gaps in research and extension for pest management for macadamias in Australia
- Continue research as required on current key pests
- Develop a truly integrated and sustainable management approach
- Maintain and improve industry resources in pest diagnostics and IPM tools
- Maintain and build capability to respond and deal with new and emerging pests
- Build strong links to other macadamia industry programs

The larger IPM program brings together a team of highly experienced researchers with considerable experience, specifically in pest management in macadamias and in IPM extension and adoption. As part of the larger program the NSW DPI Team will take on leadership of major components of the research. The research is taking a regional approach, customising strategies for the 4 major growing regions in Australia and their differences in pest complexes.

The research will include following aspects:

- Laboratory and field ecology and biology studies of pests, including life cycle studies and field monitoring of selected pests and beneficials
- Diagnostic and response to new emerging pests
- Development and testing of cultural control methods for selected pests
- Laboratory screening of IPM compatible chemicals
- Testing of IPM strategies in the field and monitoring of selected pests and beneficials, in four different regions and in collaboration with professional pest consultants
- Co-lead industry adoption

This 5 year research project started in January 2017. Initial monitoring and laboratory and field trials have commenced. Initial finding will be reported on.

6.2 Maddox, C.D.A., Simpson C., Newton, I., Stacey, P., Stacey, P., Huwer, R., Purdue, I., Robertson, D., Janetzki, A. and Maddox, C., (2017) Amblypelta spp management for NSW and SE QLD avocado and macadamia orchards. Can we reduce the spray frequency with better timing?

Amblypelta spp. management for NSW and SE QLD avocado and macadamia orchards. Can we reduce the spray frequency with better timing?
Maddox, Simpson, Newton, Phil and Patti Stacey, Huwer, Purdue, Robertson, Janetzki, and Carly Maddox
Pheromone trapping of *Amblypelta lutescens* in Childers on avocado and hedge trapping in Custard apple in NSW show that spray timing can be vastly improved if you target the flights correctly. Lower trap numbers and hotspot targeting are being run this season to confirm this. Issues with labelling of the new commercial pheromone traps, they don't catch *A. nitida*, THEY ONLY CATCH *A. lutescens* THEREFORE WE WILL NOT SUPPORT THEIR USE IN NSW.

6.3 Maddox, C.D.A., Huwer, R., Purdue, I., Robertson, D., Janetzki, A., Pretorius, J., Newell, B., Ford, Quinlan, K., Griffiths, M., Seago, A., Gopurenko, D. and Mitchel, A. (2017) The rise of scolytid beetle activity ....is it just the hot weather?

C.D.A. Maddox[1], D Gopurenko[2], RK Huwer[1] ,D. Robertson[1] ,A. Janetzki[1] , and I. Purdue[1]
B. N.ewell [3,] C. Ford[3,], J. Pretorius[3,], K. Quinlan[4], M. Griffiths[5], M. Dawes[6], A. Seago[7], A. Mitchell[8].

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3. Macadamia growers in NSW, Queensland
4. MPC production consultant Alphadale
5. QLD DAF Eco sciences Precinct Brisbane QLD
6. SCU Scanning Electron microscope unit Lismore NSW
7. NSW DPI Scolytid taxonomy unit Orange NSW
8. Australian Museum Taxonomy College st Sydney NSW

The rise in scolytid beetle activity in the last 3 seasons for orchard crops has corresponded with a significantly drier periods during the summer production in eastern Australia. The use of various pheromone lures and a range of flight trap designs have been looked at to assess the pest incidence and the effect they have on tree health. Lightning strikes are often a key precursor to scolytid attack on dying trees, the use of ethephon has also caused scolytid attack in some sites. The apparent expansion of some more serious pest species may lead to a rethink on the need to manage the pests more effectively especially if the plant disease vector scenario of a laurel wilt style organism is confirmed.

The range of pests encountered in the NSW and QLD macadamia and avocado production districts will be discussed and seasonal patterns of some key species will be discussed.

6.4 Huwer, R.K. and Maddox, C., Purdue, I., Bright, J. and Hickey, M. (2019) Update on integrated pest management in Australian macadamias. 2nd International Macadamia Researcher Forum 5-6-November, Lingcang, China.

Update on integrated pest management in Australian macadamias

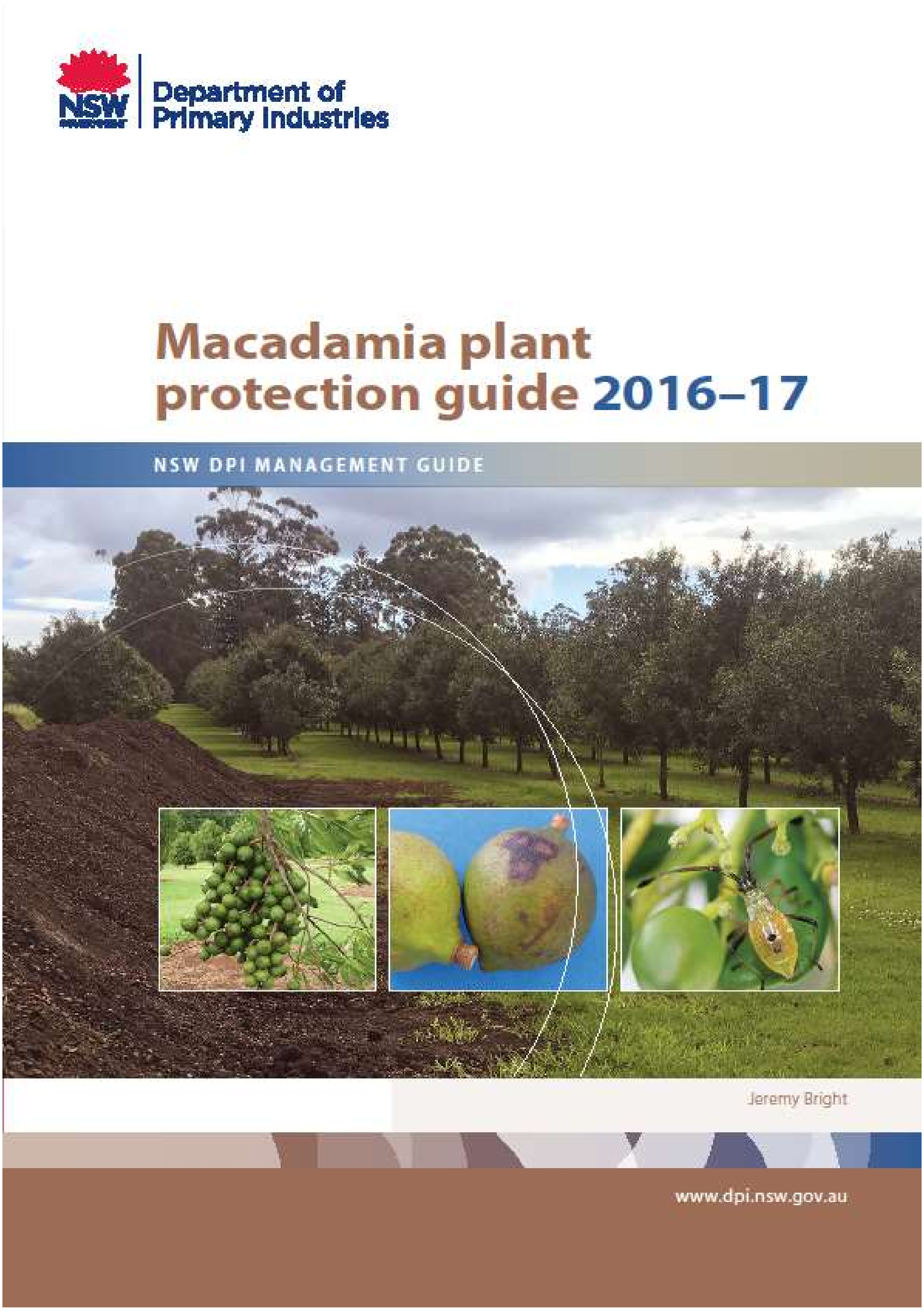
Ruth Huwer, Craig Maddox, Ian Purdue, Jeremy Bright, Mark Hickey

The development of an IPM strategy in macadamias takes a holistic approach taking the whole pest complex of pest in macadamias into account in the major growing regions in Australia. The program emphasises on interaction of pests and beneficials over the season. The main aim is conserving existing natural enemies and making the orchard more resilient to pests. Cultural control and also new IPM compatible chemicals are being investigated.

Two years into the research, an update on some highlights of the project progress will be presented.

Appendix 7.: Plant Protection Guides

7.1. Bright, J. (2016) Macadamia Plant Protection Guide 2016/17



7.2. Bright, J. (2018) Macadamia Plant Protection Guide 2018/19

NSW Government | Department of Primary Industries

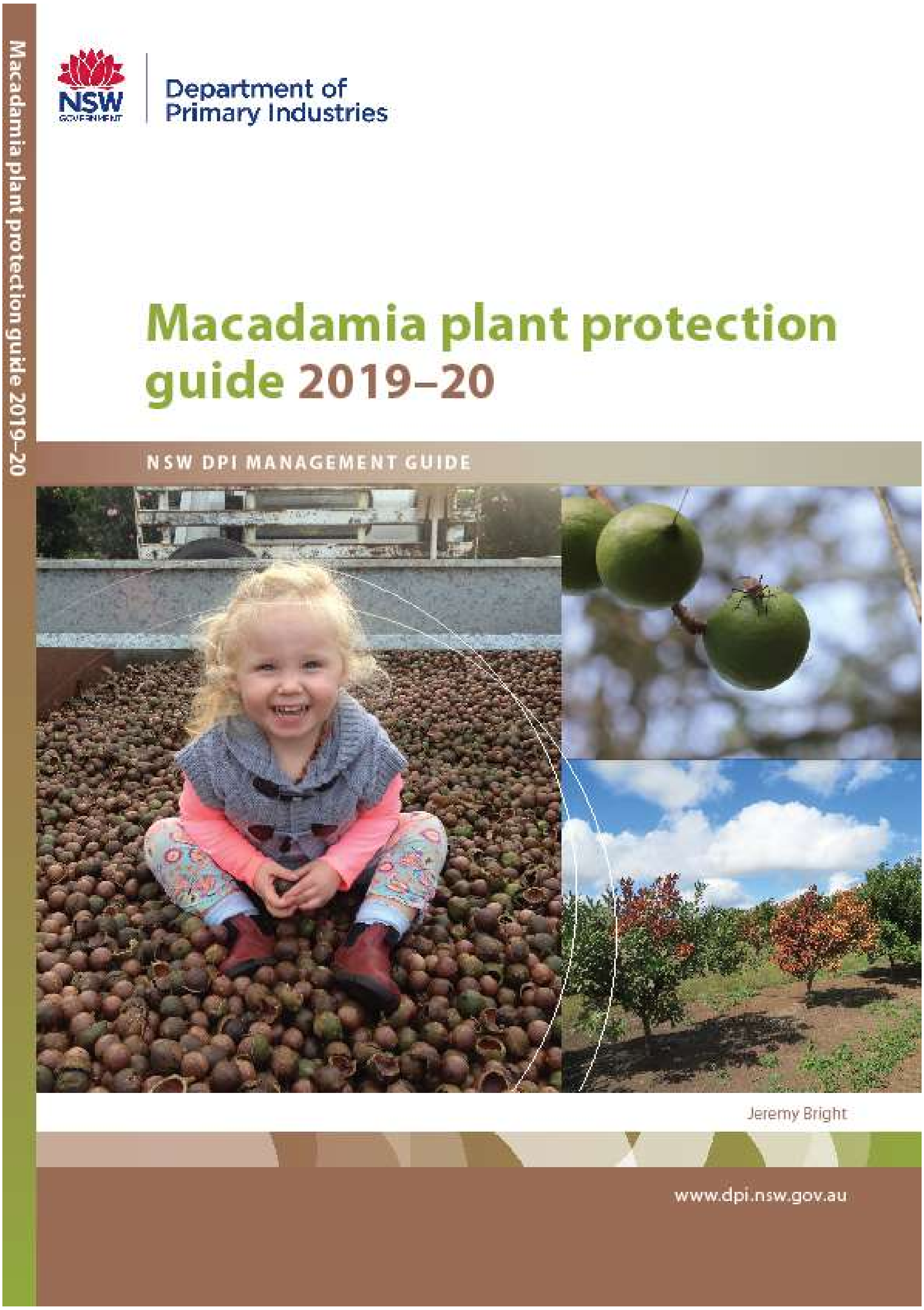
Macadamia plant protection guide 2018–19

NSW DPI MANAGEMENT GUIDE

Jeremy Bright

www.dpi.nsw.gov.au

7.3. Bright, J. (2019) Macadamia Plant Protection Guide 2019/20



7.4. Bright, J. (2020) Macadamia Plant Protection Guide 2020/21

NSW GOVERNMENT | Department of Primary Industries

Macadamia plant protection guide 2020–21

NSW DPI MANAGEMENT GUIDE

Jeremy Bright

www.dpi.nsw.gov.au

7.5. Bright, J. (2021) Macadamia Plant Protection Guide 2021/22

NSW GOVERNMENT | Department of Primary Industries

Macadamia plant protection guide 2021–22

Jeremy Bright

Development Officer – Macadamia
NSW Department of Primary Industries
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M: 0427 213 059
E: jeremy.bright@dpi.nsw.gov.au
W: www.dpi.nsw.gov.au

7.6. Huwer et al. (2016) Fruit spotting bug management guide

NSW Department of Primary Industries

Fruitspotting bugs 2016

NSW DPI MANAGEMENT GUIDE

Ruth Huwer, Craig Maddox, Jeremy Bright, Mark Hickey, Ian Newton & Stephanie Alt

Horticulture Innovation Australia

www.dpi.nsw.gov.au

Appendix 8.: Prime Facts

8.1. Bright, J. (2018) Macadamia seed weevil, life cycle and monitoring

Department of Primary Industries
primefact

Macadamia seed weevil (*Kuschelorhynchus macadamiae*) life cycle and monitoring

August, 2017, Primefact 1586, first edition

Jeremy Bright, Macadamia Development Officer, Horticulture Unit, Wollongbar Primary Industries Institute

Macadamia seed weevil (previously referred to as Sigastus weevil) is a pest that infests macadamia orchards. So far, serious infestations of Macadamia seed weevil have been confined to the NSW Northern Rivers and far North Queensland. This article outlines the latest information on monitoring and controlling Macadamia seed weevil and how to prevent its spread to other macadamia-growing regions.

Figure 1. Macadamia seed weevil lays its eggs between the husk and soft shell of the macadamia.
Image: Craig Maddox NSW DPI.

Life cycle

Calendar sprays and poorly timed cultural practices to reduce carryover population are unlikely to be effective. The key to control is better understanding of the Macadamia seed weevil life cycle. With this knowledge, growers can manage the pest with just two strategic spray applications per season.

8.2. Bright, J. (2018) Macadamia seed weevil orchard management

NSW GOVERNMENT | Department of Primary Industries

primefact

Macadamia seed weevil (*Kuschelorhynchus macadamiae*) orchard management

August 2017, Primefact 1585, first edition

Jeremy Bright, Macadamia Development Officer, Horticulture Unit, Wollongbar Primary Industries Institute

An integrated approach to Macadamia seed weevil (previously referred to as Sigastus weevil) control is the most effective way to manage the pest in the long term. The timely use of cultural controls to minimise the population at the beginning of the season can reduce the reliance on chemicals at a later stage. Also important is understanding the key factors that contribute to high Macadamia seed weevil populations. At least five have been identified, as follows:

- out-of-season flowering and nut set
- inadequate spray coverage
- neglected orchards
- poor management of orchard floor
- alternate host (not yet known).

While growers do not have control over all of these factors, it is important to identify and implement any actions that can help reduce the potential for high Macadamia seed weevil populations developing. Key actions are as follows:

Out-of-season flowering and nut set (*limited control*)

Macadamia seed weevil populations appear to become high when flowering season is extended, resulting in out-of-season nut set. Small, soft shell, out-of-season nuts allow the weevil to lay its eggs and build up in numbers. Continual out-of-season flowering can create a very high base population of Macadamia seed weevil. While growers have limited control over lace bugs, they can help by reducing out-of-season flower and not allowing nut to reach the minimal 10 mm for Macadamia seed weevil larvae development.

Inadequate spray coverage (*can control*)

Growers have total control over ensuring that spray coverage, application and rates are appropriate by doing the following:

- calibrating your sprayer annually
- slowing down when applying chemicals
- timing your spray for maximum impact.

Coverage is essential to eliminate adult populations and stop egg laying. However, larvae in the fallen nut will not be totally eliminated. Therefore, the next step is to remove and destroy fallen nuts to significantly reduce pressure for the season. Remember, control of Macadamia seed weevil is about population reduction as elimination is almost impossible. We strongly recommend that when spraying, growers incorporate a wetter to achieve better coverage.

8.3 Bright, J. (2020) Leptocoris in macadamia.

Department of Primary Industries

primefact

Leptocoris in macadamia

January 2020, Primefact 1716, First edition

Jeremy Bright, Development Officer – Macadamia, Wollongbar

Leptocoris species (commonly called soapberry bugs, family Rhopalidiae), are widely distributed throughout NSW and Queensland. They will leave their native host and attack cultivated plants such as macadamia.

Risk period

Table 1. The highest risk period for *Leptocoris* species bugs is from nut set to harvest.

Pre-flowering	Early flowering	Peak flowering	Nut set	Pea size nut and spring flush	Shell hardening to harvest	Harvest to pre-flower

Pest identification

The adult *Leptocoris* spp. is reddish–brown, has a narrow body, is winged and about 12 mm long (Figure 1). Underneath the body is dull red with a dark green area in the middle of the abdomen. Legs and antennae are black. *Leptocoris* spp. nymphs have a bright red abdomen with a brown–black head (Figure 2). There are most likely two species of *Leptocoris*; *L. rufomarginatus*, found in Northern NSW and *L. tagalicus*, found in the Amamoor region, Gympie. Both species will feed on macadamia.

Damage

Ideally the native host plants such as the foam bark tree (*Jagera pseudorhus)* and golden rain tree (*Koelreuteria elegans)* will carry *Leptocoris* spp. while macadamia are susceptible. If however, the native host has no crop, *Leptocoris* spp. will seek out macadamia. An incursion will generally be a large aggregation of *Leptocoris* spp. into the macadamia crop.

The damage will appear similar to that caused by fruit spotting bug (FSB) and green vegetable bug but damage to the kernel will be shallower (Figure 3). The damage from all of these pests will render the kernels unsaleable.

NSW DPI entomology staff have produced research that suggests that, through dry weather such as experienced in 2019–2020, fruit spotting bug pressure is low and *Leptocoris* spp. pressure is high. Once rainfall returns, fruit spotting bug pressure increases and *Leptocoris* spp. pressure decreases.

Figure 1. *Leptocoris* spp. adult. Photo: Ruth Huwer.

Figure 2. *Leptocoris* spp. nymph. Photo: Ruth Huwer.

www.dpi.nsw.gov.au

8.4 Bright, J. (2020) Macadamia lace bug management and control.

NSW Government | Department of Primary Industries | primefact

Macadamia lace bug management and control

July 2020, Primefact 1661, Third edition

Jeremy Bright, Macadamia Development Officer, Horticulture Unit, Wollongbar Primary Industries Institute

Introduction

Macadamia lace bugs (*Ulonemia* spp.) are native to northern NSW and Atherton, Queensland. Macadamia species and other similar Proteaceae plants are their native host. There are at least four macadamia lace bug (MLB) species, with Ulonemia decoris, which is the most damaging, found in NSW. Once established, MLB populations can increase rapidly and become self-sustaining.

Pest identification

Macadamia lace bugs are small insects, approximately 3–4 mm long (Figure 1). This makes them difficult to see with the naked eye, therefore it is important to look for symptoms to identify their presence in your orchard. They are named for the intricate 'lace-type' pattern on their hemelytra and thorax. Adults lay eggs into the plant tissue and nymphs emerge within days to begin feeding. The nymphs go through five instar stages before becoming adults. The adults can fly well and have been reported to disperse to other populations up to 20 km away, making it easy for them to recolonise in areas from which they had previously been eradicated.

Macadamia lace bug lifecycle

1. One adult female lace bug can produce up to 21 nymphs in 6 days.
2. Eggs are laid inside florets (you need to dissect the flower to see them) and at 25 °C, full maturity can be reached within 12–19 days.
3. All five instars (stages of insect growth and development) can damage the flower.
4. Reports of 20–30 nymphs on each raceme in infected orchards are common.
5. Lace bug remains in the orchard throughout the year. During non-flowering periods, they hibernate on the macadamia tree bark until the next flowering occurs.
6. Lace bug populations decline when flowering concludes, but once a food source (e.g. flowers) becomes available, the population increases dramatically.

A Northern rivers grower tracked macadamia lace bug population growth during flowering on his organic macadamia orchard. Using daily misting of trees with pyrethrum (knock down spray), the insects would fall onto a drop sheet where they could then be counted. Figure 2 shows the increase in the number of adult lace bugs per square metre after flowering. It is important to note that 100 lace bug per square metre equates to 1 million lace bugs a hectare.

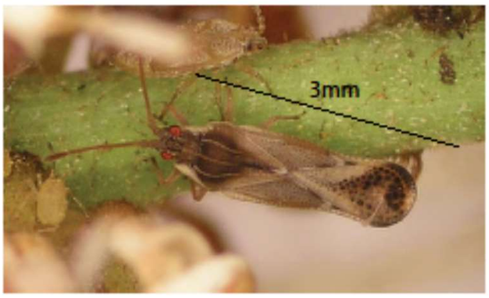

Figure 1. Adult macadamia lace bug (Ulonemia decoris, approximately 3 mm long) on a raceme. Nymphs are also present, directly above and to the left of the adult. Photo: Craig Maddox.

www.dpi.nsw.gov.au

8.5 Bright, J. (2020). Fruit spotting bug in macadamia.

NSW Department of Primary Industries

primefact

Fruit spotting bug in macadamia

September 2020, Primefact 1779, First edition

Jeremy Bright, Development Officer – Macadamia

Fruit spotting bug (FSB) has become the most significant macadamia pest since an effective biological control option was established for macadamia nut borer. The macadamia industry benchmark report (Project MC18002) has continually shown that late FSB damage is consistently the primary reason for nuts being rejected at factory stage.

Risk period

Table 1. The peak risk period for fruit spotting bugs is from peak flowering to harvest.

Pre-flowering	Early flowering	Peak flowering	Nut set	Pea size nut and spring flush	Shell hardening to harvest	Harvest to pre-flowering

Two types of FSB are known in Australia; *Amblypelta nitida Stål* (*A. nitida*) and *Amblypelta lutescens lutescens* (*A. lutescens*). Both feed on macadamia fruit and flowers and have multiple host plant species (Table 2). *A. nitida* is prevalent in Northern NSW and South East Queensland, while *Amblypelta lutescens* can be found from the Queensland border through to Cape York (Figure 1).

Figure 1. Fruit spotting bug distribution in Australia. Green shows where *A. nitida* is found and red *A. lutescens*.

Life cycle

Fruit spotting bugs pass through 3–4 generations a year; one in spring, one or two in summer and one in autumn (Figure 2–Figure 6). Adults from the autumn generation survive the winter to begin a new generation in spring.

Table 2. Types of fruit spotting bug in Australia.

Species	*Amblypelta nitida Stål*	*Amblypelta lutescens lutescens*
Distribution	From 17°S to 35°S (Figure 1)	From 11°S to 27°S (Figure 1)
Number of host plant species	56	111
Diet	Feeds only on fruit and flowers	Generally feeds on fruit, shoots and flowers, although rarely on macadamia shoots
Days to develop from egg to adult at 20 °C	63	79
Days to develop from egg to adult at 25 °C	45	50

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8.6 Bright, J. (2020) Green vegetable bug in macadamia.

Department of Primary Industries

primefact

Green vegetable bug in macadamia

September 2020, Primefact 1781, First edition

Jeremy Bright, Development Officer – Macadamia

Green vegetable bug (*Nezara viridula*) adults and nymphs will feed on macadamia nuts at all stages. When disturbed, the green vegetable bug (GVB) releases a strong aroma to deter predators.

Risk period

Table 1. The highest risk period for green vegetable bugs is from peak flowering to harvest.

Pre-flowering	Early flowering	Peak flowering	Nut set	Pea size nut and spring flush	Shell hardening to harvest	Harvest to pre-flower

Pest identification

The adult green vegetable bug is 15 mm long, green and shield-shaped (Figure 1). The nymphal stage looks similar to the adult, but with a range of green, yellow and black markings. Females lay egg clusters of 40 to 80 eggs, which are pale yellow but become pink over time. They will hatch in about one week.

Figure 1. Adult green vegetable bug.

The nymphs develop through five stages before becoming adults. The complete life cycle takes approximately 5–8 weeks and there are about 3–4 generations a year. The bug will overwinter on other host crops, under bark or in farm sheds. In warmer coastal areas, GVB will feed and breed all year round.

Damage

There might not be any signs of GVB damage on the shell, but when the kernel is extracted, the signs will be obvious (Figure 2) and similar to those caused by FSB (see Primefact 1779 Fruit spotting bug in macadamia). Most damage occurs from early shell-hardening onwards. Lack of external damage requires pest monitors to physically crack open the nuts to assess them.

Figure 2. Green vegetable bug damage to macadamia nuts. Photo: Craig Maddox.

www.dpi.nsw.gov.au

8.7 Bright, J. (2020) Macadamia nut borer.

NSW Department of Primary Industries

primefact

Macadamia nut borer

September 2020, Primefact 20/778, First edition

Jeremy Bright, Development Officer – Macadamia

The macadamia nut borer (*Cryptophlebia ombrodelta*) lays its eggs on the husk and the larvae burrow through the nut shell to eat the kernel. Macadamia nut borer (MNB) will cause premature nut fall, particularly during the oil accumulation stage (around December to February in Northern NSW). MNB also attacks mangroves, so pressure can be greater on farms adjoining mangroves.

Risk period

Table 1. The peak risk period for macadamia nut borer is from pea size nut to harvest.

Pre-flowering	Early flowering	Peak flowering	Nut set	Pea size nut and spring flush	Shell hardening to harvest	Harvest to pre-flowering

Pest identification

The adult MNB is a moth. The female has a wingspan of up to 25 mm. They are reddish-brown with a distinctive black triangle marking on the hind margin of each forewing (Figure 1).

MNB eggs are scale-like and are laid singularly on the surfaces of green husks. Eggs can be found anywhere on the nut, but are often laid along the suture line. They are ivory white when first laid but turn red just before hatching (Figure 2). Eggs that have been parasitised by wasps will appear black after about five days (Figure 3).

Figure 1. Macadamia nut borer adult. Photo: Jeremy Bright.

Figure 2. Macadamia nut borer egg. Note, reddish colour indicating nearly ready to hatch. Photo: Chris Fuller.

Figure 3. Parasitised macadamia nut borer eggs appear black after about five days. Photo: Chris Fuller.

www.dpi.nsw.gov.au

8.8 Bright, J. (2020) Macadamia seed weevil.

Department of Primary Industries
primefact

Macadamia seed weevil

September 2020, Primefact 20/782, First edition

Jeremy Bright, Development Officer – Macadamia

Introduction

The macadamia seed weevil (*Kuschelorhynchus macadamiae*) relies on out-of-season flowering and small soft-shell nuts for egg-laying. After the eggs are laid inside the husk, the nuts will usually fall. These nuts should be mulched and destroyed to break the cycle. If left unchecked, macadamia seed weevil (MSW) can become a major pest for macadamia. Importantly, MSW is so far confined to the Northern Rivers NSW and Mareeba districts in far north Queensland, so strict on-farm biosecurity measures should be enforced when moving any machinery or other equipment from infested areas to non-seed weevil areas.

Risk period

Table 1. The peak risk period for macadamia seed weevil adults is from pre-flowering to shell hardening.

Pre-flowering	Early flowering	Peak flowering	Nut set	Pea size nut and spring flush	Shell hardening to harvest	Harvest to pre-flowering

Pest identification

Adult weevils are grey–brown, about 6 mm long (Figure 1) and can be in the orchard all year. During winter they will often be found in groups on the ends of branches. As the weather warms, the weevils will wait until the nuts have reached a vulnerable size, approximately 8 mm in diameter, in which to lay their eggs (Figure 2). The fully grown larva can be up to 10 mm long.

Figure 1. Macadamia seed weevil. Photo: Craig Maddox.

Damage

The female weevil scarifies an area about 3–4 mm wide on the husk in to which she lays a single egg. This will be obvious as a triangular lay mark at the stem end of the fallen nuts (Figure 3). After egg-laying, the female weevil will chew about halfway through the stem to induce nut drop. When the egg hatches, the larva will consume the whole kernel (Figure 4), then pupate and exit the nut as an adult. Larva development depends on the period before shell hardening because once the shell hardens, the developed weevil is not able to exit. Damage after shell hardening will appear as grazing marks all over the husk, similar to a golf ball appearance (Figure 5).

Figure 2. A macadamia seed weevil lays its egg on a chewed patch of husk. Photo: Craig Maddox.

Appendix 9.: Monitoring and Evaluation Plan

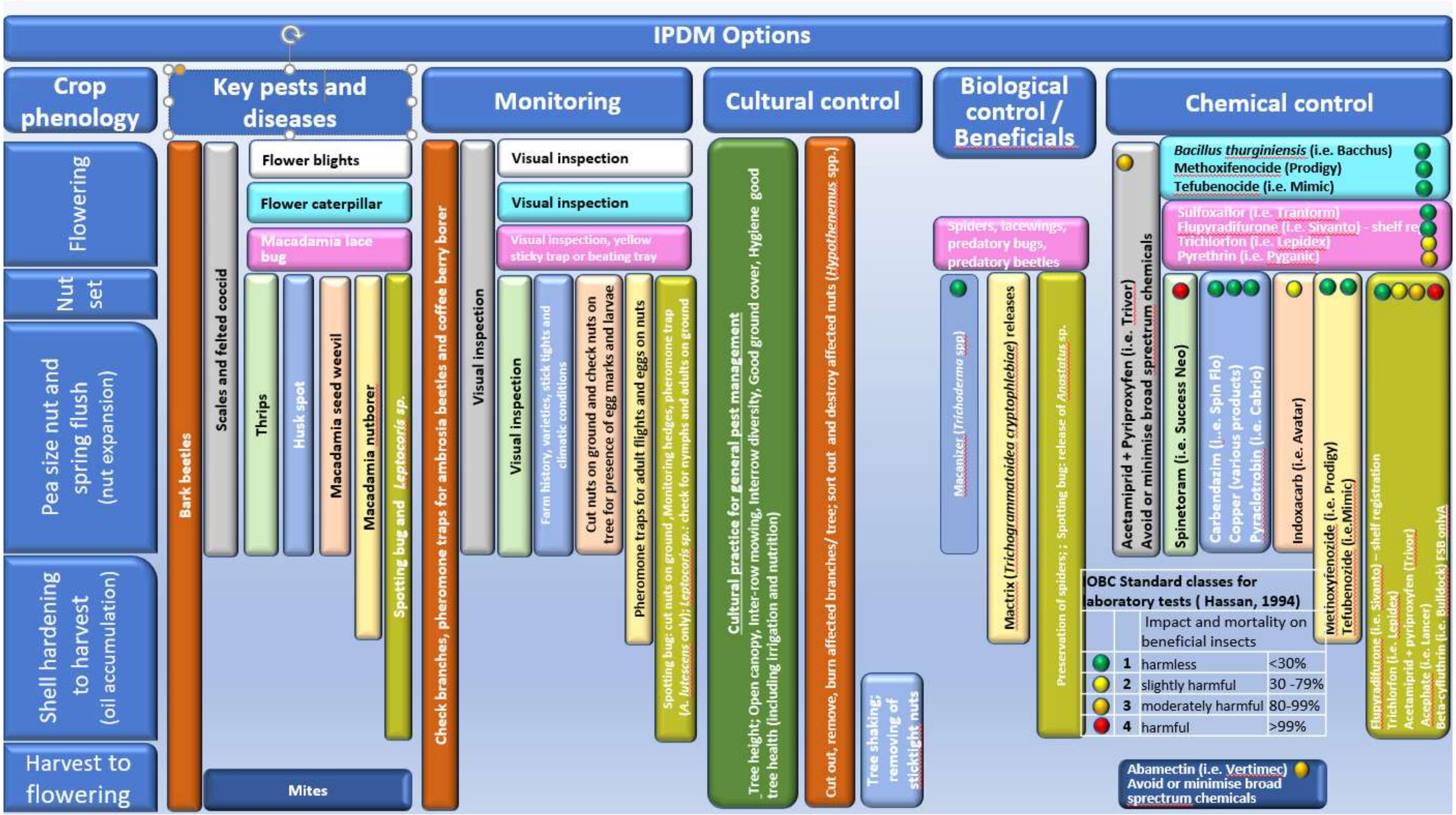
Monitoring & Evaluation Plan

Horticulture Innovation Australia

IPM Program for the
Macadamia Industry
MC16003-8

January 2017

Appendix 10.: IPM options



Document purpose

The purpose of this document is to provide a Monitoring and Evaluation Framework and Evaluation Plan for the IPM Program for the Macadamia Industry. This will guide the data collected for review and reporting purposes of the program.

Program purpose

The overarching objective of the program is to develop and extend knowledge and practices that support macadamia growers to have a sustainable pest resilient farming system. Specifically, the services are to:

- Extend current knowledge on IPM of arthropod pests in macadamia orchards
- Identify and undertake strategic, adaptive and participatory research to support the further development of an IPM program for macadamias
- Work with existing and other networks to communicate and extend knowledge and practices in whole-farm IPM for arthropods on macadamia that will maximise IPM adoption.

Macadamia Industry – Strategic Investment Plan 2014-2019 (SIP)

- Objective 1: Sustainably increasing the productivity of Australian macadamia farms
- Objective 3: Improving stakeholder confidence in the Australian macadamia industry
- Strategic investment areas
    - Sharing knowledge and facilitating the implementation of productivity improvements
    - Promoting industry successes to increase the confidence and investment of the industry

Program approach

The Macadamia industry has a commitment to undertaking research and development (R&D) that provides the knowledge and practices to enable growers to undertake integrated pest management (IPM) on their farm. Significant research has been undertaken on important arthropod (insect and mite) pests that effect macadamia nut yield and /or quality, such as macadamia nut borer, fruit spotting bug and banana spotting bug, MLB and *Sigastus* weevil, but an IPM program that informs a whole-of-farm approach to pest management (as opposed to a pest by pest approach) is yet to be developed. As a consequence, non-target effects on other pests as well as on beneficials, such as secondary pest outbreaks, have not been fully incorporated into an IPM plan. The R&D program outlined here is a whole-of farm approach to managing primarily arthropod (insect and mite) pests on macadamia farms.

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Program components

Monitoring and AWM

Pest Consultants (MC16004)
- Monitoring orchard sites
- Setting up new AWM groups
- Field test new monitoring tools

NSW DPI (MC16004)
- Develop monitoring program
- Whole-of-orchard IPM trials with pilot groups
- Collate research into management strategy

Biology and Ecology

NSW DPI (MC16004)
- Survey for pests and beneficials
  Lifecycle and ecology studies
- Beneficial colonies
- Investigate new biocontrol options

Bio Resources (MC16008)
- Ecology of beneficials

Benchmarking

DAF (MC16005)
- Benchmarking loss, damage
- Identify emerging threats
- Financial advice on IPM practices, inc BCAs

NSW DPI (MC16004)
- Collect baseline data for Benchmarking IPM practice,

NSW DPI (MC16004)
- Collect baseline data for Benchmarking IPM practice,

Cultural Practices

Bio Resources (MC16008)
- Inter-row management desktop study
- Inter-row mgt field studies

NSW DPI (MC16004)
- Collate and communicate improved cultural techniques
- Student on margin and landscape ecology

Program Coordination

Program coordinator (MC16003)
- Identify and link to opportunities
- Track progress
- Facilitate Steering committee
- Stakeholder Engagement Strategy
- Coordinate final report

IPM Extension and Adoption

IPM Technologies (MC16006)
- Leadership for IPM extension and adoption
- Survey current practice
- Design IPM extension strategy

NSW DPI (MC16004)
- Diagnostic service
- Provide linkage with existing projects

Pest Consultants (in MC16004)
- Extension to growers

Bio Resources (MC16008)
- Inter-row management

Entomopathogens

USQ (in MC16004)
- PhD on entomopathogens in field
- Test life stages

DAF (MC16005)
- Entomopathogens isolation and production

NSW DPI (MC16004)
- Support to PhD student
- Field trials

Insecticide trials

NSW DPI (MC16004)
- Lab screening: efficacy, compatibility
- Refer to Hort Innovation program (MC12003) for field trials

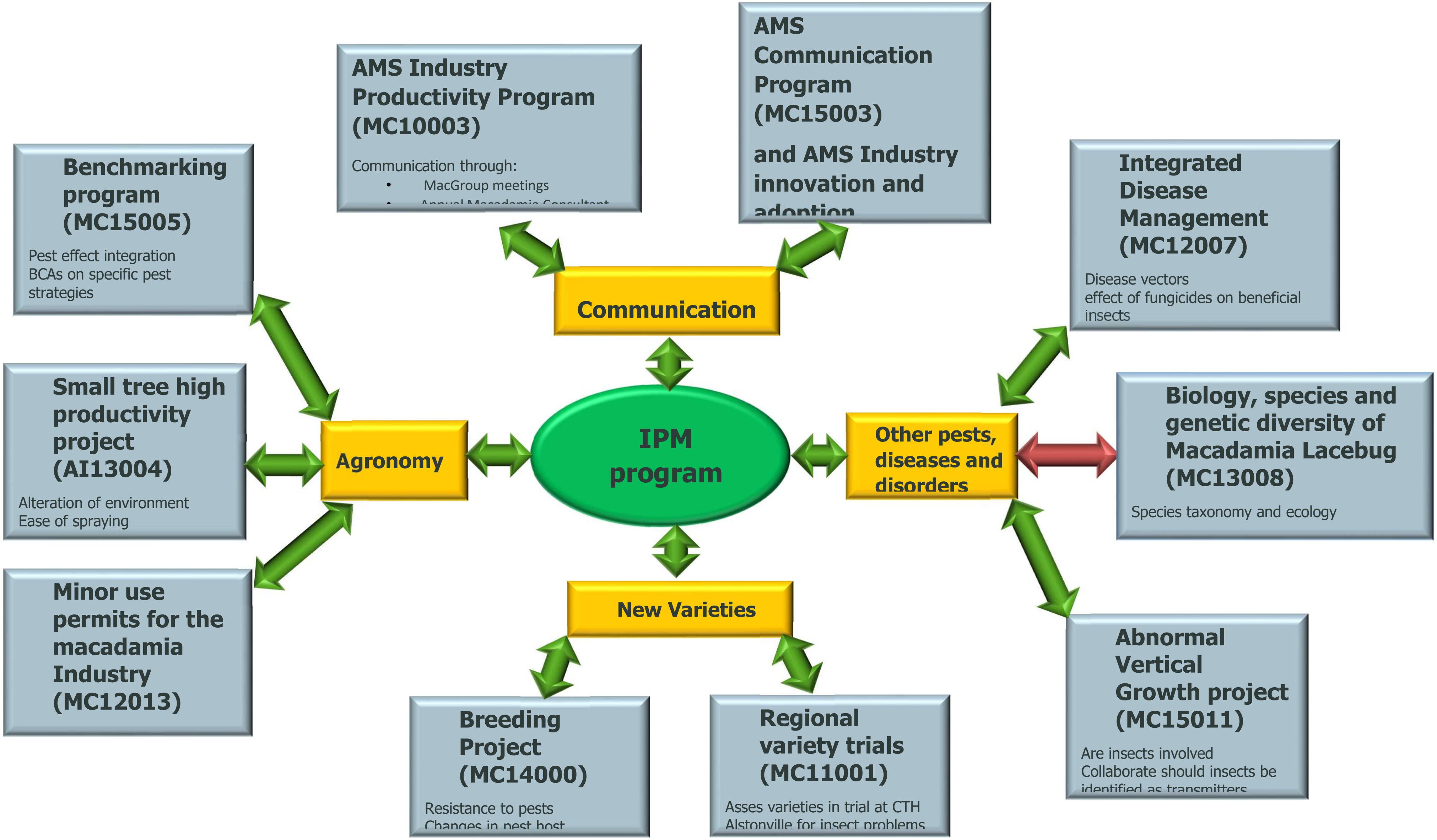
Semiochemicals

NSW DPI (MC16004)
- Collection of pest volatiles for analysis
- Pheromone traps and trap crops

SCU (in MC16004)
- Analysis of volatiles

USC (MC16007)
- semiochemical response
- Behavioural studies
- Field trial recs

DAF (MC16005)
- Support A nitida pheromone trials


AMS Industry Productivity Program (MC10003)
Communication through:
• MacGroup meetings
AMS Communication Program (MC15003)
and AMS Industry innovation and
Benchmarking program (MC15005)
Pest effect integration
BCAs on specific pest strategies
Integrated Disease Management (MC12007)
Disease vectors
effect of fungicides on beneficial insects
Communication
Small tree high productivity project (AI13004)
Alteration of environment
Ease of spraying
Agronomy
IPM program
Other pests, diseases and disorders
Biology, species and genetic diversity of Macadamia Lacebug (MC13008)
Species taxonomy and ecology
Minor use permits for the macadamia Industry (MC12013)
New Varieties
Breeding Project (MC14000)
Resistance to pests
Regional variety trials (MC11001)
Asses varieties in trial at CTH
Abnormal Vertical Growth project (MC15011)
Are insects involved
Collaborate should insects be

Program log frame

Program Name: IPM Program for the Macadamia Industry **Number:** MC16003-8

Date Started: 1/12/2016
Completion date: 28/02/2022

Evaluation Level	Program Details	Performance Measures	Evaluation Methods

Broader Goals
Potential longer term effects on industry productivity, profitability, environmental and/or social benefits
 	
Contribution to industry Objectives
• Macadamia Industry SIP
• Horticulture Innovation Australia
	Potential Long Term Effect
	
	Macadamia Industry – Strategic Investment Plan 2014-2019 (SIP)
	• Objective 1: Sustainably increasing the productivity of Australian macadamia farms
	• Objective 3: Improving stakeholder confidence in the Australian macadamia industry
	• Strategic investment areas
	  ○ ID opportunities to improve productivity in existing orchard base [or, in this case maintain productivity even though less use of broad spectrum pesticides]
	  ○ Promoting industry successes to increase the confidence and investment of the industry
		Extent to which IPM strategies and practices are used in the Macadamia industry
		
		• The extent of reduction of highly toxic or bioaccumulative pesticide use and of broad spectrum chemicals and their replacement with more targeted, sustainable chemicals
		• The extent of reduction in nut loss and in rejections due to insect damage
		• The extent of improvement in profitability and sustainability of the industry due to IPM strategies being used over time.
			[Not necessarily the direct responsibility of the funded Program]
			
			• Industry surveys/reports
			• Surveys of stakeholders
			• Collated data from the benchmarking component of the Program
			• Industry benchmarking data
			• Regional production data
			• Consultants' meeting surveys

Immediate Program Outcomes [expected to be achieved in the life of the program] • Extent of Awareness • Gains in Knowledge and Skills • Extent of practice change • Indicative benefits • Barriers and Enablers	***By February 2022:*** **Industry level** • Across-industry agreement of IPM definition and key components and widespread agreement that IPM is a valid, profitable and sustainable approach to Macadamia production	**Industry level** • The extent of agreement with the definition and the validity of IPM across the industry and the level of awareness of key components, improvement in understanding, skills and motivation to incorporate IPM into management and advice.	*Collaboration with evaluation being used in Macadamia Innovation and Adoption Program – questions specific to IPM* – program specific methods where appropriate • Feedback sheets from participants of extension activities/industry meetings - questions specific to effects on understanding, skills and motivation re IPM.

Evaluation Level	Program Details	Performance Measures	Evaluation Methods
	Capacity and Practice change • Increased understanding of biology and ecology of insects by consultants, researchers and growers – underpinning interest in IPM and willingness to progress and adopt • 80+% of scouts are using new/improved tools • 40+% of consultants/scouts and producers (by ha) have adopted or refined their use of two or more of the key IPM components (tools, chemicals, beneficials, lures, management approaches – e.g. monitoring thresholds) • 50% of consultants are using best management (BM) reports as a tool for increasing the uptake of IPM • Coordinated chemical management as part of AWM • Reduction of use of broad spectrum insecticides by 20+% • Increased professional/scientific capacity within industry – graduates; existing researchers **Indicative Effect** • One-third reduction in insect damage • Increased productivity, profitability and sustainability at farm level	**Capacity and practice change** • The number of producers and the production base represented (and advisers) who have added one or more of the key IPM components to their enterprises (or advice) influenced by the program compared to target. • Changes in broad spectrum chemical use compared to target – and sales of beneficials, tools and other recommended products • Changes in the number of consultants using best management data to encourage IPM compared to target. • Extent of increase in macadamia research knowledge and interest in researchers. **Benefits** • The calculated and measured effects of the changes in terms of their indicative effect on productivity and/or reduction in costs and sustainability and farm gate value – farm level and collated industry level. • Reductions in the extent of insect damage compared to target • Barriers to change and benefits, learning and issues identified for future action.	• Follow-up adoption surveys of producers engaged in activities. • Final adoption survey – across sample of producers and consultants. • Narratives • Case studies • Tracking of data on insect damage at factory over time
Influencing Activities [expected to be undertaken during the program] • Communication activities	**Communication** • On-going liaison with and materials provided to Macadamia Communications Project; Mac Bulletin	• The number, type and topics of papers and communication articles and posts, their effectiveness/user-friendliness and their access by producers and their advisor.	*Collaboration with evaluation being used in Macadamia Innovation and Adoption Program and Communications project – questions*

Evaluation Level	Program Details	Performance Measures	Evaluation Methods
• Extension Activities – field days, farm walks	**Extension activities** ***Overall – across program*** • On-going liaison and joint activities with Macadamia Innovation and Adoption program ○ Attend and engage with MacGroups • Presentations at conferences • Publication of scientific papers • Distribution, promotion and use of IPM Guide ***Benchmarking*** • Economic scenarios included in IPM guide • BM reports and economic analyses distributed and made available to consultants and producers ***Biology and Ecology*** • Engagement with other researchers • Grower and crop consultant training – improved understanding • Biosecurity awareness activities ***Monitoring and Attractants*** • Field days ***Chemical Control*** • On-going liaison with industry re recommended chemical management strategy using different platforms ***Extension development*** Field days on demonstration sites	• Extent of awareness of IPM program, outputs and messages and interest and confidence in the information and tools being produced. • The extent to which consultants/scouts and producers (and the production base they represent) are engaged in program activities and their reaction (perceived value) to those activities – compared to target. • The number, type and quality of engagement activities undertaken compared to planned – support by stakeholders, reactions, and commitment shown.	*specific to IPM* – program specific methods where appropriate • Media analysis – google stats. Newsletter circulation and opening information. • Feedback on producer surveys about the different communication and extension activities in terms of their value and use to them • Program records on communication materials provided, information circulated, demonstrations, extension activities, participation – location, numbers and production base. • Feedback sheets – questions on reactions, value, process. • Observation/reflection sheets/team debriefs by team members.
Outputs and Products [expected to be developed from the program] • New/adapted technology	***Overall Coordination*** • Milestone and Final Reports • Program Steering Committee Minutes • M&E Plan • Gap Analysis	• Extent to which internal reports meet requirements and needs	. • Response by Horticulture Innovation on outputs and reports submitted.

Evaluation Level	Program Details	Performance Measures	Evaluation Methods
• New information products or packages • New understanding or knowledge	• IPM Guide ***Benchmarking*** • Report from best management group surveys ***Biology and Ecology*** • Information packages for researchers, consultants and growers • Workshop materials and presentations ***Monitoring and Attractants*** • Lures/attractants based on thresholds • Inter-row recommendations to maximise beneficials ***Insect Pathology*** • Isolates of fungi identified for commercialisation • Best-bet formulation for testing • Report/paper on best fungi • Workshop materials ***Chemical Control*** • Recommendations on chemical strategy as part of IPM guide • Regionally customised and relevant case studies as part of an IPM Program • Permits for IPM compatible chemicals • Review of IPM compatible chemicals ***Extension development*** • Summaries of demonstrations • Fact sheets • Manuals • Videos ***Cross-program*** • Conference articles • Media and communication articles	• The number and type of extension materials developed, their quality, rigour and appropriateness. • Extent of confidence in the economic analysis and efficacy of chemicals, new tools. • Number and type of new compatible chemicals identified and permits obtained. • The extent to which required reports and other administrative outputs are completed to the satisfaction of program management and funders.	• Program records on communication and extension materials and reports produced. • Communication and media statistics – including Google stats • Feedback from stakeholders – and through producer surveys. • Relevant questions in feedback sheets, surveys, interviews and debriefs • Peer review of journal/conference papers and technical outputs

Evaluation Level	Program Details	Performance Measures	Evaluation Methods
	• Website content • Scientific publications		
Research and Development [expected to be undertaken during the program] • On-farm trials and testing activities • Development of extension or training packages	***Overall Coordination*** • Plan and coordinate meetings – including Steering Committees, Program team meetings • Establish and facilitate use of knowledge base • Approve milestones • Refine and maintain M&E Plan and activities • Facilitate collaborative communication ***Benchmarking*** • Analysis of reject data from factories • Collection, collation and analysis of BM data • Working with BM groups • Analysis of productivity data separated into farms adopting IPM strategies versus those not • Economic assessment of IPM strategies ***Biology and Ecology*** • Insect survey (DPI and Scouts) • Identification of knowledge gaps in insect biology and ecology • Studies on population dynamics • Literature review ***Monitoring and Attractants*** • Development and testing of lures to aggregate pests and optimised timing of pesticide application • Development of *Sigastus* lure • Trials to maximise beneficials ***Insect Pathology*** • Researching insect colony management • Isolation of cultures and characteristics	• Number and type of internal and stakeholder meeting held, their purpose at their effectiveness • Extent to which program plans and reports and other outputs meet milestone and reporting requirements • Effectiveness of collaborative communication • Details, rigour and effectiveness of trials undertaken, tools or pesticidess tested (including biooesticides) • Number, type and efficacy of lures developed – including Sigastus lure • Detail of pest lifecycle and ecology	• Program Milestone reports with details of activities undertaken and issues • Informed person and researcher interviews about activities and value. • Interviews/debriefs with Program team members • Questions in producer/consultant survey relevant to research development activities.

Evaluation Level	Program Details	Performance Measures	Evaluation Methods
	• Production of spores for trials • Testing of existing best-bet fungi bioassays Literature review on Macadamia pests and control ***Chemical Control*** • Laboratory screening of chemicals on selected pests and beneficials • Selection and recommendation of chemicals for field efficacy trials • Testing chemical management strategy and evaluate against selected beneficials • Recommend and test management strategy and evaluate against beneficials on farm/case study sites ***Extension development*** • Undertake IPM baseline - in year 1 • Pilot of ARGA Wide Forecasting • Establishment of demonstrations on farm.		
Foundational Activities [planned to be used to undertake and advise the program] • Program team – including producer members • Funds and in-kind	**Governance** • Steering Committee (Scouts, Growers, Adoption Specialist, IDO, Program Coordinator) • Program Management Team • Researcher team • Budget	• Extent to which effective management processes are in place and in use. • Make-up of Steering Committee, perceived value of meetings and their influence on the program. • Satisfaction of program team members with coordination and support • Extent to which promised funds are received, and used as per budget	• Program records on management processes and meetings • Program team debrief • Web survey questions to researchers • Feedback sheets to Steering Committee at each meeting – satisfaction, issues, input and action.

M&E action plan

M&E Method [from Evaluation Methods column]	**Purpose/Focus**	**Details**	**Responsibility and Timing**
Negotiated questions in M&E activities by Macadamia Innovation and Adoption Program • MacGroup Survey • Consultant's survey • Annual Growers' survey	• Piggy back on M&E activities already being planned – avoiding duplication. • Gain feedback on awareness, intentions, use and issues relevant to IPM program	• Negotiate specific questions with Innovation and Adoption team to be included as appropriate.	• Program Coordinator IPM to work with Program team and negotiate and coordinate with Program leaders I&A – to fit in with planned timing throughout the program
Feedback sheets	• To gather immediate capacity gains from specific IPM activities – workshops, seminars, field days.	• Use an agreed pro-forma type that captures key demographics, reactions, gains in understanding, skills and intentions – and support needed	• Program coordinator provides proforma; activity leaders responsible for adapting and using at events • Used at each group event
Narratives	• To capture known or observed direct effects of activities and/or information on target group – consultants/scouts and growers – and show link to program	• Follows a set structure – stakeholder type; topic area; link to program activities; effect on thinking; actions taken; changes in practice/adoption; observed or expected benefits.	• Program coordinator provides the proforma • Relevant program team requested to submit 3 narratives with milestone reports after year one of the program.
Case studies	• To capture in-depth evidence of costs and benefits resulting from adoption of IPM strategies and practices	• Identify key growers who have made a change as a result of the program. On-farm visits to gather information and analysis. Similar structure to narrative- but in more detail.	• Program coordinator to encourage.
Steering Committee	• Test ideas and strategies with steering committee members • Gain input to target development	• Steering committee approval of research strategies and proposed treatments • Steering committee identification of on-farm issues	• Program Coordinator through steering committee meetings

Example data collection instruments

Field day participant feedback sheet

[example only – for modification and development]

Thanks for providing this feedback. It is important that we are able to understand how useful the event was and how we can improve future field days.

Date:

Location:

1. Which group best describes your role:

- ☐ Producer/Manager
- ☐ Farm employee
- ☐ Consultant
- ☐ Government employee
- ☐ Service provider
- ☐ Other (Please describe)

2. If a producer, please give an approximate idea of the size of your orchard?

Hectares: Av NIS:

3. Overall, how relevant would you rate the field day to you and your enterprise?

Not at all relevant □0 □ 1 □ 2 □ 3 □ 4 □ 5 □ 6 □ 7 □ 8 □ 9 □ 10 Highly relevant

Comments:

4. What could have made the field day (even) more beneficial to you?

Comments:

5. At the field day what level of new knowledge or understanding did you gain about:

5.1 ……..?

No new knowledge □ 1 □ 2 □ 3 □ 4 □ 5 □ 6 □ 7 □ 8 □ 9 □ 10 A significant amount

5.2 ………..?

No new knowledge □ 1 □ 2 □ 3 □ 4 □ 5 □ 6 □ 7 □ 8 □ 9 □ 10 A significant amount

5.3 ……….?

No new knowledge □ 1 □ 2 □ 3 □ 4 □ 5 □ 6 □ 7 □ 8 □ 9 □ 10 A significant amount

6. What is

a key message that you are taking away from the (event)?

7. As a result of what you have heard at the (event / forum), what actions (if any) have you been prompted to take following the (workshop/meeting/forum/field day) – please tick any that are appropriate:

- ☐ Reassessing …………. practice
- ☐ Changing your approach/advice to ……
- ☐ Discuss possibilities with my consultant/clients
- ☐ Seek extra information or training ……
- ☐ Come back to the next field day
- ☐ Other actions:

7.7 Please give details of what you are planning to follow up and/or take actions on:

8. Please indicate what other information or assistance you might need to act on the information you have gained:

9. Please make any other comments or suggestions about the event or [ ] it's management:

Thankyou for your feedback

Steering committee meeting feedback sheet

Thank you for providing this quick feedback on the meeting. I am keen to ensure that meetings fulfil their purpose and remain productive. Your feedback will help keep us on track. The responses will be collated to provide a short overview – individuals will not be linked to responses.

1. Overall, how useful did you find the meeting in terms of understanding the current situation of the program?

   Not useful □ 0 □1 □2 □3 □4 □5 □6 □ 7 □8 □9 □10 **Very useful**
   Comments/explanations:

2. How useful did you find the meeting in terms of providing input into the program direction?

   Not useful □ 0 □1 □2 □3 □4 □5 □6 □ 7 □8 □9 □10 **Very useful**
   Comments/explanations:

3. How satisfied are you that you (personally) had full opportunity to provide the level of input you wished at the meeting?

   Not satisfied □ 0 □1 □2 □3 □4 □5 □6 □ 7 □8 □9 □10 **Very satisfied**
   Comments/explanations:

4. How well did the meeting structure and process work for you?

   Not very well □ 0 □1 □2 □3 □4 □5 □6 □ 7 □8 □9 □10 **Very well**

5. What could have (further) improved the meeting process for you?

6. How satisfied are you with the way the different agenda items were dealt with and the steps that were agreed?

   Not satisfied □ 0 □1 □2 □3 □4 □5 □6 □ 7 □8 □9 □10 **Very satisfied**
   Comments/explanations:

7. Please note any specific items that you would like to make (further) comment on:

8. What are the pressing issues that you see need to be addressed by the program in the next few months?

9. Please make any other comment about the meeting or the matters addressed (use the back of the page if more space is needed).

Thanks for this feedback. Feel free to discuss any aspect with the program team

Narratives and case studies

Purpose

To capture real situations of changes in understanding, attitudes or practice across target groups. Project staff informally become aware of changes/effects that occur but this anecdotal data often does not find its way into the evaluation data. Narratives are not 'random samples' and do not quantify to what extent such changes have occurred across a population but they are **real** instances of change and can illustrate the types of changes that are occurring and indicate their value and effect. If enough are systematically collected they can provide data illustrating certain kinds of change. They can also be used to illustrate quantitative assessments of change. Case studies are more detailed analyses of actual situations and allow statements to be made about the broader potential effect.

Narratives and case studies are useful for capturing effects on other researchers, technical advisors, policy people and funders – depending on the context and target of the project.

Timing

Narratives should be captured cumulatively over the life of the project and be the responsibility of all Program members interacting with target groups. A goal should be to attach a number of narratives to each milestone report.

Case studies are best captured towards the end of the project to highlight effects that have occurred as the result of change practices. Support may be required to capture and measure the effects using a case study approach. Technical specialists and economists could help flesh out and quantify these cases. The information should include the results of interviews, discussion, observation and analysis, and be as specific as possible, with supporting data. Photos and other evidence of changes are also useful in case studies.

Approach

The approach is to capture instances of effect in a short summary form under some structured headings – as they occur. Structured **narratives** are short stories describing the effect that has occurred as a result of a project. They follow a set structure and should be written regularly throughout a Program (which differs from case studies which are normally written towards the end of a project). The narrative (or story) describes the link between the activities in a project and the desired outcomes. These provide an illustration of the effect that has been achieved, or has the potential to be achieved. And, where enough narratives are systematically collected, collated and analysed, they start to quantify what change is happening 'on the ground'. A small selection of narratives provides the basis for more in-depth analyses of **case studies**.

Structure

Narrative headings

1. Date
2. Contributed by ….
3. The issues captured in the narrative. These can be linked to the KRAs:
4. The situation of the producer/stakeholder
5. The specific activities/processes, which triggered a change
6. The change (new understanding, attitudes, practice) that occurred
7. The observed/expected effect of that change
8. Other comments/observations

Case Study headings

1. Context of 'the case' – for example, the group and specific decision-making area.
2. What actions/new approaches were taken *as a result of* project information or activities – by whom and where, and what was the situation beforehand (the benchmark)?
3. What were the aims of taking these new actions/approaches and how were they implemented?

4. What specific results were observed or recorded?
5. What does this convert to in terms of improved investment decisions, management, productivity, environmental or social outcomes?
6. What is the projected benefit/cost (qualitative and/or quantitative)?
7. What has happened with these results – who has picked up on them, how are they being applied? How is it being packaged/spread for others?
8. What are the indications for effect over the next three years plus?

Example Narrative (simulation only)

Date:	15th September 2017
Recorder:	Jeff Coutts
Outcome/s:	IPM Management
Actors:	Jenny Kahn is a macadamia grower from Ballina, with an orchard size of 100ha.
Event:	Jenny attended a demonstration on how to strip mow her orchard to maximise a positive environment for beneficials.
Reaction:	Jenny immediately saw the effect in the samples that she was shown and was convinced that this might work in her orchard, reducing her need for chemicals.
Action:	***As a result*** she talked with her consultant and they decided to use the strategy in orchard management over the next 12 months with on-going extra attention to monitoring of both beneficials and pest insects.
Effect:	The scouting reflected the advantage of more beneficials and Jenny ended up using 40% less pesticides – and no broad spectrum chemicals. There was no increase in rejections and production was 5% more than the average of previous years.
Other:	Jenny is sharing her experience with her neighbours who are very interested in seeing its relevance and effect for their own farms.

To maximize value from these narratives they should follow the same format and be systematically collected by project team members. It is suggested that a range of stories are collected on different outcomes, such as on practice changes, partnerships, social changes.