Department of
Primary Industries and
Regional Development

GOVERNMENT OF
WESTERN AUSTRALIA

Australian Truffle Orchards

Integrated Pest and Disease Management Manual

Acknowledgements and contributors

Funding
This Manual is based on research undertaken in the AgriFutures™ Emerging Industries Program project PRJ-009832 *Pests and Diseases of truffles and their host trees in Australia*, 2015-2019. This project was jointly funded by AgriFutures™ Emerging Industries Program, Department of Primary Industries and Regional Development (DPIRD) Western Australia, Australian Truffle Growers Association (ATGA), Truffle Producers Western Australia (TPWA), the Australian National University (ANU) and Department of Primary Industries New South Wales (NSW DPI).

Truffle growers of Australia are acknowledged for providing access to their truffle orchards during that project.

Coordinating author
Alison Mathews

Contributing authors
Stewart Learmonth, Alison Mathews and Alec Mccarthy (DPIRD); Celeste Linde (ANU); Anne Mitchell (Manjimup Underground), Ainsley Seago (DPI NSW), Alan Davey (Advyron).

Project team and contributors
Helen Collie (DPIRD), Peter dal Danto (AgAware Consulting Pty Ltd), Alan Davey (Advyron R. S.), John de Majnik (AgriFutures Australia), Harry Eslick (Truffle and Wine Co.), Duncan Farquhar (AgriFutures Australia), Diana Fisher (DPIRD), Heather Gustin (DPIRD), Alan Jacob (DPIRD), Stewart Learmonth (DPIRD), Celeste Linde (ANU), Alison Mathews (DPIRD), Anne Mitchell (Manjimup Underground), Janet Paterson (Truffle and Wine Co.), Ainsley Seago (DPI NSW), Peter Stahle (ATGA), Paul Webb (Truffle and Wine Co.).

Images
Where photos and images used in this Manual were not provided by contributing authors, acknowledgement of the source is included in the image credit list at the end of the document.

ISBN: 978-0-6482627-6-3

CONTENTS

About this manual

This Integrated Pest and Disease Management (IPDM) Manual is a collation of information from the research project PRJ-009832 *Pests and diseases of truffle and their host trees in Australia*, 2015-2019 together with information from a range of other sources.

The 'Pests and diseases' project clarified the identity of the more abundant pest and disease agents and their pest status in Australian truffle orchards. This Manual has been produced as a resource for Australian truffle growers to identify the risks posed by these agents and relevant details to help prevent them from affecting truffle production.

The information in this Manual is designed to partner the *Australian Truffle Orchards - Pest and Disease Field Guide*. The *Field Guide* assists growers in identifying agents present while the *Manual* has more detailed information on each agent to assist in managing them. Both documents are available on the DPIRD website, www.agric.wa.gov.au.

Both this *Manual* and the *Guide* are dynamic publications where information will be edited as more is learnt about the agents that occur in Australian truffle orchards.

In this manual, pest refers to any invertebrate or vertebrate that causes damage to a truffle or truffle host tree.

What is IPDM?

IPDM is a strategy that takes into account the whole crop and surrounding ecosystem. Pest and disease management decisions are based on economic thresholds using one or several of all appropriate pest management tools available while minimising the hazard to people, the environment and the crop.

Successful IPDM is dynamic; evolving as on-farm experience and new knowledge are acquired.

In IPDM, prevention plays as big a role as cure. The section, 'Establishing and maintaining a healthy orchard', provides information on how to minimise the risk of pests and diseases becoming an issue in your orchard. It includes information on tree health, orchard hygiene and biosecurity.

The section, 'Pests, diseases and disorders', provides information on the appearance, life cycle and control of the more common invertebrate and vertebrate pests and diseases found in truffle orchards. It includes beneficial and benign invertebrates, as well as some major exotic pests and diseases not currently present in Australia. It is important to become familiar with these exotics so any incursion can be reported quickly to help prevent their establishment.

In the section, 'Monitoring methods for use in truffle orchards', there are recommendations on how to monitor both in your orchard and during harvest and truffle grading. Monitoring resources, such as identification posters and score sheets are included in the Appendix.

Steps involved

IPDM is not one simple control measure but rather a process, the details of which vary with crop, region and farm. The key aspects to any IPDM program are:

Step 1 Understand – Learn about the different diseases and pests for the crop. What are the most important diseases, pests, beneficials and benign agents? Learn how to identify them. Understand the interactions between them and their environment as well as their seasonal cycles. This helps to make more informed management decisions.

Step 2 Prevent – Management practices can be put in place to exclude, prevent or discourage pests and diseases from becoming established or causing further damage in the crop.

Step 3 Monitor – Find out what is actually in your crop. Ongoing monitoring as part of an IPDM program helps to build information on: where in the crop invertebrates and disease are present; at what time of year they are present; how many there are; is management required; and was the management successful.

Step 4 Action Thresholds – Every pest/crop situation has a threshold below which control is not economically viable i.e. the cost of damage by the pest is lower than the cost of control. Thresholds vary from pest to pest and with individual growers/managers and their own level of comfort with pest risk.

Step 5 Control – When monitoring, if action thresholds suggest management is needed, choose a sustainable technique that is least disruptive to beneficial agents in the crop system and has least negative impact on the crop and the environment. Control options can fall into one of the following categories:

- *Biological* – this includes predators, parasites, pathogens and competitors that will kill or disadvantage the pest. They are often referred to as beneficials.
- *Cultural* – this includes pre-plant cultural practices such as site selection and ground preparation that can help prevent and/or manage pests and diseases. There are also crop management practices including weeding, pruning, plant nutrition and irrigation control that help reduce pest reproduction, dispersal and survival, and enhance tree health.
- *Mechanical/physical* – these are operations or tools that physically kill or exclude a pest or disease and include tillage, mowing, traps, plant guards and electric fencing.
- *Chemical* – In IPDM, chemical pesticides are not excluded but should be used with consideration and where possible, select those that have minimal impact on non-target organisms as well as the orchard and surrounding environment. They should be integrated with other management options. Check the APVMA website for information on products that are permitted for use in truffle orchards. Always read and follow minor use permit and label instructions.

Step 6 Evaluate/Review – After taking action, assess and evaluate its effectiveness. Continued monitoring is part of this. Keep abreast of any new information that improves the success and sustainability of pest management.

IPDM in truffle orchards

All of the steps of an IPDM program can be applied in truffle orchards.

This document provides information to help you understand, prevent, monitor, control and evaluate.

There are currently no action threshold recommendations with set numbers for any truffle pests. However, there are broad recommendations for slugs and slaters and as you gain more experience in monitoring and evaluating pests, diseases and damage in your orchard you will gain knowledge and confidence as to when control may be necessary. Information from other sources and interacting with other growers adds knowledge to this process.

Project team members Stewart Learmonth and Helen Collie conducting tile monitoring in a truffle orchard. Regular monitoring and understanding the pests and diseases present are key components of any IPDM strategy.

Establishing and maintaining a healthy orchard

There are many different factors to take into account when planning, establishing and maintaining a truffle orchard. In this section, only aspects of orchard establishment and maintenance that relate to pest and disease management are covered, namely tree health and orchard biosecurity. For information on truffle orchard planning and management as a whole refer to the relevant pages on the DPIRD website, www.agric.wa.gov.au.

Tree health

Healthy trees that are not under stress are less likely to be attacked by a range of insect pests. Endophytic fungi and bacteria that live within healthy plants without causing harm are also less likely to become pathogenic and cause disease. Healthy trees can also better tolerate pests and diseases so that they will not die or have adverse long-term impacts.

Site selection and planning

Ensuring good tree health starts with site selection and planning of the truffle orchard.

The orchard site should have the correct slope and soil texture, depth and structure to allow adequate drainage. Poorly drained soil can lead to waterlogged and stressed trees. If the site does not naturally drain well, some form of engineering solution may be required to reduce waterlogging. This option can be expensive.

The water available for irrigation should be the right quantity and quality for requirements. Poor quality water, e.g. high salt content, can lead to stressed trees. It is advisable to have water quality tested.

There may be pests, diseases and weeds present on site before the orchard is established. It is worth the time and effort to determine if there is a pest risk and removing or minimising these prior to planting. Management becomes much more difficult and expensive after trees are planted. Some pests, diseases and weed management techniques used prior to planting include:

- Removing grass, particularly kikuyu, and leaving the area bare for as long as possible to reduce the number of soil borne pests such as African black beetle.
- Removing as many roots and woody material, if any, from previous land use to reduce the risk of carry-over of wood rot inoculum and competing mycorrhiza.
- Remove or supress competing weeds by cultivation or with herbicides. Weeds can harbour tree pests and compete with young trees reducing their vigour.

Tree spacing varies widely among orchards and there is no set recommendation. The factors of tree spacing that impact on tree health and pest and disease management come into play once trees mature and the canopies increase in size. Ensure there will be:

- adequate air flow around the foliage to reduce the risk of foliar pathogens developing, such as powdery mildew and,

- adequate light penetration to the ground making the orchard floor less hospitable to pests such as slugs, slaters and millipedes.

Alison Mathews in an orchard with close tree spacing that has led to a closed canopy with minimal light and air penetration as trees have grown.

Planting stock is the foundation for a successful enterprise. Plants should be adequately inoculated with the correct truffle species, robust, free of pests and show no signs of disease.

Orchard management

Once trees are planted, maintain them in good health. Key components to healthy trees are nutrition and water management.

While the truffle fungus can help access nutrients in the soil not normally available to trees, the nutrients still need to be present, even if only in small amounts. The use of fertilisers in truffle orchards is the subject of ongoing research but many orchards will require some fertiliser inputs over their productive life. Of particular note, especially in younger trees, are iron, manganese, copper and zinc, as the high pH needed for truffle production may lead to their reduced availability. Leaf analysis can be done to ascertain nutrient levels.

Once established, both oaks and hazelnuts trees can grow quite well under semi-drought conditions but irrigation is still required in many areas to supplement rainfall to ensure good truffle production. The amount and frequency of irrigation for efficient truffle production is important to understand because over- or under-watering may affect truffle disease load, increase tree stress and promote certain invertebrate pests of truffles.

Tree pruning and management of hazelnut tree suckers is also required as the orchard matures to maintain adequate airflow and light penetration.

De-suckering of hazelnut trees.

On farm biosecurity

On-farm biosecurity, or hygiene, is about minimising the risk of unwanted plant, animal and microbiological organisms entering your property. The measures outlined below intend to help protect truffle orchards from new and invasive pests as well as competing mycorrhizal fungi.

There are biosecurity/quarantine measures in place at the national and state levels to reduce the risk of exotic pests, diseases and weeds entering

Australia and moving between states. Plant Health Australia (PHA), on behalf of the Australian truffle industry, has developed a biosecurity plan for the truffle industry. It focuses on exotic pests, those not known to exist in Australia or that are under active management, which have been identified to pose a threat to the industry. PHA provide information on threat identification, pest risk assessments, risk mitigation and preparedness.

It is important to have good biosecurity hygiene practices in place at farm and orchard level as well. There are already pests and diseases of truffle orchards present in Australia that may not be in your orchard and you need to be alert to these as well as being prepared for possible future incursions of exotic pests, diseases and competing mycorrhizal fungi. Good biosecurity hygiene practices will minimise the risk of new pest issues from entering your orchard and spreading undetected within your orchard.

Unwanted pest issues in your truffle orchard can lead to:

- reduction of product quality through direct damage or competition
- reduction of yield through product loss from damage and/or competition from other mycorrhizal fungi
- loss of reputation in the market due to contamination with inferior products.

It is impractical to stop all movement onto your property, but by developing and following a practical farm biosecurity plan, you can minimise the risk of pest and disease threats entering and becoming established. The Farmbiosecurity web site has biosecurity resources and templates to help develop your farm biosecurity plan.

Competing fungi

Other ectomycorrhizal fungi can outcompete or replace the *Tuber melanosporum* (black truffle) on host roots. This can result in reduced or contaminated yield. *T. indicum* (Chinese truffle), *T. sinense* and *T. himalayense* are exotic species and are all listed as having medium overall risk to the Australian truffle industry in the PHA biosecurity plan due to their ability to displace *T. melanosporum*.

Another species that may outcompete the desired truffle species if allowed to colonise orchard tree roots is *T. brumale* (winter truffle). In contrast to the three species mentioned in the previous paragraph it is already present in Australia in some truffle orchards.

Prior to importing truffles and/or truffle inoculum for consumption or propagation consult with your relevant state authority or department as restrictions may apply.

There is also a range of endemic fungi in Australian soils that may be potential competitors to *T. melanosporum*, including *Scleroderma spp.* Miguel (2013) considers the replacement of desirable ectomycorrhizae by native ectomycorrhizal fungi is one of the most important causes of truffle cultivation failures.

If not already present in the soil prior to planting, competing and contaminant fungi can find their way into an orchard in a number of ways:

- Introduced in soil on machinery, equipment, shoes and/or animals that have been on other properties
- On the plant stock used if the incorrect species has been used as inoculum or if plants have been

contaminated by endemic fungi in the nursery.

How to implement good on-farm biosecurity and hygiene

The key to good on-farm hygiene is to reduce the introduction of foreign soil and plant material into your orchard to the lowest practicable level and minimising the spread of pests within your truffle orchard. The key areas are:

- Fencing and signage
- Access roads and machinery and vehicle movement
- People management - including staff, tourists and contractors,
- Production practices
- Animal management

Disinfectants are used in good on-farm hygiene practices to disinfect footwear, machinery, vehicles and equipment to prevent the spread of unwanted fungi and soil-borne diseases. For truffle orchards chlorine based bleach is a good option.

A farm biosecurity sign such as this one can be placed at your farm entrance

Fencing and signage

Orchards should have secure external fencing with appropriate signage and gates that can be kept closed. Additional internal fences may be required if there are multiple blocks on the farm, particularly if they have differing pest status, e.g. new versus established blocks.

A biosecurity sign template for the main farm entrance is available via the Farmbiosecurity website.

Access roads and machinery and vehicle movement

Best practice is to minimise the movement in and out of the truffle orchard. All non-essential vehicles should stay out of production areas. Around the property use designated road ways for vehicles to reduce the amount of traffic in production areas.

Access roads to sheds, workshops, tourism facilities and carparks should be as short as possible, ideally constructed of a hardstand material, and located well away from the truffle orchard or ensure any water run-off is directed away from the truffle orchard and any water storage facilities.

Only drive in paddocks when necessary and particularly avoid driving in production areas in wet, muddy conditions. Driving vehicles in the truffle orchard not only provides a biosecurity risk but may also compact the soil which can affect the development of the truffles. Restricted areas should be fenced and signed and if necessary locked, and if you do have a high risk area, consider having specific equipment designated to that area.

Farm machinery including tractors, mowers, spreaders and sprayers should be cleaned prior to entry into the truffle orchard, preferably before they leave the previous property. The cleaning at your property should be a secondary clean to remove anything picked up during transportation. This is particularly important for vehicles and equipment that visit other truffle orchards, such as contractor vehicles. Use an orchard

vehicle, not external vehicle, for the transport of visitors around the property

It is preferred to have a designated wash-down bay for all vehicles, machinery and equipment. It should have high pressure water and/or air, brushes and scrapers for cleaning. Ideally a wash-down site is located between the properties main driveway and farm roads for easy access when entering and exiting property, is a sealed pad or compacted gravel and directs run-off away from production areas and any water storage resource. A waste water collection sump, with an appropriate over-flow run-off, is a good addition.

A well planned wash down bay should be located for easy access when entering and exiting the property.

When washing down a vehicle, wash from the top down. Take particular note of the tyres and wheel arches, grills, undercarriage, ute trays and floors. Thorough pressure washing is usually sufficient, but in a high-risk situation (suspect foreign fungi or soil borne disease) a disinfectant or steam cleaning should also be considered. It is good practice to regularly wash vehicles that are kept on site as well.

People management

People entering the property, including staff, contractors, utility providers and tourists may bring contaminants from overseas, interstate and/or other properties. It is vital that people are informed of the need for biosecurity measures and that they comply with your procedures.

Clear signage reminds staff and visitors of their farm hygiene obligations

Truffle dogs and their handlers are an integral part of a truffle orchard operation. Because they often operate on more than one property, they pose a biosecurity challenge. Dogs must be considered in any biosecurity and hygiene protocols. Ensure that the handler's boots are free of soil and dogs are clean, particularly their feet/booties. Any vehicles and equipment they are bringing onto the truffle orchard must be treated to the same protocols as any other.

While tourism activities, including orchard walks and truffle hunts, play an important role in the industry, they also pose a biosecurity challenge. Such activities need to be evaluated as part of the overall biosecurity plan for your truffle orchard and business.

Below are some procedures you could implement on your property:

- Limit the number of entry points to the property and ensure adequate signage to inform visitors of the hygiene requirements for entering the property.
- Have a visitor checklist to ensure they are aware of designated parking areas, wash down stations and wash down protocol, permitted and off-limits areas.
- All staff should be briefed on the importance of biosecurity and of the on-farm hygiene practices in place. Staff induction should include the cleaning process of footwear and equipment on entering and exiting the property.
- A footbath should be installed at the entry to the orchard and used every time people work in that area. Footwear needs to be re-cleaned as moving in and out of the orchard.
- Alternatively, provide footwear that is to be worn on the farm only and not taken off site and is preferably left at the entrance to the orchard, or use disposable overshoes.
- Clothing should also be clean and dirt free, on-farm or disposable overalls may be used.

Sanitising footbaths may be fixed or portable. A basic portable foot bath kit is easy to put together. Each kit should contain a scrubbing brush to ensure footwear is free of soil and other organic matter prior to sanitising, diluted bleach (10%) as the sanitiser and a large plastic tub with a sponge in the base. The bleach is poured over the sponge and people step onto the sponge to sanitise their shoes by thoroughly soaking the soles. The kit should be cleaned regularly.

A portable foot bath is simple and inexpensive to set up

Permanent footbaths can be installed at the entry to the orchard

Production practices

The management practices listed below not only help to prevent unwanted soil and plant material entering your property they also ensure you are well placed to prevent spread within your truffle orchard and quickly identify any new pest issues:

- Ensure you know the pest status of your propagation material to the extent of current technology, record the source and consider using Australian Truffle Growers Association ‘Validated Seedling

Tree Evaluation Program (AVSTEP)'.

- Remove weeds and volunteer plants that could act as alternate hosts and harbour unwanted mycorrhiza or pest problems.
- Minimise water runoff and soil water erosion that can carry soil around the site – both into the truffle orchard and from block to block within the orchard.
- Conduct regular surveillance of the truffle orchard and associated yards, including around your wash down bay, sump and water collection run-off areas, to pick up trouble spots and potential pest incursions.
- Record any pest issues found within and nearby the orchard and report anything unknown – the MyPestGuide Reporter app provides a quick and efficient method of reporting pest issues and having unknown suspect pest agents identified.
- Ensure your staff can identify key pest and disease threats.
- Regularly clean and disinfect tools and equipment such as pruning saws, secateurs, hand trowels, and containers to minimise the potential for spread.

Animal management

Animals, either livestock or wildlife, can introduce contaminant fungi and pests into a truffle orchard, therefore:

- Regularly check and maintain fences. The standard of fencing will largely be dependent on the expected level of pressure from animals, namely: kangaroos, pigs and rabbits.
- Prevent livestock movement into the truffle orchard.
- If necessary, implement a feral animal control program. You may need to work with neighbours to co-ordinate feral animal control. Consult your local council and relevant state Department for information on regulations or permits that might be required.

Electric fencing can help prevent animals from neighbouring paddocks, properties and bush from entering the truffle orchard

References and/or further reading

This section has been largely taken from the DPIRD publication 'Truffle orchard on-farm hygiene', available on the DPIRD website, www.agric.wa.gov.au.

Invertebrate pests and non-pests and Diseases

The following section provides information on the most common invertebrates and diseases found in truffle orchards to enable identification and understanding of the agents and inform management decisions.

This is not an exhaustive pest and disease list and with the industry in its infancy, others are likely to be identified in the future. Truffle growers are encouraged to report any suspicious disease or pest affecting trees or truffles to the relevant state Agriculture Department.

While a range of tree species act as host for truffles, only oaks (*Quercus* spp.) and hazelnuts (*Corylus avellana*) are considered in this section.

Invertebrates

Many different invertebrate species reside in or move through truffle orchards and if monitoring is undertaken a large variety can be observed. It must be noted that not every invertebrate found in a truffle orchard is a pest. Some may only be considered pests for a portion of their or the crops lifecycle and others can be beneficial or benign. Table 1 provides a summary of all of the invertebrates outlined in this manual and if they are a pest of the host tree, the truffle or a non-pest. Non-pests are those that are beneficial, benign or have not been observed to cause damage but their pest status requires further clarification.

For those that are pests of host trees some may be present in both newly established and mature orchards. Young trees are more susceptible to attack from a number of pests, while older trees can sustain higher levels of damage without any economic damage or long term harm. Those pests likely to cause economic damage in young orchards only are indicated in Table 1 by the icon.

Some invertebrates impact the irrigation system more than the trees themselves. These are indicated in the table by the icon. They generally interfere by blocking mini-sprinklers, which reduces effectiveness of irrigation and in turn impacts on tree health and truffle production.

Managing invertebrates

Management options are provided on each pest factsheet but there are some methods that are applicable to all of the major truffle pests; slugs, slaters and millipedes. All of these pests are ground dwelling and prefer moist, dark habitats with access to organic matter. By making the orchard floor less favourable for these pests their numbers should reduce accordingly.

Management techniques include pruning branches to allow in more light and removing hazelnut suckers and leaf litter to reduce habitat.

A variety of techniques and machinery is used in orchards to remove leaf litter. Tractor-mounted blowers help remove leaf litter in small to medium orchards by blowing it out of the production area. In larger orchards blowers are used to accumulate leaf litter into rows so a forage harvester or vacuum machine can then pick it up for removal from the orchard. Hand held blowers may be used in small areas. When machinery is used, operations are most often done in

spring and early summer, after harvest but before truffle initiation.

Tractor mounted leaf blower used to clear leaf litter from orchard rows

Leaf collector used to pick up leaves from orchard floor

Leaves picked up from the orchard floor are removed from the production area

Covering of truffles is one of the most common management practices to reduce the incidence of pest and disease damage. Not only has it been shown to reduce the incidence of rot but also reduces invertebrate access to growing truffles. When truffles grow at or near the soil surface and cracks in the soil result, the truffle can come in direct contact with pests. Only 'Australian truffle beetle' is thought to actively seek out truffle, however, other pests will eat truffle if they come upon it, covering of truffles reduces this risk. Orchard soil or sand or soils that has been bought in can be used to cover truffles. Soil with less than 20% clay content is more free-draining and will help prevent the area over the truffle remaining wet and possibly promoting truffle rot. Truffles may have to be covered multiple times as their continued growth leads them to become exposed or form larger cracks in the soils above.

Continued growth of truffles means that they may have to be covered multiple times over the course of a season.

Pest may be present in both newly established and mature orchards but is likely to cause economic damage only in young orchards.

Pest may interfere with operation of mini-sprinklers.

Table 1 Invertebrate pests and non-pests of truffles and their host trees

Invertebrates	Host trees	Truffle	Non-pest	Page
Ants	●		●	20
Aphids	●			21
Beetles - African black beetle	●	●		23
Other cockchafers		●		26
Australian truffle beetle		●		28
Predatory beetles			●	33
Spring beetle	●			35
Stinking longicorn	●			37
Wireworm		●		39
False wireworm & bronzed field beetle			●	41
Centipede - garden			●	43
Earwigs		●	●	44
Flat worms			●	47
Fungus gnat and other flies		●	●	48
Grasshopper - wingless	●			51
Millipedes		●		53
Mites - general	●			57
Hazelnut gall mite	●			59
Hazelnut mite	●			60
Moths - Fruit tree borer	●			61
Heliothis	●			63
Lightbrown apple moth	●			65
Oak leaf miner				67
Painted apple moth	●			69
Pot worms			●	71
Scales - soft	●			72
Slaters		●		75
Slugs		●		79
Snails - Garden snail	●			84
Small pointed snail	●			86
Springtails		●	●	88
Thrips - greenhouse	●			91
Weevils - Apple weevil	●	●		93
Fuller's rose weevil	●	●		96
Garden weevil	●	●		99
Hypsomus weevil	●			102
Redlegged weevil	●			103
Whitefringed weevil	●	●		105

Exotic pests				
European truffle beetle		●		107
Truffle fly		●		108

Diseases

Table 2 provides a summary of all of the diseases outlined in this manual and whether they are a pest of the host tree or the truffle.

The most common diseases of trees in truffle orchards are fungal diseases that cause mildew, necrotic spots on leaves, rusts, cankers, and rots to the trunk or roots. Bacterial and virus diseases are important diseases in some other countries but apart from bacterial blight of hazelnut trees, little is known of their occurrence or importance to evergreen oak (holly oak or holm oak, *Quercus ilex*), English oak (pedunculate oak, *Q.robur*) and common hazel (*Corylus avellana*) in Australia.

Truffle orchardists should be aware that variability in tree vigour of both oak and hazelnut trees may occur and is not necessarily related to the presence of a primary disease agent. The practice of growing host trees from collected seed that is not true to type results in trees that are genetically variable. This variability is often reflected in the range of tree vigour during tree establishment. For trees with an apparent symptom that could be considered a disease, confirmation of the presence of a primary causal agent is required for a diagnosis.

Several of the more common pathogens found in truffle orchards are endophytes, meaning they can be present in trees but only cause disease when the tree is otherwise stressed. Other pathogens can be considered opportunistic pathogens, requiring suitable conditions for disease expression. For these reasons preventative practices and maintaining good tree health are important in disease management

Further information on diseases affecting hazelnut trees in eastern Australia is available from the note '[Pest and disease analysis in hazelnuts]' on the Department of Primary Industries NSW website, dpi.nsw.gov.au.

Managing diseases

It is recommended that general orchard hygiene principles be followed, regardless of whether a disease is present in a particular orchard or not. This is because prevention is better than subsequent disease management. Also, diseases are mobile, they have propagules that are transmitted by wind, rain, soil and humans. Furthermore, many diseases are not host specific and may be present in alternative hosts such as occur in native forest and fruit orchards in the vicinity of truffle orchards, providing inoculum pressure. Thus, when conditions in the truffle orchard favours infection by pathogens, it may only be a matter of time before diseases arrive.

Good orchard hygiene practices include:

- Remove dead or dying plant material from the orchard as it will be a source of fungal pathogen inoculum.
- Only prune when at least 24 hours of dry weather is expected. Rain on open wounds encourages germination of pathogen spores, which may lead to infection.
- Maintain air flow in the orchard by pruning lower branches in particular. Site selection and orchard layout also influence air flow and should be taken into account in the orchard planning stage. Airflow reduces humidity within the orchard, thereby

minimising favourable conditions for pathogen infections.

- Use footbaths at the entrance of orchards to prevent the spread of soil borne pathogens such as Phytophthora.
- Source disease free nursery stock.
- Avoid having irrigation sprinklers close to tree stems.

Choose truffle host species carefully according to climatic conditions of the orchard to also help in preventing disease. For instance, *Quercus ilex* is more susceptible to stem and dieback diseases in high rainfall areas than under drier conditions.

Table 2 Diseases of truffles and their host trees

Diseases	Host trees	Truffle	Page
Australian honey fungus	●		110
Bacterial blight	●		111
Discula	●		113
Oak powdery mildew	●		115
Root and root collar diseases	●		116
Stem diseases and dieback	●		118
Wood rot	●		120
Truffle rot		●	122
Exotic diseases			
Sudden Oak death	●		125
Pierce's disease	●		127
Eastern filbert blight	●		129

Pest and Disease factsheets

The following factsheets provide information on the commonly found invertebrates and diseases in Australian truffle orchards.

The factsheets include information to guide identification, understanding, monitoring and management for each agent. When the more common pitfall traps and tile monitoring methods are recommended, refer to the *Orchard monitoring* section of this manual for more detail on how to conduct these.

Ants

Pest/Non-pest

Family Formicidae

Summary

The foraging nature of ants and because they nest underground, suggest ants in general may play a role in the spreading of truffle fungus spores within orchards, in which case they are beneficial. Some, however, do become pests. The native species of ant, *Cardiocondyla atalanta*, occurs across Australia in both wet and dry habitats. It is known to block mini-sprinklers in a truffle orchard. Adults cluster inside mini-sprinklers when not in use. This is most likely to occur in truffle orchards where the ant has established colonies. The main control methods are mechanical/physical.

Native ant associated with blocking mini-sprinklers

Details

C. atalanta are about 1.5mm long and while this particular species has been identified as being responsible for blocking sprinklers in one orchard, other species may also cause the same problem.

Identification of ants is a job for a specialist. Considering that different control methods may be relevant for different species, any ant found to be a problem should be sent for correct identification. Ants can be collected using sticky tape. Stick the ants to the tape and attach the tape, sticky side down, to a light-coloured piece of card and contact your local agricultural department for information on where to send them.

Management options:

Mechanical/Physical

The problem of ants blocking mini-sprinklers may be overcome simply by increasing the water pressure. Alternatively, a different type of sprinkler may avoid the problem.

The type of mini-sprinkler that gets blocked by ants. They crawl into the lower blue section when the sprinklers are not in use.

Aphids

Family Aphididae

Summary

Aphids occur on both the major truffle tree hosts – oaks and hazelnuts. Aphids are sap-sucking insects. If abundant, their feeding adversely affects tree health but this level of infestation has not been observed so far in truffle orchards. While aphids are capable of spreading viruses, this has not been relevant for trees in truffle orchards. To date, aphid species recorded from hazelnut trees are the green peach aphid *Myzus persicae*, which occurs across Australia, and the hazelnut aphid *Myzocallis coryli* which is present in eastern Australia but yet to be confirmed as present in Western Australia. Unidentified species have been observed on oak and hazelnut trees.

Winged and wingless aphids on a hazelnut leaf.

Description

Aphids are soft-bodied insects and as adults can be wingless or winged, bearing one pair of frail wings. Adults are about 2mm long. They can be distinguished from other insects of similar size and shape such as whitefly nymphs because aphids have a pair of tube-like structures called cornicles on the tip of the abdomen. Adults produce live young called nymphs. They usually occur on the underside of leaves.

Lifecycle

Generally, aphids are most abundant in spring and autumn. There can be more than one generation per year.

Behaviour

Infestations of aphids commence in a truffle orchard with the arrival of winged females. Aphid flight is passive so they are subject to wind speed and direction for dispersal. When in an air stream, aphids react to colour change to alter their flight characteristics to attempt to land in growing crops. This explains why some infestations commence on edges.

On a new host, winged aphids produce wingless adults. Winged insects are formed in response to a population increase or diminishing food quality.

Crops attacked

Green peach aphid has a wide host range of non-grass hosts including many horticultural tree and plant crops. Hazelnut aphid is likely to be more host specific as would the unidentified aphid species found on oaks.

Damage

The sap-sucking activity of aphids deforms foliage, especially near the growing tips, and reduces tree vigour. Aphid populations are unlikely to be high enough on mature trees to cause such an effect, but may reduce tree vigour in newly planted trees.

Monitoring and thresholds

During autumn and spring, check the underside of leaves for the presence of aphids. This is more important in newly planted orchards because low populations may affect tree vigour. This

is unlikely to be the case for mature trees which can tolerate a reasonable number of aphids before tree health is affected. Unless aphid feeding starts to affect shoot health, the wide range of natural control agents that attack aphids can reduce their numbers quickly.

Management options:

Aphids on an oak leaf – black aphids have been parasitised by a wasp

Biological

There is a range of naturally occurring beneficial insects that attack aphids including wasp parasites and predators such as ladybirds, hover flies, lacewings and damsel bugs.

In moist conditions, a fungal disease can also help control aphids.

Mechanical/Physical

Aphids can be washed off plants during heavy rain.

African black beetle Pest

Heteronychus arator

Summary

African black beetle is a non-native pest of trees, pasture, horticultural crops and particularly turf. Highest populations occur in kikuyu pastures. They occur primarily in coastal parts of Australia, but are not reported from Tasmania or the Northern Territory. Adults are the main pest stage in truffle orchards because they can kill trees up to two years after transplanting and very occasionally attack truffles. Larvae are yet to be associated with damage to trees or truffles. Adults are present year around with fewer present in late spring to early summer. They may be residents, or fly into an orchard. Monitor truffle orchard sites before planting to determine abundance and risk for damage. Adults are nocturnal and soil borne during the day. At night they walk on the soil surface. The main control methods are cultural and mechanical.

African black beetle adult feeding on a truffle

African black beetle larva

Description

Adult African black beetle are shiny black and about 10mm long. During the day they shelter in soil and at night can walk across the soil surface and on balmy nights especially in autumn take flight to disperse. They feed on roots, below ground tubers such as potatoes and bark of the stems of plants near ground level. Such feeding can kill plants.

Other ‘cockchafer’ beetles and dung beetles can be a similar size to African black beetle adults but are not shiny black.

Larvae have not been implicated in damage to host trees or truffles. They are soil borne, feed on plant roots and are typical of cockchafers: ‘C’ shaped, with a strongly sclerotised brown head with prominent black jaws, three pairs of well-developed legs on the thorax, white thorax/abdomen and a distended anal end.

Lifecycle

There is only one generation per year. Winter is spent as non-mated adults. They mate in late winter/early spring, and commence laying eggs. Larvae develop from spring to mid-summer

after which they pupate in the soil and emerge as adults. Beetles feed any time after emergence from summer to the following spring. When air temperature and humidity are high they undergo short range dispersive flights, usually in late summer/autumn. Summer moist areas of kikuyu support the highest populations of African black beetle. The extensive root system of this pasture species can tolerate the feeding of the beetle and its larvae.

Behaviour

Damage to truffle host trees is most likely to occur by a resident population of beetles. If orchards are located near or replace areas of kikuyu pasture they would be susceptible to resident populations and also those dispersing by flight, especially in late summer/autumn, or 'walk-ins' from adjacent areas. Crawling adult beetles will congregate around the base of trees to feed.

Crops attacked

Adult African black beetle attack stems of potatoes, treelings such as blue gum and truffle host trees, grapevines, olives as well as underground parts of plants such as roots and tubers. Adults are also pests of establishing pasture especially ryegrass-based pasture and are a pest of turf. They occur in kikuyu based pastures in equilibrium with this grass. They have occasionally attacked truffles.

Larvae are root feeding pests primarily in amenity turf. They have not been implicated in damage to plant stems and in truffle orchards have not been observed to feed on truffles.

Damage

African black beetle adults are chewing insects. In truffle orchards, the main type of damage is from feeding on the bark of young trees near ground level that can occur at almost any time of year but is most likely in late summer/autumn with newly emerged adults and after dispersive flights. Flayed bark tissue near the soil surface is evidence of their feeding as well as wilting plants. Severely affected trees will succumb and die.

Flayed tissue on the base of the trunk of plants is characteristic of feeding by African black beetle adults

Adults have occasionally been observed feeding on truffles. Damage to truffles is unusual because the abundance of the beetle most likely declines in mature truffle orchards such that the size of resident populations is likely to be low.

The larval stage has not been implicated with damage to truffle host trees or truffles.

Monitoring and thresholds

After a site is selected for a truffle orchard, if it has been covered with strong pasture growth, especially a kikuyu based pasture, it should be checked for beetles. This is done by using pitfall traps spaced across the site. More information on pitfall traps is in the monitoring section. Inspect the traps weekly over a couple of months. If more than an average of three beetles is caught per trap per week, preventative action to protect trees will be required.

Alternatively, spade sampling can be undertaken. Dig a square spadeful of soil to about 15cm deep at multiple locations across the site and check the soil for beetles and larvae. Knowing the surface area of each spade sample and the number of samples taken the average abundance of beetles per square meter can be calculated. If it is near three or more beetles per square metre, action will be required.

Management options

Biological

African black beetle is soil borne for most of its life, with only the hard-shelled adults crawling on the soil surface and mainly at night. Because of this naturally occurring predators are unlikely to assist with its management.

A parasitic nematode that attacks the larval stage of African black beetle is available commercially. This is suitable where the insect is a pest of turf but unlikely to be of benefit in a situation going from pasture to planting truffle host trees.

Cultural

Where sites selected for planting a truffle orchard has been found to be infested with African black beetle, the longer the site can be kept free of vegetation, the greater the chance that the beetle populations will decline to non-damaging levels. Care should be taken to ensure removing vegetation for a period of time will not make the site susceptible to wind or water erosion.

Tree guards installed at planting to prevent ringbarking of young trees by African black beetle adults

Mechanical/Physical

Newly planted truffle host trees can be protected from attack by African black beetle adults by placing trees in a corflute or similar type growth tube buried to about 5cm. This physically prevents crawling beetles from accessing the stem of trees. Ensure that the planting hole is free of African black beetle before planting, as any beetles trapped inside will attack the tree. Be aware that use of such guards may provide habitat for other pests such as snails that can damage young trees.

Other cockchafer beetles — Pest

Yellowheaded cockchafer, *Sericesthis* spp.
Redheaded pasture cockchafer, *Adoryphorus coulonii*
Blackheaded pasture cockchafer, *Aphodius tasmaniae*

Description

These native cockchafer beetles or scarabs, are closely related to African black beetle. They occur in south eastern Australia. The soil borne larvae are pasture pests. Adults can be distinguished by their size, shape, colour and markings on their wing covers. Larvae can be distinguished by the colour of the head capsule, legs and pattern of spines on their abdomen.

Yellowheaded pasture cockchafer adult.

Yellowheaded pasture cockchafer larva.

Damage

Unlike African black beetle, adults are relatively short-lived and are unlikely to kill newly planted trees. Larvae are present for a longer period. They have not been reported to damage trees, but may damage truffles.

Redheaded pasture cockchafer adult.

Redheaded pasture cockchafer larva.

Monitor

They may be residents, or fly into an orchard. Monitoring or control methods

are not discussed because their pest status is unknown.

Blackheaded pasture cockchafer adult.

Blackheaded pasture cockchafer larvae.

Australian truffle beetle — Pest

Thalycrodes* sp. nr. *australe

A wide range of native truffles occur in Australia and various species of beetles that rely on them to complete their development have been identified. To date only Australian truffle beetle (*Thalycrodes* sp.) has been recorded in culinary black truffle (*Tuber melanosporum)* orchards as an obligate truffle-feeding insect.

Summary

"Australian truffle beetle" (ATB) is a native insect and truffle is an obligate host required by it to complete its life cycle. The beetle is the first such invertebrate to be identified in Australian truffle orchards. The beetle has been given its unofficial common name because it is believed to occur across Australia, with the possible exception of the Northern Territory. Its actual identity is yet to be confirmed, but members of this genus occur mainly in coastal regions with some locations further inland and one as far north as near the tip of Cape York Peninsula, Queensland.

FIGURE 3: The distribution of *Thalycrodes* species in Australia – from Atlas of Living Australia (https://www.ala.org.au/).

Adults and larvae feed on truffles rendering the truffle unmarketable. Little is known of the biology of the insect. Adults are present in larger numbers from late spring to mid-summer. They occur in native forest and disperse into truffle orchards where they can build up large populations. Larvae have been observed in truffles in May and through winter. The main control methods are cultural and mechanical.

'Australian truffle beetle' adult.

The larval and pupal stages of 'Australia truffle beetle'.

Description

Adult ATB are honey-brown, have clubbed antennae and bear rows of short spines behind their head and along their back. They are about 3mm long. They have wings so disperse by flight. There are males and females.

With the exception of dispersal by flying and mating, which is assumed to take place above ground, adults probably spend most of their lives underground feeding on truffles and laying eggs on and in truffles.

'Australian truffle beetle', centre and look-a-like insects found in truffles; insect on the left is unidentified and insect on the right is *Cyrtusiola* sp.

'Australian truffle beetle', lower photo, and look-a-like lesser pasture cockchafer adults that may be present in truffle orchards.

Other similar sized beetles occur in truffles orchards. Some of these can be found in damaged truffles but are not the primary cause of the damage, and others feed on ground cover plants in truffle orchards. These beetles can be distinguished from ATB by their colour, shape of their antennae, presence of spines and lustre. These other beetles:

- may be a different colour
- lack the distinct clubbed antennae
- do not have rows of spines on the back
- are shiny.

Larvae of Australian truffle beetle also feed on truffles. They are white to cream coloured and grow up to 4mm long. They have a brown head and black jaws, and bear three pairs of very short legs on the thorax. Larvae are soil borne and when they complete their development, pupation most likely occurs underground, either in or near the truffle.

Australian truffle beetle larva

European truffle beetle adult – they differ from Australian truffle beetle, lacking the 'club' antennae and rows of spines on their back.

The European truffle beetle, *Leiodes cinnamomeus*, is a major pest of

truffles, especially in the Mediterranean region. This beetle has not been recorded in Australia. It is a different beetle family and can be distinguished from ATB because it does not bear clubbed antennae and lacks the rows of fine hairs on the back. More detail on this can be found in the section 'Exotic pests of truffles'.

Lifecycle

The lifecycle of ATB is not well understood and challenging to determine because most of it takes place underground.

There are most likely multiple generations per year. In the laboratory, an egg in January developed into an adult in eight weeks. Within a truffle orchard producing the winter harvested black truffles, adults first appear in monitoring traps in spring and thereafter numbers increase into summer. At this time, these adults are assumed to be newly-emerging, unmated beetles. It is not known whether these adults emerged from delayed development of pupae that formed on the previous season's unharvested truffle or whether the adults may have been quiescent until the new season's truffle started forming in late spring.

Being an obligate truffle feeder, the beetles must complete their life cycle on truffle. After mating, eggs would need to be laid near or in truffle. ATB would be expected to be able to detect truffles at any stage – from early formation to being over-ripe. All stages of truffle are likely to be an acceptable food source for the adult beetle and its larvae.

Mature larvae have been observed at the start of the truffle harvest season in late May. Therefore, larvae are most likely to have been present much earlier and most likely after the beginning of the new season's truffles start forming in December when adult numbers are high. They have been found in truffles harvested throughout the winter months.

Behaviour

The source of an infestation is from adjacent areas of native forest where native truffles occur. They would be present prior to orchard establishment in areas where native bush is present; however, they would not survive the multiple years between clearing and cultured truffle growth without a truffle food source. Beetles would be attracted to truffle producing orchards by the scent of black truffle and, in comparison with the likely low density of occurrence of native species of truffles, the aroma from a truffle orchard would be immense.

Given multiple generations are likely to occur each year, the build-up in numbers and therefore damage is probably rapid.

Crops attacked

ATB are obligate feeders on native and exotic species of truffle.

Damage

ATB adults and larvae are chewing insects. The presence of the beetle in a truffle is first apparent from pinholes about 2mm in diameter in the peridium. Both stages have been found tunnelling through truffles. The feeding tunnels are the same diameter as the insect – about 1 to 2mm and can honeycomb the truffle. The often-extensive nature of the tunnelling makes it difficult to trim off damage because so much of the gleba of a truffle can be affected.

Pinholes in the peridium of truffles by 'Australian truffle beetle'.

Honeycomb of tunnels in a truffle caused by 'Australian truffle beetle'.

Damaged truffle should be trimmed off as feeding introduces soil particles into truffles and remains in the tunnels. The insect itself may also be present – they are not removed when truffles are washed prior to grading. Live insects are not permitted in products exported from Australia.

To detect the presence of the beetle and its damage demands careful scrutiny of truffles when they are in the grading room, being prepared for market. The extra time taken to grade infested truffles as well as the loss in the value of downgraded truffles and portions of infested truffle discarded as waste, are all aspects of the loss an infestation of ATB causes.

'Australian truffle beetle' may still be present in truffles even after cleaning

Monitoring and thresholds

The insect and feeding signs are difficult to detect during harvest as the adults and pinholes in the surface of truffles are small and the truffles are usually covered in dirt or mud. The presence of ATB in an orchard is most likely to be first noticed when the insect or its characteristic damage is observed in the grading room.

The presence of ATB in the orchard can be confirmed by using pitfall or pipe traps. If placed in a grid across the orchard and serviced regularly these traps can be used to determine the extent, seasonality and number of ATB in an orchard.

There is more information on how to set up pitfall and pipe traps as well as the beetle attractant solution in the monitoring section of this manual

Management options

Biological

Naturally occurring biological control agents are unlikely to assist with ATB management. The ATB is soil borne for most of its life, adults crawl on the soil surface probably for a relatively short time and the soft-bodied larval stage is likely to be inside a truffle underground. As a result, there is limited opportunity

for biological control agents to access them.

Cultural

There are no tested cultural management practices. As the truffle beetle uses truffle as an obligate food source, the removal of as much truffle as possible from the orchard during harvest, including partially rotten truffles, may reduce their food source to a point that the beetles are unable to complete their development. However, the impact of this on spore levels and future truffle production is not known.

Mechanical/Physical

The wet bait attractant appears to be very effective as a monitoring tool for ATB adults. Research is required to determine whether increasing the density of such traps could be used as a 'catch and kill' technique to reduce numbers. Two trap set-ups have been used for monitoring, a pitfall trap and a pipe trap. The pitfall traps is similar to those used to monitor other ground dwelling pests. The pipe trap has been designed to reduce bi-catch. The PVC pipe sleeve extends above ground level but has holes drilled into it at ground level to allow access to the beetle but not larger animals. Further information on both traps types can be found in the monitoring section of this manual.

Wet pitfall trap used to monitor and possibly to trap and kill 'Australian truffle beetle'.

Wet pipe trap with lid.

Predatory beetles

Non-pest

Including **Carabidae** and **Staphylinidae**

Summary

The most common beneficial agents observed in truffle orchards are the ground dwelling predatory beetles of the families Carabidae and Staphylinidae. Other invertebrates that are predatory such as earwigs or more benign agents such as vegetable beetle are included elsewhere in this manual. Many species of spiders occur in truffle orchards, they are regarded as generalist predators and are not included in this publication.

Metallic green carabid beetle.

Shiny black carabid beetle.

Description

Carabid adults occur in a range of sizes and are hard shelled. Most are dark coloured and shiny or some are brightly coloured or metallic. Adults and the soil dwelling larvae have prominent jaws. Adults eyes are prominent and on the side of the head. The hardened wing covers have grooved stripes running their length.

Staphylinid adults also occur in a range of sizes. Most species observed in truffle orchards have been dark coloured. They are more elongate than carabids with a shortened rectangular shaped wing cover, exposing half, or more, of the abdomen.

Black staphylinid beetle – note short wing covers.

Lifecycle/Behaviour

Adults of both groups of predators are nocturnal, seeking shelter in litter on the orchard floor during the day. Adults either do not fly or are not strong flyers. Larvae are soil borne.

Carabid beetles collected in a pitfall trap

Carabid beetle attacking a slug.

Agents attacked

Like most predatory invertebrates, carabids and staphylinids feed on a range of soft-bodied organisms – the larvae within the soil while the adults prey on invertebrates that occur on the soil surface. Observations in the laboratory confirmed that carabids will feed on slugs but not slaters in this instance and a staphylinid beetle larva will attack millipedes. Reports on observations from elsewhere suggest that some carabids will fed on slaters and some staphylinids will feed on springtails.

Staphylinid beetle larva attacking a millipede.

Spring beetle

Pest

Colymbomorpha vittata

Summary

Spring beetle is a native insect and is an occasional pest of plantation trees, horticultural crops and ornamental plants, especially roses. They occur primarily in the southwest coastal region of Western Australia, and are not reported from the eastern states or the Northern Territory. Adults are the only stage reported in truffle orchards. They disperse from areas of native vegetation in warmer weather during spring only, primarily feeding on leaves and flower petals. Larvae are root feeders and are thought to occur in areas of native vegetation where adults lay eggs. Control of spring beetles is not considered necessary except for newly planted trees up to about two years old especially in years when the beetles are very abundant.

Spring beetle adult feeding on a hazelnut leaf.

Description

Adult spring beetle are shiny metallic green/brown/yellow with stripes along their wing covers. They are flat/rounded in shape with prominent branched antennae and long legs bearing prominent spines. They are about 12mm long.

Larvae are soil borne; they feed on decaying organic matter when young then plant roots and tubers. They are C shaped, white to cream coloured with a brown head, have three pairs of legs on the thorax and distended darker abdomen that contains food and soil.

Lifecycle

Little is known of the details of the life cycle. The autumn and winter period is most likely spent in the larval stage in the soil. Adults emerge in spring and disperse. Spring beetle invades orchards only during spring to early summer.

Behaviour

Spring beetle adults prefer feeding on young leaf tissue near the near growing tip and on petals. When disturbed, adults feign death and fall to the ground. They are more likely to be present on warmer days.

Crops attacked

Adult spring beetle feed on a range of native and horticultural tree crops, especially deciduous fruit tree crops. They also feed on leaves and petals of roses and very occasionally apple fruitlets. They have been observed feeding on foliage of hazelnut and oak trees.

Damage

Spring beetle adults are chewing insects. They feed mainly on young leaves. While their feeding is obvious on new growth, because the insects are present for a relatively short period of time this feeding is not considered important. If the beetles are very

abundant and trees less than two years old from transplanting, they may slow tree growth. The larval stage has not been implicated with damage to truffle host trees of truffles.

Feeding by spring beetle adults cause a windowing effect on leaves.

Spring beetle damage to young foliage of an evergreen oak.

Monitoring and thresholds

Trees in truffle orchards adjacent to native vegetation are most likely to be infested, but in years when beetle numbers are high, any orchard can be infested by spring beetle.

Check trees in spring for signs of leaf feeding and confirm whether spring beetles are the cause.

Unless trees are young and beetles are very abundant, the leaf loss is unlikely to be important.

Management options

Because spring beetle most likely breeds outside truffle orchards in native vegetation and the adults invade by aerial dispersal, biological and cultural control options do not provide effective management.

If trees are young and damage appears to be high, applying repellent spray of natural products may help.

Stinking longicorn

Pest

Stenoderus suturalis

Summary

Stinking longicorn is a native insect. Larvae are borers and have been recorded feeding within branches of hazelnut trees. Infested braches become weakened and may snap. This beetle occurs in the southern half of Australia, mainly near the coast. Adults are present during spring to early summer feeding on flowers of native and introduced trees. Truffle orchards would become infested by adults flying in from nearby native vegetation. The main control method is cultural - healthy, vigorous trees are less likely to be attacked.

Male and female stinking longicorn adults.

Description

Adult stinking longicorn are black with tan wing covers and long black antennae and legs. They are about 8mm long. Larvae are typical of cerambycids having a broad thorax and white well-defined body segmentation and are legless. Mature larvae are about 20mm long.

Larval stage of stinking longicorn borer.

Lifecycle

Little is known of the details of the biology of this insect but it is likely there is only one generation per year. Adults are most abundant in spring to mid-summer. They lay eggs into notched areas of branches of trees and larvae bore along the interior of branches and the stems. They most likely spend the summer and winter feeding inside plants and emerge in spring.

Behaviour

Adults are non-damaging. They feed on flowers and are readily seen on blossom clusters during the day. Mating adults may be observed on flowers. They chew oviposition sites for egg laying and after hatching, larvae commence boring along branches and stems of plants.

Crops attacked

A range of native and exotic species of trees are attacked. In truffle orchards, hazelnut trees are susceptible to attack.

Damage

The larvae of stinking longicorn are the damaging stage. By tunnelling, they weaken the branch or stem in which they are feeding and it may snap or die.

External symptoms of cracks and sap exudate in a hazelnut branch from stem boring by stinking longicorn larva.

Monitoring and thresholds

Despite their obvious colour pattern, adult stinking longicorn may not be seen within a truffle orchard. They would likely be most abundant in adjacent native vegetation where they may be observed in clusters on trees in flower.

Infestation of branches and stems by the damaging larval stage is unlikely to be detected until the larvae are reasonably advanced. At this time, cracks in the bark may lead to signs of sap exudation. In these areas, larvae may be found within the damaged plant.

Management options

Biological

Because stinking longicorn is a native insect, there may be predators and parasites of adults and larvae, but there is no information on this. The level of parasitism is limited because larvae bore within plant tissue and it likely has little impact on the population.

Cultural

It is common for adults of insects where larvae bore within plant tissue to prefer trees that are under stress as suitable for laying their eggs. Stressed plants may exude odours that attract woodborers. This is likely to be a favourable food plant because it is already weakened making it less able to withstand the attack and cope with the damage.

Ensuring plants are not nutrient deficient and receive adequate but not excessive irrigation is important to preventing infestation by any pest and particularly woodborers.

Mechanical

If hazelnut trees are pruned to have multiple stems, any that are infested can be pruned and destroyed to reduce the chance of further infestation within the orchard. By having multiple stems, if any are pruned the tree itself will survive and continue to support a truffle bearing root system.

True wireworms/click beetles

Family Elateridae

Summary

There is a large number of species of true wireworms, or click beetles, in Australia. The soil borne larvae occasionally damage truffles. Most wireworms are native species and some are known pests in other crops, such as the potato wireworm and the sugar cane wireworm. Neither of these species is known to occur in Western Australia. The species of wireworms whose larvae have been found to damage truffles have not been determined. The information here is of a general nature. Because monitoring in truffle orchards has shown their abundance to be very low and in terms of damage to truffles considered incidental, they are regarded to be a minor pest, and therefore their management is not considered here.

Larval stage of true wireworm/click beetle.

Description

Larvae of true wireworm are a soil borne. They are usually long cylindrically shaped, cream to yellow/orange, with black jaws and have a flat plate with protruding spines on the tail. They may grow to 40mm long and about 5mm in diameter. Larvae pupate in the soil to emerge as the adult click beetle. Adults are hard-shelled, flattened, dull brown to grey beetles with a district gap behind their head/prothorax and wing covers. As their common name indicates, they can 'click' to right themselves if upside down, by using a spine on the underside of their body that snaps into an adjacent notch. Adults are nocturnal and capable of flight.

True wireworm/click beetle adult.

True wireworm larvae and adults may be confused with the much more common ground insect false wireworm or vegetable beetle and other members of the beetle family Tenebrionidae such as bronzed field beetle. They occur in pasture and have been observed in truffle orchards – see next section for details on these beetles.

Lifecycle/Behaviour

True wireworm larvae are long lived going through many moults. Some take up to seven years to complete their development in the soil before they pupate to emerge as the adult click beetle. Adults mate and lay eggs most likely in late spring to summer.

The larvae are true soil insects while adults live above ground.

True wireworms occur in land especially pasture before it is planted to truffle host trees. As truffle orchards age, it would be expected that the abundance of wireworms would decline.

Crops attacked

Larvae feed on both decaying organic matter and occasionally seedlings, growing plants and below ground crops such as potato tubers. Adults feed on decaying organic matter and growing plants. While larvae damage crops, adults are not considered to be pests. Only the larval stage has been observed feeding on truffles.

Damage

Feeding by wireworm larvae would result in a circular hole in truffles that would require cutting out. The feeding would result in extra time to prepare truffles and the truffle would be downgraded. Monitoring to date has found the proportion of truffles damaged by wireworm larvae to be very low.

Monitoring and thresholds

Whether wireworm requires monitoring would depend on the experience in individual truffle orchards.

The prevalence of wireworm larvae could be assessed using cut pieces of potato tubers. Tubers are buried to about 5cm and placed as a grid across an orchard. Their location should be marked with flagging tape and checked two to four weeks later for presence of larvae. The proportion of tubers attacked would indicate the risk of damage to truffles and what to expect during grading.

False wireworms and bronzed field beetle Non-pest

Family Tenebrionidae

False wireworm *Gonocephalum* sp.

Bronzed field beetle *Adelium brevicorne*

Summary

Both larvae and adults of these beetles may be commonly found in truffle orchards. They are not true soil insects, occurring mainly in the litter layer on the soil surface. They feed on decaying organic matter and seedlings of pasture plants and vegetables and have not been observed or reported as pests of truffles or their host trees.

Larval stage of false wireworm/vegetable beetle.

False wireworm/vegetable beetle adult.

Description

Larvae of vegetable beetle and bronzed field beetle occur in the litter layer on the soil surface feeding on organic matter and occasionally growing plants near ground level. They are not true soil insects so larvae are less likely to feed on truffles compared with true wireworm larvae.

Vegetable beetle larvae are straw coloured and long and cylindrical, but without the obvious black jaws and flattened plate on the tip of the abdomen that are characteristic of true wireworm larvae. They have not been observed feeding on truffles. Adults also feed on decaying organic matter, occasionally also attacking vegetable seedlings and rarely climb plants to chew foliage. They are about 1cm long, flattened dull brown to grey beetles and are nocturnal.

Bronzed field beetle life cycle – left to right: larva, pupa, newly emerged adult, hardened adult.

Bronzed field beetle larvae are dark brown and grow to 12mm long and 2-3mm wide with 12 body segments, the last one having two distinct upturned spines. They also occur on the soil surface. Adults are shiny bronze/black

beetle and similar in size to false wireworm adults.

Lifecycle/Behaviour

These beetles have one generation per year with larvae most abundant through winter. Adults are present most of the year with breeding mainly occurring in autumn.

Crops attacked

Both adults and larvae feed on living plants especially young plants but also feed on decaying organic matter. Crops attacked include pasture species, broadacre crops such as canola and vegetables, especially seedlings.

Damage

Feeding on seedlings could result in poor establishment, but these insects are unlikely to damage young truffle trees or truffles.

Monitoring and thresholds

Adults and larvae are more prevalent where leaf litter and decaying organic matter is present. If tile monitoring with bran for other invertebrates, these beetles may be encountered.

Centipedes - Garden

Non-pest

Class **Symphyla**

Summary
Garden centipedes or garden symphylans have been observed in low numbers associated with truffles. They can feed on roots where they cause poor plant establishment. The identification and pest status of symphylans on truffles requires clarification

Garden symphylan on a truffle.

Description
Garden symphylans are white, centipede-like soil arthropods that grow to about 6mm long when mature and have a pair of prominent antennae. They are soft bodied and translucent with only two body parts, head and trunk. Unlike insects, they have legs on most trunk segments, with the number of legs increasing from 5 to 6 pairs to 12 pairs when mature.

Lifecycle/Behaviour
Breeding occurs in spring and autumn. Overlapping generations can occur with eggs, juveniles and adults present at the same time. They can move rapidly through the pores between soil particles, and are typically found from the surface down to a depth of about 50cm, depending on soil moisture and temperature, and food availability.

Crops attacked
Some species are pests of vegetable crops and tree seedlings whilst other species are predatory. To date they have not been observed feeding on truffles.

They are primarily herbivores and detritus feeders living deep in the soil, under stones, in decaying wood, and in other moist places where they feed on the root hairs and rootlets.

Damage
Garden symphylans feed on germinating seeds and below ground parts of plants and can sometimes cause crop failure.

Monitoring and thresholds
Garden symphylans abundance can be measured by plant sampling, soil core sampling or using a piece of sliced potato as bait. Their sometimes clustered distribution, or whether the populations is at depth at the time of sampling can make monitoring unreliable if not undertaken with rigour and consideration of its biology.

Observations during harvest and grading are required to clarify the currently uncertain pest status of symphylans for individual orchards; and to determine whether any management practices need to be implemented.

Management options
Cultivation and identification of natural enemies and their preservation are the main methods of reducing populations of symphylans.

Earwigs

Pest/Non-pest

Order Dermaptera

European earwig, *Forficula auricularia*

Predatory earwigs, *Labidura* spp.

Summary

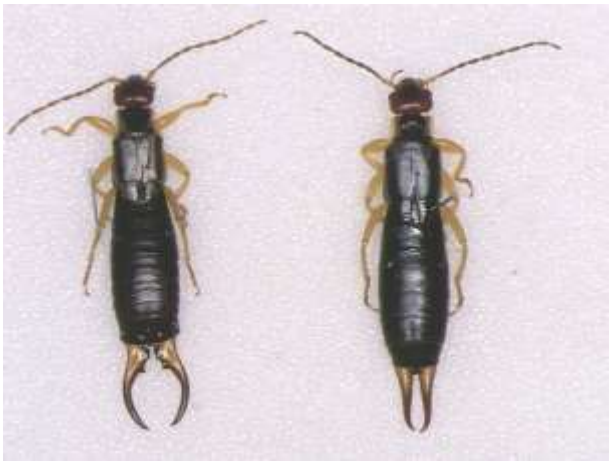
A number of species of earwigs have been recorded in truffle orchards. Both exotic and native species of earwigs occur in Australia. These include ones associated with damage to truffles such as European earwig, an as yet unidentified species and others that are predatory. Species that have damaged truffles have been in low numbers so the pest status of this group is regarded as being minor.

Unidentified black earwig implicated with damage to truffles.

Description

Earwigs are flattened insects with an elongated body and bear a pair of pincers on the last abdominal segment. Male earwigs generally have more curved pincers than females. The pincers are used to capture prey and for defence. They fold their membranous wings under the short thickened cover. The antennae are thread-like with at least 8 segments. Earwigs have chewing mouthparts.

European earwig is an exotic species that occurs in the southern higher rainfall areas of Australia. Adults grow to 24mm long and have uniform brown bodies that are smooth and shiny with light brown/yellow legs, pincers and 'shoulders'.



Male (left) and female European earwigs.

Male (top) and female predatory earwig, Labidura truncata.

Another species of earwig, yet to be identified, has been observed to feed on truffles. It is uniformly black and grows to about 12mm long. It is usually present in lower numbers than European earwig.

The *Labidura* genus of earwigs are predatory, feeding on soft-bodied insects such as caterpillars. They are red-brown with straw-coloured markings and are up to 45 millimetres long. Members of this genus occur across Australia. Males have long slender pincers with a tooth near the middle of the inner edge. They often occur in small numbers unlike the large numbers that can characterise European earwig infestations

Lifecycle/Behaviour

European earwigs have at least two generations per year, the first in late winter and the second during spring. Female earwigs normally lay about 20 to 30 and sometimes up to 50 eggs in clutches in a burrow excavated in the soil and will guard them until they hatch.

Earwigs are mostly nocturnal and often hide in small, moist crevices during the day. Some species of earwigs are attracted to light.

Earwigs are commonly found in dark, sheltered environments and are common under rocks, logs and the bark of trees. Many species frequent suburban backyards and homes.

Crops attacked

Earwigs are mostly scavengers, but some are omnivorous or predatory and eat a wide variety of plant and animal material. European earwigs feed on live plant tissue, decaying organic matter as well as being predators of small soft-bodied insects such as aphids. They are an establishment pest of some broadacre crops such as canola, attack leafy vegetables, cherries and foliage of grapevines.

At least two species of earwig have been observed to feed on truffles – European earwig and an unidentified black earwig.

Damage

European earwigs are both harmful and beneficial to crops, as they eat both the foliage and some soft-bodied insects such as aphids and caterpillars. Some species of earwigs including European earwig, have caused establishment problems in canola crops, and reduced the value of leafy vegetable crops and cherries.

Earwig feeding on truffles produces deep cavities that results in them being downgraded. They have not been observed in large numbers so are regarded as a minor pest.

An unidentified black earwig and damage to a truffle.

Monitoring and thresholds

Earwig abundance may be assessed when monitoring for slugs and slaters using baited tiles. Also, they may be monitored using single faced corrugated cardboard bands wrapped around the trunk of truffle host trees.

If present, earwig damage to truffles may be observed in the orchard during hunting and harvesting.

Management options

Biological

Poultry have been reported to feed on European earwig, but may be

problematic if kept in truffle orchards for long periods due to their scratching and dust bathing habits. Short term placement may be beneficial, for example immediately after harvest.

Cultural

The following cultural activities that are suggested to reduce the prevalence of slugs and slaters may reduce earwig abundance also:

Removal of ground cover such as weeds and fallen leaves within the orchard and vegetation along fence lines.

Cultivation may induce deeper formation of truffles so they are protected by a layer of soil.

Many truffle orchardists cover truffles as they develop and increase in size. The expansion of truffles as they grow results in them breaching the soil surface, cracking the soil surface and softens the soil around the truffle. These effects make truffles more likely to be damaged by earwigs. Covering truffles provides a physical barrier to earwigs as well as protecting them from sunburn and the potential to induce rots.

Removing unwanted suckers from hazelnut trees helps create a less favourable orchard floor environment for earwigs. If suckers are not managed leaf litter accumulates providing a favourable habitat, acting as a refuge for earwigs.

Earwigs prefer a moist environment. After truffle host trees have established and irrigation is for the benefit of the truffles, apply only what is required for good truffle production.

In terms of the moisture and temperature within a truffle orchard, maintaining a reasonably open canopy will aid in making the ground floor environment less desirable as a habitat for earwigs.

Flatworms

Non-pest

Phylum Platyhelminthes

Summary

Flatworms are soft bodied invertebrates that have no body cavity and no specialised circulatory or respiratory organs hence their flat body form and common name. They live in shaded, moist, decaying organic matter situations such as occurs in leaf litter of the tree line of truffle orchards. Their presence is often the source of growers' enquiry, so while they are not regarded as pests in the truffle orchard, some information is provided here to clarify their identification and some aspects of their biology.

Striped flatworms in a truffle orchard.

Description

Flatworms have a flat ribbon-like or leaf-like shaped body, with a glistening, moist appearance. The types observed in truffle orchards vary in length up to about 30mm and range in colour from pale yellow with stripes, to orange and black.

Lifecycle/Behaviour

Moisture, oxygen and nutrient uptake is through the whole surface of the body and so makes them vulnerable to fluid loss, and restricts them to moist terrestrial environments such as leaf litter. The digestive cavity has only one opening for both ingestion and excretion.

Crops attacked

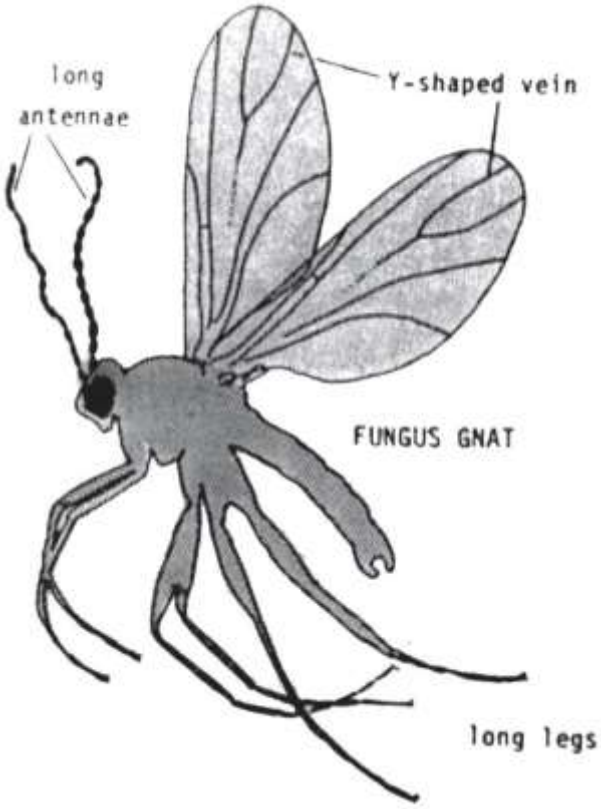
Flatworms that occur on the floor in truffle orchards are most likely to be free-living. Such flatworms are mostly predators. The flatworms observed in truffle orchards have not been identified to species, so their diet is not known. If they are predatory, it is possible they could feed on small invertebrates such as springtails, or that their main diet is decaying organic matter.

Fungus gnats and other flies — Pest/non-pest

Fungus gnats

Family Sciaridae

Summary
Various species of flies are associated with truffles. It is unclear whether they are primary pests or opportunistic when found on truffles. They are most commonly seen on truffles already damaged or infected with rots. Larvae of fungus gnats (Family Sciaridae) are important pests of mushrooms and greenhouse nurseries and are the most common fly species seen on truffles. Their pest status requires clarification. Management includes cultural and biological methods.



Line drawing of a typical fungus gnat fly.

Fungus gnat adult fly.

Fungus gnat larvae in a rotten truffle.

Description
Fungus gnat adults are frail mosquito-like flies about 2.5mm long. They have long thin legs and antennae, and dark bodies. Adult fungus gnats can be distinguished from other types of flies in having a characteristic Y-shaped vein on each of their single pair of wings. Larvae grow to about 8mm and have slender white bodies with a shiny black head capsule.

Lifecycle/Behaviour
The abundance of fungus gnats is influenced by the presence of decaying organic matter on the orchard floor and high moisture levels. Adult fungus gnats

are weak flyers and relatively short lived. Females lay more than 100 eggs so populations can build up quickly. Eggs are laid in the soil or on truffles if exposed.

If decaying organic matter and fungi is not readily available, fungus gnat larvae feed on plant roots and can spread root diseases.

Crops attacked

Larvae are the main pest stage and are primarily fungus feeders. In the absence of fungus, they will feed on root hairs and organic matter, including leaves touching the soil. Larvae may feed on the insides of roots and even stems of large plants.

Pupae of an unidentified fly on a rotten truffle.

Damage

Fungus gnats are a major pest in cultivated mushroom houses and plant nurseries. They have been found associated with damaged truffles and in some cases appear to have caused primary damage to intact truffles.

The condition of the truffle e.g. how firm it is and the presence of cracks may make them more likely to be damaged by fungus gnat larvae.

Larvae of other flies that are not in the fungus gnat group, have also been observed in truffles. Their pest status requires clarification and they are yet to be identified.

Monitoring and thresholds

Because the pest status of flies, including fungus gnats, is not well known, this section is not discussed.

Management options

A range of management options has been developed for fungus gnats in mushroom houses and plant nurseries where they are important pests. Given the uncertainty of their pest status no management strategies have been developed for truffle orchards however the references included here may be considered for relevance to situations in orchards where they are considered pests.

The following orchard management practices that make the truffle orchard less suitable for pests such as slugs and slaters would be relevant for reducing the abundance of fungus gnats:

Removal of ground cover such as weeds and fallen leaves within the orchard and vegetation along fence lines.

Cultivation may help reduce numbers and also induce deeper formation of truffles so they are protected by a layer of soil.

Many truffle orchardists cover truffles as they develop and increase in size. This expansion of truffles results in them breaching the soil surface, cracking the soil surface and softens the soil around the truffle. These effects make truffles more likely to be damaged by ground dwelling invertebrates. Covering truffles provides a physical barrier as well as

protecting them from sunburn and the potential to induce rots.

Removing unwanted suckers from hazelnut trees helps create a less favourable orchard floor environment for fungus gnats. If suckers are not managed leaf litter accumulates providing a favourable habitat.

Fungus gnats prefer a moist environment. After truffle host trees have established and irrigation is for the benefit of the truffles, apply only what is required for good truffle production.

In terms of the moisture and temperature within a truffle orchard, maintaining a reasonably open canopy will aid in making the ground floor environment less desirable as a habitat for fungus gnats.

Grasshoppers - wingless

Pest

Phaulacridium vittatum

Summary

Wingless grasshopper is a native insect and is a pest of trees, pasture, horticultural crops and turf. Highest populations occur in pastures from where the insect disperses to adjacent crops. They occur primarily in the higher rainfall coastal parts of the southern half of Australia. Adults are the main mobile stage but the immature nymph stage also causes damage. They are more important in newly transplanted truffle orchards and trees up to two years old. These grasshoppers are present from mid-spring to early autumn. Monitor newly planted truffle orchards. The main control methods are biological, cultural and mechanical.

Wingless grasshopper adults.

Description

Wingless grasshoppers, as their common name implies, are mainly wingless but some adults have wings. Adults are about 20mm long. They are light brown with a darker coloured back. There are two forms of adults – they may or may not have white strips along each side of the head and thorax. Newly emerged nymphs are small at about 2mm long and dark grey.

Lifecycle

There may be more than one generation per year depending on seasonal temperature and rainfall. Nymphs emerge in spring from overwintering eggs pods laid in the soil. These mature to adults in early to mid-summer. Adults lay eggs in batches or pods in areas of well-drained soil, often on ridges. These eggs either hatch if laid in summer, or overwinter if laid in autumn.

Behaviour

Damage to truffle host trees is most likely to arise from grasshoppers dispersing from adjacent areas of pasture. The least mobile stage is the newly emerged nymph. As grasshoppers mature, their ability to disperse increases. They do not form flying, migrating masses like plague locusts.

Crops attacked

Wingless grasshopper attacks a wide range of weeds and native and cultivated plants and trees.

Damage

They are leaf feeding primarily, but can chew green bark on young trees and around the growing tip. If this feeding occurs on young trees, it can kill them.

Monitoring and thresholds

Wingless grasshoppers may lay eggs in the same area each year. Once a site has been selected for a truffle orchard, checking for the location of egg beds in adjacent paddocks by observing where newly emerged nymphs occur can help with future monitoring and control.

Adults are the easiest identifiable stage but check in spring for newly emerged

nymphs that often feed on prostrate plants and flowers.

Management options

Biological

There is a range of naturally occurring insect and nematode parasites and pathogens that attack wingless grasshopper but these cannot be relied upon to reduce numbers sufficiently to prevent damage.

A commercially available *Metarhizium* fungus is effective if applied when wingless grasshopper is in the early nymphal stages. Depending where egg beds of the grasshopper are located, applications may be applied away from the truffle orchard.

Poultry can be effective in reducing numbers of wingless grasshoppers but require management to maintain. Their behaviour within truffle orchards may be counter-productive to truffle formation.

Cultural

Planting areas of tall grass around the periphery of a truffle orchard may at least slow the progress of dispersing grasshoppers.

Mechanical/physical

Where sites for egg beds of wingless grasshopper are known, ripping them during winter may reduce their survival rate.

Millipedes Pest

Class Diplopoda

Summary

A range of millipedes have been recorded from Australian truffle orchards. The most common species are exotic and include the shiny black Portuguese millipede, *Ommatoiulus moreleti,* which occurs in the cooler coastal regions across southern Australia, and *Cylindroiulus latestriatus*, a small brown millipede which is currently listed as occurring in WA only. These and at least two other species, all of which are introduced to Australia, have been confirmed to feed on truffles in laboratory tests or from field observations. At least three other species collected from truffle orchards are native, their abundance in truffle orchards is usually low. Management is largely based on cultural control, though there are a biological option for at least Portuguese millipede.

Native millipedes from Australian truffle orchards, left to right: *Akamptogonus novarae* occurs across southern Australia and southern NSW, *Myallosoma* sp. and *Taxidiotisoma* sp. from southern NSW.

Description

Millipedes are arthropods with very elongated cylindrical bodies of more than 20 segments. There are two pairs of jointed legs on each body segment, except on some just behind the head.

A range of species of millipedes has been recorded from Australian truffle orchards. The most common species are Portuguese millipede *O. moreleti*, which are shiny black and about 45mm long when mature and *C. latestriatus*, a small brown millipede approximately 25mm long.

One of the more common exotic millipedes recorded in Australian truffle orchards, Portuguese millipede (*Ommatoiulus moreleti*)

'Brown millipede' (*Cylindroiulus latestriatus*),

Other species have been recorded across Australia, sometimes in moderate numbers in eastern Australia. These include one species with long legs that give an overall 'hairy' appearance (*Brachyiulus* sp.), a striped millipede (*Solaenodolichopus* sp), a species that can form its body into a corkscrew/spiral shape (*Ophyiulus pilosus*) and a grey, pale millipede (*Brachydesmus superus*). Native species have also been recorded in NSW.

Brachyiulus sp.

Solaenodolichopus sp

Ophyiulus pilosu

Brachydesmus superus

Life cycle/Behaviour

Much research has been undertaken on Portuguese millipede because of its pest status in domestic situations and more recently in broad acre no-till cropping. There has been comparatively little research on the other species and little is known of their life cycles.

Portuguese millipedes reproduce in autumn and early winter and at this time are quite mobile sometimes causing issues by invading homes. About 200 yellowish-white eggs the size of a pinhead are laid per female in the soil. An immobile, legless stage hatches after about a week. Millipedes go through a series of moults, each time adding legs and body segments until mature after two years. In the first year, Portuguese millipedes are quite small at about 15mm long. Millipedes are vulnerable during moulting because their shell is soft.

Portuguese millipedes are one of the few millipede species attracted to light. As a defence mechanism, the millipede secretes a pungent yellowish fluid that repels would be attackers. This stains clothes permanently and irritates eyes. Millipedes in other groups secrete hydrogen cyanide for the same purpose.

Crops attacked

Millipedes primarily feed on decaying organic matter. Some feed on fungi or suck plant fluids, and a small minority are predatory. Millipedes are generally harmless to humans but can become household or garden pests and damage seedlings. Millipedes can occasionally damage horticultural crops such as melons, strawberries, tomatoes and potatoes. In no-till broadacre crops, damage to canola seedlings has occurred. While at least four species of millipedes are known to be able to feed on truffles, because they generally occur in low numbers the degree to which they may do this in the field is not known. Their pest status requires clarification.

The brown millipede *Cylindroiulus latestriatus* on a truffle.

Damage

Portuguese millipedes can remove the periderm (skin) of immature and mature truffles exposing the gleba (flesh) and also make neat shallow holes the same diameter as their body. In an orchard with high millipede numbers, a high proportion of truffles had what appeared to be millipede damage, although the extent of damage to each truffle was low.

The brown millipede, *C. latestriatus,* occurs in large numbers in some truffle orchards and has been observed to remove the periderm of immature truffles. Its pest status requires clarification.

Portuguese millipedes removing the peridium of immature truffle.

Monitoring and thresholds

Millipedes have been recorded from both truffle baited tile and pitfall trapping. Observations during covering of truffles, hunting and harvesting will clarify their presence and levels of damage in truffles.

No threshold has been suggested for any species of millipede while their pest status is unclear.

Management options

Biological

Some spiders, beetles and scorpions will eat millipedes, but these predators are unlikely to reduce numbers significantly.

The parasitic nematode, *Rhabditis necromena*, was released in South Australia in 1988. Whether effective or coincidentally, the pest status of the Portuguese millipede has decreased in many areas in South Australia since then. The nematode occurs in millipede populations in WA and may have

reduced numbers there also. These nematodes attack only millipedes and are active during late autumn and winter. Nematodes may take several years after introduction to reduce millipede numbers, especially in areas adjoining bushland which can support enormous populations of the pest.

Cultural

Removal of ground cover such as weeds and fallen leaves within the orchard and vegetation along fence lines will help reduce the abundance of millipedes.

Cultivation may help reduce numbers and also induce deeper formation of truffles so they are protected by a layer of soil.

Many truffle orchardists cover truffles as they develop and increase in size. This expansion of truffles results in them breaching the soil surface, cracking the soil surface and softens the soil around the truffle. These effects make truffles more likely to be damaged by millipedes. Covering truffles provides a physical barrier to millipedes as well as protecting them from sunburn and the potential to induce rots.

Removing unwanted suckers from hazelnut trees helps create a less favourable orchard floor environment for millipedes. If suckers are not managed leaf litter accumulates providing a favourable habitat and millipede refuge.

Millipedes prefer a moist environment. After truffle host trees have established and irrigation is for the benefit of the truffles, apply only what is required for good truffle production.

In terms of the moisture and temperature within a truffle orchard, maintaining a reasonably open canopy will aid in making the ground floor environment less desirable as a habitat for millipedes.

Chemical

Baits containing iron EDTA that are available for control of slugs and slaters in truffle orchards under the Agricultural Pesticides and Veterinary Medicines Authority minor use permit PER87270 have been shown to have little effect on Portuguese millipede. They have not been assessed for efficacy against other species of millipedes.

Mites - General

Pest

Subclass Acarina

Summary

A range of species of mites has been recorded on truffle tree hosts. To date no mites are regarded as significant with respect to tree health. Nevertheless, it is worth being familiar with the symptoms of mite feeding to help confirm the cause of any adverse symptoms on trees.

Description

The symptoms and potential severity of mite feeding varies for each species. Because mites are small, recognising their feeding symptoms is more practical than being able to recognise the mites themselves. If mites are suspected of causing damage, plant samples need to be collected and sent to a specialist to confirm the cause.

Symptoms on the lower leaf surface of oak of yellowing adjacent to the veins caused by mites.

Symptoms on the upper leaf surface of oak of yellowing adjacent to the veins caused by mites.

Some details on the more host specific mites; hazelnut gall mite and hazelnut mite, are provided in the following factsheets.

Damage

An unidentified species of mite occurs on oak leaves in Western Australia but may also be present in eastern Australia. Its presence is associated with leaf discolouration adjacent to the veins on the underside of oak leaves, resulting in characteristic pale shadowing adjacent to the veins. The pest status of this leaf feeding mite is unknown.

Predatory mite feeding on a pest mite on an oak leaf.

Bryobia mite (*Bryobia rubrioculus*), two-spotted mite (*Tetranychus uritcae*) and European red mite (*Panonychus ulmi*) may occasionally attack trees. Symptoms of an infestation include yellowing/silvering leaves and if the infestation is heavy, premature leaf-drop.

Monitoring and thresholds

Once damage symptoms are observed, observations of other symptoms as well the mites and their eggs can assist in identification. These mites are small, but easily seen with the aid of a 10x hand lens.

Two-spotted mites create webbing underneath the leaves but bryobia mite does not. Eggs of bryobia mite and European red mite are red, whereas those of two-spotted mite are near pearl coloured.

Management options

Predatory mites readily occur with two-spotted mite and to some extent with European red mite infestations. A predatory mite occurs where the unidentified oak pest mite has been found. Predatory mites are usually absent in bryobia mite infestations but research is being conducted into suitable predatory mites.

Other naturally occurring predators include small ladybird beetles, lacewings, predatory fly larvae and predatory thrips.

Hazelnut gall mite

Pest

Phytoptus avellanae

Summary

Hazelnut gall mite, or hazelnut big bud mite, is a key pest of hazelnut trees overseas and is known to occur in eastern Australia, and for this reason, care should be taken with sourcing planting material.

Hazelnut gall mites are microscopic and in heavily infested hazelnut trees can be present in large numbers in susceptible tissue in protected locations such as the growing tip and buds.

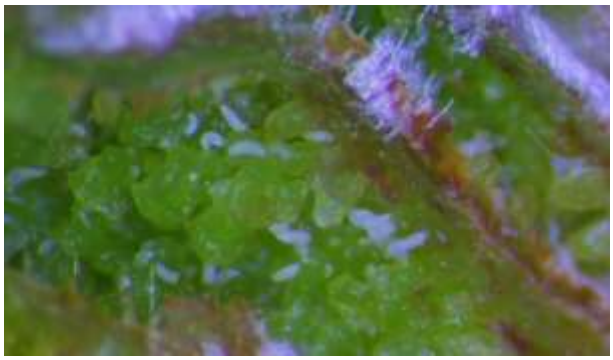
Deformed bud on hazelnut tree caused by hazelnut gall mite.

Description

This mite belongs to the eriophyid group of mites. They are so small, at 0.3mm long, that a high-powered microscope is required to see them. Their presence is first detected when growing tips become distorted

Lifecycle/Behaviour

Mites feed within buds until the bud, if healthy, expands. The mites move to infest new buds as they form. The entire life cycle takes place on the tree. After leaf fall, mites remain within buds during winter. In moving from old buds to new ones, wind may disperse mites, enabling them to colonise other trees. A second form of this mite is leaf feeding.



Infestation of hazelnut gall mites with eggs in a deformed hazelnut bud.

Crops attacked

The main host for this mite is hazelnuts.

Damage

Mites infesting buds reduce tree vigour by adversely affecting normal tree growth.

Monitoring and thresholds

An infestation would be suspected if new shoots appears stunted and growing tips are enlarged or have a gall-like appearance. Samples of buds need to be examined under a microscope to confirm gall mites as the cause.

Management options

Biological

Predatory mites and other mite predators may occur that help control hazelnut bud mite.

Cultural

When establishing or expanding a truffle orchard, check new plants for the presence of hazelnut bud mite. Pruning infested parts of trees may help reduce their prevalence and risk of spread to other parts of the same tree and other trees in the orchard.

Chemical

Some work has been undertaken in New Zealand on the timing of sulphur sprays to help control this mite.

Hazelnut mite

Pest

Tetranycopsis horridus

Summary

Hazelnut mite has been recorded relatively recently in Australia, so far in Victoria and New South Wales only. It occurs in Europe, China and USA. This leaf-feeding mite reduces tree vigour. To help limit its spread, hazelnut growers are requested to report its suspected presence to their state pest enquiry service.

Hazelnut mite adult.

Description

Hazelnut mites are red/black and characterised by the presence of many spines on their back. It is similar in size to the more common two-spotted mite that occurs on a wide range of horticultural crops. The eggs of the mite are red. The mite feeds on the lower leaf surface.

Lifecycle/Behaviour

The mite overwinters in the egg stage. These hatch in spring and the active mites feed and occur as multiple generations from spring to autumn.

Crops attacked

As well as hazelnut trees, other truffle orchard host trees such as oaks and pines are attacked also. Other hosts include walnuts, beans, willow and alder. Some hazelnut varieties appear to be more susceptible.

Damage

Symptoms on leaves from feeding include white or yellowish feeding spots on the upper leaf surface. Mite feeding results in loss of leaf function and reduced tree health.

Hazelnut mite egg.

Hazelnut mite nymph.

Monitoring and thresholds

The presence of the mite can be detected by checking for the characteristic signs of feeding and then checking for the mites themselves on the underside of leaves. They are easily detected with a 10 times hand lens

Management options:

Biological*:*

Predatory mites and other predators may occur and help control this pest.

Cultural:

Carefully inspect new plants coming into the orchard for the presence of the mite.

Fruit tree borer

Pest

Maroga melanostigma

Summary

Fruit tree borer is a native insect that occurs across Australia, mainly in coastal higher rainfall areas and inland irrigated areas. The larva is the damaging stage, boring into native trees and introduced horticultural crops. In truffle orchards, hazelnut trees have been attacked. The main control method is cultural.

Description

Fruit tree borer moth.

Moths of fruit tree borer have a wingspan of about 40mm, white forewings with a black dot near the centre and grey and white hindwings. The tip of their abdomen is yellow and they have orange hairs near the top of their legs.

Larvae bore into trees covering the holes with dark brown silk and frass. They have a dark brown head and pale brown body sparsely covered with hairs.

Lifecycle

The life cycle is completed every one, or sometimes two, years depending on the host. Moths emerge from late spring to autumn, with most present late spring to mid summer. After eggs are laid, larvae bore into the host tree. Most of the life cycle is spent in the larval stage.

Larval stage of fruit tree borer.

Behaviour

Moths from nearby infested areas of native vegetation may invade truffle orchards. Moths are attracted to light at night so it is assumed they are nocturnal. The habit of larvae being a woodborer has made detailed studies difficult and effective control efforts problematic.

Webbed sawdust from fruit tree borer larva feeding on hazelnut

Crops attacked
The range of hosts attacked by the wood boring larvae includes native trees and horticultural crops including citrus, figs, grapevines, pecans and prunes. They have damaged hazelnut trees in orchards, especially in eastern Australia.

Damage
Feeding by larvae results in weakened stems that are susceptible to snapping in windy condition. Branches can be killed and tree vigour adversely affected.

Monitoring and thresholds
Even though fruit tree borer moths are large and easily distinguished from other moths, infestation of trees is first noticed by the presence of sawdust-like material webbed together, hanging on the side of a tree with some bark removed and a cavity in the trunk created by the larva.

The need for action would depend on the extent of infestation of individual trees.

Management options
Biological
Despite this insect being native to Australia, natural enemies play little or no role in regulating abundance.

Successful biological control of this insect had been achieved in pecans in eastern Australia by releasing a species of mass reared parasite that is apparently no longer available.

Cultural
Stressed trees are more likely to be selected by moths as an egg laying site. Maintaining vigorous, healthy trees with appropriate fertiliser and irrigation management helps prevent infestation and assists trees in tolerating an infestation.

Hazelnut trees are especially susceptible to attack. For orchards in areas subject to attack by the borer, trees should be managed so that they have multiple stems. In this system, tree survival can be aided by removing and destroying infested limbs and branches. The undamaged stems can be maintained to minimise any reduction in the root system for truffle production.

Mechanical/physical
For low to moderate infestations, poking a wire down tunnels made by larvae to try to kill them may reduce damage.

Heliothis Pest

Native budworm (*Helicoverpa punctigera*) and corn earworm (*H. armigera*)

Summary

These two species of heliothis are native insects. They have a wide host range and in years when very abundant, the larvae may attack foliage of truffle host trees. They occur across Australia. Adults are present from early spring up to early winter. They overwinter as soil borne pupae. Moths are strong flyers and can invade orchards from some distance away. Monitor truffle host trees for damage to leaves and growing tips. To date, these species of moths have been recorded infrequently in truffle orchards so are not regarded as a major pest. The main control method is biological.

Heliothis moth.

Description

Heliothis moths are arrow-head shaped at rest. They have pale brown forewings and two-tone coloured hindwings – dark grey on the outer half and cream coloured next to the thorax. Moths are about 2cm long. They are strong flyers and nocturnal. Each adult can lay hundreds of eggs, with eggs being laid singly. Eggs are white when first laid and develop a black dot when near hatching.

Larvae are cream coloured when they hatch but can range in colour from brown to green pink and near black as they mature. They have lateral white stripes. They grow to about 3cm long. When mature they burrow into the soil, form an earthen cell and pupate.

Heliothis larva.

Lifecycle

Winter is spent as diapausing soil borne pupae. They emerge as moths in spring. There may be up to four generations per year depending on seasonal conditions.

Behaviour

Moths are strong flyers and can travel over long distances. They require a nectar meal before being able to lay eggs which are laid near growing tips and young leaves.

Crops attacked

Heliothis larvae attack a wide range of crop plants including broadacre crops, vegetables and deciduous fruit crops. They very occasionally attack truffle host trees. They also feed on weeds.

Heliothis larva and damage to leaf and immature hazelnut.

Damage

While heliothis larvae are mainly leaf feeding, when infestations are heavy growing tips may be attacked affecting tree shape. All growing points on young trees could be killed, adversely affecting tree shape and even survival.

Monitoring and thresholds

In years when heliothis is very abundant, moths may be seen feeding on nectar in flower clusters during the day. The first sign of an infestation of heliothis larvae is windowing of young leaves. Gross leaf loss may occur in heavy infestations. Pheromone traps that use a synthetic form of a chemical that females release to attract a mate may be installed to act as a warning that the insect is present.

Moths may be observed at lights at night. Eggs may be observed near growing tips.

Management options

Biological

Because the two species of heliothis are native insects, a suite of natural control agents exist that attack the egg, larval and pupal stages. With an invasion of large numbers of moths, these natural control agents would not be present in sufficient numbers to prevent damage.

The bacterial pathogen *Bacillus thuringiensis* (BT) is a biological control agent specific for control of moth larvae. If applied when larvae are young and small will give control. Should heliothis become a consistent pest of trees, consideration could be given to obtaining registration of relevant products.

Lightbrown apple moth Pest

Epiphyas postvittana

Western fruit moth, *E. pulla*

Summary

Lightbrown apple moth (LBAM) is a native insect that feeds on a wide range of native and exotic plants of economic importance. A closely related species 'western fruit moth' (*E. pulla*) is endemic to Western Australia and is more prevalent than the accidentally introduced LBAM in some parts of WA. The main practical difference between the two species is that a different synthetic attractant lure or pheromone is required to monitor moths of each species. Otherwise the two species are very similar and are considered singularly in the following.

Larvae attack the growing tips of plants and have caused damage to truffle tree hosts in nurseries. This indicates they may be important occasionally in newly planted orchards, although this has yet to be reported. LBAM occurs across Australia and is more abundant in higher rainfall areas close to the coast. Adults are present from early spring up to early winter. They overwinter as near mature larvae. They may fly into an orchard or be resident. Monitor young truffle host trees for damage to leaves and growing tips. The main control methods are chemical/biological.

Description

Adult lightbrown apple moth are bell-shaped at rest and have two-tone coloured forewings – dark brown on the outer half for males and light brown for females. Moths are about 1cm long. They are weak flyers and nocturnal. Adults lay a flat raft egg mass containing 20 to 30 eggs. The egg mass is pale green when first laid and darkens as eggs mature.

Larvae are lime green caterpillars with a brown head. They grow to about 2cm long and produce silk and web leaves together to form a chamber within which they feed.

Lightbrown apple moth adult.

Lifecycle

Winter is spent as near mature larvae on the host plant. They pupate and emerge as moths in early spring. There may be up to four generations per year depending on seasonal conditions.

Lightbrown apple moth larva and associated leaf damage and webbing.

Behaviour

Moths are weak fliers and are likely to be resident within an orchard or fly in from nearby infested plants. Egg

masses are laid near growing tips and on upper leaf surfaces. Larvae are associated with webbing and pupate on the plant.

Crops attacked

Larvae of lightbrown apple moth attack a wide range of crop plants especially deciduous fruit tree crops. They have only been reported feeding on truffle host trees in a nursery situation. They also feed on some weeds.

Damage

Lightbrown apple moth larvae are minor pests in nurseries where the growing tip may be killed affecting tree shape. The same damage may be important in newly transplanted trees.

Monitoring and thresholds

The first sign of an infestation of lightbrown apple moth is clumped leaves from webbing by larvae and dead leaf tissue. Where the insect is consistently present, pheromone traps that use a synthetic form of a chemical that females release may be installed to act as a warning that the insect is present. Pheromone lures for both species are required in certain parts of Western Australia.

Moths may be observed at lights at night. Egg masses are very cryptic on leaves and are unlikely to be noticed.

Management options

Biological

Because lightbrown apple moth is a native insect, a suite of natural control agents exist that attack the egg, larval and pupal stages. Their effect may be low in nurseries where free access by these agents may be restricted.

The bacterial pathogen *Bacillus thuringiensis* (BT) is a biological control agent specific for control of moth larvae. If applied when larvae are young and small will give control. Should lightbrown apple moth become a consistent pest of trees, consideration could be given to obtaining registration of relevant products.

Cultural

Removing alternative broadleafed plants such as clover and capeweed from the orchard floor would help reduce the abundance of this insect.

Chemical

Where lightbrown apple moth is a consistent pest, consider using mating disruption, which is based on flooding the area with synthetic pheromone.

Oak leaf miner

Pest

Phyllonorychter messaniella

Summary

Oak leaf-miner is an introduced insect. It was first recorded in Victoria in 1976. It is found on oak trees in truffle orchards across Australia. Adults and the leaf-infesting larvae are present year round in evergreen oaks. The moths are weak flyers and may arrive in truffle orchards in already infested trees. Generally they are not thought to affect tree health. They are subject to attack by natural enemies which would limit their potential for heavy infestation.

Oak leaf miner moth.

Description

Oak leaf-miner moths are light brown with dark brown and white markings on the forewing. They are relatively small moths at 3 to 4mm long and have a wingspan of around 7mm. They lay eggs on the underside of leaves. After hatching, larvae feed/mine below the lower epidermis of the leaf causing characteristic blister like symptoms on leaves. These appear as necrotic areas on the upper leaf surface. When mature, larvae pupate within the mine and adults emerge from the pupal case, which protrudes from the mine.

Oak leaf miner larva exposed under the leaf epidermis of an oak.

Oak leaf miner pupa which had formed from a larva feeding under the leaf epidermis of an oak.

Lifecycle

Evergreen oaks support infestations of oak leaf-miner continuously. For deciduous oaks, the infestation of oak leaf-miner is low in spring but builds quickly as new leaves form.

Behaviour

Moths are weak flyers so would spread slowly after the initial infestation.

Crops attacked

Oaks are the favoured host but others include beech, birch and chestnut.

Symptoms of oak leaf miner feeding by larvae on upper leaf surface.

Characteristic blisters on lower leaf surface by oak leaf miner larvae.

Damage

High levels of leaf-mining activity is present in some areas suggesting tree heath may be compromised. This may be the case especially in areas where newly planted trees are adjacent to an infested older orchard.

Monitoring and thresholds

The first signs that oak leaf-miner is present are the necrotic brown patches on leaves. When the underside is checked, the characteristic blisters will be evident.

The extent of the infestation will indicate whether tree health is compromised.

Management options

Biological

The suite of natural enemies consisting of at least nine species of parasitic wasps and one lacewing predator have been recorded attacking oak leaf-miner and should help keep numbers in check.

Painted apple moth and Western tussock moth Pest

Teia anartoides* and *T.athlophora

Summary

Painted apple moth is a native insect with a wide host range including native and exotic trees, horticultural crops and garden ornamentals. It has been reported to feed on trees in truffle orchards in eastern Australia. This insect was the subject of a successful eradication program in New Zealand after an incursion. It is not known to occur in Western Australia. A related species, western tussock moth (*T. athlophora*) occurs in Western Australia, and has been observed feeding on foliage of truffle trees. To date, these species of moths have been infrequently recorded in truffle orchards so are not regarded as a major pest.

Painted apple moth male.

Description

Male moths have brown forewings with darker waves and bright yellow and brown hind wings. They are 10mm long with a wingspan of about 20mm. The adult male Western Australian species of moth has similar colour forewings, but grey/brown hind wings. Female moths are light brown, about 10mm long, wingless and lay a mass of white circular eggs covered in hairs, near where they have emerged from their pupal case.

Larvae of painted apple moths and their WA relative are hairy with occasional tufts of longer hairs and reasonably brightly coloured. They are approximately 25mm long when mature.

Wingless female western tussock moth and egg mass.

Lifecycle

Painted apple moth/ western tussock moth is present from spring to autumn and may have up to four generations per year. Wingless female moths lay eggs from which hatching larvae disperse on silken threads with the aid of wind. The larvae feed in groups, at least during the early stages of development.

Behaviour

Because females are flightless, they rely on emitting a pheromone to attract males. A synthetic version of this pheromone was developed for painted apple moth for the New Zealand eradication program. Despite the females being flightless and therefore not readily able to select a host plant for laying their eggs, larvae have a wide host range so dispersal from where eggs are laid would likely result in larvae finding a suitable host.

Crops attacked

In truffle orchards, they have been reported to attack hazelnut trees.

Damage

Painted apple moth/ western tussock moth larvae are foliage feeders. Should natural enemies not be present when infestations occur, leaf loss could adversely affect tree health, especially in newly planted orchards.

Larvae of western tussock moth and associated feeding on hazelnut leaves.

Monitoring and thresholds

An infestation of painted apple moth/western tussock moth would be confirmed when leaf loss or the larvae themselves are observed.

Should painted apple moth be a consistent pest, the synthetic pheromone identified could be used to monitor for moths as a warning tool for their presence.

To date, these species of moths have been infrequently recorded in truffle orchards so are not regarded as a major pest.

Management options

Biological

Because the two species of moths are native insects, a suite of natural control agents exist that limit their abundance.

The bacterial pathogen *Bacillus thuringiensis* (BT) is a biological control agent specific for control of moth larvae. If applied when larvae are young and small will give control. Should painted apple moth become a consistent pest of trees, consideration could be given to obtaining registration of relevant products.

Potworms

Non-pest

Family Enchytraeidae

Summary

Potworms are in the same group of invertebrates as earthworms. They are detritus feeders and require moist situations in order to thrive. They are commonly seen with or in truffles that have been damaged by other agents and are in very moist situations.

Potworm in a rotten truffle.

Description

Potworms have the same appearance as earthworms except lack any distinguishing external features on their body and are white, except for their gut contents which are similar in colour to the food they have been consuming. The potworms most commonly observed associated with truffles are approximately 5mm long and about 0.2mm diameter when fully grown.

Lifecycle/Behaviour

Potworms require reasonably moist situations to survive, for example high moisture situations in compost will favour their presence over earthworms.

Crops attacked

Potworms feed on decaying organic matter but are also known to feed on fungi and nematodes.

Damage

Potworms lack the mouthparts to be primary pests of truffles. They may be present with truffles when other agents have already damaged them and conditions of high moisture are present, allowing the potworms to feed in the softened truffle tissue. Other damage that may result in the presence of potworms with truffles includes; rots, feeding by other invertebrates or cracks in the peridium.

A truffle with rot, infested with potworms.

Monitoring and thresholds

Potworms will be most noticeable in the grading room.

Management options

Potworms are not regarded as primary pests so management options are not required.

Scales - soft

Pest

Family Coccidae

Summary

Soft scales are non-native sap-sucking insects that can reduce tree vigour on a wide range of mainly exotic tree crops, especially horticultural tree crops, both deciduous and evergreen. Soft scales occur in the southern half of Australia in irrigated horticultural areas or the higher rainfall regions closer to the coast. The scale covering forms as part of the insect itself, in comparison to hard scales where the insect remains attached to its host plant after the scale covering is lifted. Scale infestation is rare in truffle orchards.

A species of soft scale, tentatively identified as frosted scale (*Parthenolecanium pruinosum*), as well as a species tentatively identified as Chinese wax scale (*Ceroplastes sinensis*) have infested hazelnut trees in truffle orchards. Heavy infestations will kill branches and possibly the trees themselves. Soft scales may be present in orchards as a result of an infestation of nursery stock, accidental incursion or from the wind dispersing the crawler stage from nearby alternative infested host plants. Soft scale become resident pests. Ants may be associated with a scale infestation to harvest honeydew excretions and protect the scale from natural enemies. Honeydew excretions can result in the build-up of black sooty mould fungus. Each scale is capable of producing hundreds of eggs so numbers may build up quickly. The main control methods are cultural.

Frosted scale on a hazelnut tree.

Chinese wax scale on a hazelnut tree.

Description

Adult scale are near circular and about 8mm long. Frosted scale adults are dark brown and may have frosting near the edge. Chinese wax scale is grey with darker markings on the top and around the edges. As they mature, females commence laying eggs under the scale covering and, eventually, the female's body is replaced by eggs. The eggs are ovoid and there may be up to 500 per scale. At this stage, the eggs appear like fine sand. Eggs hatch to produce the mobile crawler stage which is oval, flattened, pale brown and about 0.25mm long. Crawlers emerge from the scale covering through a tiny aperture between the scale and the host plant.

Eggs under a Chinese wax scale after the adult has completed egg laying.

Because scale are sapsuckers, they produce honeydew which is deposited on leaves and stems. Fungus grows on this excretion producing black sooty mould.

Lifecycle

There may be one or two generations per year. Winter is spent as immature nymphs. Scales complete their development in spring and commence egg laying in late spring. Egg production continues until the female is replaced by its eggs under the scale covering. Egg hatch commences in December. The crawlers disperse then settle and commence feeding and form a scale covering. They may complete their development and commence a second generation. Scale development slows during winter.

Behaviour

Infestations of scale start on the new growth from crawlers selecting the softer plant tissue after leaving the adult scale to settle. Old scale shells remain on the tree for some time until they eventually dry out and fall off.

Sooty mould stains the trees for some time and eventually fades and also becomes less obvious if new wood is not infested.

Scale insects have a symbiotic relationship with some species of ants. Soft scales exude honeydew that the ants harvest. In return, ants help protect the scale from natural enemies and sometimes carry nymphs around the tree canopy to spread the infestation.

Black sooty mould on an olive tree infested with black scale

Crops attacked

Scale infestation is rare in truffle orchards and only hazelnut trees have been observed to be susceptible. Soft

scales attack a range of horticultural trees crops.

Damage

Feeding by scale reduces tree vigour and can affect shoot growth. Associated sooty mould can interfere with photosynthesis.

Monitoring and thresholds

The first sign that trees are infested with scale is the presence of black sooty mould or the scale insects themselves.

The stage of adult scales in relation to how soon they may commence egg laying can be readily determined by removing individual scale and examining them with a 10X hand lens. If they have commenced laying, the bottom of the scale will be covered with eggs. As egg production ceases, the entire scale cover will be full of eggs. After this time, egg hatch commences and crawlers will be present. This can be verified by use of the hand lens.

'Clouds' of Scale crawlers appear once hatching commences

Timing of hatching can also be determined by collecting twigs with scales attached and placing in a transparent container, such as a glass jar, with small holes in the lid. When eggs hatch, brown clouds of crawlers will appear on the walls of the container.

Considering that scale is a resident pest problem, any presence should be managed to avoid a build-up.

Management options

Biological

Parasitic wasps, specialist scale-feeding ladybirds and generalist predators such as lacewings and spiders feed on scale. But they are unlikely to keep an infestation in check.

Wasp parasite of the Chinese wax scale

Cultural

If a scale infestation is detected early, infested branches can be pruned and destroyed outside the orchard.

Chemical

Horticultural spray oils such as a summer oil can effectively smother and control the mobile crawler stage of scale insects. A series of sprays over the duration of egg hatch is required for such a short term chemical. Should scale become a consistent pest of trees, consideration could be given to obtaining registration of relevant products.

Slaters

Pest

Common pill bug (*Armadillidium vulgare*)

Common rough woodlouse (*Porcellio scaber*)

Slaters, along with slugs, are the most important invertebrate pests in truffle orchards due to their distribution and abundance. They feed directly on truffles. The damage from slugs and slaters is difficult to distinguish and the agent responsible can only be clarified through monitoring.

Summary

Slaters are land-based crustaceans. Common pill bug and common rough woodlouse are introduced and occur mainly in the southern half of Australia and in the higher rainfall regions closer to the coast. They have been recorded in high numbers in truffle orchards and other species of slaters may occur in truffle orchards also. As well as the common names pill bug and wood lice, slaters are also known as sowbugs, based on their resemblance to pigs. A native slater species, flood bug (*Australiodillo bifrons*) has been reported as a pest of broadacre cropping in inland eastern Australia, but has not been recorded in truffle orchards to date. Slaters usually feed on decaying organic matter. They have become important pests in minimum-tillage broadacre crops, damaging seedlings. In truffle orchards, slaters feed on truffles, commencing when they start to size in early summer, especially where they breach the soil surface. The main management methods are biological, cultural, mechanical/physical and chemical.

Description

Slaters are land-based crustaceans. They are hard shelled with a flattened, oval shaped body and usually grey but can be brown or near orange. They have seven body segments, each with a pair of legs. Adults vary in length up to about 20mm. They have two pairs of antennae, one obvious pair and a shorted pair. Pill bugs possess the ability to roll into a tight ball when threatened.

Slaters range in colour and size. The half white slaters in the bottom left quarter of the photo are part way through moulting.

The more common slater species found in truffle orchards are the common pill bug (*A. vulgare*) and common rough woodlouse (*P. scaber*).

Lifecycle/Behaviour

Slaters usual mate in spring. Females retain fertilised eggs and young slaters on their body before the first moult when the young become independent. In the early stages, slaters have only six body segments.

Slaters are nearly always present in moist habitats especially where there is a high level of organic matter. Slaters often occur in large numbers. They are nocturnal seeking shelter under plant debris and rocks and logs during the day. Observations have shown that slaters are attracted to light.

Slaters seek shelter under leaf litter in a truffle orchard.

The blood of slaters contains haemocyanin where copper is required for oxygen transport. Slaters may consume their own faeces to conserve copper and to maintain bacteria that aid with nutrient absorption from their diet including assisting cellulose breakdown.

Crops attacked

Slaters have sclerotised mouthparts and while they feed mainly on decaying organic matter, they also attack seedling plants in broadacre and horticulture crops. In a rare case, slaters climbed into the canopy of apple trees and damaged near mature fruit. Slaters also feed on fungi, carrion and dung. In truffle orchards, they feed on truffles as well as other food sources already described.

Slater feeding damage to a truffle

Slaters can create deep cavities from feeding

Damage

Signs of feeding on truffles by slaters is difficult to distinguish from that by slugs. Slaters feeding on truffles results in shallow or deep holes, gauges and large cavities. This has adverse impacts in terms of; lost weight of the truffle by that directly fed upon and from removing the damage portion to present a smooth face, downgrading of the class of truffle and the extra time required in washing and preparing damaged truffles for sale.

A higher percentage of shallow forming truffles are damaged by slaters and slugs compared to those that form and grow deeper in the soil. Truffles that become exposed are the most likely to be fed upon.

Feeding damage by slaters may lead to higher levels of rot in truffles.

Monitoring and thresholds

The abundance of slaters can be assessed by tile monitoring. The details of this method are provided in the monitoring section of this manual.

Determining a threshold can be clarified by regular monitoring during the season and also from damage assessment at harvest over seasons. Research to date indicates that slaters are most likely to cause significant damage to truffles when their abundance is reasonably high, suggested to be near an average of around 6 to 10 per tile.

Management options

The main management approach to reduce the prevalence of slaters in truffle orchards is cultural and involves modifying orchard attributes to make them less suitable for slater survival. This should be combined with the activity of covering truffles to help shield truffles from attack.

Biological

Predatory beetles that occur in truffle orchards may attack slaters. Some poultry will feed on slaters and unlike slugs, they would be more likely to be detected during the day. Poultry also require management to maintain and their behaviour in truffle orchards may be counter-productive to truffle formation.

Cultural

The following cultural activities are relevant to reducing the prevalence of slugs as well as slaters.

Removal of ground cover such as weeds and fallen leaves within the orchard and vegetation along fence lines will help reduce the abundance of slaters.

Cultivation may help reduce numbers and also induce deeper formation of truffles so they are protected by a layer of soil.

Many truffle orchardists cover truffles as they develop and increase in size. This expansion of truffles results in them breaching the soil surface, cracking the soil surface and softens the soil around the truffle. These effects make truffles more likely to be damaged by slaters. Covering truffles provides a physical barrier to slaters as well as protecting them from sunburn and the potential to induce rots.

A large congregation of slaters found near a truffle 5cm below the soil surface.

Removing unwanted suckers from hazelnut trees helps create a less favourable orchard floor environment for slaters. If suckers are not managed leaf

litter accumulates providing a favourable habitat and slater refuge.

Slaters prefer a moist environment. After truffle host trees have established and irrigation is for the benefit of the truffles, apply only what is required for good truffle production.

In terms of the moisture and temperature within a truffle orchard, maintaining a reasonably open canopy will aid in making the ground floor environment less desirable as a habitat for slaters.

Mechanical/physical

Slaters are attracted to light. The possibility of using lights over pitfall traps to mass trap and kill slaters is suggested for evaluation and possible implementation in truffle orchards that are either reasonably small or have hot spot infestations. This method is yet to be evaluated for effectiveness.

Pitfall traps are a potential management technique that requires further assessment.

Chemical

Products containing iron EDTA are currently available for use against slaters under the Agricultural Pesticides and Veterinary Medicines Authority minor use permit PER87270. Always follow instructions on the product label and permit.

Slugs Pest

Black keeled slug (*Milax gagates*)

Brown field slug (*Deroceras invadens*)

Hedgehog slug (*Arion intermedius*)

Reticulated/Grey field slug (*Deroceras reticulatum*)

Striped field slug (*Lehmannia nyctelia*)

Summary

A range of species of slugs occur in Australian truffle orchards and are the most common species in broadacre cropping regions. All are introduced and have been recorded damaging truffles. Hedgehog slug is present in WA, NSW, Victoria and Tasmania, but has been recorded in just two truffle orchards so far, both in Western Australia. The other species have been recorded more broadly. Slugs commence feeding on truffles when they start to size in early summer, especially where truffles breach the soil surface. The main management methods are biological, cultural, mechanical and chemical.

Slug body parts diagram.

Description

The head bears four tentacles – the two longer upper ones are light sensory and the two lower, shorter ones sense touch and odours. The head also contains the mouthparts which is a tongue-like structure called a radula. This bears minute teeth for rasping food. The foot of slugs contains the alimentary and reproductive systems. Each slug is a hermaphrodite – it has organs of both sexes. Slugs mate with other individuals and lay batches of soft-shelled circular eggs into organic matter and crevices in the ground.

Black keeled slugs at a flaky bran bait monitoring site.

Black keeled slug is common in truffle orchards and are distinguished by the presence of a ridge or keel on their back, most obvious when they contract if disturbed.

Striped slug is common is truffle orchards and are distinguished by the presence of stripes along the top of the body. When brushed they secrete translucent/clear mucus.

Striped slug exudes clear mucus when brushed

Reticulated/grey slug exudes milky/white mucus when brushed.

Reticulated slug or grey field slug is less common in truffle orchards. They are pale brown to cream coloured and sometimes have dark patches on their body. Reticulated slugs secrete white mucus when their skin is brushed.

Brown slug (on the left) and reticulated/grey slug.

Brown field slug also occur in truffle orchards and are distinguished by their dark brown colour and no body markings.

Hedgehog slug exudes yellow mucus when brushed.

Hedgehog slug is a white slug, less commonly found in Australian truffle orchards. Hedgehog slugs secrete yellow mucus when their skin is brushed. It can be distinguished from the other species of slugs by the location of its breathing pore at the front of the mantle – it is at the posterior end of the mantle in other species.

Lifecycle/Behaviour

Slugs enter a quiescence during dry spells such as in summer in a Mediterranean climate region. Some burrow to a reasonable depth such as black keeled slug. Slug activity resumes when conditions change with an increase in moisture levels after rain and air temperature falls. This is the main time breeding occurs.

When threatened, slugs contract their body. Their slime helps to ward off predators but also a slime trail could allow predators to locate them. Slime produced by slugs is specialised and assists slugs to locate members of the same species.

Slugs are nocturnal, seeking shelter under organic matter or rocks during the

day to escape the drying effects of the sun.

Slugs may invade truffle orchards from neighbouring pasture paddocks.

Crops attacked

Unlike snails, slugs do not climb. They feed on decaying organic matter, fungi, lichen and living plant material at ground level, for example vegetables, strawberries, flowers, fallen fruit and truffles. They can damage potato tubers.

Slug damage to a truffle.

Slug eggs and feeding damage in a truffle.

Striped slug feeding on a shallow forming truffle.

Damage

Slugs damage truffles by feeding on them resulting in shallow or deep holes, gauges and large cavities. This has adverse impacts in terms of; lost weight of the truffle by that directly fed upon and from removing the damage portion to present a smooth face, downgrading of the class of truffle and the extra time required in washing and preparing damaged truffles for sale.

A higher percentage of shallow forming truffles are damaged by slugs and slaters compared to those that form and grow deeper in the soil. Truffles that become exposed are the most likely to be fed upon.

Feeding damage by slugs may lead to higher levels of rot in truffles.

Monitoring and thresholds

The abundance of slugs can be assessed by tile monitoring. The details of this method are provided in the monitoring section of this manual.

Determining a threshold can be done on an individual orchard through regular tile monitoring and damage monitoring at

harvest. Monitoring done to date has found that low numbers, suggested to be near an average of around 1 per tile, can result in a significant proportion of truffles being damaged.

Management options

The main management approach to reduce the prevalence of slugs in truffle orchards is cultural and involves modifying orchard attributes to make them less suitable for slug survival. This should be combined with operations to shield truffles from attack.

A carabid beetle that is a predator of slugs.

Biological

Predatory beetles that occur in truffle orchards attack slugs. Poultry, especially ducks, are efficient at removing snails from infested areas but with slugs being more cryptic during the day, may not be controlled by poultry as effectively. Poultry also require management to maintain and their behaviour in truffle orchards may be counter-productive to truffle formation.

Cultural

The following cultural activities are relevant to reducing the prevalence of slaters as well as slugs

Removal of ground cover such as weeds and fallen leaves within the orchard and vegetation along fence lines will help reduce the abundance of slugs.

Cultivation may help reduce numbers and also induce deeper formation of truffles so they are protected by a deeper layer of soil.

Many truffle orchardists cover truffles as they develop and increase in size. This expansion of truffles results in them breaching the soil surface, cracking the soil surface and softens the soil around the truffle. These effects make truffles more likely to be damaged by slugs. Covering truffles provides a physical barrier to slugs as well as protecting them from sunburn and the potential to induce rots.

Removing unwanted suckers from hazelnut trees helps create a less favourable orchard floor environment for slugs. If suckers are not managed leaf litter accumulates providing a favourable habitat and slug refuge.

Slugs prefer a moist environment. After truffle host trees have established and irrigation is for the benefit of the truffles, apply only what is required for good truffle production.

In terms of the moisture and temperature within a truffle orchard, maintaining a reasonably open canopy will aid in making the ground floor environment less desirable as a habitat for slugs.

Where possible and not necessarily every season, a cool burn of ground cover may help reduce slug numbers. The practice of undertaking a burn in truffle orchards has been mentioned as a practice undertaken by only a few orchardists in eastern Australia. Discuss this with other growers or a consultant before undertaking such an operation

and of course temporarily remove any irrigation equipment.

Chemical

Repellents containing garlic or wormwood have been reported to help protect plants from garden snail. Spent coffee grounds are also effective. These treatments may have an impact on slugs also.

Products containing iron EDTA are currently available for use against slugs under the Agricultural Pesticides and Veterinary Medicines Authority minor use permit PER87270. Always follow instructions on the product label and permit.

Garden snail

Pest

Cornu aspersum

Summary

Garden snail is an introduced mollusc that is present across Australia. It is most important as a potential pest of newly planted truffle host trees, but has not been reported as a major pest. Management is mainly biological, cultural and chemical.

A range of stages of garden snail on the trunk of an oak tree.

Description

The shell diameter of adult garden snails can be up to 40mm and consists of four or five spirals (whorls). The shell is generally light brown with dark brown broken bands and yellow transverse stripes. The shell opening is bordered in white. The body of the snail is grey brown and slimy and consists of a head and foot. The head bears four tentacles – the two longer upper ones are light sensory and the two lower, shorter ones sense touch and odours. The head also contains the mouthparts which is a tongue-like structure called a radula. This bears minute teeth for rasping its food. The foot of snails contains the alimentary and reproductive systems. Each snail is a hermaphrodite – it has organs of both sexes. Snails mate with other individuals and lay batches of circular soft-shelled circular eggs about 4mm diameter into organic matter and crevices in the ground.

Lifecycle/Behaviour

Garden snail goes into a quiescence during dry spells, such as in summer in a Mediterranean climate region. The snail body remains anchored to the interior of the shell and retracts into the shell when threatened, during the day, or in harsh conditions. The opening is then covered in hardened mucus to prevent moisture loss. They often attach to a substrate during periods of dry weather. Garden snail is reactivated by moisture and lower temperature. This is the main time breeding occurs. Snails are often present in clusters.

Snails are nocturnal and remain sedentary in a sheltered location during the day to escape the drying effects of the sun.

Crops attacked

Garden snail attacks a wide range of plants, from tree crops like citrus and deciduous fruit trees, including truffle host trees, to grapevines and many vegetables. They have not been reported to feed on truffles.

Damage

Garden snails climb trees to feed on leaves and will attack buds affecting shoot growth. In addition, they can chew the skin of fruit. Despite their

association with the ground, snails have not been reported to feed on truffles.

Monitoring and thresholds

Garden snails are large so their presence and abundance are easily monitored. Truffle host trees are most susceptible to being damaged in newly planted orchards. Whether any action is required to reduce their numbers will depend on the level of feeding and damage to trees.

Management options

Biological

Poultry, especially ducks, are efficient mollusc feeders, however they require management to maintain and their behaviour in truffle orchards may be counter-productive to truffle formation. Predatory beetles may attack young snails.

Cultural

Removal of ground cover such as weeds and fallen leaves within the orchard and vegetation along fence lines will help reduce the abundance of garden snail.

Cultivation may help reduce numbers and where possible and not necessarily every season, a cool burn of ground cover may help reduce numbers also. The practice of undertaking a burn in truffle orchards has been mentioned as a practice undertaken in a few orchards in eastern Australia. The impact of this practice on truffle production requires further research. Discuss this with other growers or a consultant before undertaking such an operation and of course temporarily remove any irrigation equipment.

Chemical

Repellents containing garlic or wormwood have been reported to help protect plants from garden snail as well as spent coffee grounds. Also copper bands on tree trunks can help prevent the snails accessing the canopy.

Small pointed snail — Pest

Prietocella barbara

Summary
Small pointed snail is an introduced species. It occurs across the southern half of Australia and is more abundant in higher rainfall areas. It is similar in appearance to pointed snail (*Cochlicella acuta*) but this species occurs mainly near the coast. Small pointed snail damages plants in drier broadacre areas as well as higher rainfall and irrigated horticultural regions. They also feed on decaying organic matter and can block mini-sprinklers. The main control methods are biological and cultural.

Small pointed snails clustered on the trunk of an oak tree.

Description
Small pointed snail is a conical snail with shells about 10mm long and 8mm at the widest point. It has 7 to 8 spirals (whorls). Shells are pale brown with dark brown patches. The head bears four tentacles – the two longer upper ones are light sensory and the two lower, shorter ones sense touch and odours. The head also contains the mouthparts which is a tongue-like structure called a radula. This bears minute teeth for rasping its food. The foot of snails contains the alimentary and reproductive systems. Each snail is a hermaphrodite – it has organs of both sexes. Snails mate with other individuals and lay batches of circular soft-shelled circular eggs about 0.4mm diameter into organic matter and crevices in the ground.

Lifecycle/Behaviour
The life cycle and behaviour of small pointed snail is similar to that of the garden snail. Snails go into quiescence during dry spells, such as in summer in a Mediterranean climate region. The snail body remains anchored to the interior of the shell and retracts into the shell when threatened and to prevent moisture loss during the day or in harsh conditions. They often attach to a substrate during periods of dry weather. Snails are reactivated by moisture and lower temperature. This is the main time breeding occurs. Snails are often present in clusters.

Snails are nocturnal and remain sedentary in a sheltered location during the day to escape the drying effects of the sun.

Crops attacked
Small pointed snail attacks a wide range of crops and pasture in broadacre drier areas and higher rainfall and irrigated horticultural crop areas. It can be found in tree, vine and vegetable crops,

including truffle host trees. They have not been reported to feed on truffles.

Small pointed snails can interfere with the operation of mini-sprinklers.

Damage

The presence of small pointed snail is not always associated with damage to plants. Feeding damage by the snail in truffle orchards may be important on newly planted trees, but of equal or greater impact is their interfering with mini-sprinklers.

Monitoring and thresholds

Small pointed snails are large enough to be detected by observation and checking mini-sprinklers during watering for interference with the irrigation pattern. Whether any action is required to reduce their numbers will depend on the level of feeding damage if it is observed and the proportion of mini-sprinklers that may be affected.

Management options

A combination of control methods are usually required to provide control.

Biological

Poultry, especially ducks, are efficient mollusc feeders, however they require management to maintain and their behaviour in truffle orchards may be counter-productive to truffle formation. Predatory beetles may attack young snails.

Cultural

Removal of ground cover such as weeds and fallen leaves within the orchard and vegetation along fence lines will help reduce the abundance of small pointed snail.

Cultivation may help reduce numbers and where possible and not necessarily every season, a cool burn of ground cover may help reduce numbers also. The practice of undertaking a burn in truffle orchards has been mentioned as a practice undertaken in a few orchards in eastern Australia. The impact of this practice on truffle production requires further research. Discuss this with other growers or a consultant before undertaking such an operation and of course temporarily remove any irrigation equipment.

Chemical

Repellents containing garlic or wormwood as well as spent coffee grounds may help protect plants from small pointed snail. Also copper bands on tree trunks may help prevent the snails accessing the canopy.

Springtails

Pest / Non-pest

Class Collembola

Summary

Collembola are small invertebrates that occur in truffle orchards, sometimes in large numbers. They are present in a large range of habitats associated with moisture and organic matter. They are omnivorous and indirectly responsible for decomposition of organic matter through their association with soil microbes. Their main food sources are fungal hyphae and spores, bacteria, as well as plant material and pollen. This relationship of springtails and microbes is reflected in observations of them occasionally feeding on truffles. Overall, they are considered to be a minor pest of truffles. Some cultural practices will reduce their abundance.

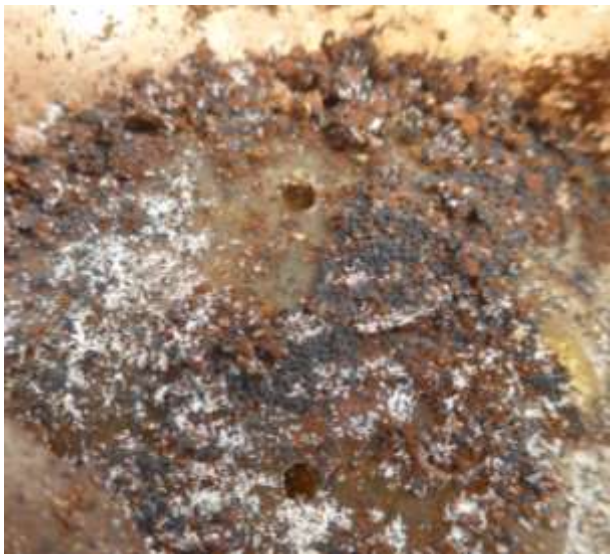
Springtails

Description

Collembola are referred to as hexapods because they have six legs and are closely related to insects but not classed as such. The most abundant Collembola species in truffle orchards are 0.5 to 3 mm long and all are wingless. They possess an abdominal, tail-like appendage that is folded beneath the body and used for jumping when threatened.

Springtails

There are two types of Collembola in truffle orchards. One group is compact dark blue/grey with a velvet-like appearance with two species identified, *Ceratophysella denticulata* and *C. gibbosa*. The other group of springtails are long and relatively thin and yellow/brown. The former type is the only one observed to feed on truffles to date but representatives of both groups have been recorded as pests of cultivated mushrooms.



Springtails (purple/grey) and their cast skins (white) in a pitfall trap.

Lifecycle/Behaviour

Adult springtails continue to moult regularly throughout their life. They are capable of rapid population growth. Male and female springtails occur and females release a pheromone to attract males. Females lay eggs. There does not appear to be any quiescence in hot or cold weather, just a slowing of population growth. They play an important role in decomposition and nutrient cycling in soil ecosystems, and are a major food source for a variety of soil predators.

Springtails are present in many habitats often occurring in dense groups. Collembola occur in moist situations wherever there is organic matter and vegetation cover. They are nocturnal, seeking shelter during the day. They are water loving and sometimes can be seen floating in puddles.

Crops attacked

The collembolan lucerne flea is a well-known pest of pasture. *C. denticulata* is regarded as a pest of edible mushrooms. *C. gibbosa* is yet to be recorded as a pest of edible mushrooms, but is likely to feed on them also. Apart from these examples, the presence of collembolans is regarded as an indication of environmental health. They have been reported as a problem to truffles occasionally, but because of their small size and association with over-ripe, already damaged or rotten truffle, their pest status may be underestimated.

Damage

Damage by springtails is more likely to occur where there are cracks and crevices in the truffle periderm where they tend to congregate. They create tiny pinholes, smaller than those created by truffle beetles or other invertebrate pests, and small galleries or pits within the truffle just under the periderm. The damage is reasonably shallow. Truffles that have been damaged by other invertebrates such as slugs or slaters, or infected with rots, may be more susceptible to being attacked by springtails.

Small pinholes and galleries in a cross section of a truffle suspected to have been caused by springtails

Springtails within small galleries in a damaged truffle. It is unknown if the springtails are primary or secondary pests.

Because of their small size and association with over-ripe, already damaged or rotten truffle, their pest status may be underestimated.

Monitoring and thresholds

The presence of springtails in an orchard does not necessarily indicate truffles will be damaged by them. Monitoring during harvest and grading should be conducted to identify the type and cause of damage that is occurring. Springtails are commonly found on harvested truffles that have been damaged previously or are rotten, but they may not be the primary cause of damage.

If springtails are suspected of causing damage to truffles, their presence in the orchard can be confirmed with pitfall traps. Adding truffle pieces to pitfall traps does not improve their efficiency. Springtails may be observed under tiles when monitoring other pests, but this method is less reliable.

Management options

Biological

Predatory carabid and staphylinid beetles that are common in truffle orchards are reported to feed on springtails.

Cultural

Management practices that make the truffle orchard environment less favourable to ground invertebrates such as slugs and slaters are also likely to make is less favourable for springtails. This should be combined with operations to shield truffles from attack.

Removal of ground cover such as weeds and fallen leaves within the orchard and vegetation along fence lines will help reduce the abundance of springtails.

Removing unwanted suckers and associated leaf litter from hazelnut trees helps create a less favourable orchard floor environment for springtails.

Springtails prefer a moist environment. After truffle host trees have established and irrigation is for the benefit of the truffles, apply only what is required for good truffle production.

In terms of the moisture and temperature within a truffle orchard, maintaining a reasonably open canopy will aid in making the ground floor environment less desirable as a habitat for springtails.

Cultivation may induce deeper formation of truffles so will be protected by a deeper layer of soil.

As truffles develop and increase in size they can breach the soil surface as well as softening the soil around the truffle. These effects make truffles more likely to be damaged by springtails. Covering truffles provides a physical barrier to springtails as well as protecting them from sunburn and the potential to induce rots.

Thrips – greenhouse thrips

Pest

Heliothrips haemorrhoidalis

Summary:
Greenhouse thrips feed on leaves of a range of ornamental and fruit crops affecting the appearance and health of plants. They also feed on the skin of fruit such as avocados, persimmons and citrus, resulting in cosmetic damage that downgrades the value of fruit or renders it unmarketable. It is likely that it is an exotic species to Australia. They occur across Australia up to the sub tropics but have not been reported from the Northern Territory. Greenhouse thrips have been observed in low abundance only on oak trees and control has not been considered necessary.

Adult and yellow nymphs of greenhouse thrips.

Description:
Greenhouse thrips are elongate cigar shaped insects about 1.5mm long with narrow fringed wings held along their body. Adults are black with white antennae, legs and wings. A white band is present across the body, formed at the point of attachment of the wings. Nymphs are white to yellow and wingless and carry a drop of excrement on the tip of their abdomen. Their presence is associated with a grey appearance to foliage as a result of their feeding.

Lifecycle:
The entire life cycle is spent on the host tree - leaves or fruit - including the pupal stage. Adults lay single eggs within plant tissue. Adults can live for up to three months.

Behaviour:
Although adults possess wings, they are relatively immobile. Therefore infestations are most likely to be localised initially and spread relatively slowly. Thrips are present on mature leaves rather than young leaves, feeding on the upper or lower leaf surface depending on the plant infested. They are most likely to feed on fruit in clusters, feeding where fruit are touching.

Crops attacked:
Greenhouse thrips feed on the leaves of a range of ornamental plants such as fuchsia, pittosporum and rhododendron, and in truffle orchards on oak tree leaves. They feed on leaves and fruit of some horticultural crops especially citrus, avocado and persimmon.

Damage:
Feeding on leaves causes them to turn grey reducing plant vigour. Only minor populations of thrips have been observed on mature oaks. They are not considered to be a major pest.

Adult and yellow nymphs of greenhouse thrips on an oak leaf and characteristic damage.

Monitoring and threshholds:

The damage to leaves is the first sign of an infestation. No threshhold for action has been set because they have not been considered to be sufficiently abundant to warrant control.

Management Options:

Biological:

A wasp parasite *Thripobius javae* occurs in eastern Australia and has been introduced to Western Australia. This wasp attacks GHT, laying an egg inside nymphs. The wasp completes its development inside the thrips to emerge as an adult. The establishment of the parasite in WA after the releases is yet to be assessed.

Cultural:

Because greenhouse thrips thrive in conditions of high humidity and sheltered situations, pruning to open the canopy and promote air movement around foliage will help reduce the favourability of the tree for infestation and reproduction.

Greenhouse thrips wasp parasite with characteristic black spots on the abdomen (top), and two pairs of frail wings (second from top), wasp pupa (second from bottom) and greenhouse thrips adult approx. 1.5mm long (bottom)

Apple weevil

Pest

Otiorhynchus cribricollis

Summary

Weevils belong to a group of beetles that have a prominent snout on which their mouthparts are located. They are very hard shelled and most are flightless. Adults feed on above ground parts of plants such as leaves and green bark. The larval stage is soft bodied, and usually soil borne feeding on plant roots and tubers.

Apple weevil is a non-native insect primarily a pest of horticultural tree crops and very occasionally vegetables. The insect survives in low populations in pasture and higher numbers in fruit orchards so can be a resident pest of newly planted truffle host trees. They occur primarily in coastal parts of southern Australia, and are not reported from Queensland, Tasmania and the Northern Territory. Adults are the main pest stage in truffle orchards because they can defoliate young trees and by feeding on green bark can kill branches and the growing tip. Trees up to two years after transplanting are most susceptible to attack. Larvae are yet to be associated with damage to trees but occasionally have been found damaging truffles. Adults are present from late November, to the end of summer but are inactive during the hot part of summer and burrow into the soil. Low numbers may over-winter. Newly planted trees that suffer leaf damage should be monitored to determine the cause. Adults are nocturnal and may burrow into soil near the stem of the plant during the day. At night they climb into the tree to feed. The main control method is mechanical. Soil borne larvae are present from autumn to late spring.

Apple weevil adult

Apple weevil larva and damage to truffle.

Description

Adult apple weevil are chocolate brown and 6 to 8mm long with rows of pits on their back bearing spines. Other parts of their body including their legs are also covered in spines. They are flightless and all are females. During the day, they may remain in sheltered parts of the canopy, burrow into soil or under moss or debris at the base of trees and at night climb into trees to recommence feeding. Their feeding results on leaves with scalloped edges and holes. They

also feed on green bark, which can kill branches and the growing tip.

Other weevils can be a similar size to apple weevil but differ in colour, shape and size.

Larvae are soil borne, feeding on plant roots and rarely on truffles. They are typical of weevil larvae: 'C' shaped, brown head capsule, obvious black jaws, legless and white to cream coloured.

Lifecycle

There is only one generation of apple weevil per year. Winter is spent mainly as soil borne larvae; low numbers of adults may over-winter. Larvae pupate in the soil and adults emerge from late November to December. Adults feed in December but become inactive during hot weather, burrowing into soil. After this time, they commence laying eggs, parthenogenitically – there are no males. Adults feed again from this time also. Eggs are laid singly on leaves but after hatching larvae burrow into the soil and feed on plant roots. More mature larvae may feed on truffles if they form near where larvae occur in the soil.

Behaviour

Because adult apple weevils are flightless, damage to truffle host trees can only occur by a resident population or adults walking in from an adjacent infested area. Adults are nocturnal, feeding at night. During the day they can be found in the upper soil surface at the base of trees and under debris, or in the tree canopy if there are places where they can harbour away from light. When disturbed, they fall to the ground and feign death.

Crops attacked

Adult apple weevils attack a wide range of tree crops especially deciduous fruit and olives. Rarely, they attack newly transplanted vegetable seedlings. They survive in pasture probably feeding on broad-leafed plants including some weed species. The soil borne larvae are not considered major pests but are a minor, occasional pest of potatoes attacking tubers. They feed on roots of the trees adults attack as well as weeds. They have been recorded feeding on truffles very occasionally.

Scalloping and holes on hazelnut leaves by apple weevil adult feeding.

Stem girdling by apple weevil adults.

Damage

Newly planted trees are damaged when weevils feed on soft green bark of branches and near the growing tip. As a result, branches and growing tips can

be killed. Such damage results in adverse tree shape as they grow. Adult feeding on leaves resulting in characteristic leaf scalloping and holes is less important. Damage to truffles by larvae can occur but is rare.

Monitoring and thresholds

Transplanted trees should be checked for feeding on leaves and bark. Dead branches and growing tips may be present. Confirm the cause by digging around the base of the tree or check the canopy at night. Single faced cardboard bands with the corrugations aligned next to the trunk of the trees provide a site where weevils congregate during the day and so can be used to monitor weevil presence.

Whether action is required depends on the abundance of weevils and the extent of damage to trees across the orchard.

Management options

Biological

Because apple weevil adults are nocturnal and hard-shelled, naturally occurring biological control agents are unlikely to assist with insect management.

Cultural

Where sites selected for planting a truffle orchard have been very weedy or the area was previously the site of a deciduous fruit tree orchard, there is some chance weevils may be present. For such sites where apple weevil is expected to occur, or have a history of being present, the longer the site can be kept free of vegetation, the greater the chance that the weevil population will be low when truffle host trees are planted. Care should be taken to ensure removing vegetation for a period of time will not make the site susceptible to wind or water erosion.

Apple weevil adults trapped in a band of artificial fibre attached to the trunk of an olive tree.

Mechanical/Physical

Newly planted truffle host trees can be protected from attack by apple weevil adults by attaching a band of fluffy crafter's batting to the trunk. The spines on the weevil's body help to trap the weevils, preventing them accessing the canopy. The effect of the bands may be enhanced if the batting is drenched with hot chilli.

Fuller's rose weevil Pest

Naupactus cervinus

Summary

Weevils belong to a group of beetles that have a prominent snout on which their mouthparts are located. They are very hard shelled and most are flightless. Adults feed on above ground parts of plants such as leaves and green bark. The larval stage is soft bodied, and usually soil borne feeding on plant roots and tubers.

Fuller's rose weevil is a non-native insect primarily a pest of horticultural tree crops. The insect survives in low populations in pasture and higher numbers in fruit orchards so can be a resident pest of newly planted truffle host trees. They occur in fruit growing regions across southern Australia. Adults are leaf feeding but the main damage they cause is blocking mini-sprinklers when laying eggs. Trees up to two years after transplanting are most susceptible to defoliation, but sprinkler blockage is an issue for an orchard of any age. Larvae are root feeding but are yet to be associated with damage to trees but because they are soil borne could damage truffles. Adults are present from late November to the end of summer. Newly planted trees that suffer leaf damage should be monitored to determine the cause. Adults feed at any time of day. The main control method is mechanical. Soil borne larvae are present from mid summer to late spring.

Description

Adult Fuller's rose weevil are grey with yellow markings on the side where the thorax and abdomen meet, and also half way along each lateral side of the abdomen. They are around 10mm long with the head and front part of the thorax narrower than the abdomen. They are not covered in spines. They are flightless and all are females. They are active during the day, feeding on leaves resulting in characteristic scalloping associated with a lot of frass. When mature, adults lay eggs as a mass, the ovipositor being nearly as long as the weevil. The gel within an egg mass dries to a hard waterproof cement-like substance. These egg mases may be laid between leaves that get stuck together or in mini-sprinklers. When egg masses are laid in a mini-sprinkler, this can interfere with the irrigation pattern or block them altogether.

Fuller's rose weevil adult and associated leaf damage.

Fuller's rose weevil larva

Other weevils can be a similar size to Fuller's rose weevil but differ in colour, shape and size.

Larvae are soil borne, feeding on plant roots and occasionally on truffles. They are typical of weevil larvae: 'C' shaped, white head capsule, obvious black jaws, legless and yellow to cream coloured.

Lifecycle

There is only one generation per year. Winter is spent mainly as soil borne larvae which pupate in the soil. Adults emerge from late November to December. After feeding they commence laying eggs, parthenogenitically – there are no males. Eggs are laid on leaves or in mini-sprinklers but after hatching larvae burrow into the soil and feed on plant roots. More mature larvae may feed on truffles if they form near where larvae occur in the soil.

Behaviour

Because adult Fuller's rose weevils are flightless, damage to truffle host trees can only occur by a resident population or adults walking in from an adjacent infested area. Adults feed and lay eggs during the day and night.

Crops attacked

Adult Fuller's rose weevils attack a wide range of tree crops especially deciduous fruit and citrus and some weeds. The soil borne larvae are not considered major pests. They feed on roots of the trees adults attack. They may feed on truffles.

Damage

The main feeding activity of Fuller's rose weevil adults is to damage leaves. It is not known to be damaging to truffle tree hosts, even on newly planted trees. The adverse effect on irrigation as a result of egg masses being laid in mini-sprinklers is the most important aspect of an infestation of Fuller's rose weevil. Damage to truffles by larvae may occur but has not been reported to date.

The yellow plug affecting the operation of this mini-sprinkler is a Fuller's rose weevil egg mass.

Monitoring and thresholds

If Fuller's rose weevil are present in an orchard, the characteristic leaf damage by adults will appear before mini-sprinkler blockage occurs. Because weevils are active during the day, they may be seen feeding on leaves. If weevils have been a problem in one season, in November the following season, stakes with the top 3cm coated in polybutane sticky material to trap weevil adults, can be driven into the ground across the orchard and to gauge the timing of their arrival, their extent and magnitude. If present on most stakes across the orchard, some action should be considered.

Because weevils feed during the day and are flightless, tapping foliage over a container can also be used as a monitoring method. If a set number of areas area checked in this way on each monitoring occasion, the abundance of weevils over time can be quantified.

Fuller's rose weevil adults trapped by polybutane sticky material pasted onto the top of a wooden post.

Management options

Biological

Because Fuller's rose weevil adults are hard-shelled and larvae are soil borne, naturally occurring biological control agents are unlikely to assist with insect management.

An egg parasite of Fuller's rose weevil occurs in eastern Australia, but its effect is low to moderate.

Cultural

Where sites selected for planting a truffle orchard have been very weedy or there is a history of this weevil being present, then cultural options should be considered. The longer the site can be kept free of vegetation, the greater the chance that the weevil population will decline to low levels. Care should be taken to ensure removing vegetation for a period of time will not make the site susceptible to wind or water erosion.

Mechanical/Physical

Because Fuller's rose weevil adults do not have the spines that are present on apple weevil adults, applying crafter's batting to trunks will not prevent weevils from accessing the canopy to feed.

With respect to the adult's egg laying affecting mini-sprinklers, certain types of sprinklers are less affected, see table 3.

Table 3 Comparison among sprinkler types for their susceptibility to being blocked by egg laying adult FRW

	% Blocked		
Mini-sprinkler	Site 1	Site 2	Site 3
Hardie Waterbird V.	2.2	2.5	0
Ein-dor 670-861-90	0	0	0
Ein-dor 670-841-90	40	7.5	14.3
Dan 2001 stake	17.8	17.5	0
Dan 2001 drop assembly	2.2	0	0
Wingfield Orbitor	2.2	7.5	0
Wingfield Challenger	0	2.5	0
Wingfield drop assembly	13.3	7.5	0
Amiad Rondo	4.4	2.5	0
Amiad Tornado one piece	0	0	0
Amiad Tornado pull apart	0	0	0
Amiad Tornado Dynamic	64.4	52.5	42.9
Nelson R 10	0	0	0
Dan upside down swivel	2.9	0	0

Garden weevil

Pest

Phlyctinus callosus

Summary

Weevils belong to a group of beetles that have a prominent snout on which their mouthparts are located. They are very hard shelled and most are flightless. Adults feed on above ground parts of plants such as leaves and green bark. The larval stage is soft bodied, and usually soil borne feeding on plant roots and tubers.

Garden weevil is a non-native insect primarily a pest of horticultural tree and vine crops and very occasionally vegetables. The insect survives in low to high populations in pasture depending on the prevalence of host plants considered to be weeds. High numbers can occur in fruit orchards. Therefore, garden weevil can be a resident pest of newly planted truffle host trees. They occur primarily in coastal parts of southern Australia, and are not reported from Queensland or the Northern Territory. Adults are the main pest stage in truffle orchards because they can defoliate young trees and by feeding on green bark may kill branches and the growing tip. Trees up to two years after transplanting are most susceptible to attack. Soil borne larvae are yet to be associated with damage to trees but may damage truffles. Adults are present from September, to the end of summer. Low numbers may over-winter. Newly planted trees that suffer leaf damage should be monitored to determine the cause. Adults are nocturnal, seeking refuge in the canopy of the host. The main control method is mechanical. Soil borne larvae are present from mid-summer to spring.

Garden weevil adults and leaf scalloping.

Description

Adult garden weevil are grey-brown, about 7 millimetres long, and are flightless. They have a bulbous abdomen with a prominent pale white V stripe across the end of the abdomen. They do not bear spines. Both sexes occur with mating required for females to be able to lay eggs. During the day, they shelter in the canopy and at night feed on all young parts of the host plant. Their feeding on leaves results in scalloped edges and holes. They also feed on green bark, which may kill branches and the growing tip.

Other weevils can be a similar to garden weevil but differ in colour, shape and size.

Larvae are soil borne, feeding on plant roots and occasionally on truffles. They are typical of weevil larvae: ‘C’ shaped, brown head capsule, obvious black jaws, legless and white to cream coloured. Larvae of garden weevil are difficult to distinguish from those of apple weevil.

The more common species of weevils found in truffle orchards; left to right apple weevil, garden weevil, whitefringed weevil, fullers rose weevil and vegetable weevil.

Lifecycle

There is thought to be one generation per year but there may be a smaller second generation, or possibly a later emergence of adults in December from the over-wintering larval stage. Winter is spent mainly as soil borne larvae; low numbers of adults may over-winter. Larvae pupate in the soil and adults emerge from September to December with most emerging from late October to November. Adults commence feeding after they emerge and commence egg laying soon after mating. Eggs are laid in clusters and may be inserted in hollow plant material or in the soil. After hatching, larvae burrow into the soil and feed on plant roots. More mature larvae may feed on truffles if they form near where larvae occur in the soil.

Behaviour

Because adult garden weevils are flightless, damage to truffle host trees can only occur by a resident population or adults walking in from an adjacent infested area. Adults are nocturnal feeding at night and during the day they seek shelter in the canopy of the host away from light.

Crops attacked

Adult garden weevils attack a wide range of tree crops especially deciduous fruit and occasionally olives and ground crops such as strawberries and vegetables. They survive in pasture probably feeding on broad-leafed plants including some weed species for example capeweed and sorrel. The soil borne larvae are not considered major pests but occasionally damage potato tubers. They feed on roots of the trees which the adults attack as well as some weeds. They may feed on truffles.

Damage

Damage to truffle host trees and truffles themselves, would be similar to that of adults and larvae of apple weevil, but apple weevil has been recorded more commonly as a pest of trees killing branches and the growing tip and the larvae occasionally damaging truffles.

Monitoring and thresholds

Transplanted trees should be checked for feeding on leaves and bark. Dead branches and growing tips may be present. Confirm the cause by checking the canopy at night. Single faced cardboard bands with the corrugations aligned next to the trunk of the trees provide a site where weevils congregate during the day and so can be used to monitor weevil presence.

Whether action is required depends on the abundance of weevils and the extent of damage to trees across the orchard.

Management options

Biological

A wasp that attacks and kills eggs of garden weevil has been identified in South Africa, the origin of this weevil. While high levels of parasitism have been recorded, the level of parasitism would be inconsistent due the cryptic nature of oviposition sites.

Research and experience by some primary producers have shown that poultry such as guinea fowl, bantams, chickens, turkeys and ducks may assist

in reducing the abundance of garden weevil by feeding on adults. Should this strategy be contemplated, protection of poultry from foxes would need to be taken into account. Poultry also require management to maintain and their behaviour in truffle orchards may be counter-productive to truffle formation

Research on the use of nematodes that specifically attack the soil borne stages of insects has shown this form of control to be unsuccessful against garden weevil. Further studies with other species and strains of nematodes may prove more successful.

Cultural

Where sites selected for planting a truffle orchard have been very weedy or the area was the site of a deciduous fruit tree orchard or vineyard, there is some chance weevils may be present. For such sites where garden weevil is expected to occur, the longer the site can be kept free of vegetation, the greater the chance that the weevil population will be low when truffle host trees are planted. Care should be taken to ensure removing vegetation for a period of time will not make the site susceptible to wind or water erosion.

Mechanical/Physical

Polybutane sticky trunk bands have been shown to be effective in excluding weevil adults from entering tree canopies. To avoid phytotoxic effects of placing such material directly on the trunk, a substrate band of impervious material would need to be applied first. Such a method is laborious and expensive.

There are missed reports on the effectiveness of trunk bands of crafters' batting in protecting host trees from attack by garden weevil adults, as used for apple weevil. Garden weevil does not possess the spines present over the body of apple weevil adults that help trap those weevils. In a laboratory experiment, the effect of the bands as a means of exclusion was enhanced when the batting was drenched with hot chilli.

Hypsomus weevil Pest

***Hypsomus* sp.**

Summary
Weevils belong to a group of beetles that have a prominent snout on which their mouthparts are located. They are very hard shelled and most are flightless. Adults feed on above ground parts of plants such as leaves and green bark. The larval stage is soft bodied, and usually soil borne feeding on plant roots and tubers.

Hypsomus weevils.

There is little information available on this exotic species of weevil from southern Africa. They are a pest in truffle orchards because adults are small enough to seek shelter in mini-sprinklers and interfere with their irrigation pattern or block them.

Adults are about 2mm long and are grey with white lateral stripes and some stripes over their back. Whether truffle host trees are food plants for adults or they feed on ground floor plants or invade by walking or flying from adjacent areas of vegetation is not known. They are abundant during summer when truffle orchards require irrigation.

Little is known also about the larval stage of this weevil. Like other insects in this group, the larvae probably feed within stems of grasses.

Hypsomus weevils on a mini-sprinkler.

More investigations are required on the biology and management of *Hypsomus* weevils to consider ways to reduce their abundance in truffle orchards. Whether particular types of mini-sprinklers are less subject to being affected by them also requires further study.

Redlegged weevils

Pest

***Catasarcus* spp.**

Summary

Weevils belong to a group of beetles that have a prominent snout on which their mouthparts are located. They are very hard shelled and most are flightless. Adults feed on above ground parts of plants such as leaves and green bark. The larval stage is soft bodied, and usually soil borne feeding on plant roots and tubers.

Redlegged weevils are native, leaf-feeding insects and are a minor cosmetic pest of cultivated native plants and other ornamental plants. They have been recorded feeding on foliage of citrus, oaks, olives, passionfruit and tagasaste. They are restricted to Western Australia and some parts of South Australia and Victoria. At least 41 different species have been identified. The weevil adults are wingless so an infestation in truffle orchards is likely to be adjacent to areas of native vegetation.

Catasarcus weevil.

Description

Adults are heavily sclerotised and about 15 mm long and are flightless. The most common species has cream coloured stripes on its head, a black thorax, yellow/cream coloured pits on an otherwise black abdomen and red/grey legs.

Little is known of the larval stage. It is most likely to be soil borne feeding on the roots of native plants or cultivated plants on which the adults have been feeding.

Life cycle

The life cycle of redlegged weevils is not well known but being such a large weevil it is likely there is only one generation per year but the duration over which they emerge is not known. Adults are abundant from late spring to late summer. Because the adults do not fly, it is likely that eggs are laid near where adults feed. Eggs are laid in clusters just below the soil surface and the larvae feed on the roots of eucalypts. It is not known how long the larvae take to develop.

Behaviour

Because adult redlegged weevils are flightless, damage to truffle host trees can only occur by a resident population or adults walking in from an adjacent infested area of native vegetation. Adults feed during the day. When disturbed, adults fall to the ground and feign death.

Crops attacked

Redlegged weevils have been regarded as a pest when they scallop leaves of native or exotic plants used as cut flowers. If they infest newly planted trees, the level of leaf loss may affect tree growth.

Feeding damage from *Catasarcus* weevil adult.

Catasarcus weevil damage to the tip of an oak tree.

Damage

Weevils chew the leaves of plants around the edges, giving a scalloped appearance. Branch death has not been observed, but tip damage has been observed on oak trees.

Monitoring and thresholds

Transplanted trees should be checked for feeding on leaves and the weevils themselves because they feed during the day and are relatively large. As well as scalloped leaves, damaged growing tips may be present.

Whether action is required depends on the abundance of weevils and the extent of damage to trees across the orchard.

Management options

To date, the abundance of redlegged weevils in truffle orchards has not been high. Because adults mainly feed on leaves only and in mature trees, it is unlikely that control of weevils would be required.

Whitefringed weevil

Pest

Naupactus leucoloma

Summary

Weevils belong to a group of beetles that have a prominent snout on which their mouthparts are located. They are very hard shelled and most are flightless. Adults feed on above ground parts of plants such as leaves and green bark. The larval stage is soft bodied, and usually soil borne feeding on plant roots and tubers.

Whitefringed weevil adult

Whitefringed weevil is a non-native insect, primarily a pest of vegetables especially root crops, pasture especially lucerne or legume-based pastures and occasionally horticultural tree crops and observed attacking oak trees when newly planted. The insect survives in low to high populations in pasture but declines to lower numbers in continuously cropped vegetable areas and in orchards. Therefore, the weevil may be present as a resident pest of newly planted truffle host trees. They occur primarily in coastal parts and irrigated areas of southern Australia and the tablelands of Far North Queensland, but are not reported from the Northern Territory. Adults are the main pest stage in truffle orchards because they can defoliate young trees. Trees up to two years after transplanting are most susceptible to attack. Larvae are root feeding and are yet to be associated with damage to trees but could potentially damage truffles. Adults are present from late spring to autumn. Newly planted trees that suffer leaf damage should be monitored to determine the cause. Adults are active during the day. The main control method is cultural. Soil borne larvae are present from autumn to mid-summer.

Description

Adult whitefringed weevil are grey with a pale stripe down each side of the body and 10 to 14mm long. Their body is covered in fine hairs. They are flightless and all are females. Their feeding on leaves results in scalloped edges and holes. Continued feeding may defoliate young trees.

Other weevils can be a similar size to whitefringed weevil but differ in colour, shape and size.

Whitefringed weevil larva

Larvae are soil borne, feeding on plant roots but have not been recorded to feed on truffles but would be capable of doing so should a truffle form near larvae. They are typical of weevil larvae: ‘C’ shaped, white head capsule, obvious

black jaws, legless and white to cream coloured.

Lifecycle
There is only one generation per year. Winter is spent mainly as soil borne larvae. Larvae pupate in the soil and adults emerge from late November to January. Adults feed as soon as they emerge. After a relatively short period of feeding, they commence laying eggs, parthenogenitically – there are no males. Eggs are laid in clusters held together by a cement that binds to soil. Egg masses are very cryptic in soil. Each weevil is capable of laying hundreds of eggs. After hatching larvae burrow into the soil and feed on plant roots and later tubers such as potatoes. More mature larvae may feed on truffles if they form near where larvae occur in the soil.

Behaviour
Because adult whitefringed weevils are flightless, damage to truffle host trees can only occur by a resident population or adults walking in from an adjacent infested area. Adults feed during the day. When disturbed on vegetation they fall to the ground and feign death.

Crops attacked
Adult whitefringed weevil are foliage feeders on a wide range of plants, for example pasture, vegetables, winegrapes, avocados and oaks. They survive in pasture probably feeding on legumes as well as other broad-leafed plants including some weed species. Survival rate is poor when they have access to grasses only. Larvae feed on plant roots of the same crops and have been a major pest of potatoes. They may damage truffles if they form near larvae in the soil.

Damage
Newly planted trees are damaged when weevils feed on leaves, adversely affecting tree vigour and growth. Damage to truffles by larvae may occur but it is unlikely to be common.

Monitoring and thresholds
Newly transplanted trees should be checked for leaf feeding. Because the adults feed during the day and are reasonably large, they should be easily seen if they are the cause. Whether action is taken depends on the extent of damage to trees across the orchard.

Management options
Biological
Because whitefringed weevil adults are hard-shelled and larvae are soil borne, naturally occurring biological control agents are unlikely to assist with insect management.

Cultural
Where a site selected for a truffle orchard has been very weedy or had legume based pasture, there is some chance weevils may be present. For such sites where whitefringed weevil is expected to occur, the longer the site can be kept free of vegetation, the greater the chance that the weevil population will be low when truffle host trees are planted. Care should be taken to ensure removing vegetation for a period of time will not make the site susceptible to wind or water erosion.

Mechanical/Physical
Whether attaching a band of fluffy crafter's batting to the trunk, as used for apple weevil, prevents the adults from accessing leaves is not known. Because adults are covered in short hairs, they may be trapped by the batting. Any effect such bands may have would be enhanced if they were drenched with hot chilli.

European truffle beetle Exotic

Leiodes cinnamomeus

This beetle causes the same damage to truffles as Australian truffle beetle (ATB), potentially rendering individual truffles a complete loss. Taxonomically the European truffle beetle (ETB) belongs to a different family of beetles, Leiodidae. The Australian beetle belongs to the family Nitidulidae. The main distinguishing characters between the two beetles are that adult ATB has club like antennae and many rows of spines along its back, whereas ETB is larger and has neither of these features.

European truffle beetle (ETB) (top) and Australian truffle (ATB) beetle (below). Note the differences, with ATB having clubbed antennae (indicated by arrow) and rows of short spines on its back.

Host range

Both larvae and adults of European truffle beetle are obligate truffle feeders and is an important pest of *Tuber melanosporum*. It is likely that any native truffles that occur in the forests of Europe, and possibly Australia, would be a suitable host for the beetle.

Distribution

As the common name implies, these beetles are native to Europe.

European truffle beetle larvae infesting an immature truffle.

Dispersal

Like ATB, ETB is capable of flight but only for short dispersal flights so that adults can locate truffle near to where they emerge. It is most likely to be moved over long distances as adults or larvae in infested truffle. Depending on the longevity of adults or larvae, they may be able to survive for reasonable periods of time in imported truffles.

Management

Research is underway in Europe to determine methods that will reduce the damage the beetles cause. Insecticides are not used to control the insect in Europe, with the main focus currently on whether trapping adults with attractants in specially designed traps will be effective in reducing populations (M. Martín Santafé, pers. comm.).

Truffle fly — Exotic

***Suillia* spp.**

Truffle flies belong to the fly family Heleomyzidae. There are many species of flies in this genus in Europe. Six have been associated with damage to black truffle in Spain (Fortea and Santafé, 2018). No obligate truffle feeding flies were identified in Australia during this project, but flies from the Heleomyzidae family occur in Australia. All flies observed on truffles during this project were regarded as opportunistic species that were either generalist fungus feeding flies such as sciarids or flies that feed on decaying organic matter.

Suillia sp. fly, adult truffle flies are about 10mm long.

Host range

Apart from truffles, the host range of this fly is not known. The flies are well adapted to locating truffles and this ability has been used by people to locate truffles for harvest. The flies use the scent of ripe truffles to indicate where they should lay eggs. Larvae dig after hatching to feed on truffles. The larvae are obligate truffle feeders.

Distribution

Truffle fly occurs in Europe.

Dispersal

Descriptions of the flight of flies as jumping rather than flying indicate that they can disperse by flight but not over long distances. If these insects are truly obligate truffle feeders, the most likely entry to Australia is via the larval stage in infested truffle. Depending on the longevity of larvae, they may be able to survive for reasonable periods of time in imported truffles.

Management

An attractant and sticky paper are available for attracting and killing truffle flies in Europe (Fortea, V.P. & Santafé, 2018), but their effectiveness is not well documented.

Summary
A range of vertebrate animals have been recorded to cause damage in truffle orchards. In a 2016 survey of growers, marsupials, including kangaroos, echidnas and bandicoots were the most frequently reported damage causing vertebrate. In descending order of frequency birds, rabbit and hares, foxes, mice, rats, pigs, deer and goats were also reported to have caused damage. Except for one instance, their prevalence was recorded as low and other than for deer and goats, their impact was also low

In severe cases bird damage may lead to ring barking of trees

Damage
Vertebrates can cause a range of damage including: damaging fences and irrigation infrastructure, damaging branches and ringbarking trees, burrowing and creating holes in the orchard floor, and also eating truffles. Where fencing or irrigation equipment is damaged, regular maintenance is needed.

Note: Vertebrates, along with invertebrates, are involved with spore dispersal of truffles. Marsupials are known to eat native species of truffles and may be attracted to cultivated truffles.

Monitoring thresholds
Regularly check trees, fences and irrigation equipment for signs of damage.

Management options
Management varies depending on the type of pest. Consult your local Department of Agriculture or biosecurity/Landcare group for advice on feral pest management control. Restrictions surround the control of native animals, consult your relevant state government department for further information.

Mechanical/physical
Fences, especially incorporating electrified wires, can exclude many of the mammals.

Quality fencing can restrict many pest mammals that may cause damage to orchard infrastructure, trees or the truffles themselves.

Australian honey fungus — Disease

Armillaria luteobubalina

Summary
Australian honey fungus is an endemic parasitic fungus that can infect the roots of most shrub and tree species, eventually killing them. In natural forests honey fungus infects and kills trees that have been weakened by some other factor, such as waterlogging, drought or lack of light. The fungus has been observed in truffle orchards in Western Australia but is also widely distributed in eastern Australia.

Fruiting body of *Armillaria* root rot.

Symptoms
The fruiting bodies of *Armillaria* root rot are honey coloured mushrooms with white to cream gills and a cream to brown stem with a collar. Apart from the characteristic fruiting bodies, symptoms of infection are white to cream fungal matting just below the bark of affected roots and stems.

Monitoring
The honey fungus fruit often in large clusters at the tree base or along the roots of infected or dead plants in early autumn.

Transmission and disease expression
The source of infection is root to root contact from diseased trees. Spores produced by the mushroom fruiting bodies during wet autumn conditions can also be dispersed by wind to neighbouring plants.

Management
The infection risk can be reduced by removing tree roots as much as possible when preparing land for a truffle orchard to remove possible onsite sources of infection. The edge of an orchard adjacent to native vegetation can also be deep ripped to reduce root growth from trees outside of the orchard into the orchard.

Bacterial Blight

Disease

Xanthomonas sp.

Summary

Bacterial blight is considered the most serious disease affecting hazelnut production worldwide. Up to 10% plant mortality may occur, with most losses in young trees, one to four years old. Plants are more susceptible when young and succulent. The pathogen rarely causes dieback of branches or stems older than three to four years but tree vigour and nut production are affected. Cultivars used for hazelnut production are affected by bacterial blight in Australia, but it is not yet known what the impact of blight is on hazelnut trees used in truffle orchards.

Leaf symptom of bacterial blight on hazelnut tree

Symptoms

One of the most characteristic symptoms is necrosis of emerging growth in late spring. Diseased shoots become necrotic and dry. Shoots may dry out entirely as the bacterium spreads downwards, girdling the base and causing dieback of the distal portion. Necrosis can spread to the stump and girdle the shoot, resulting in complete dieback. Black spot and streak may be found on young stems. Cankers and dark green water soaked areas may also be found on twigs and branches. Small, black, necrotic spot lesions are superficially present on fruits and bracts. Leaves show numerous polygonal water-soaked yellowish-green to dark-green lesions, which may merge together causing a general chlorosis of the lamina and premature leaf fall. Leaf symptoms are rare in orchards, while bud cankers, dieback of new lateral shoots and cankers are frequently observed. On fruit, oily lesions are sometimes seen on the groups of bracts and shells before lignification.

Necrotic and dry growing tip

Bacterial blight affected hazelnut tree

Monitoring

Look for necrosis of emerging growth in spring.

Transmission and disease expression

Bacterial blight usually originates from infected planting material. Infection of buds occurs in spring during vegetative growth. High early morning humidity, warmth and young plant tissue wounded by pruning or buffeting winds create ideal conditions for infection by bacterial blight. Poor environmental conditions, such as poor soil drainage, moisture stress, cold injury, mechanical equipment damage, pruning cuts, sunscald and general cultural neglect can contribute to making trees susceptible to blight.

Management

Once established, this serious pathogen cannot be eradicated, except by removal of all infected plants. Therefore, the most important element of control is to introduce only disease-free planting material. Standard hygiene practices in affected orchards such as removing and destroying affected shoots and disinfecting pruning tools may reduce the impact of the pathogen. The use of resistant cultivars is recommended when planting a new orchard. Plants that are lacking vigour are more susceptible to the disease and should not be used.

Discula

Disease

Discula quercina*, previously identified as *Gloeosporium*; teleomorph *Apiognomonia quercina

Summary

Discula is a fungus with a worldwide distribution, found on many oak species (including *Q. robur* but not *Q. ilex*), hazel, maples, beech and dogwood. It is also considered an endophyte of oaks (Moricca et al., 2016, Moricca & Ragazzi, 2011, Ragazzi et al., 2003, Ragazzi et al., 1999). In Europe, it causes a disease known as oak anthracnose (Moricca & Ragazzi, 2008). The level of disease it is able to cause when subjected to artificial inoculations, suggests it may be an underrated pathogen in cultivation of *Q. robur* in Australia.

Quercus robur leaves infected with *Discula quercina*

Symptoms

Symptoms vary depending on climate and include defoliation, twig and leaf dieback, twig cankers, leaf distortion and angular necrotic spots on mature leaves. Symptoms are usually most severe on the lower branches where moisture tends to remain for longer periods of time. Severe outbreaks have been known to kill nearly all the foliage on highly susceptible trees.

Discula quercina symptoms on oak.

Monitoring

Symptoms are most obvious on new spring growth. Outbreaks usually subside by mid-summer, as the leaves mature and become more resistant to the pathogen. Succulent growth, however, can still be attacked at any time of the growing season when wet conditions are prevalent.

Transmission and disease expression

High humidity and moisture favours new leaf infections. It is an endophyte of oaks where pathogenicity is triggered by plant stress such as drought. In Europe extended summer drought promotes the disease. In a recording in an Australian truffle orchard, trees expressed disease symptoms when drought conditions were not present. It is possible other stressors may trigger progressive dieback. Conditions that may enable other known endophytes to become pathogenic include a variety of stressors such as any physiological stress or other pathogen infection.

In the orchard mentioned *Neofusicoccum* and *Diaporthe* pathogens were also present in the diseased material, the tree canopy was dense, enclosed and continued to ground level. A dense windbreak also lead to reduced airflow, providing ideal, humid conditions for fungal sporulation and infection. It is thus likely that these multiple conditions provided the tree stress necessary for *Discula* disease progression.

Management

Improve airflow in the orchard, as high humidity, especially during spring and summer increases disease incidence. Do not overwater as it will increase humidity, facilitating infection. Minimise tree stress, e.g. over or under watering, other pathogens, to minimise disease expression in trees already infected with *Discula*.

Oak powdery mildew

Erysiphe alphitoides

Summary

The species of powdery mildew that infects oak trees is not the same as that on other plants such as grapevines and cucurbits, however similar weather conditions do promote these similarly named diseases. What is most likely a different species of powdery mildew has also been observed to occur on hazelnut trees.

This disease is not regarded as significant, but can have a minor effect on vigour of young trees.

White powdery coating on leaves of an oak infected with powdery mildew

Symptoms

Trees infected with powdery mildew have white to grey powdery spots on growing tips and leaves. This can lead to leaves with complete mildew cover and partial or severe defoliation.

Monitoring

Symptoms are most often observed on trees in spring but can occur in autumn and at other times of year in conditions of mild temperature and high humidity. Late in the growing season, older leaves are susceptible to infection by powdery mildew. Those leaves will drop at the onset of winter and the presence of mildew on them is not likely to have adverse effects on tree health or vigour the following season.

White powdery coating on leaves of an oak infected with powdery mildew, note the patch on a leaf to the left on with the mildew has been rubbed off to show the original leaf colour.

Transmission and disease expression

Oak powdery mildew is promoted by mild temperatures and wet conditions.

Management

Hazels and *Q. ilex* are less susceptible to powdery mildew than *Q. robur*. Adequate air flow can reduce the prevalence of mildew. If in a high rainfall/humidity area, consider using nursery stock with some level of powdery mildew resistance.

Root and root collar diseases

Disease

Including *Pythium* spp. and *Phytophthora* spp.

Summary

Dieback and other root diseases may affect the health of truffle trees and the effect is increased if soil is waterlogged or the tree is suffering from stress or nutrient deficiency.

Phytophthora root rot can be caused by a variety of *Phytophthora* species, although *Phytophthora cinnamomi* is the most commonly found species associated with truffle host trees in Australia*. P. cinnamomi* is a serious disease of over 800 host species including *Eucalyptus marginate,* jarrah dieback in Western Australia and general dieback of Myrtaceae and Proteaceae in Australia (Weste, 2003). It was detected in two truffle orchards, with mortality occurring in both.

Fusarium oxysporum has been isolated from *Q. robur* trees showing wilt symptoms. As for most diseases encountered on truffle-host trees, not much is known about this pathogen on *Q. robur*. However, it is a notorious pathogen with a wide host range, including trees, and mostly causes vascular wilts.

The cause of hazelnut tree dieback observed in hazelnut trees in WA is yet to be confirmed. *Fusarium* spp. have been isolated, but it is not known from the literature that *Fusarium* can cause such symptoms on hazelnut trees. However, Fusarium is known as a serious pathogen in many plants, including trees. Further work is needed to confirm the causal agents.

Symptoms of *P. cinnamomi* root disease through cut sections of tree trunks showing characteristic discolouration.

Symptoms

Symptoms include a stunted, sparse appearance, with yellowing leaves. A collar rot may be present, eventually girdling the tree. Root infection results in discoloration and root death, leading to tree death.

Collar rot symptoms from *P. cinnamomi*

Monitoring

These diseases are often not detected until infections are advanced and then exhibit initially as sparse growth, leaf chlorosis and wilting. Later, loss of vigour and general tree decline can occur. Affected trees are usually found at the bottom of a slope where water accumulates.

Transmission and disease expression

Phytophthora cinnamomi is soil borne and thus transmitted via water and soil. Disease expression usually is most pronounced at the bottom of the slope where water accumulated. Disease progression is often downhill, unless mechanically spread in the orchard with cultivation equipment.

F. oxysporum is potentially important and can occur commonly in soil, however exposing *Q. robur* to waterlogging most likely compromises the tree's resistance and allowing it to become a wilt pathogen.

Management

Soil and water management are key for *Phytophthora* root and root collar rot. When selecting a site ensure it has sufficient slope and soil with good drainage to help prevent waterlogging. It may be necessary to install drainage if the slope or other aspects of the orchard are insufficient to prevent waterlogging. Avoid cultivating from the bottom of the slope up hill, to reduce risk of pathogen spread, infection usually occurs at the bottom of a slope.

Stem diseases and dieback

Disease

Various species

Summary

Stem diseases may be caused by a range of fungi including:

- *Neofusicoccum australe* which causes Botryosphaeria dieback.
- Cytospora which causes a canker and has a wide host range but is usually only weakly pathogenic.
- Nectria which causes a canker and may have a wide host range.
- *Entoleuca* spp. which causes hypoxylon canker but this has not been recorded on truffle trees.
- *Diaporthe* spp. - *Diaporthe australafricana*, *D. neotheicola* (foeniculina) and two unidentified *Diaporthe* species. The causal agents of *Diaporthe* cankers are also known as *Phomopsis*.

It is important to note that most of these fungi are not known to cause disease in *Quercus ilex*, *Quercus robur* or *Corylus avellana*. However, that may be because in the past these hosts have received little attention for pathogens. All the probable causal agents mentioned are well known pathogens of other hosts, sometimes even of other species of oaks and hazels. To determine their status in truffle orchards future studies would be needed.

Neofusicoccum australe is a pathogen of a diversity of host species, causing dieback, which may lead to mortality.

Although *Diaporthe* are well-known pathogens of a wide range of crops, ornamentals and forest trees, they have not been reported as pathogens of oaks. However, these pathogens are likely endophytes that are triggered to become pathogenic when the trees are stressed.

External symptoms of stem canker showing cracked bark on trunk caused by *Diaporthe* species and other pathogenic fungi.

Symptoms

Lesions/cankers on stems vary in shape in size, but always show cracks in the bark as well as a depression in the stem where the cambium is diseased. Removal of the outer bark on the edge of the canker will reveal dead, brown cambium next to healthy cambium. In severe cases the stem may be girdled, resulting in tree death or branch dieback above the canker. The tree may form suckers below the canker.

Symptoms of a stem disease after bark removal showing the demarcation between healthy and diseased tissue.

A clear depression in the trunk from a stem canker caused by *Diaporthe* species and other pathogenic fungi.

Transmission and disease expression

Diaporthe and *N. australe*, are endophytes. Switching from being endophytic to a pathogen is likely related to stress such as water stress, either drought or waterlogging, predisposition by other pathogens, extreme temperature fluctuations, nutrient deficiencies and/or mechanical injuries.

Symptoms are more pronounced when, especially on *Q. ilex*, trees are grown in prolonged wet conditions, bought about either through rainfall or irrigation.

Management

If tree trunks are wet through irrigation, the system should be modified to avoid this. Dead trees should be removed, diseased branches pruned, removed and burnt to reduce the spread of inoculum. Sterilise pruning shears between cuts. Reduce tree stress.

Wood rot — Disease

e.g. *Pycnoporus* spp., *Fomitoparia australiensis* and *Stereum* spp.

Summary

Wood rot fungi are commonly found on dead stems and branches. A tree may be infected by multiple wood rot fungi species. These fungi are commonly found in wet and warm environments.

Pycnoporus species are saprophytic fungi that cause a distinctive white rot. This disease is commonly found on dead wood in native eucalypt forests, as well as shrubs and fruit trees and can also infect conifers.

Wood rot fungi such as those in the genera *Ganoderma* and *Stereum* have been observed on hazelnut trees, but they may infect any tree species.

Pycnoporus fruiting bodies

Symptoms

The *Pycnoporus* spore carrying fruiting bodies are the most obvious sign of an infection. They are corky, bright orange to red, do not have a stalk and vary in size up to 9cm across and 2cm thick. Infected branches and stems may die. Fruiting bodies of *Fomitoparia* are leathery on top and velvety below. *Stereum* (also known as Turkish tail) fruiting bodies, show characteristic concentric rings.

Fomitoparia fruiting bodies

Stereum fruiting bodies

Monitoring

Fruiting bodies persist for many months or even multiple years, and usually

appear in spring/summer after prolonged rainy periods.

Transmission and disease expression

The fungus can become pathogenic on living trees, generally infecting wood through wounds in the bark that may be caused by sunburn, pruning and mechanical or wind damage to trees. From these wounds infection can spread to healthy tissue.

Management

Remove dead or dying trees from the orchard and burn to prevent fruiting of fungi and release of inoculum. Prune when sunny and dry, preferably when there will be at least 48 hours of dry weather to help the wound seal. Minimising large open wounds.

Only plant host species suited to the site. For example, *Q. ilex* is adapted to a dry Mediterranean climate and may struggle in wet summer conditions.

Truffle rot — Disease

Summary

Truffles are susceptible to a disease syndrome known as ‘truffle rot’. Truffle rot is used to describe a range of symptoms including discoloration, softness, wetness, and is often accompanied by a foul smell. Truffle rot has been observed across Australia, resulting in losses of greater than 50% of marketable truffle yield in some orchards.

A number of fungal and bacterial species have been isolated from rotten truffles. These include several *Fusarium* spp., *Trichothecium* spp., *Ilyonectria macrodidyma* and *Clonostachys rosea* amongst others. Apart from *Trichothecium*, most of these fungi and bacteria are likely secondary pathogens of truffles predisposed by environmental conditions.

Trichothecium crotocinigenum is a fungal species with a demonstrated pathogenicity towards truffles and is most common on exposed truffles. It causes rot of the truffle flesh, and a conspicuous thin, white coating on the truffle skin which contains its spores.

An example of the wide range of symptoms of truffle rot.

Symptoms

Truffle rot typically presents as discolouration, softness and wetness of the truffle tissues and a foul smell, though sometimes may begin with a dry crumbly texture. A wide range of symptoms are observed which indicate that multiple primary or secondary disease causing agents are involved.

An example of the wide range of symptoms of truffle rot.

An example of the wide range of symptoms of truffle rot.

Monitoring

Truffle rots are often not seen until harvest and grading. Monitoring and recording of incidence and severity of

rot during harvest and grading can assist in determining to variance in rot across an orchard and the impact of any management changes on rot.

Transmission and disease expression

Truffle rot is often associated with shallow truffle formation which can lead to the truffle becoming exposed. Shallow truffles are more susceptible to a range of environmental stresses such as high temperatures, sunburn, desiccation and insect/mollusc feeding, and are more accessible to microbial pathogens. Many of these factors may cause rot alone, or the combinations of stressors interact to reduce the truffles' natural defences to a point at which disease symptoms develop. Given the shallow nature of the truffles in question, frosts, even mild ones, may increase the level of rot in an orchard with a significant proportion of shallow or surface truffles.

Management

Management practices that encourage truffles to form deeper in the soil and provide a protective covering or soil can reduce the incidence of rot. The main factors associated with truffle rot are soil management, truffle covering, tillage and irrigation.

Site selection and soil management

Truffles require a free draining soil; soil type, aspect and climate are all likely to have a significant impact on the risk of rot development.

The requirement to add lime to most soils to increase pH may also contribute to truffles forming higher in the soil given the presence of lime only in the upper soil profile. It is not yet known whether this contributes to shallow forming truffle alone or in unison with other factors.

Truffle covering

Truffles which become exposed at the soil surface can be effectively protected by covering truffles with a layer of soil. Truffles should be covered as soon as possible after becoming exposed to reduce the time exposed to harsh surface conditions. The type of soil used to cover truffles is important, however little work has been done to compare soil types. Ideally field soil should be used. Keep in mind that soils with high clay contents can hold moisture and prevent oxygen reaching the truffles which may promote truffle rot, whereas sandy soils can hold too little water resulting in desiccation of the developing truffle.

Tillage

This can significantly reduce the proportion of truffles affected by rot, presumably by promoting fewer erumpent truffles. Interestingly in trials, cultivation treatments also resulted in a reduction of the incidence of truffle rot observed in deep truffles found below the soil surface. However, caution is advised regarding cultivation as a management practice. Soil cultivation will generally cause severe damage to lateral roots, which may compromise tree vigour and have long term impacts on truffle productivity, or even result in tree death. Furthermore, many of the soils used in Australia for truffle production are prone to compaction when repeatedly cultivated because the soil structure is poor. These soils are often softer directly after cultivation, however, in the long term they generally become more compacted than they were prior to cultivation. Furthermore organic material that is critical for binding the soil particles together is rapidly lost as CO_2 following soil cultivation resulting in a permanent decline in soil quality, which will likely be counter-productive over the long term.

Cultivation has been used in Europe to disrupt pests such as slugs (P. Sourzat pers. comm.), among other reasons.

Irrigation

High volumes and frequent irrigations are associated with shallow truffles and a greater incidence of rot at all depths. The impact of irrigation on truffle rot as well as truffle productivity and host vigour will vary depending on site conditions. For example, sites with deep soils and a high soil water holding capacity can sustain longer periods between irrigation events, which may reduce truffle rot, before adverse stress of the host tree is induced, compared with soils with a low water holding capacity.

It is well known in other horticultural crops that the frequency of irrigation influences the depth of feeder roots. In truffle orchards it has been found that high rates and frequency of irrigation increased the frequency of erumpent truffles. Currently there is a huge variation in the frequency of irrigation in Australian truffle orchards.

Less frequent irrigation also results in drier soil in the top of the profile, resulting in less feeder roots surviving long enough to nurture a developing truffle.

Interestingly trials of reduced irrigation frequency also resulted in a reduction of the incidence of truffle rot observed in deep truffles found below the soil surface.

Irrigation rates however must also meet the needs of the host tree, which will vary depending on the species of host used. Supporting the survival of the host tree is important as it in turn supports the truffle throughout its development and maturity. Anecdotal evidence that lack of water in a dry summer results in a dramatic reduction in the number of truffles reaching maturity in a producing orchard supports this hypothesis.

Hypoxia and Truffle Rot

The results from soil cultivation and irrigation trials suggest a relationship between those factors and soil oxygen and gas exchange. Soil hypoxia, lack of oxygen, at depth may be driving truffle formation towards the shallower soil layers, where oxygen is more readily available. Furthermore, lack of oxygen at depth may be directly responsible for rot development in truffles, which do manage to develop below the soil surface. As well as influencing depth of feeder roots, high soil water content may lead to truffle rot through displacement of soil air spaces leading to hypoxia.

Sudden Oak Death

Exotic

Phytophthora ramorum

Phytophthora ramorum, as the common name implies, causes a sudden death in oak trees native to North America. It is a newly emerged pathogen belonging to the Stramenopila (Oomycetes). Symptoms include a stem or trunk canker with red sap oozing from the bark surface, leaf blight and twig dieback. Infection typically result in blackened shoots and dark blotching of leaves. Infection results in host death in the most susceptible tree species, whereas in less susceptible species foliar infection leads to premature leaf death and leaf drop (Rizzo et al., 2002). On *Q. ilex* infected young leaves are water-soaked, dull grey in appearance, and petioles are blackened. Lesions start at leaf margins, tips, or petioles, often progressing into the midrib veins. Initial infections also occur on shoots and extend into the petioles. If shoots are infected, they are blackened at first, but later in the season clusters of dry, dead leaves and twigs characterize branch tips. Infected mature leaves bore dry, reddish-brown, restricted lesions (Denman et al., 2005).

Widespread tree death as a result of *Phytophthora ramorum* in native oak forest in North America.

Host range

Phytophthora ramorum is known to infect over 130 plant species representing approximately 40 genera. Common ornamental host species include azalea, camellia, common beech, elder, fir, horse chestnut, larch, magnolia, maple and oak. Common commercial host species include avocado, blueberry, chestnut, hazelnut and macadamia (Grünwald et al., 2008). While most foliar hosts are not killed by the disease, they do play a key role in the spread of *P. ramorum*, acting as source of fungal spores. Many native plants in Australia, especially Proteaceae, are very susceptible to *P. ramorum*.

Red sap oozing from a trunk canker is a symptom of sudden oak death.

Distribution

Phytophthora ramorum is found throughout North America and Europe.

Transmission

Unlike most other phytopthoras, *P. ramorum* is airborne and can be disseminated by wind and rain splash. Long distance dispersal of the pathogen can occur in rivers and streams and human activities such as the movement of infected plant material, e.g. infected nursery material. Animals such as deer, squirrels, birds and snails might also act as vectors.

Management

Once *P. ramorum* infects trees, there is no known way to cure them. Phosphonate applications will suppress disease progression in early infections, but will not cure the tree. Therefore, most of the management practices are directed at preventing the spread of the disease to new plants or areas and protecting susceptible trees before they are infected.

Pierce's disease Exotic

Xylella fastidiosa

Xylella fastidiosa affects its host plants by invading their water-conducting systems, moving both upstream and downstream. In so doing, it restricts or blocks the movement of water and nutrients through the plant. Symptoms vary depending on the host plant species and its degree of susceptibility, but include marginal leaf scorch, wilting of foliage and withering of branches. Severe infections in some of the most damaging combinations of host plant and *Xylella* sub-species can result in dieback, stunting and eventual death.

With olive trees or grape vines, on which it is known as Pierce's disease, (Fig. 5.3). *Xylella fastidiosa* is considered by biosecurity specialists to be potentially the most significant threat ever faced to plant-based industries and national flora. Even eucalypts and Acacias native to Australia, are susceptible to *Xylella* ((EFSA), 2018). Australia has at least 350 native, commercial and ornamental plant species that are susceptible, potentially providing multiple hosts for transmission and evolution.

Xylella fastidiosa infection in an olive orchard in Italy.

Host range

Xylella fastidiosa is a bacterium that can cause significant dieback and death in more than a 100 woody plant species, representing more than 50 plant families. Many strains of the pathogen exists. Hosts include almonds, blueberries, cherries, citrus, macadamias, olives, grapes, walnuts etc. Not much is known about the susceptibility of truffle host trees, although a recent report suggest *Quercus ilex* is susceptible to a strain of *X. fastidiosa*. (Jeger et al., 2016), as well as *Quercus robur* and *Q. suber* (EFSA, 2018).

Distribution

The disease is widely distributed in North and South America, but was also introduced to Taiwan (pre 2013), Italy (2013), Iran (2014), France (2015) and Spain (2016). It is under eradication in some European countries.

Transmission

The disease is transmitted by anthropogenic movement of plant material and insect vectors such as sharpshooters, spittlebugs, leafhoppers and aphids which feed on plants' xylem fluid. There are several species of insects in Australia which could act as vectors and spread *Xylella fastidiosa*. Even though such insects usually only fly short distances of up to 100 metres, they can be carried much longer distances by the wind.

Long-distance spread can occur by the movement of infected plants for planting. These plants can act as a source of the bacteria for the feeding insects, which can then transmit it to other hosts. There can also be some transfer of the bacterium between neighbouring plants via root grafts.

Management

Disease management employs the same general set of tools as for other vector-borne plant pathogens. Because there are currently no truly *Xylella*-resistant varietals available, management relies on a combination of efforts to control vectors and reduce pathogen supply. Vector control can take the form of biological control, chemical control, and other methods of reducing vector abundance or activity. Reducing pathogen supply includes removing infected material and reservoir plant hosts in adjacent habitats.

Eastern filbert blight

Exotic

Anisogramma anomala

Eastern filbert blight caused by the fungus *Anisogramma anomala*, causes potentially fatal cankers on the trunk and branches on cultivated hazel, *Corylus avellana,* as well as on wild hazel (*Corylus* spp.) (Figs. 5.1 and 5.2). In the 1960s, the disease spread on infected plant material to Oregon, where it then threatened US hazelnut production in the Willamette Valley. In the US, entire hazelnut orchards have been lost to the disease.

Once cankers form, they can expand at a rate of 30cm/year. This causes canopy and yield loss and can cause death of mature trees in 5-15 years with younger trees being killed within 4-7 years. As the canopy dies back, new shoots and suckers may emerge from the tree base and these in turn become infected and die. Infected trees may not show symptoms for up to two years.

Host range

Hazels, *Coryllus* spp.

Distribution

Eastern filbert blight is caused by a fungus known as *Anisogramma anomala*, native to Eastern North America and currently only present in North America.

Transmission

New infections are usually as a result of infected nursery stock. The fungus cannot spread over large distances as cool wet weather and rain splash is needed for dispersal and infection.

Management

Resistant cultivars have been bred in the US, but are unavailable at present in Australia. In Oregon, scouting for cankers, therapeutic pruning, and copious fungicide applications are reported to be necessary, but costly measures, to continue hazelnut production in the presence of the disease.

Eastern filbert blight dieback in hazelnut trees.

Eastern filbert blight fruiting bodies on an infected hazelnut branch.

Monitoring methods for use in truffle orchards

Monitoring for truffle pests takes place in the orchard and at grading. Often both types of monitoring are required to determine pest risk and the need for management. The cause of damage seen at harvest is not always conclusive and needs orchard monitoring to confirm which pest agents are present. Conversely, the presence of pest agents in the orchard does not necessarily lead to economically significant levels of damage at harvest, so harvest assessments will help determine thresholds for management.

Pest type, abundance, distribution and seasonality varies from orchard to orchard. By conducting your own regular monitoring you will gain an understanding of which pests are in your orchard, their abundance, orchard hot spots and the impact of any control methods you use. If you are trialling management techniques in only sections of the orchard, ensure you also monitor in a control/un-treated area to allow for comparison.

The equipment and methods for the most commonly used truffle orchard monitoring techniques are detailed below as well a pictorial guide of the invertebrates and damage most likely to be observed during harvest and grading.

Tile monitoring is recommended for the major truffle pests; slugs and slaters and will also provide you with information on the presence of millipedes, predatory beetles, earwigs and less reliably springtails.

Pitfall traps are the recommended monitoring technique for Australian truffle beetle and springtails and also African black beetle prior to orchard establishment. It will also provide you with information on the presence of millipedes and predatory beetles.

Tile monitoring

Slugs and slaters are among the most important pests of truffles. When abundant, they cause significant damage to truffles. The level of slug and slater pressure in your orchard as well as the presence of other pest and predator invertebrates can be gauged by monitoring with tiles. Invertebrates you may find when monitoring with tiles include:

- slugs
- slaters
- millipedes
- earwigs – pest and predatory
- beetle adults, including potential pests: click beetle, vegetable beetle, African black beetle; and predators: carabids, staphylinids.

You will need:

- 20 cm square bathroom tiles. For orchards of up to 4ha, ten to twenty tiles along one to two rows is recommended. For large orchards more tiles are recommended to ensure good coverage and that hot spots are not missed.
- Flaky bran (available from a feed merchant or hardware store) and teaspoon.
- Score sheet. There is an example in the appendix that can be altered to suit.
- Field guide to help identify invertebrates.

Method

1. Plan the location of tiles so they are evenly spaced across the orchard but also practical and not overly time consuming to service.

Placing tiles evenly along rows allows for good coverage and more efficient servicing. If monitoring in two rows use those that around one third in from the edge of the orchard.

2. Place tiles close to a tree – this is where we find slugs and slaters occur more; the tiles are out of the way of orchard operations; and are more easily located when monitoring. To help in relocating the tile mark the tree with bright coloured flagging tape or ribbon.

Monitoring tile placed close to a tree and in the tree line

3. Before placing each tile, clear the ground the tile will sit on to remove leaves and small pebbles. This makes observing and counting easier.

An area is cleared of moss and grass prior to placing the bran and tiles

4. Place one heaped teaspoon of flaky bran on the ground in the centre of where the tile will sit and place the tile on top.
5. Two days later check under each tile. Record the types and numbers of invertebrates present.
6. We recommend removing bran after monitoring so that slugs and slaters can redistribute as normal so as not to bias future monitoring.
7. Lean tile up against the tree until monitoring is repeated.

Record all invertebrates of interest either on the tile or on the ground under where the tile lay.

Repeat monitoring every four weeks or as time permits. Monitoring can be done before and after a control technique is applied to help determine the effectiveness of the control, although be aware that some control methods may take more time to have an impact on pest levels. Also, be aware that pest numbers will likely fluctuate, monitoring regularly over time will give a clearer picture of pest number trends compared to one-off and less regular monitoring.

Pitfall monitoring

Tile monitoring is a simpler monitoring technique due to the basic equipment needed and minimal time required to install in the orchard. However, there are some pests that are more accurately monitored with pitfall traps and these include:

- African black beetle – prior to orchard establishment
- Australian truffle beetle
- Springtails

Pitfall traps are buried into the ground with the open top at ground level. They are designed to capture anything that is walking over the soil surface which then falls in. When invertebrates are being targeted only small containers are needed for the trap. The level of sophistication of the containers can vary widely too.

You will need:

- At least ten pitfall traps to enable representative monitoring of the orchard area.
- A trowel, small hand auger or post hole shovel.
- White, or light coloured, bucket.
- Score sheet. There is an example in the appendix that can be altered to suit.
- Field guide to help identify invertebrates.

Method

1. Plan the location of traps so they are evenly spaced across the orchard or alternatively place in areas of interest, e.g. a truffle damage hot spot or when a particular management technique has been applied.
2. Place traps in the tree line and as close as practicable to the trunk– this ensures they are out of the way of orchard operations and are more easily located when monitoring. You may encounter large tree roots if digging close to the trunk.
3. Dig a hole, making sure it is the right depth so the container top will sit at ground level.
4. Install the pipe sleeve and/or container, backing filling the hole so there is level ground around the trap entrance.
5. Add any bait that is being used and put trap cover in place.
6. Two weeks later check each pitfall trap. The easiest way to do this is to pull the container out of the ground and tap the contents into a light coloured bucket. Record the types and numbers of invertebrates present.
7. If traps are left longer than two weeks the contents can start to decompose making identification difficult.
8. Between monitoring rounds containers can be taken out or covered to prevent them filling with excess insects.

Example pitfall trap installed in an orchard.

An example of pitfall trap components.

When a pitfall traps similar to the one show above is use the PVC pipe is dug into the ground to provide a sleeve for the trap container, allowing it to be retrieved and re-installed without soil falling into the hole. The funnel, with collection container attached, is placed into the sleeve. The funnel prevents invertebrates from escaping once in the trap. The container has a mesh base to prevent it from filling with water from rainfall and irrigation. A solid cover and mesh reduces the amount of leaves, nuts and acorns that fall into the trap potentially clogging or filling it while still allowing access for invertebrates.

There are many variations on the style of pitfall trap that can be used. The following photos show a system when the same in-ground components are used but a lower lid is placed over it. The low lid reduces even further the amount of leaves and other matter getting caught in the trap. Chicken wire has been wrapped around a tile and the ends of the wire are bent up to create 'legs', holding the lid off the ground. This trap was designed specifically for truffle beetle, the 'legs' could be made longer for capture of larger invertebrates.

Another pitfall trap example.

The type and amount of specimens found will vary from orchard to orchard, below are examples collected during the pest and disease project.

Carabid beetles

Springtails

Slaters and ‘brown’ millipedes

Australian truffle beetle (ATB)

For Australian truffle beetles, the best results are achieved when a liquid bait is used to attract them to the trap. The bait is made up of a 1:1 beer and molasses mix with a small amount of yeast. Use a solid base container and add approximately 30mm of the bait to each container.

A modified pitfall trap, called a pipe trap, has been designed specifically to monitor for Australian truffle beetle. This trap excludes larger insects and is easier to contain the liquid bait attractant without rainfall or irrigation leading the solid base container to overflow. As with the pitfall trap a PVC sleeve is used but the sleeve extends above ground level and has a series of small, 5mm diameter holes drilled all around it at ground level to allow access for the beetles. The solid based container sits within the sleeve, with its top below the access holes. The trap has a slip-on lid.

When using a liquid bait a solid based collection container is used.

After a period of one to two weeks in the field, the liquid is retrieved and poured through nested mesh sieves. The top sieve has 4mm mesh to allow beetles to pass through but retain larger insects and litter and the lower sieve has a 0.5mm mesh to allow fine soil particles and liquid to pass through but retain truffle beetles. Insects are examined to record the number of truffle beetles present.

Pipe trap used for ‘Australian truffle beetle’ monitoring

Harvest and grading assessments

Along with regular orchard monitoring, harvest damage assessments can help you to gain an understanding of the level of your invertebrate pest and truffle rot problems, the main causal agents and the impact of any management techniques undertaken.

Invertebrate pests can cause extensive damage to truffles. Much of this damage goes unseen, until harvest and grading, by which time most of the perpetrators are no longer in or on the truffle. While it can be difficult to differentiate between the feeding damage at this stage, some general feeding patterns can help narrow down the possible culprit.

During harvest, notes can be made on any pests that may be present on or in truffles.

Damage assessments should take place after truffles have been cleaned. The dirt on truffle fresh out of the ground can mask some damage, reducing the perceived degree of damage and covering some feeding holes all together.

Records should be made of damage observations at grading. This information is useful to determine rates of damage over time and to make comparisons between truffles harvested from different areas of the orchard.

Truffle beetle

The most distinctive damage is that caused by the Australia truffle beetle (*Thalycrodes sp*. Family Nitidulidae). Both the adults and the larvae are obligate truffle feeders. They make holes approximately 1mm in diameter and can tunnel extensively within a truffle, creating galleries.

Adults and larvae can be found in the tunnels within truffles even after harvest and washing. Adult truffle beetles are very small, approximately 2-3mm long and 1- 1.5mm wide. They are a honey brown colour with distinctive clubbed antennae and rows of hairs on their back. Truffle beetle larvae are pointed at both ends, have a brown head, tiny legs on the thorax and a segmented body. For more information on the beetle refer to the fact sheet.

Pinholes in the truffle surface caused by ‘Australian truffle beetle’.

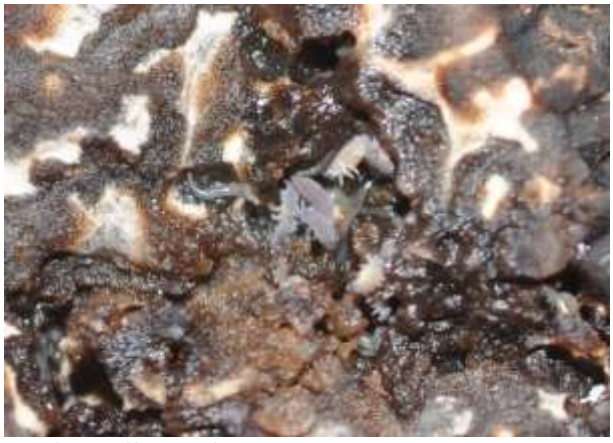
Internal galleries caused by truffle beetle

'Australian truffle beetle' larvae found after the truffle has been through the washing process.

Invertebrates in the grading room

Other invertebrates that can be found in and on truffles at harvest are springtails, pot worms, fly larvae and fungus gnats.

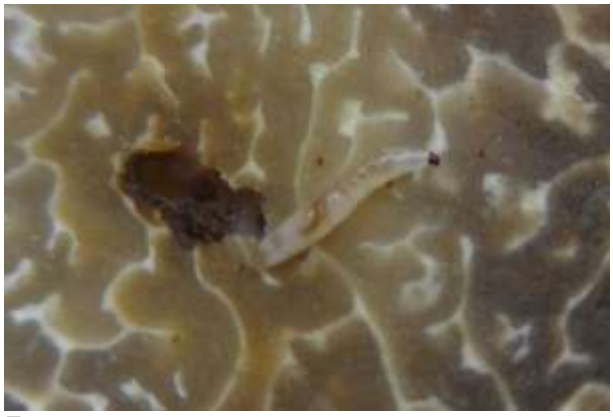
Other than springtails these are thought to be secondary pests, meaning they only feed on truffle that is unsound. The truffle may have already had feeding damage or rot, developed cracks or been soft or over mature. It is uncertain the degree to which springtails cause primary feeding damage, damage associated with them is outlined below.



Springtails and potworms

Pot worm

Fungus gnats



Fungus gnat

Fly larvae

Fly maggot pupae

Holes and cavities

The most common damage observed is that by caused by slugs and slaters. Their feeding damaged is indistinguishable in the grading room and is characterised by deep and uneven cavities, holes and gouges. Damage is more common in shalow and exposed truffles and the parts of truffle that were more accessible to slugs and slaters in the field.

Millipedes can produce uneven holes, or shallow pits the same diameter as them as well as browse the peridium.

Slug and slater damage is indistinguishable. The causal agent can be narrowed down through in field monitoring and observations during harvest.

A truffle with extensive slug/slater feeding damage that was exposed above the soil surface when growing.

Portuguese millipedes browsing the peridium of an immature truffle

'Brown' millipede feeding on truffle

Weevil larvae, African black beetle larvae and African black beetle adults produce holes the same diameter as their bodies, between 5 and 10mm.

African black beetle larva

African black beetle adult

Black earwigs produce uneven holes.

Earwig with truffle damaged through feeding.

Springtails damage is more likely to occur where there are cracks and crevices in the truffle periderm where they tend to congregate. They create tiny pinholes, smaller than those created by truffle beetles or other invertebrate pests, and small galleries or pits within the truffle just under the periderm. The damage is reasonably shallow. Truffles that have been damaged by other invertebrates such as slugs or slaters, or infected with rots, may be more susceptible to being attacked by springtails.

A cluster of tiny pinholes most likely caused by springtails.

Photo credits

Page 20

Native ant, image courtesy: Gibson, L. (2008) *Cardiocondyla paranuda* (*Cardiocondyla paranuda*) Updated on 5/14/2018 5:29:15 AM Available online: PaDIL - http://www.padil.gov.au.

Page 26

Yellowheaded pasture cockchafer adult, image courtesy: SARDI.

Yellowheaded pasture cockchafer larva, image courtesy: cesar.

Redheaded pasture cockchafer adult, image courtesy: Jon Augier Museums Victoria.

Redheaded pasture cockchafer larva, image courtesy: SARDI.

Page 27

Blackheaded pasture cockchafer adult, image courtesy: Jon Augier Museums Victoria.

Blackheaded pasture cockchafer larvae, image courtesy: SARDI.

Page 28

European truffle beetle adult, image courtesy: Víctor Pérez Fortea.

Page 48

Line drawing of a typical fungus gnat fly, image courtesy; Nursery and Garden Industry Australia.

Fungus gnat adult fly, image courtesy: Manuel Lopez.

Native millipedes from Australian truffle orchards, image courtesy: the Western Australian Museum.

Page 59

Deformed bud on hazelnut tree, image courtesy: www.naturespot.org.uk.

Infestation of hazelnut gall mites with eggs in a deformed hazelnut bud, image courtesy: Magnus Gammelgaard.

Page 60

Hazelnut mite adult, image courtesy: Alain Migeon.

Hazelnut mite egg, image courtesy: Alain Migeon.

Hazelnut mite nymph, image courtesy: Alain Migeon.

Page 61

Fruit tree borer moth, image courtesy: Donald Hobern, Maroga melanostigma.jpg, available online: https://commons.wikimedia.org/wiki/File:Maroga_melanostigma.jpg.

Larval stage of fruit tree borer, image courtesy: Mark Hartley, treedoc.com.au.

Page 64

Heliothis larva and damage to leaf and immature hazelnut, image courtesy: G. Anderson.

Page 65

Lightbrown apple moth adult, image courtesy: T. M. Gilligan & M. E. Epstein, TortAI (http://idtools.org/id/leps/tortai/).

Page 67

Oak leaf miner moth, image courtesy: Patrick Clement, available online: https://commons.wikimedia.org/wiki/File:15.039_BF321_Phyllonorycter_messaniella_(5669279458).jpg.

Page 69

Painted apple moth male, image courtesy: Walker, K. (2007) painted apple moth (*Teia anartoides*) Updated on 8/12/2013 4:02:34 PM Available online: PaDIL - http://www.padil.gov.au.

Page 79

Slug body parts diagram, image courtesy: Slug Portal, Oregon State University.

Page 107

European truffle beetle adult, image courtesy: Víctor Pérez Fortea.

European truffle beetle larvae infesting an immature truffle, image courtesy: Víctor Pérez Fortea.

Page 108

Suillia sp. fly, image courtesy: Katja Schulz, Heleomyzid Fly (34916388016).jpg, available online: https://commons.wikimedia.org/wiki/Category:Suillia#/media/File:Heleomyzid_Fly_(34916388016).jpg.

Page 110

Fruiting body of Armillaria root rot, image courtesy: H. Eslick.

Page 113

Discula quercina symptoms on oak, image courtesy: Nancy Pataky, University of Illinois Plant Clinic.

Page 125

Widespread tree death as a result of Phytophthora ramorum in native oak forest in North America, image courtesy: www.suddenoakdeath.org.

Red sap oozing from a trunk canker, image courtesy: Bruce Moltzan, USDA Forest Service, Bugwood.org.

Page 127

Xylella fastidiosa infection in an olive orchard in Italy, image courtesy: USDA-ARS.

Page 129

Eastern filbert blight dieback in hazelnut trees, image courtesy: Jay W. Pscheidt.

Eastern filbert blight fruiting bodies on an infected hazelnut branch, image courtesy: Jay W. Pscheidt.

References and further reading

Establishing and maintaining a healthy orchard

Department of Primary Industries and Regional Development, 2019, 'Cultivation of black truffles in Western Australia', viewed January 2019 https://www.agric.wa.gov.au/new-horticulture-crops/cultivation-black-truffles-western-australia?page=0%2C3,Department of Primary Industries and Regional Development, Western Australia, Perth.

Department of Primary Industries and Regional Development, 2019, 'Truffle orchard on-farm hygiene', viewed January 2019 https://www.agric.wa.gov.au/new-horticulture-crops/truffle-orchard-farm-hygiene**,** Department of Primary Industries and Regional Development, Western Australia, Perth.

De Miguel, AM, Agueda, B, Sánchez, S, Parladé, J 2014, 'Ectomycorrhizal fungus diversity and community structure with natural and cultivated truffle hosts: applying lessons learned to future truffle culture', *Mycorrhiza*, vol. 24, Supplement 1, pp. 5-18.

Invertebrate pests and non-pests and Diseases

Snare, L 2006, 'Pest and disease analysis in hazelnuts', Horticulture Australia Limited project no NT05002.

Ants

Department of Primary Industries and Regional Development, 2019, 'Ant identification is the key to successful control', viewed January 2019 https://www.agric.wa.gov.au/invasive-species/ant-identification-key-successful-control?page=0%2C1 Department of Primary Industries and Regional Development, Western Australia, Perth.

Seifert, B 2008, 'A cryptic sister species of *Cardiocondyla nuda* (Mayr, 1866) (Hymenoptera: Formicidae)', *Myrmecologische Nachrichten* vol. 11, pp. 43-48.

Aphids

Broughton, S 2017, 'Aphids in citrus', viewed January 2019, https://www.agric.wa.gov.au/citrus/aphids-citrus, Department of Primary Industries and Regional Development, Western Australia, Perth.

Snare L 2006, *Pest and Disease Analysis in Hazelnuts*, Hort Innovation Project NT05002, NSW Department of Primary Industries.

Snare L 2010, *Hazelnut grower's handbook*, 79pp, NSW Department of Primary Industries.

African black beetle

cesar, African black beetle, viewed January 2019, http://www.cesaraustralia.com/sustainable-agriculture/pestnotes/insect/African-black-beetle.

Learmonth, S 2017, 'African black beetle in horticulture', viewed January 2019, https://www.agric.wa.gov.au/olives/african-black-beetle horticulture?page=0%2C4, Department of Primary Industries and Regional Development, Western Australia, Perth.

Other cockchafers

Cesar, Yellowheaded cockchafer, viewed January 2019, http://www.cesaraustralia.com/sustainable-agriculture/pestnotes/insect/yellowheaded-cockchafer.

Cesar, Redheaded pasture cockchafer, viewed January 2019, http://www.cesaraustralia.com/sustainable-agriculture/pestnotes/insect/redheaded-pasture-cockchafer.

Cesar, Blackheaded pasture cockchafer, viewed January 2019, http://www.cesaraustralia.com/sustainable-agriculture/pestnotes/insect/blackheaded-pasture-cockchafer.

Australian truffle beetle

Arzone, A 1971, 'Reperti ecologici ed etologici di Liodes cinnamomea Panzer vivente su *Tuber melanosporum* Vittadini (Coleoptera Staphylinoidea). (Ecological and ethological findings of *Liodes cinnamomea* Panzer living on *Tuber melanosporum* Vittadini (Coleoptera Staphylinoidea))', *Centro di Entomologia Alpina e Forestale del Consiglio Nazionale delle Ricerche*, Italy, vol, 158, pp. 317-357.

Bougher NL & Lebel T 2001, 'Sequestrate (truffle-like) fungi of Australia and New Zealand', *Australian Systematic Botany*, vol. 14, pp. 439–484.

Hochberg ME Bertault G Poitrineau K Janssen A 2003, 'Olfatory orientation of the truffle beetle, *Leiodes cinnamomea'*, *Entomologia Experimentalis et Applicata* vol.109, pp. 147-153.

Houston, TF & Bougher, NL 2010, 'Records of hypogeous mycorrhizal fungi in the diet of some Western Australian bolboceratine beetles (Coleoptera: Geotrupidae, Bolboceratinae)', *Australian Journal of Entomology*, vol. 49, pp. 49–55.

Houston, TF 2011, 'Egg gigantism in some Australian earth-borer beetles (Coleoptera: Geotrupidae: Bolboceratinae) and its apparent association with reduction or elimination of larval feeding', *Australian Journal of Entomology*, vol. 50, pp. 164–173.

Kirejtshuk, AG Lawrence, JF 1992, 'Review of the *Thalycrodes* complex of genera (Coleoptera: Nitidulidae) endemic to the Australian region', J. Aust. ent. Soc., vol. 31, pp. 119-142.

Martin-Santafe, M Perez-Fortea, V Pedro Zuriaga, P Barriuso, J 2014, 'Phytosanitary problems detected in truffle cultivation in Spain, A review', *Forest Systems*, vol. 23 (2), pp. 307-316.

Morcillo, M Sanchez, M Vilanova, X 2015, *Truffle Farming Today, a Comprehensive World Guide*, Micologia Forestal & Aplicada, Barcelona.

Seago, A 2014, Australian truffle beetles and the insect fauna of truffieres, viewed January 2019, http://docplayer.net/55963015-Australian-truffle-beetles-and-the-insect-fauna-of-truffieres.html.

Predatory beetles

Cesar 2008, 'Beneficial carabidae beetle', PestFacts south-eastern, issue no.4 16th June 2008.

Spring beetle

Department of Primary Industries and Regional Development Western Australia, 2018, 'Spring beetles in truffle orchards', viewed January 2019, https://www.agric.wa.gov.au/newsletters/trufflepestsdiseases/australian-truffle-pest-disease-newsletter-issue-7-december-2018?page=0%2C6#smartpaging_toc_p6_s0_h2, Department of Primary Industries and Regional Development, Western Australia, Perth.

Stinking longicorn

iNaturalist, *Stenoderus suturalis*, viewed January 2019, https://www.inaturalist.org/taxa/469350-Stenoderus-suturalis.

Wireworm

cesar, 'True wireworm', viewed January 2019, http://www.cesaraustralia.com/sustainable-agriculture/pestnotes/insect/true-wireworm.

McDonald, G 1995, 'Wireworms and False Wireworms', viewed January 2019, http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/pest-insects-and-mites/wireworms-and-false-wireworms, Agriculture Victoria.

Horne, PA & Horne, JA 1991, 'The life-history and control of *Hapatesus hirtus* Candeze (Coleoptera: Elateridae) in Victoria', *Aust. J. Agric. Res*., 1991, vol. 42, pp. 827-34.

False wireworm

cesar, 'Bronzed field beetle', viewed January 2019, http://www.cesaraustralia.com/sustainable-agriculture/pestnotes/insect/bronzed-field-beetle.

Micic, S & Severtson, D 2018, 'Management of bronzed field beetle – a pest of canola in southern Western Australia', viewed January 2019, https://www.agric.wa.gov.au/pest-insects/management-bronzed-field-beetle-pest-canola-southern-western-australia, Department of Primary Industries and Regional Development, Western Australia, Perth.

Micic, S & Learmonth, S 2018, 'Identifying soil beetle pests', viewed January 2019, https://www.agric.wa.gov.au/pest-insects/identifying-soil-beetle-pests?page=0%2C1, Department of Primary Industries and Regional Development, Western Australia, Perth.

Garden centipede

Jesse, W & Dreves, AJ 2019, 'Biology and Control of the Garden Symphylan', Pacific Northwest Pest Management Handbooks, viewed January 2019, https://pnwhandbooks.org/insect/ipm/garden-symphylan.

Waterhouse, JS 1968, 'Studies on the garden symphylan, *Scutigerella immaculate* (Symphyla: Scutigerellidae)' *The Canadian Entomologist*, vol. 100 (2), pp. 172-8.

Earwig

Grains Research and Development Corporation 2013, 'European earwig', viewed January 2019, https://Grains Research and Development

Corporation.com.au/__data/assets/pdf_file/0019/134281/final-hr-Grains Research and Development Corporation-earwigs-fact-sheet-pdf.pdf.pdf.

Widmer, M Micic, S Learmonth, S 2018, 'Management of European earwig', viewed January 2019', https://www.agric.wa.gov.au/pome-fruit/management-european-earwig?page=0%2C1, Department of Primary Industries and Regional Development, Western Australia, Perth.

Flatworms

Wikipedia 2019, 'Flatworm', viewed January 2019, https://en.wikipedia.org/wiki/Flatworm.

Fungus gnat

Greenlife Industry Australia. 'Fungus gnat pest management plan for production nurseries', viewed January 2019, https://www.ngia.com.au/Attachment?Action=Download&Attachment_id=1845.

Clift, AD (1979), 'The pest status and control of insects and mites associated with cultivated mushrooms in Australia', *The Mushroom Journal*, vol. 75, pp. 113–116.

Clift, AD & Larsson, SF 1984, 'The incidence and ecology of *Lycoriella mali* (Fitch) (Diptera: Sciaridae) in the commercial culture of two species of mushroom in NSW', *General and Applied Entomology*, vol.16, pp. 49–56.

Shamshad, A 2010, 'The development of integrated pest management for the control of mushroom sciarid flies, *Lycoriella ingenua* (Dufour) and *Bradysia ocellaris* (Comstock), in cultivated mushrooms', *Pest Management Science*, vol 66 (10), pp. 1063–1074.

Grasshopper

NSW Department of Primary Industries 2017, 'Wingless grasshoppers', Primefact 631 sixth edition, NSW Department of Primary Industries.

Emery, R 2019. 'Wingless grasshoppers and their control', viewed January 2019, https://www.agric.wa.gov.au/spring/wingless-grasshoppers-and-their-control?nopaging=1, Department of Primary Industries and Regional Development, Western Australia, Perth.

Millipede

Grains Research and Development Corporation, 2013, 'Black Portuguese Millipedes & Slaters', Fact sheet, Grains Research and Development Corporation, Barton ACT.

Australian Environmental Pest Managers Association Ltd, 2019, Black Portuguese millipedes, viewed January 2019, https://aepma.com.au/PestDetail/41/Black%20Portuguese%20Millipedes.

Wikipedia, 2019, viewed January 2019, https://en.wikipedia.org/wiki/Millipede.

Smith, A 2019, *Mitigating Snails, Slugs and Slaters in Southern Western Australia - Grower Case Studies*, Grains Research and Development Corporation.

Widmer, M 2019. 'Portuguese millipedes', viewed 2019 https://www.agric.wa.gov.au/pest-insects/portuguese-millipedes, Department of Primary Industries and Regional Development, Western Australia, Perth.

Mites – General

Department of Primary Industries and Regional Development 2019, 'Managing mites in WA deciduous fruit trees' viewed November 2019, https://www.agric.wa.gov.au/pome-fruit/managing-mites-wa-deciduous-fruit-trees?nopaging=1.

Gall mite

Ozman SK 2000, 'Some biological and morphological differences between gall and vagrant forms of *Phytoptus avellanae* Nal. (Acari: Phytoptidae)', *International Journal of Acarology*, vol.26:3, pp. 215-219.

Hazelnut mite

Agriculture Victoria, 2016, 'Hazelnut mite - New mite species found in hazelnut orchards in Australia', viewed January 2019, http://agriculture.vic.gov.au/__data/assets/pdf_file/0004/314257/Hazelnut-mite_web.pdf.

Yalia, MP Razmjoua, J Khanjanib, M li Golizadeha A & ehdi Hassanpoura M 2012, 'Life history traits of *Tetranycopsis horridus* (Canestrini and Fanzago) (Acari: Tetranychidae) at three constant temperatures', *International Journal of Acarology*, pp. 1–6.

Fruit tree borer

Common, IFB 1990, *Moths of Australia*, Melbourne University Press.

Marte, S. P 2007, *Fruit-tree borer (Maroga melanostigma): investigations on its biological control in prune trees*, M. Sc. (Honours), Univ. Western Sydney.

Zborowski, P & Edwards, T 2007, *A Guide to Australian Moths*, CSIRO Publishing.

Heliothis

Queensland Department of Primary Industries and Fisheries, 2005, 'Understanding Helicoverpa ecology and biology in southern Queensland', *Agdex No.612*, Queensland Department of Primary Industries and Fisheries.

Micic, S & Lord, A 2019, 'Native budworm moth trapping in Western Australia', viewed January 2019, https://www.agric.wa.gov.au/pest-insects/native-budworm-moth-trapping-western-australia?page=0%2C3, Department of Primary Industries and Regional Development, Western Australia, Perth.

Light brown apple moth

Australian Table Grape Association, 2019, 'Light brown apple moth', viewed January 2019, http://www.australiangrapes.com.au/pest-monitoring/light-brown-apple-moth/.

Williams, D 2000, 'Light brown apple moth', *AG0093*, Agriculture Victoria, viewed January 2019, http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/pest-insects-and-mites/light-brown-apple-moth-in-orchards.

Oak leaf miner

Bashford, R Elliott, HJ 1989, 'Studies of the oak leafminer Phyllonorycter messaniella (Zeller) (Lepidoptera: Gracillariidae) in southern Tasmania', *Papers and Proceedings of the Royal Society of Tasmania*. Vol.123, pp. 223-8.

Common, IFB 1976, 'The oak leaf-miner, Phyllonorycter messaniella (Lepidoptera: Gracillariidae) established in Australia', *J. Aust. ent. Soc*. vol. 15, pp. 471-473.

New, TR 1981, 'The oak leaf-miner, Phyllonorycter messaniella (Zeller) (Lepidoptera: Gracillariidae) in Melbourne', *Aust. J. Zool*. Vol.29, pp. 895-905.

Painted apple moth

Esperance Fauna, 2019, viewed January 2019, http://esperancewildlife.blogspot.com.au/2009/05/teia-athlophora-tussock-moth.html

Coffs Harbour Butterfly House, 2019, viewed January 2019, http://lepidoptera.butterflyhouse.com.au/lyma/athlophora.html.

Common, IFB 1990, *Moths of Australia*. Melbourne University Press.

Suckling, DM Barrington, AM Chhagan, A Stephens, AEA Burnip, GM Charles, JG Wee, S 2007, 'Eradication of the Australian Painted Apple Moth Teia anartoides in New Zealand: Trapping, Inherited Sterility, and Male Competitiveness. In: Vreysen M.J.B., Robinson A.S., Hendrichs J. (eds) *Area-Wide Control of Insect Pests*. Springer, Dordrecht. pp 603-615.

Zborowski, P & Edwards, T, 2007, *A Guide to Australian Moths*, CSIRO Publishing.

Potworms

Wageningen University & Research, Enchytraeids (potworms), 2019, viewed January 2019, https://www.wur.nl/en/Research-Results/Chair-groups/Environmental-Sciences/Soil-Biology-Group/Research-1/The-Soil-Biota/Enchytraeids-potworms.htm.

Soft scale

Learmonth, S & Broughton, S, 2018,' Black scale in olives', viewed January 2019, https://www.agric.wa.gov.au/olives/black-scale-olives?nopaging=1, Department of Primary Industries and Regional Development, Western Australia, Perth.

Broughton, S, 2007, 'Scale in citrus', viewed January 2019, https://citrusaustralia.com.au/wp-content/uploads/fn2007_citrusscale_sbroughton.pdf, Department of Primary Industries and Regional Development, Western Australia, Perth.

Smith, D Beattie, GAC & Broadley, R (Eds.) 1996, *Citrus pests and their natural enemies: integrated pest management in Australia*, Queensland Department of Primary Industries, Brisbane.

Slaters

Grains Research and Development Corporation, 2013, 'Black Portuguese Millipedes & Slaters', Fact sheet, Grains Research and Development Corporation, Barton ACT.

Cesar 2016, 'Preparing for slaters', PestFacts south-eastern, issue no.1 12th May 2016

Micic, S 2017, Diagnosing slaters in crops, viewed January 2019, https://www.agric.wa.gov.au/mycrop/diagnosing-slaters-crops, Department of Primary Industries and Regional Development, Western Australia, Perth.

Smith, A 2019, *Mitigating Snails, Slugs and Slaters in Southern Western Australia - Grower Case Studies*. Grains Research and Development Corporation.

slugs

Department of Primary Industries and Regional Development, Western Australia, 2019, 'Snail and slug control', viewed January 2019, https://www.agric.wa.gov.au/pest-animals/snail-and-slug-control Department of Primary Industries and Regional Development, Western Australia, Perth.

Micic, S, 2018, 'Identification and control of pest slugs and snails for broadacre crops in Western Australia', viewed January 2019, https://www.agric.wa.gov.au/grains/identification-and-control-pest-slugs-and-snails-broadacre-crops-western-australia Department of Primary Industries and Regional Development, Western Australia, Perth.

Smith, A 2019, *Mitigating Snails, Slugs and Slaters in Southern Western Australia - Grower Case Studies*. Grains Research and Development Corporation.

Tulli, M C, Carmona, D M, López, A N, Manetti, P , Vincini, A M, Cendoya, G, 2009, 'Predation on the slug *Deroceras reticulatum* (Pulmonata: Stylommatophora) by *Scarites anthracinus* (Coleoptera: Carabidae)' *Ecologia Austral.* vol.19, pp. 55-61.

Wikipedia, 2019, Slug, viewed January 2019, https://en.wikipedia.org/wiki/Slug.

Garden snail and small pointed snail

cesar, 2015, 'Small pointed snail', viewed January 2019, http://cesaraustralia.com/sustainable-agriculture/pestnotes/insect/Small-pointed-snail.

Department of Primary Industries and Regional Development, Western Australia, 'App helps grain growers better control snails', viewed January 2019, https://www.agric.wa.gov.au/news/media-releases/app-helps-grain-growers%E2%80%99-better-control-snails Department of Primary Industries and Regional Development, Western Australia, Perth.

Identification Technology Program, 'Terrestrial mollusc tool', viewed January 2019, http://idtools.org/id/mollusc/index.php, USDA.

Johnstone, R, 2019, 'Managing snails in citrus orchards', viewed January 2019, https://www.agric.wa.gov.au/citrus/managing-snails-citrus-orchards Department of Primary Industries and Regional Development, Western Australia, Perth.

Micic, S, 2018, 'Identification and control of pest slugs and snails for broadacre crops in Western Australia', viewed January 2019, https://www.agric.wa.gov.au/grains/identification-and-control-pest-slugs-and-snails-broadacre-crops-western-australia Department of Primary Industries and Regional Development, Western Australia, Perth.

Smith, A 2019, Mitigating Snails, Slugs and Slaters in Southern Western Australia - Grower Case Studies. Grains Research and Development Corporation.

Wikipedia, 2019, 'Garden snail', viewed January 2019, https://en.wikipedia.org/wiki/Cornu_aspersum.

Springtails

Greenslade, P & Clift. A, 2004, Review of pest arthropods recorded from commercial mushroom farms in Australia. *Australasian Mycologist* vol. 23 (3) pp. 77-93.

Menta, C García-Montero, L G Pinto, S Conti, F D Baroni, G & Maresi, M, 2014, 'Does the natural "microcosm" created by *Tuber aestivum* affect soil microarthropods? A new hypothesis based on Collembola in truffle culture', *Applied Soil Ecology* vol. 84 pp. 31–37.

Wikipedia, 2019. 'Springtail', viewed January 2019, https://en.wikipedia.org/wiki/Springtail.

Thrips

Martin NA, 2018, 'Greenhouse thrips - *Heliothrips haemorrhoidalis*. Interesting Insects and other Invertebrates', *New Zealand Arthropod* Factsheet series number 105, viewed 4 June 2019, http://nzacfactsheets.landcareresearch.co.nz/Index.html.

Apple weevil

Micic, S & Learmonth, S 2018 'Identifying soil beetle pests', viewed January 2019, http://entnemdept.ufl.edu/creatures/orn/beetles/fuller_rose_beetle.htm Department of Primary Industries and Regional Development, Western Australia, Perth.

Yates, L Spafford, H & Learmonth, S 2007, 'Apple weevil (*Otiorhynchus cribricollis*) management and monitoring in Pink Lady™ apple orchards of south-west Australia', *Plant Protection Quarterly* vol. 22(4), pp. 155-159.

Fullers rose weevil

Gyeltshen, J & Hodges, A, 2019, 'Fuller rose beetle', viewed January 2019, http://entnemdept.ufl.edu/creatures/orn/beetles/fuller_rose_beetle.htm, University of Florida.

Micic, S & Learmonth, S 2018 'Identifying soil beetle pests', viewed January 2019, http://entnemdept.ufl.edu/creatures/orn/beetles/fuller_rose_beetle.htm Department of Primary Industries and Regional Development, Western Australia, Perth.

Garden weevil

Learmonth, S 2018, 'Garden weevil in vineyards', viewed January 2019, https://www.agric.wa.gov.au/pome-fruit/garden-weevil-vineyards Department of Primary Industries and Regional Development, Western Australia, Perth.

Micic, S & Learmonth, S 2018 'Identifying soil beetle pests', viewed January 2019, http://entnemdept.ufl.edu/creatures/orn/beetles/fuller_rose_beetle.htm Department of Primary Industries and Regional Development, Western Australia, Perth.

Redlegged weevil

Atlas of living Australia, 2019, '*Catasarcus* spp.', viewed January 2019, https://bie.ala.org.au/search?q=Catasarcus.

Whitefringed weevil

Micic, S Learmonth, S 2018, 'Identifying soil beetle pests', viewed January 2019, http://entnemdept.ufl.edu/creatures/orn/beetles/fuller_rose_beetle.htm Department of Primary Industries and Regional Development, Western Australia, Perth.

European truffle beetle

Fortea, VP Santafé, MM 2018, 'La Sanidadad en Truficultura – Guía de identificación de agentes nocivos en truficultura (Heathy truffles – an identification guide for harmful agents in truffle farming)', *Truffle Association of Teruel, Spain*, Ed Government of Aragon.

Morcillo, M Sanchez, M Vilanova, X 2015. *Truffle Farming Today, a Comprehensive World Guide*, Micologia Forestal & Aplicada.

Pérez-Andueza, G Ruíz, JI Ortiz, A Saucedo C and Herrero, F 2013, The truffle beetle Leiodes cinnamomeus (Coleoptera, Leiodidae), key pest of black truffle (Tuber melanosporum) in Central Spain: bioecological contributions and mass trapping control. *Paper presented at the 1st International Congress of Trufficulture, Tereul*, 5-8 March 2013.

Truffle fly

Fortea, VP Santafé, MM 2018, 'La Sanidadad en Truficultura – Guía de identificación de agentes nocivos en truficultura (Heathy truffles – an identification guide for harmful agents in truffle farming)', *Truffle Association of Teruel, Spain*, Ed Government of Aragon.

Morcillo, M Sanchez, M Vilanova, X 2015. *Truffle Farming Today, a Comprehensive World Guide*, Micologia Forestal & Aplicada.

Vertebrate pests

Trappe J Claridge. A. 2010. 'The hidden life of truffles' *Scientific American* April pp. 78-84.

Australian honey fungus

Fungimap 2018, 'Australian Honey Fungus', viewed January 2019, https://fungimap.org.au/armillaria-luteobubalina-australian-honey-fungus/, fungimap, south Yarra.

Agriculture Victoria 2010, 'Armillaria root rot' *AG0155*, Agriculture Victorian, viewed January 2019, http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/plant-diseases/fruit-and-nuts/stone-fruit-diseases/armillaria-root-rot.

Bacterial blight

Plantwise knowledge bank, 'Hazlenut blight', CABI, viewed January 2019, https://www.plantwise.org/knowledgebank/datasheet/56930.

Lamichhane, JR Varvaro, L 2014. 'Xanthomonas arboricola disease of hazelnut: current status and future perspectives for its management', *Plant Pathology* vol. 63 pp. 243-54.

Discula

Maddau, L Perrone, C Andolfi, A Spanu, E Linaldeddu, BT Evidente, A 2011, 'Phytotoxins produced by the oak pathogen Discula quercina', *Forest Pathology* vol. 41 pp. 85-9.

Moricca, S Linaldeddu, BT Ginetti, B Scanu, B Franceschini, A Ragazzi, A 2016, 'Endemic and Emerging Pathogens Threatening Cork Oak Trees: Management Options for Conserving a Unique Forest Ecosystem', *Plant Disease* vol. 10 pp. 2184-93.

Moricca, S Ragazzi, A 2008, 'Fungal endophytes in Mediterranean oak forests: A lesson from Discula quercina', *Phytopathology* vol. 98 pp. 380-6.

Moricca, S Ragazzi, A 2011, 'The Holomorph Apiognomonia quercina/Discula quercina as a Pathogen/Endophyte in Oak', In: Pirttilä A, Frank A, eds. *Endophytes of Forest Trees. Forestry Sciences*, vol. 80. Springer, Dordrecht.

Ragazzi, A Moricca, S Dellavalle, I 1999, 'Epidemiological aspects of Discula quercina on oak: inoculum density and conidia production. Zeitschrift Fur Pflanzenkrankheiten Und Pflanzenschutz', *Journal of Plant Diseases and Protection* vol. 106 pp. 501-6.

Ragazzi, A Moricca, S Capretti, P Dellavalle, I 2000, 'Analysis of Discula quercina isolates from Quercus spp. Zeitschrift Fur Pflanzenkrankheiten Und Pflanzenschutz', *Journal of Plant Diseases and Protection* vol. 107 pp. 170-5.

Ragazzi, A Moricca, S Capretti, P Dellavalle, I Turco, E 2003, 'Differences in composition of endophytic mycobiota in twigs and leaves of healthy and declining Quercus species in Italy', *Forest Pathology* vol. 33 pp. 31-8.

Sahashi, N Kubono, T Miyasawa, Y Ito, S 1999, 'Temporal variations in isolation frequency of endophytic fungi of Japanese beech', *Canadian Journal of Botany-Revue Canadienne De Botanique* vol. 77 pp. 197-202.

Root and root collar diseases

Department of Biodiversity, Conservation and Attractions 2019, 'Phytophthora dieback', viewed January 2019, https://www.dpaw.wa.gov.au/management/pests-diseases/phytophthora-dieback, Department of Biodiversity, Conservation and Attractions.

Weste, G 2003, 'The dieback cycle in Victorian forests: a 30-year study of changes caused by Phytophthora cinnamomi in Victorian open forests, woodlands and heathlands', *Australasian Plant Pathology* vol. 32 pp. 247-56.

Stem diseases and dieback

Akay, Ş Ekiz, G Kocabaş, F Hameş-Kocabaş, EE Korkmaz, KS Bedir, E 2014, 'A new 5,6-dihydro-2-pyrone derivative from Phomopsis amygdali, an endophytic fungus isolated from hazelnut (Corylus avellana)', *Phytochemistry Letters* vol. 7, pp. 93-6.

Battilani, P Chiusa, G Arciuolo, R Somenzi, M Fontana, M Castello, G Spigolon, N 2018, 'Diaporthe as the main cause of hazelnut defects in the Caucasus region', *Phytopathologia Mediterranea* vol. 57 pp. 320-33.

Diogo, ELF Santos, JM Phillips, AJL 2010, 'Phylogeny, morphology and pathogenicity of Diaporthe and Phomopsis species on almond in Portugal', *Fungal Diversity* vol. 44 pp. 107-15

Gonthier, P Gennaro, M Nicolotti, G 2006, 'Effects of water stress on the endophytic mycota of Quercus robur', *Fungal Diversity* vol. 21 pp. 69-80.

Guerrero, J Pérez, S 2013, 'First report of Diaporthe australafricana-caused stem canker and dieback in european hazelnut (Corylus avellana L.) in Chile', *Plant Disease* vol. 97 pp. 1657.

Meng, L Yu, C Wang, C Li, G 2018, 'First Report of Diaporthe amygdali causing walnut twig canker in Shandong Province of China', *Plant Disease* vol. 102 pp. 1859.

Mullerin, S Smith, JA 2015, 'Bot canker of oak in Florida caused by Diplodia corticola and D. quercivora', *FOR318*. School of Forest Resources and Conservation, UF/IFAS Extension.

Sahashi, N Kubono, T Miyasawa, Y Ito, S 1999, 'Temporal variations in isolation frequency of endophytic fungi of Japanese beech', *Canadian Journal of Botany-Revue Canadienne De Botanique* vol. 77 pp. 197-202.

Sanchez, M.E Venegas, J Romero, MA Phillips, AJL Trapero, A 2003, 'Botryosphaeria and related taxa causing oak canker in southwestern Spain', *Plant Disease* vol.87 pp. 1515-21.

Serrano, MS Romero, MA Jimenez, JJ De Vita, P Ávila, A Trapero, A Sánchez, ME 2015, 'Preventive control of Botryosphaeria canker affecting Quercus suber in southern Spain', *Forestry*, vol. 88,pp. 500-7.

Slippers, B Wingfield, MJ 2007, 'Botryosphaeriaceae as endophytes and latent pathogens of woody plants: diversity, ecology and impact', *Fungal Biology Reviews* vol. 21 pp. 90-106.

Udayanga, D Castlebury, LA Rossman, A.Y Hyde, KD 2014, 'Species limits in Diaporthe: molecular re-assessment of D. citri, D. cytosporella, D. foeniculina and D. rudis', *Persoonia* vol. 32 pp. 83-101.Truffle rot.

Eslick, H 2012, 'Identifying the Cause of Rot in Black Truffles and Management Control Options', *RIRDC Publication No. 12/005*.

Eslick, H 2013, 'Identification and management of the agent causing rot in black truffles - Part 2 Identifying the Cause of Rot in Black Truffles and Management Control Options', *RIRDC Publication No. 12/005*.

Eslick, H 2016, 'Factors Affecting Truffle Production and Quality in Western Australia', *Ph. D. thesis.* School of Veterinary and Life Sciences Murdoch University, Perth, Western Australia.

Sudden oak death

Denman, S Kirk, SA Brasier, CM & Webber, JF 2005, '*In vitro* leaf inoculation studies as in indication of tree foliage susceptibility to *Phytophthora ramorum* in the UK', *Plant Pathology*, vol. 54 pp. 512-521.

Grünwald, NJ, Goss, EM & Press, CM 2008, '*Phytophthora ramorum*: a pathogen with a remarkably wide host range causing sudden oak death on oaks and ramorum blight on woody ornamentals', *Molecular Plant Pathology*, vol. 9, pp. 729-740.

Rizzo, DM Garbelotto, M Davidson, JM Slaughter, GW & Koike, S 2002, '*Phytophthora ramorum* as the cause of extensive mortality of *Quercus* spp. And *Lithocarpus densiflorus* in California', *Plant Disease*, vol. 86: 205-214.

Pierce's disease

European Food Safety Authority (EFSA) 2018, 'Update of the *Xylella* spp. host plant database', *EFSA Journal*, vol. 16.

Jeger, M Bragard, C Caffier, D Chatzivassiliou, E Dehnen-Schmutz, K Gilioli, G Grégoire, J Jaques Miret, JA MacLeod, A Navarro, MN Niere, B Parnell, S Potting, R Rafoss, T Rossi, V Urek, G Van Bruggen, A Van Der Werf, W West, J Winter, S De La Fuente, L Spotti Lopes, JR Tramontini, S Andueza, M & Candresse, T 2016, 'Susceptibility of *Citrus* spp., *Quercus ilex* and *Vitis* spp. to *Xylella fastidiosa* strain CoDiRO', *EFSA Journal*, vol. 14.

Appendix 1 – Monitoring score sheets

TRUFFLE PEST MONITORING - 50 TILES

Site:												Date bran placed:							Date checked:		
Tile	ABB	Beetle	Beetle	Earwig			Slug					Snails		Slater	Millipede				S'tails	Other
no.		Carabs	Staphs	EE	Prd	Blk	Br	Hd	Kl	Rt	St	GS	SPS		Port	Bwn	Hry	Strp		
1																				
2																				
3																				
4																				
5																				
6																				
7																				
8																				
9																				
10																				
11																				
12																				
13																				
14																				
15																				
16																				
17																				
18																				
19																				
20																				
21																				
22																				
23																				
24																				
25																				
26																				
27																				
28																				
29																				
30																				
31																				
32																				
33																				
34																				
35																				
36																				
37																				
38																				
39																				
40																				
41																				
42																				
43																				
44																				
45																				
46																				
47																				
48																				
49																				
50																				

TRUFFLE PEST MONITORING WITH TILES

Name on score sheet		Explanation
ABB		African black beetle
Beetle	**Carabs**	Predatory carabid beetles
	Staphs	Predatory staphylinid beetles
Earwig	**EE**	European earwig
	Prd	Predatory tan/black earwigs
	Blk	Black earwig
Slug	**Br**	Brown slug
	Hd	Hedgehog slug
	Kl	Black keeled slug
	Rt	Reticulated/grey slug
	St	Striped slug
Snail	**GS**	Garden snail
	SPS	Small pointed snail
Slater		Slater
Millipede	**Port**	Portuguese millipede
	Bwn	Brown millipede
	Hry	"Hairy" millipede
	Strp	Striped milliped
S'tails*		Springtails/collembolans

* Springtail numbers scored as L (low) = 1-50
M (medium) = 50-200
H (high) >200

TRUFFLE PEST MONITORING WITH TILES

Site:			Date bran placed:
			Date checked:
Tile No.	Slugs	Slaters	Other
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			
13			
14			
15			
16			
17			
18			
19			
20			
21			
22			
23			
24			
25			
26			
27			
28			
29			
30			
31			
32			
33			
34			
35			
36			
37			
38			
39			
40			
41			
42			
43			
44			
45			
46			
47			
48			
49			
50			

Appendix 2 – Field monitoring identification sheet

Common invertebrate species found in truffle orchards

Field identification sheet to be used in conjunction with the field monitoring scoring sheet for truffle orchardists undertaking pest monitoring activities

Slugs

Black keeled slug

Reticulated/Grey slug has white exudate when the skin is brushed

Brown slug

Striped slug

Hedgehog slug

Hedgehog slug has yellow exudate when the skin is brushed

Millipedes

Portuguese millipede

'Hairy' millipede

Brown millipede and springtails

'Striped' millipede

Slaters

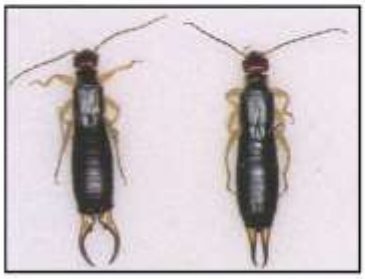
Springtails

Not to scale

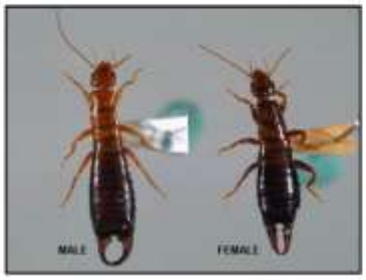
Common invertebrate species found in truffle orchards

Field identification sheet to be used in conjunction with the field monitoring scoring sheet for truffle orchardists undertaking pest monitoring activities

Earwigs



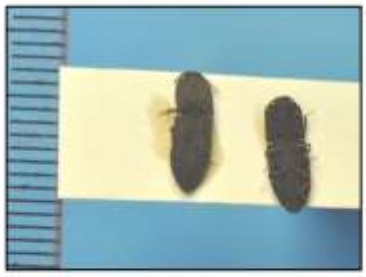
European earwig— 12mm long



Predatory earwig—15 to 20 mm long

'Black' earwig— 8mm long

Beetles - potential pests



Click beetle

Vegetable beetle

African black beetle

Beetles - predatory

Carabids

Staphylinids