Nursery levy at work: **Nursery Production Plant Health & Biosecurity Project**

Herbivorous mites

A pest management plan for production nurseries

Mites as production nursery pests

The purpose of this pest management plan is to provide production nurseries with knowledge of the range of mites that commonly can cause damage to plants, how they can be identified and effectively managed. Production nurseries are ideal environments for mite pests because plants are often lush and actively growing. As a result, mite populations can sometimes increase very quickly and produce outbreaks that cause severe damage. There are five major groups of mites that can cause damage to plants: spider mites, tarsonemid mites (e.g. broad mite and cyclamen mite), flat mites, eriophyid mites and astigmatid (bulb) mites.

Fig. 1. Cycad

All mites are small, but some mites are so tiny that they cannot be observed without significant magnification. In fact, of the four groups, only spider mites can be consistently observed with only a hand lens. There are two major consequences that result. First, low populations of mites tend to cause very little or undetectable levels of damage. Populations can grow and spread within a nursery without being observed. Noticeable damage only occurs when relatively large numbers are present and can often seem to appear as if overnight, particularly if specific monitoring is not carried out. Second, damage caused by mites can often be similar to that caused by some other factors, e.g. nutrient deficiency, environmental conditions, insect damage (particularly thrips) or even treatment with plant hormones or accidental herbicide damage. Therefore, misidentification is a common problem that can lead to mismanagement. For both of these reasons it is important to either purchase a dissecting microscope, a high quality USB microscope or send samples for identification to a diagnostic laboratory to have mites confirmed before management actions are implemented. These tools will also be discussed in more detail later on.

It is important to realise that not all mites found on plants are plant pests. In fact, many mites found on plants are predators of mites and small insects. Some mites may be benign, feeding on pollen, dead and decaying plant matter or fungi growing on the surface of plants, e.g. black sooty mould. There are numerous commercially available predatory mites that are suited to the management of some pest mites. These will also be discussed below.

Nursery & Garden Industry Australia
Nursery Production Plant Health & Biosecurity Project
BUILDING INDUSTRY CAPACITY & MANAGING RISKS
Horticulture Innovation Australia
Queensland Government

This pest management plan is split into three sections. In the first section the appearance, biology and damage caused by each group of mites is discussed. Since management options for each group are similar, cultural management, biological control and use of pesticides to manage mites are discussed in the second section. The final section has specific recommendations for each mite group.

Section 1: Herbivorous mites

Where can mites be found?

Mites that cause damage to plants can be found on most above ground plant parts, but are most commonly found on leaves, growing tips and within flower buds. Certain species may also be present on stems, fruit and under leaf sheaths (particularly grasses and grass-like plants). Some eriophyid mites will also be inside galls (unusual plant growths) that are normally found on leaves, but not always. Damage to below ground parts is typically restricted to bulbs and a small number of plant species.

Spider mites (Family Tetranychidae)

Spider mites are the most commonly encountered group of pestiferous mites in production nurseries and horticulture in general. All spider mites can produce silk, hence their common name, but some species produce more than others. There are over 1,200 species of spider mites described globally from over 70 genera. All species of spider mites feed on plants and virtually every plant species has at least one, but probably multiple, spider mite species that can cause significant damage. Two-spotted mite (*Tetranychus urticae*) is probably the most notorious and widespread. As such, there is a factsheet devoted entirely to the biology and management of two-spotted mite available on the NGIA and NGIQ websites. Many other species from the genus *Tetranychus* are plant pests in Australia and around the world, as are species from *Oligonychus*, *Schizotetranychus*, *Bryobia* and others. Different plants are more likely to be attacked by certain spider mites species than others. Do not assume that because you have spider mites it is always two-spotted mite. While this may be the most widespread and common species, there are many species of spider mites that can appear virtually identical until they are closely examined on a microscope slide by a specialist diagnostician. In many cases, male individuals must be prepared on their side to examine their reproductive organs before identification can be made to species level with confidence.

Spider mite lifecycle

All species of spider mites share some general biological characteristics. All spider mites have long

Fig. 2. Spider mites and webbing on citrus (above), chlorotic stippling (middle) and spider mites and their cast-off skins (below).

needle-like mouthparts used to suck the contents from plant cells. They are soft bodied and often are red, green orange or yellow in colour. In most instances, females are far more common than males. Females are larger than males and have an ovoid body shape compared to males, which are slightly narrower and have an angular body shape, particularly at the posterior end of the body. Females also tend to be slower than males. Adult spider mites are about half a millimetre in length. Eggs are generally spherical, opaque white in colour, though some may be slightly yellow, orange, red or brown. Eggs are not visible to the naked eye but can be seen with a x10 handlens with careful observation. Eggs hatch into larvae that have only six legs, not eight. Spider mites then have two nymphal stages before turning into an adult. All nymphs and adults have eight legs. Immature stages are similar in appearance to adults, but are smaller and may have slightly different colouration. With each moult the individual also gains body hairs, with adults having the full complement of hairs.

Development from egg to adult often takes only 1-2 weeks during optimal temperatures, but can be longer at cooler temperatures and for certain species. Females start laying eggs after just a few days, may lay 10 or more eggs per day and may live for about a month. In cooler climates, female spider mites overwinter in protected areas of the plant. A distinct cool period, followed by warm conditions, may be required before they reactivate and start laying eggs again during warmer periods. Most spider mites in Australia will not overwinter, particularly in protected cropping structures.

At low densities, spider mites tend to be present on the underside of leaves. As populations increase, however, individuals may be present anywhere on the plant and may be seen in relatively large masses. Exceptions occur, for example, *Oligonychus perseae* occurs on the upper surface of avocados and occur under a thick layer of silk. However, this species is not known to occur in Australia; any spider mites present in large numbers on the upper surface of avocado should be reported to your local biosecurity organisation for identification.

Spider mite damage

Spider mites damage plants by removing the contents of parenchyma plant cells. Typically, this causes tiny yellow-white spots on the upper leaf, called stippling. As populations increase and continue to damage plants, the damage sites may develop into larger irregular white or greyish coloured regions, which is more likely to occur between leaf veins. Yellowing and or bronzing of leaves may also occur as can leaf and stem death. Some species will produce so much silk that the entire plant is covered in silk and perhaps millions of individuals writhing on the plant in masses. Under such scenarios, damage may also include leaf burning, defoliation and even plant death, particularly of smaller plants. Populations are more likely to build up to damaging levels during warm, dry conditions. Many species of spider mites are highly polyphagous, potentially damaging a large number of host plant species. Other species are quite host specific, only feeding on a small number of closely related plants.

Spider mite spread

Spider mites can be spread around production nurseries very easily by staff brushing against infested plants and on tools. They can also be spread with the wind and will crawl between plants that have touching foliage. Individuals are more likely to move off unhealthy plants, be it from spider mite damage or some other cause.

Monitoring for spider mites

Spider mites are very easy to detect at a low population using the plant beating method. Spider mites can be detected efficiently on the beating tray with only very slight symptoms to the crop. Once spider mites are found on the tray, look in more detail for stippling and chlorotic leaves. If no obvious symptoms can be seen, look on the underside of leaves closely to determine the extent of the infestation.

Tarsonemid mites (broad mite and cyclamen mite)

There are only a few genera of tarsonemid (pronounced: tar-so-nee-mid) mites that feed on plants and two species cause the majority of damage to nursery crops: broad mite (*Polyphagotarsonemus latus*) and cyclamen mite (*Phytonemus pallidus*). Both cause similar damage but broad mite has a more extensive host range than cyclamen mite. Both species are essentially microscopic (being about 0.1-0.3mm long) and generally require a microscope to be observed with confidence; they will be very difficult to observe with x10 handlens. They can be observed with USB microscopes sometimes but not always. Females tend to be ovoid and may have light brown to deep amber colouration, though female broad mites may be dark green in colour on certain host plants. Males are smaller than females, tend to be more circular to globular in shape and the

last pair of their legs are much stronger than females. Males are opaque in colour, but develop into a light brown to amber colouration over time. Broad mites can be identified to species level very easily by observing their eggs. Broad mite eggs are dome-like, with a flat base and have white polka-dot structures on top (tubercles). Cyclamen mite eggs are more typical, being opaque and ovoid in shape. Larvae have six legs and are whitish in colour and often appear pointed at the back of the body.

Tarsonemid lifecycle

Tarsonemid mites have only three lifestages: egg, larva and adult. Nymphs tend not to occur. As such, their lifecycle occurs very quickly, often in a week or less at moderate temperatures. The exact development time will vary with temperature, other environmental conditions (particularly humidity) and host plant species. For example, broad mites complete their development in just over 2 weeks at 15°C, but only 4 days at 30°C. Females lay about 1-5 eggs per day over 1-2 weeks. The lifecycle of cyclamen mite can take a little bit longer in some conditions. At 15°C cyclamen mite develops from egg to adult in about 20 days, but occurs in 6 days under optimal conditions. As such, populations can build up very quickly. Both species develop throughout the year when temperatures are suitable.

Most individuals are female, with males being relatively rare. Females can lay eggs without mating. For broad mites, an unfertilised egg results in a male individual, whereas fertilised eggs become female. However, unmated cyclamen mite females can lay eggs that result in male or female individuals. Male broad mites will carry quiescent female larvae on their back. When larvae emerge as adult females, the male will mate with her.

Tarsonemid damage and host range

Broad mites tend to damage young leaves and growing tips, mainly on the underside of leaves. At high infestations, leaves do not expand normally and tend to be deformed, crinkly and small. Flowers have a distorted appearance or have discoloured rays. Plant growth may effectively stop when all growing tips are infested and the plant may die when damage is severe for extended periods of time. On some host plants plant growth may crack, swell and necrotic areas may occur, similar to damage caused by herbicide. Broad mite damage can also be mistaken for virus infection and even nutritional disorders.

Broad mites have been reported from at least 57 plant families including some monocots (e.g. orchids) and many dicots including weed species. Many vegetable crops are severely affected, including beans, brassicas, capsicums, chillies,

Fig. 2. Typical deformation caused by broad mites on azalea (above), male holding a nymphal female (middle) and nymph and eggs (below).

cucumbers, tomatoes, potatoes and eggplants. Many fruit crops are also damaged including citrus, avocado, blackberry, melons, mango, passionfruit raspberry and grapes. Ornamental crops are also damaged including camellias, datura (weed and ornamental species), gerberas, impatiens, basil, African violet, begonia, chrysanthemum, cyclamen, dahlia, fuchsia, verbena, zinnia, pittosporum and hibiscus among many other species; some weeds are also damaged.

Cyclamen mites also damage young leaves and flowers. However they typically feed on the upper leaf surface, particularly when leaves are folded. Leaves can appear twisted, curled, deformed and fail to expand normally. Some host plants, e.g. gerbera, may have bronzed patches along midribs and flowers become deformed. Cyclamen mite also has a wide host range, but not quite as much as broad mite. This includes cyclamen, African violet, azalea, begonia, chrysanthemum, gerbera, geranium, petunia, snapdragon and other ornamental species.

Tarsonemid spread

Broad mites and cyclamen mites can spread short distances by walking, particularly when leaves of adjacent plants are touching. They may also be spread by wind, infested equipment and hitch hiking on insects. Broad mites are known to hitch-hike on a number of whitefly species, e.g. silverleaf and glasshouse whitefly.

Monitoring for tarsonemid mites

Tarsonemid mites can be difficult to detect at low populations, before damage starts to occur. It is essential to record plant species and varieties that are susceptible to tarsonemid mites and the conditions associated with the infestation, e.g. warm spring conditions. Identify the plants in the nursery that are most susceptible and monitor these more closely. Where practically feasible, remove a growing tip and examine it under the microscope during high risk periods, even if it looks completely healthy. At the very least, frequently monitor (twice per week) the health of growing tips and flowers of highly susceptible species during high risk periods. Remove growth that looks suspicious and examine it under the microscope. Once you are confident at identifying tarsonemid mites under the microscope, it may be possible to be confident examining plants in the field with a x20 hand lens.

Flat mites (Family Tenuipalpidae)

Flat mites are also commonly known as false spider mites because they are in a closely related family to spider mites. However, they do not produce silk and they are not spider mites. All flat mites are herbivores that tend to be flat and orange to red in colour. While all are herbivores only a few groups have species that have become economic pests. *Tenuipalpus* and *Brevipalpus* are the largest genera and tend to have most of the economically damaging species. Some species are relatively large and can be observed without magnification, others can only be seen with a microscope.

Similar to spider mites, flat mites have specialised mouthparts used to suck the contents of plant cells. Flat mites tend to have dorsal ornamentation and ridges on their back that can be elaborate and even appear beautiful at high magnification. Adults range in size between 0.2-0.4mm in length. Eggs tend to be ovoid in shape and are often orange to red in colour. Larvae and nymphs tend to be light orange in colour, with colouration becoming darker with each stage. However, some species are relatively pale.

Flat mite lifecycle

Flat mites have a similar lifecycle to spider mites, having an egg, larva, two nymphal stages and an adult stage. Few species of flat mites have been studied in detail, therefore the biology of some species may differ significantly from the below generalisation. However, many species of flat mites are parthenogenetic (all female), i.e. females can lay eggs without mating and their offspring are always female. Males tend to be rare, if they occur at all. Adult flat mites may live as long as two months. Development from egg to adult can take 3-4 weeks. Usually only one egg is laid per day, but may be higher for some species.

Flat mite damage and host range

There is a great deal of variation in the type of damage caused by flat mites depending upon the plant species and where they feed. Feeding on leaves can cause damage similar to spider mites (chlorotic stippling), but can also cause brownish discolouration along either side of the midrib of the lower leaf, cupping of the leaves, reduced size of leaves and may even cause leaf senescence. Feeding on growing tips may cause damage similar to broad mites, with distorted new growth and small deformed leaves, perhaps in

combination with a corky appearance of the stems. Some species of flat mites inject saliva into the plant that probably increases the amount of damage to the host beyond the removal of cell contents. Flat mites may also be present under the leaf sheath of grasses and grass like plants, causing necrotic lesions to occur on the stem, which may reduce growth and increase the likelihood of secondary infection.

Many plant species can be damaged by flat mites including various cacti and succulents, including Euphorbias, passionfruit, rhododendron, gardenia, Aphelandra, citrus, hibiscus, holly, viburnum and pecan. Some species have a relatively wide host range, perhaps being able to survive on as many as a 1,000 host species. However, not all hosts would support development enough to cause significant damage. Flat mites can be present at low rates without causing damage. Some of the species known to have a wide host range probably represent cryptic species, i.e. they look the same but have distinct biological traits.

Viruses vectored by flat mites

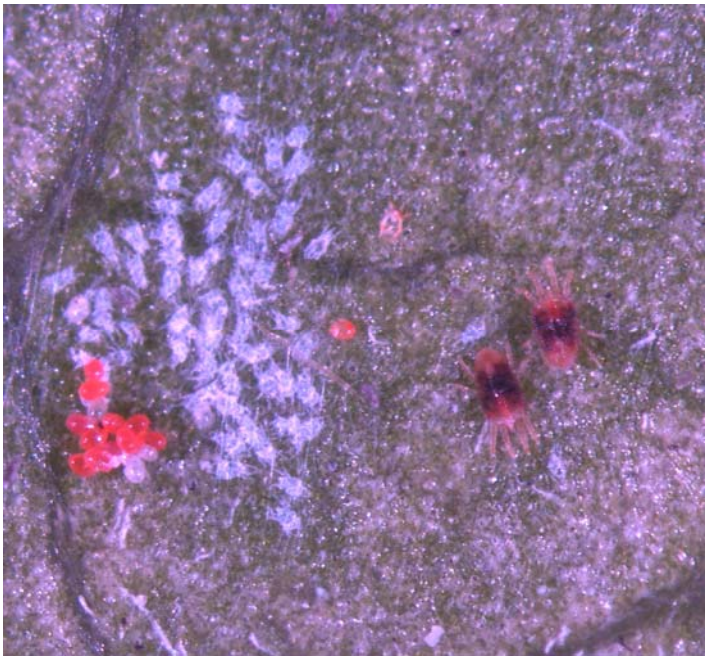
The three most common and economically important flat mites (*B. phoenicis*, *B. californicus* and *B. obovatus*) are known to vector a number of viruses, some of which can be very serious (e.g. *Citrus leprosis virus* in North and South America). Probably the most common in Australia is *Orchid fleck virus*. Little research has been conducted in this area, but what has been done points to the possibility that many ornamental plants could become infected with plant viruses vectored by these three mite species. In general, symptoms of plants infected with viruses transmitted by flat mites include: 1) chlorotic and or necrotic spots and ringspots on green leaves and green spots or ringspots on yellow (senescent) leaves, 2) chlorotic and or necrotic spots on stems, 3) chlorotic or brown spots usually depressed on fruits, and 4) brown spots on the flowers. Most of the known viruses vectored by flat mites are not known to be present in Australia.

Flat mite spread

Flat mites tend to be slow moving, but will probably still disperse short distances to nearby plants if foliage is touching. They probably are also wind dispersed. The most important method of spread is in infested, non-symptomatic planting material.

Monitoring for flat mites

Large flat mites that can be observed without magnification can be monitored by plant beating and directly observing leaves with a hand lens, particularly if plant material is damaged. For most species, however, which are too small to observe



Flat mite damage on Aphelandra (above) and *Euphorbia milii* (middle). *Brevipalpus* adults, eggs and cast-off skins (below).

with a x10 hand lens, microscopic examinations must be completed. Monitoring recommendations as per tarsonemid mites apply to small flat mites. Refer to the monitoring methods in section 2 for more details on microscopic examinations.

Eriophyid mites (Family Eriophyidae)

Where broad mites and cyclamen mites are tiny, eriophyid (pronounced: air-ee-o-fy-id) mites are miniscule in size. They are often about 0.1mm long and are rarely more than 0.2mm long. Individual mites cannot be observed without magnification (at least a x20 hand lens is required), but a devoted microscope with x30-x40 magnification is best. They can occasionally be observed using USB microscopes but they often lack the resolution required to confidently detect them, particularly when they are present in low numbers.

Eriophyid mites are worm-like or tubular in shape and often are tapered at one or both ends. They are unique in the mite world in that they have only 2 pairs of legs throughout their lifecycle. They are almost always white to light grey in colour. There are about 3000 species described in this family, from over 200 genera; many more species and genera exist that are not yet described. Many species of eriophyids are of economic importance to specific plant species, causing abnormal growth or sufficient damage to cause plants to be unsaleable. High infestations in some fruit and vegetable crops can also cause significant yield reductions and in rare occasions even plant death.

Eriophyid mite lifecycle

Eriophyids develop through egg, larva, nymph and adult stages and complete their development in about a week (at 25°C). They tend to have males and females. Females can lay up to three eggs per day for a month under good conditions. Their eggs are about half the size of adults and are generally white or opaque in colour and oval in shape.

Eriophyid damage and host range

Different species of eriophyids cause different types of damage to their host plant and this has given rise to many common names including rust mite, gall mite and blister mite. The presence of eriophyid mites often goes completely unnoticed until populations are high enough to cause significant observable damage. Each species is generally quite host specific, being adapted to one or a small number of relatively closely related host plant species. For example, tomato russet mite (*Aculops lycopersici*), causes damage to a small number of solanaceous plants including tomatoes, potatoes, tobacco, pepper and petunia, whereas many other species only cause damage to one host plant species.

Each species of eriophyid mite generally feeds on one area of the plant such as expanded leaves, young leaves and growing tips, flower buds or fruit. Some species produce galls or masses of unusual plant growth, in which they live. The type of damage produced on particular host plant species can provide a clue as to the species causing it. Keep in mind that there are many species of eriophyid mites that have not been described, even if they are well recognised, e.g. galls formed on banksia seed pods are caused by at least one undescribed species from the genus *Aceria*.

Eriophyids feeding on the **growing tips** tend to cause leaves to be small and deformed; petioles are often short as are internodal length. This damage is similar to that caused by broad mites and is often referred to as ‘witch’s broom’. Some species may cause growing tips to become necrotic and die. Damage to flowers and flower buds can cause bud distortion, stunting or russeting. Feeding on **fruit** can cause bronzing/ russeting damage, fruit deformity or premature fruit/nut drop. In addition, some species inject a toxin into the plant that cause some abnormality, e.g. stop the ripening of fruit (drupelets) of certain berries.

Feeding on **leaves** may also cause silver or brown discolouration (often referred to as russeting, bronzing or silvering), leaf spotting, leaf curling and or premature leaf drop. Some species may induce the development of outgrowths on leaves or petioles. Outgrowths are dense areas of leaf hairs (called erinea) in which mites take shelter. Erinea are generally bright pink, glossy crimson or sometimes other earthy colours and cause only minimal pocketing of the leaf. Mites are not always easy to observe within erinea, as they tend to shelter deep within the mass of hairs. Light heat, e.g. from a lamp, will often cause individuals to move out of the erinea to be more easily observed or collected. **Blisters** are similar to erinea but cause the leaf to cup or pucker in some way. Blisters can also become necrotic over time as the plant cells die.

Many species of eriophyids may produce **true galls**. Galls are produced by the plant as a reaction to feeding. Galls range in size and shape depending upon the host plant, plant part and mite species in question. The galls are typically green, pink or red and may be bright or dull in colour. Some galls are more yellow or

orange in colour and some may be green with a tinge of red. Most commonly, galls appear on upper leaves, but may also occur on petioles, stems, flower buds and flowers. Galls that are on leaves have the gall on the upper surface and have a tiny entrance on the lower leaf surface. Mites within the gall have an ideal environment to live and are relatively protected from predators and contact insecticides. Galls can be long and finger like with a pointed or rounded tip. Others are dome, bladder, dimple or wart-like in shape. Sometimes the galls are very irregular and globular, others are quite discrete and regular. Galls often appear clumped and may almost completely cover the leaf and may sometimes cause it to be grossly contorted. The gall itself is produced as the immature leaf expands and will not change once the leaf is mature, even if mites are killed using pesticides. In most instances galls on leaves do not affect the growth rate or production of their host, but can change their appearance such that they are no longer saleable.

Eriophyid dispersal

Since these mites are so tiny, they tend not to disperse far by walking. However, for microscopic organisms they can move surprising distances, i.e. centimetres, relatively quickly. Infested plants with foliage touching healthy plants may also become infested. The main dispersal mechanism is by wind. They may also be spread by other organisms, such as insects, other mites and birds. Movement of infested plants is by far the most common method for dispersal by these organisms in relation to production nurseries.

Eriophyid mites are amazingly robust, for soft-bodied microscopic organisms. Eriophyid mites have been collected alive from fresh snowfalls, indicating that they were in the atmosphere and brought back to earth with falling snow. This finding supports the notion that aerial dispersal is very important for eriophyid mites.

Monitoring for eriophyid mites

Like many flat mites and tarsonemid mites, plant material must be examined under a microscope to observe eriophyid mites. Fine forceps are often helpful to tease apart closely growing leaves in the tips or flower buds. They are also helpful for dissecting soft plant tissue suspected to be an eriophyid gall. Information relevant to monitoring for tarsonemid mites is relevant to eriophyid mites. For more information on how to complete a microscopic examination refer to the methods in section 2.

Eriophyids as vectors for plant diseases

Specific species of Eriophyid mites are known to vector fungal, viral and perhaps even bacterial

Eriophyid erinea on litchi (above), distorted growth on bougainvillea (middle) and tomato damage (below) and close up of growing tip (insert).

pathogens, many of which are not known to be present in Australia or have restricted geographic range. For example, mango bud mite vectors the mango malformation pathogen, *Fusarium mangiferae*, a fungus that causes severe distortion and dwarfing of new growth. It has been reported in the Northern Territory and Queensland but infected trees were destroyed and the disease has not reoccurred. *Rose rosette virus* occurs in North America and causes severe dwarfing of all commercial cultivars and is transmitted by an eriophyid mite. A number of eriophyids are known to transmit wheat and other grain crop viruses. Other eriophyid species are considered to vector a pathogen to their host plant, but in many cases the exact pathogen is not currently known.

Astigmatid mites, including bulb mites

There are a small number of mites that damage horticultural crops including bulbs, roots and foliage of nursery and flower crops from the cohort Astigmatidae. This is a large group of mites that has relatively few economic species relevant to production nurseries. Some species can cause major economic losses to stored plant and meat products. Most free-living, terrestrial astigmatid mites are not plant feeders but instead feed on fungi, nematodes or decaying organic matter. The majority of astigmatid mites are parasites of insects, birds and other vertebrates. Some free living aquatic species also occur.

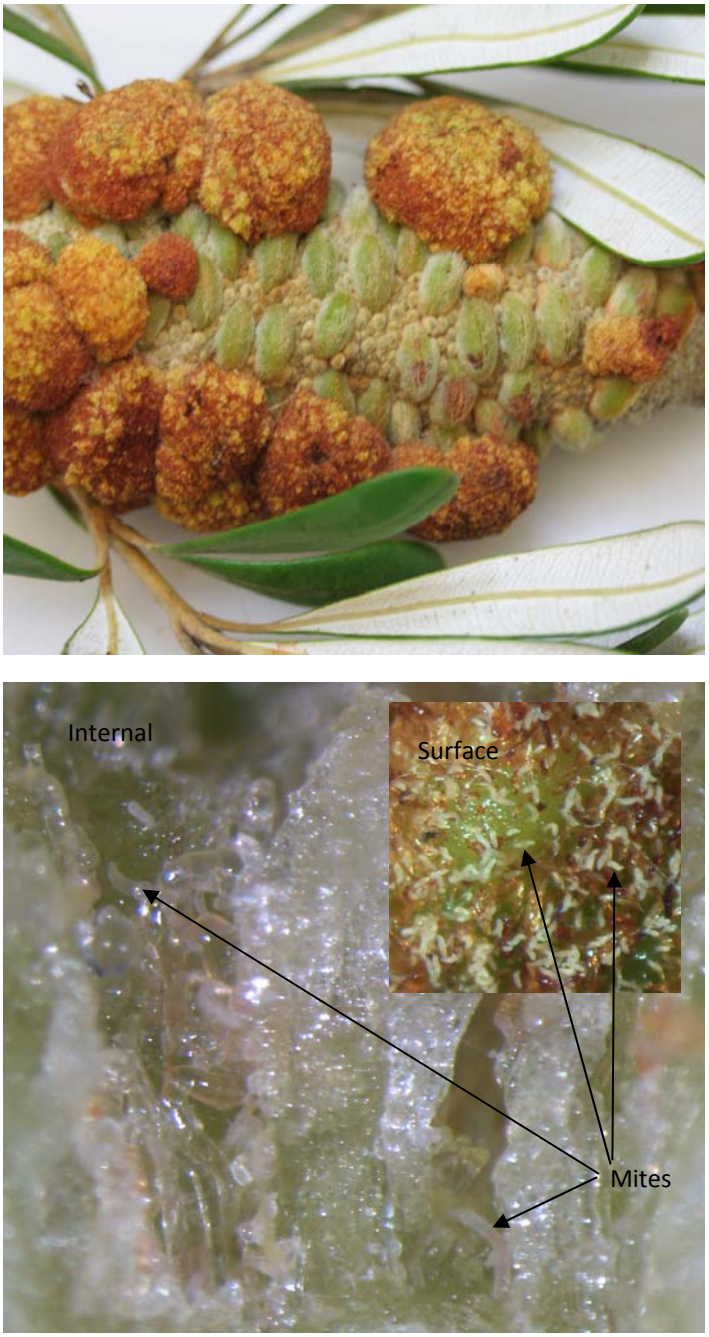
Bulb mites are medium-sized mites that can often be seen without magnification, ranging in size from about 0.3-0.9mm in length. They are soft-bodied, pale whitish to brownish in colour and often appear like over-filled, slightly elongate balloons. The back of their bodies have many long hairs making them appear like a pin-cushion. They tend to be slow moving.

Astigmatid lifecycle

These mites have an egg, larva, nymphal and adult stages; most species can have three nymphal stages, but some only ever have two. Their development normally takes from 1-3 weeks, depending upon temperature (about a week near 30° C). Development generally ceases around 10°C. Bulb mites often can lay many eggs over their lifetime. For example, females from the genus *Rhizoglyphus* have been reported as laying about 400-500 eggs over their lifetime.

Bulb mite damage and host range

Typically, bulb mites cause dark brown streaks on bulbs and roots and growing tips and leaves may become distorted. If the infestation continues without management the whole bulb can become completely



Eriophyid erinea on banksia (above), internal cross-section and surface of the erinea (middle and insert) and eriophyids on a leaf.

rotten quickly. Healthy bulbs are more resistant to mite damage than unhealthy bulbs, i.e. bulbs that have been bruised or infected with a plant pathogen are more likely to be colonised by bulb mites. Different species of bulb mites damage different plant species. However, common host plants of the genus *Rhizoglyphus* are most often associated with plants from the Liliaceae family including, *Allium* spp., *Freesia*, *Lilium* spp., gladioli and hyacinth, but *Narcissus*, *Eucharis*, iris, orchids, dahlia and tulip can also be damaged.

Some species of *Tyrophagus* have also been recorded damaging cucurbits, begonia, tomatoes, capsicum, gerbera, viola and kalanchoe. These mites have sometimes been known to cause injury to young leaves and flowering buds. On cucurbits, *Tyrophagus* species can cause numerous small holes and yellowish spots and may become skeletonized on the upper surface. Leaves of watermelon, tomato and capsicum seedlings become lustrous, discoloured and deformed, dwarfed or stunted. Gerbera buds damaged had few fully expanded petals and had malformed flower bases. Flowers of viola and cyclamen can become infertile from damage to anthers. Damaged shoots of kalanchoe had narrow brown streaks and corky tissue. Light infestations on flower bulbs can cause feeding marks on developing leaves that become deformed and develop streaks or corky spots. High infestations may produce damage similar to *Rhizoglyphus* mites, described above.

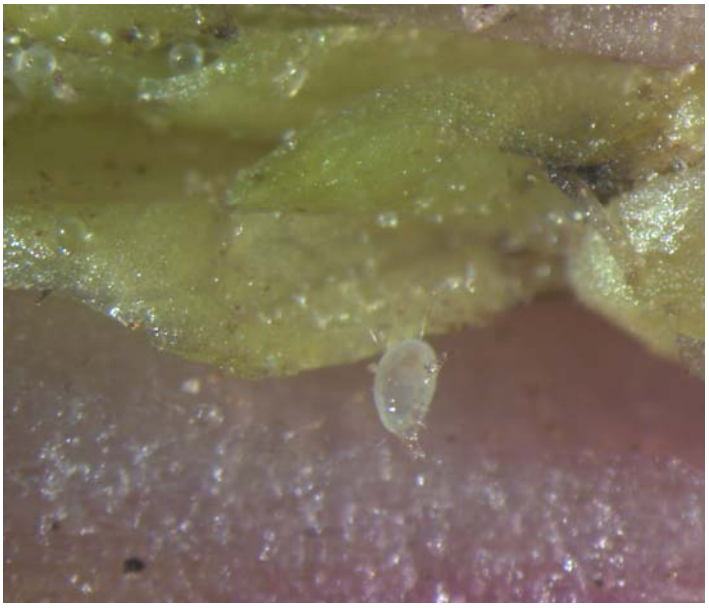
These mites may also be a vector for soil-borne fungal pathogens, such as *Fusarium* and *Verticillium*. Disease infestations such as those caused by *Pythium* spp. may also be increased in the presence of moderate populations of bulb mites and these diseases.

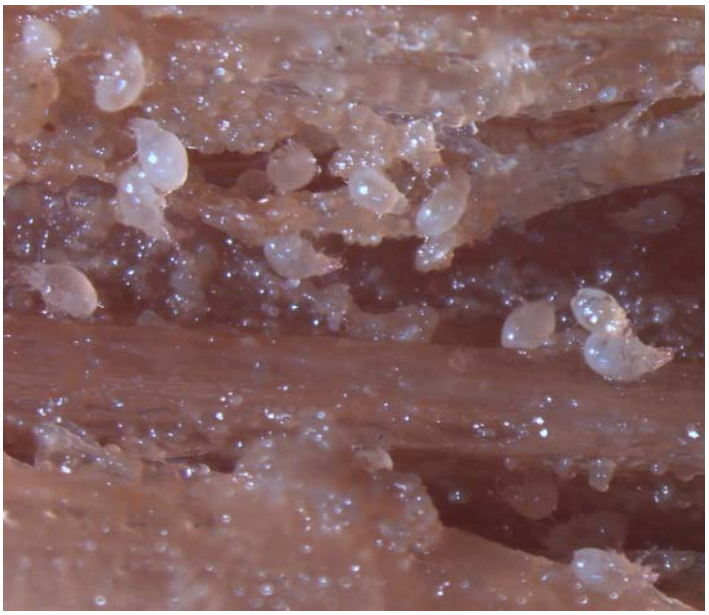
Bulb mite dispersal

During adverse conditions bulb mites attach to insects or other arthropods to disperse away. As indicated above, bulb mites have either two or three nymphal stages. During good conditions, development only goes through two stages. During adverse conditions (e.g. poor food quality or quantity, high concentrations of waste products, extremes of temperature and humidity and very high population densities), three nymphal stage occurs. This extra stage looks significantly different from the first and third nymphal stage (which normally occur) and is adapted to attach to arthropod hosts and ride them away from the adverse conditions.

Monitoring for bulb mites

Plants that are susceptible to bulb mites and showing signs consistent with their damage should be examined closely, preferably by examining the bulb or root material under a microscope. This may





Erinea on birch (above - photo byS. Katovich, USDA Forest Service), and typical bladder gall (photo by M. Zubrik, Forest Research Institute - Slovakia, both Bugwood.org), Acarid mite in the growing tip (no damage evident) (middle) and mites in internal plant tissue associated with *Chalara* and *Geotrichum* (below).

require one to remove the soil from around the bulb. The skin of the bulb may have to be examined closely to observe mites. The bulb itself can be cut open and examined carefully.

Section 2: Management of mites

All mite groups discussed above can be managed using a combination of cultural, biological and chemical management strategies. Some species of mites are prone to the development of pesticide resistance. Therefore it is important not to rely on pesticides as the sole method of management. Use as many different methods to manage mites as possible. As with all pests and diseases, regular monitoring is critical, particularly for those plant species that are prone to damage.

Monitoring for mites

Before any informed management decision can be made, knowledge of the extent of the infestation is required so that the most appropriate actions can be undertaken. The best way to collect such information is to regularly monitor your crop. Mites must be monitored using different methods, depending on their size. Relatively large mites like spider mites, astigmatid mites on foliage and some flat mites can be monitored by using a beating tray or directly examining abnormal growth with a x10 hand lens. Tarsonemid mites and many flat mites can sometimes be observed on plants using a x20 hand lens but are easier to observe using a microscope. Eriophyids are difficult to observe without a microscope, even using a x20 hand lens. More detail is provided on how to best use these methods to detect each group of mite later in section 2.

Regardless of the method used, always record the results in a systematic way. If recording results on a paper datasheet, transfer information to an electronic database or spreadsheet (for examples of paper datasheets refer to the Biosecure HACCP manual). The most important advantage of an electronic system is that information can be searched much more easily than a filing cabinet full of paper datasheets. Electronic data can also be sorted easily on many different variables and manipulated to produce visual representations of the data, i.e. graphs. This can be important for analysing the pattern of damage across different seasons, host plant species or varieties and different areas in the nursery.

The importance of monitoring for pests cannot be stressed enough. Monitoring for pests can allow for their management when their populations are relatively low or in a relatively small area. Early management of the problem is easier to treat and results in fewer losses and therefore takes less time and costs less.

Visual examination (in crop)

Best practice pest management involves specifically monitoring the health of plants on a regular basis, i.e. at least weekly. This monitoring should include mites, insect pests, diseases, weeds and other growing aspects of the production system that contribute to plant health. It can be tempting to rely on workers noticing plant problems while completing their daily duties. While this is a good start, early warning signs of pest and disease problems are more likely to be missed by staff focussed on other tasks than staff specifically assessing the health of the crop. The exact method to achieve full coverage of the nursery will be different for each nursery and may depend on the number of staff involved in the business, the area over which plants are grown, how different growing areas have been split up, the number of different plant species/varieties grown and other operational considerations. The main thing is that a large proportion of plants in *all* sections of the nursery are observed and individuals showing unusual symptoms inspected in more detail (see methods below).

Some mites feed on bulbs and roots. If abnormal growth is observed and no above ground cause can be identified easily, it is important to examine the roots. For plant species that are susceptible to bulb mites, it may be important to remove the growing media and examine the bulb with a handlens or under a microscope.

Plant beating

While visually examining plant health (described above), it is best to also conduct a monitoring technique called plant beating. This involves gently, but firmly, hitting the foliage against a beating tray (which can be a folder, bucket or plastic plate). One can hit multiple plants against the tray at one time, even moving 5 metres or so before examining the tray. Look for anything that is moving. Once something is found, a x10-20 hand lens can be used to inspect the catch and record results.

It is important that the foliage is hit against the tray, not the tray against the foliage. The beating tray should be a single colour; white or black is preferable as this will allow moving organisms to be more visible. Beating plants is a relatively efficient way of monitoring for insects and mites that can be knocked from plants, including spider mites, some flat mites, astigmatid mites, predatory mites and many other non-mite groups, e.g. aphids, thrips, lady beetles, leaf beetles, small caterpillars, whiteflies and a variety of other insects. Basically anything that can be easily dislodged from the foliage may be found on the tray, including benign organisms like springtails and bark lice.

Microscopic examination

Abnormal growth that is observed when conducting visual examinations and or plant beating should be examined at higher magnification if the cause of the symptoms could not be ascertained in the field. This may involve taking a plant or part of a plant to look at it under a stereo microscope or USB digital microscope. Treat the plant material with care, it may have pests or diseases present that could be spread through the nursery. It is best to place the material in a zip-lock bag or remove the pot minimising the amount that it comes in contact with other plants. Examine the damaged plant tissue under the microscope keeping in mind that the damage may have been caused by mites feeding on the growing tip; they may not be present on older foliage. Also, make sure that you go to a sufficient magnification such that you will observe even the smallest mites, preferably about x40. If in doubt and the system is equipped with a camera, take a photo. If the system is not equipped with a camera it may be possible to purchase a camera that fits in the eye piece tube and connects to a computer via USB. Also refer to special notes on monitoring bulb mites and eriophyid mites that may occur in galls in their specific section.

Purchasing a microscope or USB digital camera microscope

The equipment that you purchase will depend on your operation, the knowledge of staff managing pests and disease and their inclination towards examining plant material. For entry level equipment, the budget is of minor concern as a basic microscope can be purchased for less than $500 (with a camera) and USB digital microscope less than $100. Keep in mind that you get what you pay for. If you are uncertain that you will use the equipment then it is recommended to start small. Identify staff that are keen to look at plant material for mites and other insects and nurture this trait; your business will benefit in the long run.

USB microscopes can be purchased very cheaply from eBay and other sources for as little as $25 (sometimes even including shipping). These cameras will be effective at observing relatively large mites, like spider mites, and other insects; anything is better than nothing. Small mites (broad mites and eriophyid mites) will be difficult to visualise unless you are lucky or have very high quality equipment (which currently cost about $500 – Dino-Lites). Even then, sometimes it is difficult to distinguish plant hairs with eriophyid mites. No doubt, this technology will increase over time and be more suited to visualising small mites.

While these systems have a number of great qualities (e.g. they all can take pictures and they often go to relatively high magnifications), they have a number of drawbacks. Samples are often difficult to manipulate, particularly when the equipment must be placed very close to the sample itself or when dealing with fast moving mites. There is only one knob to adjust both the magnification and focus, which causes further difficulties manipulating the sample. The physical stand of the very basic equipment is often inadequate and may fall apart. Higher quality stands can be purchased separately that allow the microscope to be moved up and down and aid in the manipulation of the sample. Also, long working distance models are available that allow you to work with your sample more easily (i.e. they have a greater distance between subject and microscope). However, both of these aspects increase the price such that a devoted microscope and camera set up is comparable. Therefore, we recommend giving yourself the best chance to have a pleasant and successful experience looking for mites at a reasonable price: buy a real microscope not a USB microscope.

In most instances, stereo (dissecting) microscopes will be required. These microscopes allow for plant or other material to be placed under the objective (a relatively wide lens) for examination. Most modern stereo microscopes can have the focus adjusted independently of the magnification. Major advantages of a microscope over a USB microscope are: 1) the image is crisp and clear, not digitally distorted, 2) it is much easier to manipulate the sample with hands or tweezers and 3) very small mites can be observed and clearly distinguished from leaf hairs and other structures.

If you are considering purchasing a stereo microscope for the first time there are a number of specifications to examine. First, the extent to which the magnification can be adjusted is called the zoom ratio. It is recommended to purchase a microscope that has a zoom ratio of at least 1:4. This would mean that you would have the capacity to observe material from a x10 to a x40 magnification and everywhere in between

(assuming that the eyepieces provide x10 magnification). Some basic systems have only set magnifications. If purchasing such equipment make sure that it has a relatively low magnification (around x10) and a relatively high magnification (about x40). However, it is preferable to purchase equipment with a zoom ratio, not set magnifications. Second, purchase a trinocular microscope system with a camera. Binocular systems have only two tubes (for your eyes) to observe the material. If you already have a binocular system, you can purchase cameras that sit into the eyepiece and allow you to take pictures. Trinocular systems have a third tube for the camera, so you can look down the microscope and have a picture on a computer at the same time. The camera also allows for taking pictures that can be emailed to gain greater information from specialists or printed out for training purposes.

Third, there are a great number of cameras available on the market. Like standard digital cameras, the quality of the image is measured in megapixels (MP). It is recommended to purchase a camera that is at least 1.3MP. If you would like to take pictures of tiny mites then at least 3MP (e.g. broad mites or eriophyid mites) would be better. Fourth, stereo microscopes require an overhead light source. Some systems come with a ring light on the objective itself. If it does not come with a light then purchase one or two cheap LED desk lights with adjustable necks (preferably two so that you can have one on either side – which helps to reduce shadows). In almost all cases the camera comes with software to take pictures, but it is worth checking.

Start with basic stereo microscope that can be purchased online from private companies and through eBay. If you find you are using it consistently and would like to upgrade the system significantly, consider purchasing from a reputable and professional microscope supplier, e.g. Olympus, Nikon, Zeiss, Leica etc. It will cost more but the quality will also be higher and normally comes with a person to provide technical support that can visit your business and train your staff in the use of the equipment. Furthermore, software that is sold for their camera systems is more sophisticated than very basic software and normally provides a better image.

It is not recommended to purchase a compound microscope unless the user has had formal training. Compound microscopes must have the material placed on a slide and generally require a greater level of technical knowledge and expertise.

All equipment requires a certain amount of maintenance and cleaning to extend the life of the equipment. The most of important points are to only clean the lenses with a microfiber cloth, similar to sunglasses, and covering the microscope with an appropriate cover when not in use. More detailed storage and maintenance of microscopes can be found online.

Cultural management

The importance of regular monitoring cannot be emphasised strongly enough, not just for mites, but all pests and diseases. Under favourable conditions, many mite species can reach damaging levels within a week; management actions are best implemented at low populations that have not caused significant damage to the crop. Refer to the monitoring section above for details on how to detect mites in nursery crops. Cultural management actions that will reduce the likelihood that mites will infest or reinfest your crop include:

- Always inspect incoming stock for infestations of all pests and diseases, including mites. Preferably hold all stock in a separate area for a number of weeks before incorporating with the rest of your nursery stock.
- Remove or quarantine highly infested plants. Plants being thrown out with mites should be placed in a covered bin in a relatively isolated area to reduce the chance of reinfestation. Do not be deceived by their small size, mites can move around the production area relatively easily if not treated with care.
- If possible, grow highly susceptible plants under protected cropping that may be modified to exclude a wide range of pests, particularly spider mites.
- Reduce staff movements to areas of the nursery that are known to have mite populations. Visit these areas last and do not re-enter ‘clean’ areas.
- Establish patterns of mite infestations in your nursery identifying time periods that are more at risk, host plant species and varieties that may be susceptible/tolerant to mite damage. If possible, grow varieties that receive less damage from mites.
- Conserve natural enemies by only spraying pesticides when monitoring indicates that numbers will reach damaging levels. Preferably, only apply products that have a small impact on predator populations, i.e. avoid applying organophosphate, pyrethroid, neonicotinoid and similar products. Refer to the pesticide section below for more details.

- If pesticides are required, apply to hot-spot areas and high risk plants, i.e. not a blanket spray. This will help conserve natural enemies.
- Many species of mites thrive in hot, dry conditions. High humidity, including that produced by overhead watering, can reduce the growth of spider mite population. However, overhead watering can increase the incidence of fungal and bacterial diseases so must be used strategically.
- Remove weeds from within and around the growing area that could be acting as alternative hosts for mites.
- For mites that cause plant growth to become stunted or deformed, e.g. tarsonemid and eriophyid mites, it is recommended to remove heavily infested plant material before applying pesticides. The deformed plant growth is unlikely to be saleable and its removal will reduce the populations such that subsequent management techniques are more effective.
- Only propagate from uninfested material. This may sound obvious, however, mites that are not visible without magnification may be present at very low numbers and rapidly build to damaging levels. Furthermore, plants that are multiplied by separating plants or bulbs may have mites present that are not immediately obvious (e.g. flat mites under the leaf sheath of Dianella and bulb mites). Therefore, if the plant species has a history of mite infestation, examine at least a subset of the plant material to be propagated to ensure that mites are not present.

Biological control

Many spider mites can be managed with commercially available predators or with predators that naturally occur in the nursery. Predators can be extremely effective if applied when mite populations have not caused significant and widespread damage. There are a number of advantages for using predators over pesticides. Predators move between plants in search of mites, feed on many stages of the pest, including eggs. They can provide long term management of mites under good environmental conditions and never damage plants. Some species of predators feed on multiple groups of mites making them more versatile for preventing mite populations (refer to Table 1).

Biological control can also be used on short term crops, particularly plants that are susceptible to mite damage. Some predator species, e.g. *Typhlodromus occidentalis*, sit in the crop and wait for prey to occur on the plant. Such species are ideal for short term crops and for application at the beginning of high risk periods.

Californicus feeding on a spider mite (above), cucumeris (middle - photo by Biological Services) and killer mite (photo by M. Steiner).

Similar to pesticides, application of commercially available predators may not always be possible. Predators may not be effective in very hot conditions (generally above about 35°C) or at very low temperatures (below about 10°C). When only a small number of plants are infested it may not be economically feasible, though some suppliers have small packs that are suitable for areas of about 50 square metres. The application of highly residual and broad-spectrum pesticides (insecticides, miticides and fungicides) will also preclude the successful release of almost all predator species. It is always recommended to communicate with the biological control agent producer before releasing predators to ensure the best possible outcome until you are relatively experienced with the predator.

As indicated in Table 1, there are 6 predators commercially available in Australia suited to the management of different groups of mites in production nurseries. All predatory mites commercially available in Australia have a distinctive body shape that can be easily recognised with a little practice. All stages in their lifecycle are tear-drop shaped and have relatively long legs. They also tend to move much faster than pest mites. Immature stages of predatory mites tend to be lighter in colour than adults and normally have fewer body hairs, but otherwise their appearance is very similar. More information on each of these species can be found online by the producer of that species.

Californicus

Californicus (*Neoseiulus californicus*) is a predator of spider mites and tarsonemid mites. It can tolerate a relatively wide range of environmental conditions. Californicus is effective up to about 35°C, but can survive short periods greater than 40°C and even freezing temperatures. It also is effective at lower humidities, but still prefers high humidity. It feeds on a variety of other mite species including flat mites, eriophyid mites and pollen; but they may not be effective in reducing significant pest populations of these groups. When spider mites and other food is unavailable this species tends to remain in the crop, feeds on pollen and alternative food sources until prey mites become available. Its development time is faster than many spider mite species. This mite is available through Bugs For Bugs (Qld) and Biological Services (SA).

Cucumeris

Cucumeris (*Neoseiulus cucumeris*) is a small (about 0.5 mm), tear-drop shaped, opaque predatory mite that looks similar to californicus (below) and is of the same family as persimilis. Cucumeris feeds on a variety of prey including tarsonemid mites, thrips, pollen and a variety of other small insect and mite prey. Spider mites, eriophyid mites and perhaps flat mites may sometimes be consumed but it is unlikely to be effective in reducing significant pest populations of these groups. Development of cucumeris takes about 8-11 days at 20 -25°C and subsequent adults live for about 3 weeks. No development occurs below 13°C (but survives night time temperatures of about 4°C) or above 32°C. They prefer conditions greater than about 65% RH. Females lay about 30 eggs over their adult life. Cucumeris can be used in most greenhouse and nursery crops and will persist without prey when pollen is available. While cucumeris has been used successfully for pest control in cucumbers, capsicums, eggplants, gerberas, roses, chrysanthemums and other potted plants, they are not effective on tomatoes or geraniums due to leaf structure and toxic plant exudates. Cucumeris is made

Table 1. Commercially available predatory mites and mites they control.

Predator name	Commercial supplier	Mite groups managed
Californicus	Biological Services Bugs For Bugs	Mainly spider mites and tarsonemid mites. Flat mites and eriophyid mites may be consumed incidentally.
Cucumeris	Biological Services	Mainly tarsonemid mites. Flat mites, spider mites and eriophyid mites may be consumed incidentally. Bulb mites on foliage may also be consumed.
Killer mite (*Geolaelaps aculeifer*)	Biological Services	Bulb mites in growing media only, not on foliage.
Montdorensis	Bugs for Bugs	Mainly tarsonemid mites. Flat mites, spider mites and eriophyid mites may be consumed incidentally. Bulb mites on foliage may also be consumed.
Occidentalis	Biological Services	Spider mites
Persimilis	Biological Services BioWorks Bugs For Bugs	Spider mites
Naturally occurring insect and mite predators	NA - the 'bush'	Many species of predators naturally occur, some of which will feed on each group of mites.

commercially available through Biological Services (SA and WA).

Killer mite

Killer mite (*Geolaelaps* (*Hypoaspis*) *aculeifer*) is a relatively large, brown to orange coloured, soil-dwelling predatory mite (about 1 mm in length). Nymphs and adults feed on bulb mites, thrips pupae that pupate in the soil and on a variety of other soil organisms, including nematodes, springtails, fungus gnat larvae, root aphids and other soil inhabiting mites. This species digs relatively deep (about 100mm) and therefore is most suitable for the management of bulb mites in the soil. The killer mite takes about 12 days to complete development at 27° C, but up to 40 days at 16°C and can survive for long periods scavenging on soil arthropods without specific pest prey. Temperatures above about 30°C are detrimental and activity below 10°C is very low. Soil conditions do not always reflect outside air temperatures and this should be taken into account when deciding to use soil predators. Direct sun on the container of plants may increase the temperature for media within pots compared to air temperature. By contrast, soil in the shade may be substantially cooler than air temperature. Females lay about 3-4 eggs per day under good conditions. Biological Services is the only provider of the killer mite.

Montdorensis

Montdorensis (*Typhlodromips montdorensis*) is a native Australian predatory mite in the same family as persimilis. Montdorensis feeds on broad mites and bulb mites that may be present on foliage, whiteflies, thrips larvae, a variety of other small insects and mites. Eriophyid mites, flat mites and spider mites may sometimes be consumed, but montdorensis is unlikely to reduce significant pest populations of these groups. It is a pale, teardrop-shaped mite which is about 0.5 mm in length (Fig. 8); the exact colour of the mite changes depending on prey that has been eaten. Development of montdorensis takes about 1 week at 25°C and females can lay 2 to 4 eggs per day (about 50 eggs over a 4-week lifespan). Montdorensis prefers warmer temperatures, 20-30°C being optimal. Adults are able to tolerate up to 40°C for a short period, but eggs and immatures cannot. At temperatures below 11°C montdorensis becomes inactive, but as long as daytime temperatures are warm it will remain active throughout the year. Eggs require a relative humidity of greater than 70%, otherwise significant numbers fail to develop. Montdorensis is made commercially available in Australia by Bugs for Bugs.

Occidentalis

Occidentalis (*Typhlodromus occidentalis*) is similar to californicus in that it can withstand more extreme

Montdorensis (above) and occidentalis (middle) feeding on a spider mite eggs and persimilis feeding a spider mite.

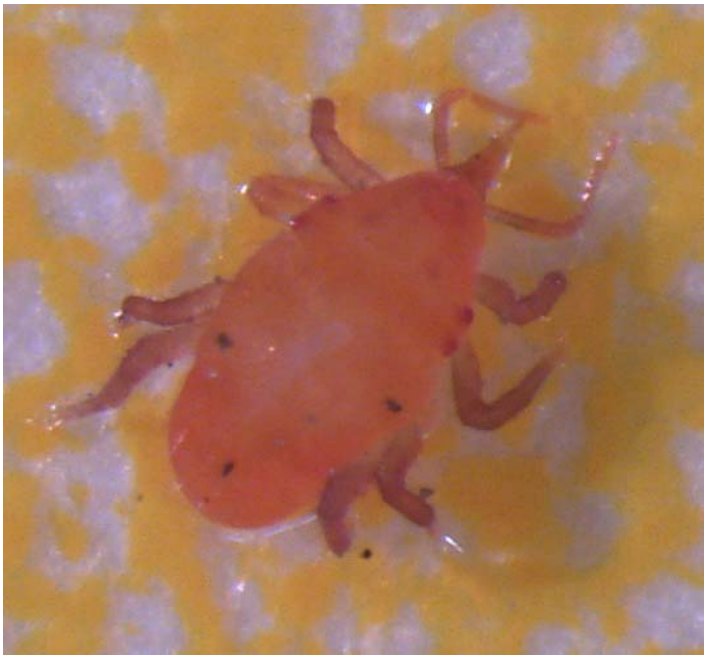
environmental conditions, perhaps more so than any other commercially available predatory mite. Optimal conditions are between 20 and 32°C (but can survive well up to 40°C) and greater than 40 to 50% humidity, although a lower humidity may be tolerated if prey are abundant. Its development is a little bit slower than californicus but is still similar to many species of spider mites. Once populations establish in a crop, occidentalis can remain inactive during very low temperatures and will become active again once temperatures increase, as long as pesticides that cause mortality are not applied. Similarly, if prey species are not available it tends to remain in the crop, relatively inactive, until they are available. This mite is only available from Biological Services.

Persimilis

Persimilis (*Phytoseiulus persimilis*) is a red coloured mite that is about 0.5 mm long and used to control spider mites only, specifically from the subfamily Tetranychinae. Basically, if spider mites look like two spotted mite, persimilis will be effective. The colouration of persimilis deepens with time; immature stages are lighter in colour, adults tend to be deep orange to red. They complete their lifecycle very quickly, often faster than spider mites, and are voracious feeders. As a result they can completely eliminate spider mites from the crop. In the absence of food they disperse or die out. Temperatures between 20-30°C with humidity greater than 60% are optimal for management of spider mites with persimilis. This predator is the most efficient of all commercially available spider mite predators and will often be the best and easiest predator to begin biological control in a production nursery setting. Persimilis is available through Biological Services (SA and WA), BioWorks (NSW) and Bugs For Bugs.

Naturally occurring predators

There are a large number of naturally occurring predatory mites and insects that will feed on different groups of pest mites and small insects. As described above, predatory mites can be distinguished from pest groups by their characteristic tear-shaped body and fast movement. One of the most common predatory mites encountered in nurseries that are not commercially available are species from the family Bdellidae (pronounced dell-id-ee). These bright red to orange mites are extraordinarily fast and are often very large (about 1-2mm long) and have been recorded as having reduced some spider mite populations. Cunaxid mites (pronounded coo-nax-id; closely related to bdellid mites) have been recorded feeding on a wide variety of mites including eriophyid and spider mites. Mites from the family Phytoseiidae (pronounced: fight-o-say-id-ee) are commercially available (e.g. cucumeris, montdorensis, persimilis and others). Numerous other species from this family are not commercially



Stethorus (above) from a distance and close up (insert), bdellid mite on a sticky trap and anystid mite, which is about 2mm long (below).

available but will feed on a diverse array of pest mites from all pest groups. Many other predatory species exist from a large number of mite families, e.g. Anystidae, Erythraeidae, Penthaleiidae, Stigmeiidae, Tydeidae and others.

Many species of mites will also feed on pollen and other small soft bodied organisms, e.g. springtails, newly hatched caterpillars, whiteflies, thrips and other arthropods. These predators will naturally disperse into nursery crops from gardens, natural environments and wind currents. They can be conserved by limiting the application of broad spectrum and long residual pesticides over relatively large areas. Flowering plants in and around the growing area may also be helpful for conserving natural enemies. Garden plants should be monitored from time to time to ensure they are not harbouring significant pest populations.

A number of insects can also be significant mite predators. For example, very small, black lady beetles from the genus *Stethorus* are voracious spider mite predators. Predatory midge fly larvae, lacewings, predatory thrips, pirate bugs and other small insect predators feed on a variety of mite pests.

Predatory midge fly larva (above - photo by W. Cranshaw, Colorado state university, Bugwood.org) and a predatory thrips (below - photo by John Duff).

Chemical control

There are a large number of pesticide products that can be used against mite pests in a production nursery. These include active ingredients from ten mode of action groups, plus products that have not been classified into a mode of action group. Appendix 1 lists all products available for use against certain mite pests on host plants in the nursery sector. Not all products will be suitable for all businesses and products from additional active ingredients may be used for specific crop plants that are not included. It is always recommended to check each label or minor use permit to ensure that it covers your situation. Also, refer to the nursery pesticide application best practice manual for additional information (http://www.ngia.com.au/Category?Action=View&Category_id=694).

The use of chemicals against mite pests in production nurseries is likely to be unavoidable, at least on limited occasions. Regular, scheduled use of pesticides against mite pests is not recommended and can be reduced by shifting time spent making up chemicals and applying products to time spent monitoring crops for pests. Pesticides are recommended for use against mites under a variety of circumstances.

- When only a relatively small area of plants have an infestation, e.g. less than 50m^2.
- When pest numbers are very high it is recommended to apply an appropriate product, preferably after having removed unsaleable stock or selected stems of damaged plants. After pesticide application, a suitable biological control agent may then be released to clean up the remaining pest mites.
- Commercially available predators are unlikely to be effective at reducing eriophyid mites once they have reached damaging levels. Therefore, pesticides are likely to be required, refer to section 3 for more detail.
- Under environmental conditions that are not conducive to the success of predators, e.g. very hot or cold conditions.

- When broad spectrum and or long residual products have been applied that will reduce the efficacy or completely kill predators. The exact time frame depends on the product in question, however, many organophosphate and synthetic pyrethroid products can impact predator populations even 3 months after they were applied. In these cases, low residual products should be used until biological control agents can be released into the area (Table 2).
- In most cases, infestations that occur just prior to the sale of a product will require a pesticide application. However, in some cases predators may still be suitable, depending upon where you are located (and the length of time it takes for predators to arrive), when the stock will be shipped, the level of infestation present, the level of damage the crop can withstand and customer considerations. Some customers may be happy to receive product being forewarned that, for example, low level spider mites are present but that predators have been applied at a sufficient rate to clean up the problem within a week.
- In cases where other pests can only be managed by the use of broad spectrum and long residual products.

Mode of action

Pesticides disrupt normal physiological processes in insect and mite pests. In most instances, when a product is first developed, the exact method that mortality occurs is not known. Many pesticides have been studied to determine exactly how they cause mortality to insect pests, others have not. When it has been worked out with a reasonable amount of confidence, the active ingredient is placed in a mode of action (MoA) group. Some MoA groups have many active ingredients (e.g. 1B - organophosphates), other MoA groups have only one or a small number of known active ingredients (e.g. 12B – organotin miticides). The group is characterised by a number and sometimes has a letter after the number. Active ingredients from the same letter - number combination are considered to cause mortality in exactly the same way, even if the product name is different. Active ingredients with different numbers cause mortality in a significantly different manner. However, when active ingredients have the same number but a different letter, they are considered to be closely related, but cause mortality by slightly different means. It is always important to know the MoA group of products that you are applying for management of any pest, be it an insect, mite, fungus or weed. Consecutive applications of products from the same mode of action group increases the risk that pesticide resistance may occur. For more information on MoA groups refer to the Insecticide Resistance Action Committee website and their classification scheme document.

It is also important to understand how each product comes in contact with mites. Some products have a contact mode of action, only being effective when they directly contact the mite. Other products are systemic, enter and move through the plant and enter the mite after they ingest plant tissue. Translaminar products have limited systemic effects. They move across the leaf from one side to the other, but do not move from one leaf to another. When choosing a product be aware of its mode of action as it can impact efficacy (Appendix 1). For broad mites, which are often in tight, protected growing tips, translaminar or systemic products are required; contact products will be less effective in most instances. However, most spider mites can be readily managed with contact products.

Table 2. Toxicity and residual activity of active ingredients registered against mites in relation to predatory mites and insects. Note that some products may cause negative effects to some predator species for a greater length of time after application than others; particularly when applied frequently. Therefore, ***this is just a guide.***

	Very short residual (basically while product is wet)	Short residual (about 1-2 weeks)	Long residual 3+ weeks
Low toxicity	Bifenazate Clofentezine Fenbutatin oxide Hexythiazox	Azadirachtin Oil products	
Moderate toxicity	Potassium salts	Propargite Sulphur	
High toxicity		Abamectin Diafenthiuron Emamectin benzoate Milbemectin Pyridaben Tebufenpyrad	Bifenthrin Dicofol Etoxazole Imidacloprid (spray) Lambda-cyhalothrin Maldison Omethoate Tau-fluvalinate

Section 3: Recommendations

For each group of mites, it is recommended to put in place monitoring and cultural management practices discussed in section 2. Not only will this reduce the impact of all pest mite groups, it will also have a similar effect for many other insect pest groups and assist in managing other aspects of crop health. However, different predators and pesticides are available for each mite group and therefore slightly different management strategies should be used. With each group, recommendations provided below are unlikely to cover every situation possible. Therefore, follow the logic and modify the recommendations based on your experience with the pest on each host plant at your business. Biological control and rotating pesticides between 3 or more mode of action groups substantially reduces the risk of inducing pesticide resistance.

Spider mite recommendations

Very low level populations that are in isolated areas should be monitored regularly to ensure that infestations do not increase to damaging levels. If sufficient naturally occurring predators are present, no action may be required. There are relatively small packs of persimilis available for use against most spider mites encountered in production nurseries that are commercially viable if the infestation is over about 50m^2. Table 3 provides a guide on possible management strategies under a range of scenarios. As discussed above, refer to the biological control agent producers for advice on optimising the effectiveness of predators in your nursery.

Table 3. Summary of recommendations to manage spider mites using biological control, pesiticides and a combination of both of these approaches.

	Low infestation	Moderate infestation	High infestation
Biological management	Release persimilis, californicus or occidentalis.	If plants are highly susceptible to damage, refer to combination approach below. Otherwise, release persimilis, californicus or occidentalis but at higher rates.	Refer to combination approach.
Combination	Release persimilis, californicus or occidentalis.	If plants are susceptible to spider mite damage, release persimilis, californicus or occidentalis 3-5 days after application of a low residual pesticide (if possible apply in combination with an oil product): Bifenazate Azadirachtin Group 10A product	As per moderate infestation, however, apply a suitable pesticide, monitor pest populations, apply a pesticide from a different mode of action group if populations are still high, then release predators 3-5 days later.
Pesticide management only	If predators are not to be conserved, rotate between: Oil products Group 6 product Group 10 product Group 12 product Sulphur product (not to be applied within two weeks of oil products) Tebufenpyrad Azadirachtin Bifenazate Products from the below groups can be added if required, but have very broad spectrum effects for relatively long residual periods Group 1B product Group 2B product Group 3A product Group 4A product		

Tarsonemid mite recommendations

If monitoring indicates a low level infestation with negligible damage to plants biological control is the best option. If possible, release californicus, cucumeris or montdorensis predators. If damage is substantial and populations high, as indicated by microscopic examination, remove affected tissue/plants and then apply pesticides, rotating between:

- Group 6 product + oil
- Group 10 product (ensure very good coverage)
- Sulfur product (do not apply within 2 weeks of any oil product)
- Apply group 1B and 2B products only if predators are not to be conserved (ensure very good coverage)

Once populations are relatively low, as indicated by microscopic examination, release californicus, cucumeris or montdorensis predators, assuming other factors do not prohibit their release.

Flat mite recommendations

Infestations of flat mites can be challenging using current tools available. Remove badly damaged and deformed plants/stems/leaves to reduce populations and employ other cultural practices to reduce populations. For low level populations, it may be possible to release californicus, cucumeris or montdorensis, however, they may not be effective against all species of flat mites. Therefore it is important to consult the biological control agent producer to determine if they have experience with the combination that you are dealing with. For higher populations, it will be necessary to apply pesticides. If populations are underneath the leaf sheath of the plant or otherwise protected, systemic or translaminar products are recommended. Otherwise, contact products are sufficient. Pesticides that have registration/permit against flat mites include certain products from the following mode of action groups:

- Group 6 product (add oil if possible)
- Group 10
- Group 12
- Some oils
- Sulphur (do not apply within 2 weeks of any oil product)
- Group 1B, but only if predators are not to be conserved

Eriophyid mite recommendations

The recommendations for eriophyid mites are basically identical to that of flat mites, except different pesticides are registered (see below). Eriophyids that produce galls can be particularly challenging, however, and must be treated separately. Only translaminar or systemic products will reach inside the gall to kill mites. Remove as much infected plant material as possible and then apply pesticides. However, in the case of consistent reinfestations that cause plants to be unsalable, use of resistant varieties will be critical. If galls are attractive, it may be possible to market the plant with the unusual growth, perhaps with information about the mite on the plant label. As a last resort, grow an alternative plant species.

- Group 6 product (add oil if possible)
- Group 10
- Group 12
- Some oils
- Sulfur (do not apply within 2 weeks of any oil product)
- Group 1B, 2B and 3A products, but only if predators are not to be conserved

Astigmatid mites, including bulb mites

Whenever possible, low to moderate infestations should be treated with killer mites. For plant species susceptible to bulb mite damage it is recommended to release killer mites when the plants are potted up. This is the preferred method for managing bulb mites found in the growing media as there is only one systemic product (omethoate) available for use against bulb mites and this is as a foliar application. Bulb mites should

have a systemic product applied as a drench. Systemic products applied to foliage must have downward movement to be effective against bulb mites in the growing media. To our knowledge, such a product is not currently available. Furthermore, some bulb mites are resistant to pesticides.

Selected references

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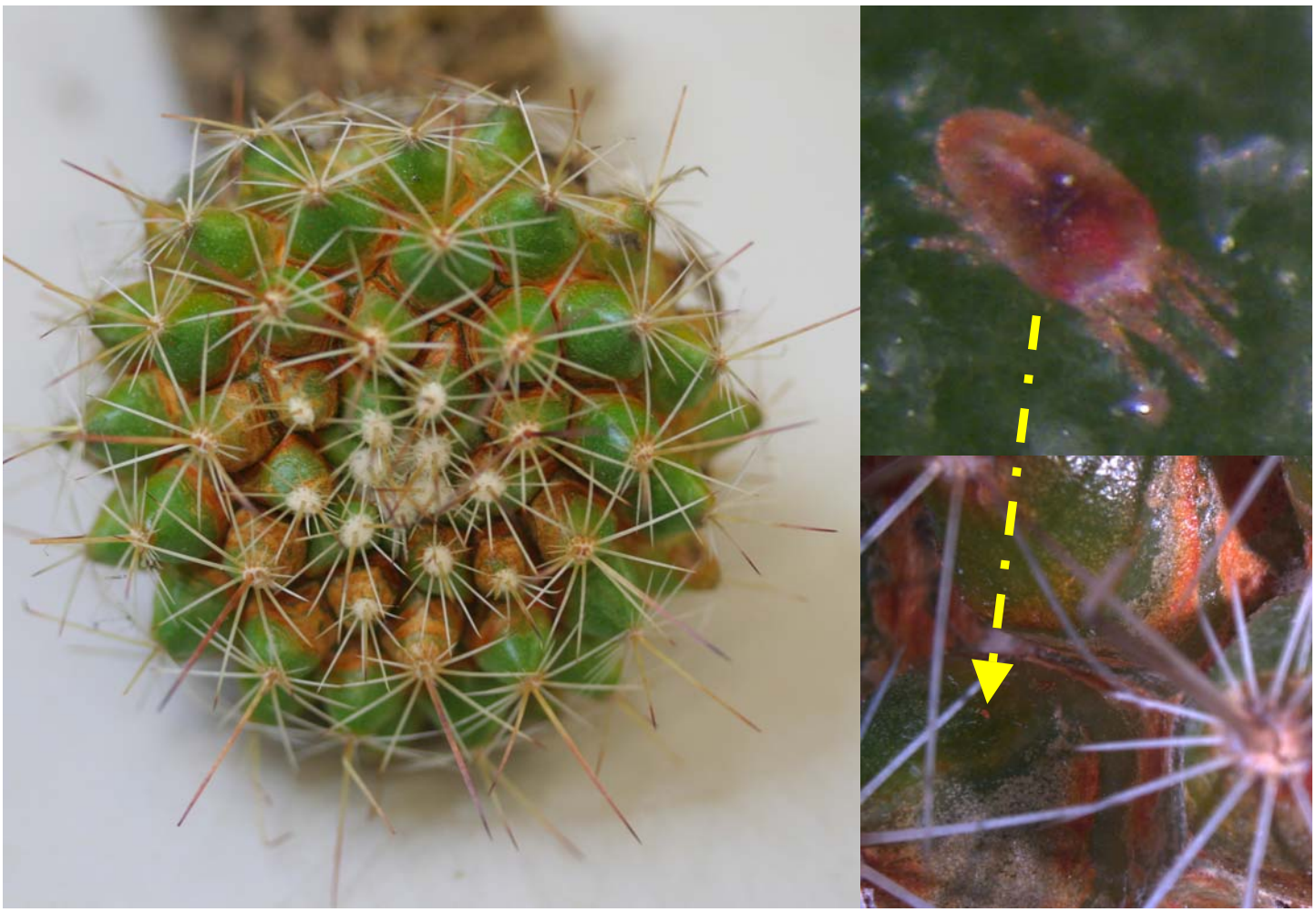

Damage caused by *Brevipalpus russulus* on *Echinocactus* (left), close up of *B. russulus* (top right) and close up of permanent damage.