Department
for Environment
Food & Rural Affairs

fera

FIELD GUIDE TO INVASIVE ALIEN INVERTEBRATES IN THE SOUTH ATLANTIC UK OVERSEAS TERRITORIES

PART 2 – PLANT DAMAGE

Chris Malumphy, Sharon Reid, Rachel Down, Jackie Dunn,
Debbie Collins and June Matthews

FIELD GUIDE TO INVASIVE ALIEN INVERTEBRATES IN THE SOUTH ATLANTIC UK OVERSEAS TERRITORIES

Part 2 Plant Damage

Chris Malumphy, Sharon Reid, Rachel Down, Jackie Dunn, Debbie Collins and June Matthews

First Edition

Fera Science Ltd., National Agri-food Innovation Campus, Sand Hutton, York, YO41 1LZ, United Kingdom

https://fera.co.uk/

Published digitally: May 2019

Suggested citation: Malumphy, C., Reid, S., Down, R., Dunn., J., Collins, D. & Matthews, J. 2019. Field Guide to Invasive Alien Invertebrate Pests in the South Atlantic UK Overseas Territories. Part 2 – Plant Damage. Defra/Fera. 44 pp.

Frontispiece
Top row: Asian Tiger Mosquito *Aedes albopictus* adult © Susan Ellis, Bugwood.org; Fall armyworm *Spodoptera frugiperda* adult © Fera; Pumpkin fly *Dacus bivittatus* adult female © Fera. Second row: Sheep tick *Ixodes Ricinus* adult © Fera; South American tomato moth *Tuta absoluta* larvae © Fera; European earwig, *Forficula auricularia* adult male © Pudding4brains. Third row: Big-Headed Ant *Pheidole megacephala* worker © Alexander L. Wild; Brown soft scale *Coccus hesperidum* adult female © C. Malumphy; Fall armyworm *Spodoptera frugiperda* larva © Fera. Bottom row: Oriental Fruit Fly *Bactrocera dorsalis* adult © Fera; Harlequin ladybird *Harmonia axyridis* adults © Bugwood.org; Red Imported Fire Ant *Solenopsis invicta* worker © April Noble, Bugwood.org.

Contents

4. Field diagnosis of plant damage caused by invertebrates

Determining the cause of plant damage in the field can be difficult as there are many biotic (pests and plant pathogens) and abiotic (drought, frost, nutrient deficiency, pollution, herbicides) factors that cause similar field symptoms. The process is further complicated by the fact that there are often several interacting biotic and abiotic factors involved. The most obvious factor might not be the principal problem. For example, a plant may exhibit damage caused by a large and conspicuous infestation of insects, but the underlying cause may be drought which stresses the plant making it more susceptible to insect attack. This is particularly true for plant parasitic insects such as scale insects. Another difficulty is that by the time the damage is detected, the causal agent may be no longer present. For example, emergence holes are often the first sign of an infestation of a wood-boring insect but by the time they are detected the adult insects have long since dispersed. Another common example is distorted foliage on new growth which is often due to insects feeding on the buds and young developing leaves. By the time the damage is noticeable the culprits (often sap feeding bugs) have flown off.

When plant damage is first observed it can be useful to take a step back and examine the whole plant, and neighbouring plants, to look at the distribution, pattern and degree of damage. Is the damage localised or widespread, which may be indicative of the problem being biotic or abiotic? Is there leaf discoloration, chlorosis, wilting, chewing, defoliation, flagging, dieback, bleeding, branch and stem cankers, or mortality? Is the plant likely to have been stressed by abiotic factors, such as drought, flooding, sea spray, strong wind, extreme temperatures or soil factors, and in the case of crops, poor management practices. Are the plants recently planted, and could they have been imported with the risk of introducing invasive alien pests? Once you have assessed the overall situation, you can then proceed to examine the individual plant parts. Each of the affected parts (foliage, bark, fruit, flowers, roots) can exhibit a variety of symptoms, which can be linked to groups of causal agents. If the whole plant is affected the problem may lie underground with the roots. In most cases, identifying the specific invertebrate pest (or pathogen) is beyond the scope of this guide and requires assistance from relevant experts. However, by carefully examining the symptoms and systematically comparing them with the pictures below (and in Chapter 5), you should be able to determine the most likely causal agent if it is an invertebrate.

A single pest species can induce several different symptoms depending on how long the plant has been infested, the size of the pest population and susceptibility of the host plant, and several different symptoms can be observed at the same time on the same plant. For example, sap sucking insects can cause chlorosis, necrosis, defoliation, and die back on the same plant.

Further information on how to identify the main groups of invertebrate plant pests is provided in Chapter 3.

4.1 Damage to leaves

Leaves discoloured

Chlorosis and necrosis – Sap-sucking insects and mites often cause yellowing or chlorosis of the foliage and this may be associated with necrosis and premature leaf loss. Arthropod feeding damage is usually localised, in contrast to similar symptoms caused by abiotic factors (drought, nutrient deficiency) which often affect the whole plant and/or adjacent plants. When an arthropod pest occurs at high densities it is possible for all the foliage to become chlorotic although the pest (or exuviae and frass) is usually obvious in this situation. When you find a leaf exhibiting chlorosis, it is always advisable to examine the lower surface as this is where the invertebrates are often located.

Insects that typically produce chlorosis in both the immature and adult stage include leaf hoppers or sharpshooters (Cicadellidae) (Figs 4.1.1-4.1.2) and related groups of sap-sucking bugs (Hemiptera), lace bugs (Tingidae) (Fig. 4.1.3), whiteflies (Aleyrodidae) (Fig. 4.1.4), scale insects (Coccoidea) (Fig. 4.1.5-4.1.6), aphids (Aphidoidea), thrips (Thysanoptera) (Fig. 4.1.7), spider mites (Trombidiformes: Tetranychidae) (Fig. 4.1.8) and flat mites (Trombidiformes: Tenuipalpidae).

Some plants may exhibit discolouration at the feeding site, for example the armoured scale insect *Duplachionaspis divergens* often induces purple discolouration on grasses (Fig. 4.1.9) and plants with variegated leaves also frequently exhibit purple spots at the feeding site (Fig. 4.1.10). Some insects lay eggs within the plant tissue which may cause discoloration (Fig. 4.1.XX).

The damage (symptoms) caused by sap-sucking insects can vary significantly depending on the size and density of the insect population. Large populations can cause considerable chlorosis, necrotic leaf loss, dieback and mortality (Figs 4.1.11-4.1.14).

Armoured scale insects (Diaspididae) have long needle-like mouthparts (stylets) which they insert into the host to remove plant sap, leaving chlorotic lines or streaks; these may darken over time leaving dark lines and marks on the foliage (Fig. 4.1.15). Some leaf beetles (Chrysomelidae) cause necrotic feeding scars on the foliage (Fig. 4.1.16).

Feeding by aphids, for example *Phylloxera glabra* (Phylloxeridae), may causes conspcius necroctic patches on the foliage (Fig. 4.1.17). Many insects lay their eggs in the leaf tissue, for example damsel flies (Zygotera) lay their eggs in the foliage of water plants and these are easily seen if the leaf is held up to the sunlight (Fig. 4.1.18).

Plant pathogens (bacteria, fungi, phytoplasmas, viruses) can also cause chlorosis and discoloration, and many of these pathogens are vectored by insects. One significant example in the Caribbean is Coconut Lethal Yellowing Disease (Fig. 4.1.19), a phytoplasma disease that attacks many species of palms, including commercially important species such as the coconut *Cocos nucifera* and date palm *Phoenix dactylifera*. It is spread by the planthopper *Haplaxius crudus* (former name *Myndus crudus*) (Hemiptera: Cixiidae) (Fig. 4.1.20).

Bronzing – Foliage that has been fed upon by large populations of sap-feeding insects or mites may turn bronze or brown in the late summer. This damage is characteristic of lace bugs (Hemiptera: Tingidae) (Figs 4.1.21-4.1.22); the adults and nymphs are found on the lower leaf surface which may also be covered with frass (black spots) (Fig. 4.1.23) and exuviae (cast skins) (Fig. 4.1.24).

Figure 4.1.1 Glasshouse leafhopper *Hauptidia maroccana* (Hemiptera: Cicadellidae) feeding damage on *Primula*, UK © C. Malumphy

Figure 4.1.2 Green leafhopper *Empoasca* sp. (Hemiptera: Cicadellidae) feeding damage on *Vitis vinifera*, Montenegro © C. Malumphy

Figure 4.1.3 *Ipomoea carnea* foliage exhibiting chlorosis due to feeding damage by Cotton lace bug *Corythucha gossypii* (Hemiptera: Tingidae), BVI © C. Malumphy

Figure 4.1.4 Chlorotic spots on the upper surface of *Euphobia* caused by *Bemisia euphorbiarum* (Hemiptera: Aleyrodidae) pupae feeding on the lower surface, Canary Islands © Crown Copyright

Figure 4.1.5. False oleander scale *Pseudaulacaspis cockerelli* (Hemiptera: Diaspididae) causing chlorosis on Fiddle leaf plumeria *Plumeria pudica*, Saint Lucia © C. Malumphy

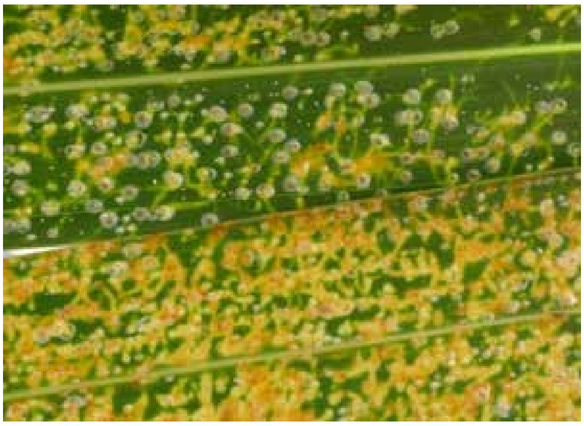

Figure 4.1.6 Coconut scale *Aspidiotus destructor* (Hemiptera: Diaspididae) on Arecaceae, Tortola, BVI © C. Malumphy

Figure 4.1.7 Severe glasshouse thrips *Heliothrips haemorrhoidalis* (Thysanoptera: Thripidae) damage on an ornamental plant, Mallorca. Tiny black spots of frass are always present with thrips feeding damage © C. Malumphy

Figure 4.1.8 Severe spider mite *Tetranychus urticae* (Trombidiformes: Tetranychidae) damage on *Choisia* sp., UK. Silk webbing is usually present with spider mite feeding damage © Fera

Figure 4.1.9 Armoured scale insect *Duplachionaspis divergens* (Hemiptera: Diaspididae) causing purple discolouration on a broad-leaved grass, Antigua © C. Malumphy

Figure 4.1.10 Florida red scale *Chrysomphalus aonidum* (Hemiptera: Diaspididae) causing purple discolouration on a variegated *Schefflera*, Canary Islands © C. Malumphy

Figure 4.1.11 An endemic cycad *Encephalartos senticosus* exhibiting chlorosis due to an armoured scale *Aspidiotus capensis* (Hemiptera: Diaspididae), South Africa © C. Malumphy

Figure 4.1.12 Lower surface of *Encephalartos senticosus* foliage smothered by *Aspidiotus capensis* (Hemiptera: Diaspididae), South Africa © C. Malumphy

Figure 4.1.13 *Encephalartos senticosus* foliage exhibiting severe chlorosis and necrosis due to *Aspidiotus capensis* (Hemiptera: Diaspididae), South Africa © C. Malumphy

Figure 4.1.14 A cycad *Encephalartos senticosus* dying due to a huge infestation of *Aspidiotus capensis* (Hemiptera: Diaspididae), South Africa © C. Malumphy

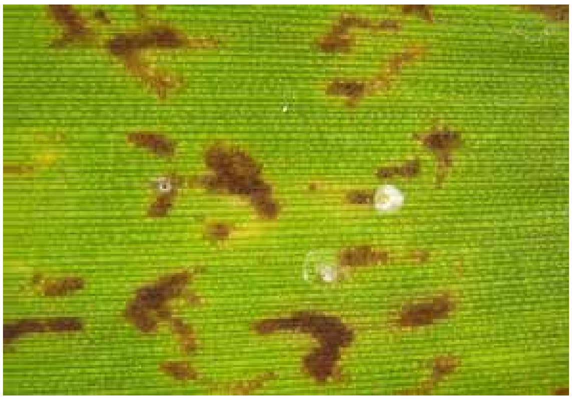

Figure 4.1.15 Necrotic streaks and marks on a bromeliad caused by Boisduval scale *Diaspis boisduvalii* (Hemiptera: Diaspididae), UK © Fera

Figure 4.1.16 Buttonwood flea beetle *Chaetocnema brunnescens* (Coleoptera: Chrysomelidae) characteristic feeding damage to buttonwood *Conocarpus erectus*, BVI © C. Malumphy

Figure 4.1.17 Chlorotic spotting on *Quercus ilex* due to feeding by *Phylloxera glabra* (Hemiptera: Phylloxeridae) becomes necrotic as the foliage matures, Italy © C. Malumphy

Figure 4.1.18 Damsel fly endophytic eggs (Odonata: Zygotera) laid in *Nymphoides* sp. foliage, Singapore © Fera

Figure 4.1.19 Suspect case of Coconut Lethal Yellowing Disease on coconut *Cocos nucifera*, Bahamas © C. Malumphy

Figure 4.1.20 American palm cixiid *Haplaxius crudus* (Hemiptera: Cixiidae), vector of Coconut Lethal Yellowing Disease © J.D. de Filippis, University of Florida, Bugwood.org

Figure 4.1.21 Platanus lace bug *Corythucha ciliata* (Hemiptera: Tingidae) feeding damage on *Platanus occidentalis* foliage, Montenegro © C. Malumphy

Figure 4.1.22 West Indian satinwood *Zanthoxylum flavum* foliage exhibiting bronzing due to an infestation of cotton lace bug *Corythucha gossypii* (Hemiptera: Tingidae), BVI © C. Malumphy

Figure 4.1.23 *Zanthoxylum flavum* foliage lower surface contaminated with dark frass deposited by cotton lace bug *Corythucha gossypii* (Hemiptera: Tingidae), BVI © C. Malumphy

Figure 4.1.24 *Zanthoxylum flavum* foliage lower surface contaminated with exuviae (cast skins) of cotton lace bug *Corythucha gossypii* (Hemiptera: Tingidae), BVI © C. Malumphy

Softer parts of the leaves eaten

Skeletonization – The soft leaf tissue is eaten by an insect with chewing mouthparts, leaving the leaf veins intact. This damage is typically caused by the larvae of some Lepidoptera (Fig. 4.1.23) and Hymenoptera, and the larvae and adults of some Coleoptera (particularly Chrysomelidae). The larvae of some species cause skeletonization (or windowing – see below) when small but consume the whole leaf as they mature and have stronger mandibles.

Windowing – The soft leaf tissue is eaten leaving either the lower or upper epidermis intact. This damage is typically caused by the larvae of some Lepidoptera (Fig. 4.1.24), Hymenoptera and Coleoptera.

Perforation or shot holes – Holes of various sizes and shapes are eaten in the soft leaf tissue leaving the larger leaf veins intact. This type of damage is typically caused by the larvae and adults of some Coleoptera (particularly Chrysomelidae and Curculionidae) (Figs 4.1.25-4.1.26). Shot holes may be left by leaf miners once they have completed their larval development, examples include Lepidoptera (Incurvariidae and Gracillariidae) and Coleoptera (Curculionidae). Shot holes can also be caused by bacterial and fungal pathogens, although typically these start as dark brown, reddish, or purplish spots and may be surrounded by a light green to yellowish halo.

Figure 4.1.25 Cutworms *Spodoptera* sp. (Lepidoptera: Noctuidae) larvae skeletonising the foliage of herbaceous plants, BVI © C. Malumphy

Figure 4.1.26 Convict caterpillars *Xanthopastis timais* (Lepidoptera: Noctuidae) causing windowing on *Clivia*, Bahamas © C. Malumphy

Figure 4.1.27 *Viburnum tinus* leaves perforated by larvae of viburnum flea beetle *Pyrrhalta viburni* (Coleoptera: Chrysomelidae), UK © C. Malumphy

Figure 4.1.28 *Solanum melongena* leaves perforated by adult flea beetle *Epitrix* sp. (Coleoptera: Chrysomelidae), Montenegro © C. Malumphy

Whole leaves or sections of leaves eaten or removed

Marginal notches – Leaf eaten at the edge. Usually caused by adult Coleoptera (e.g. Curculionidae – Fig. 4.1.27), Hymenoptera (Argidae, Tenthredinidae) and Lepidoptera. Circular sections may be cut out of the leaf edge by leaf cutter bees (Hymenoptera: Megachilidae). Various shaped sections may be cut out by leaf cutter ants (Hymenoptera: Formicidae) (Fig. 4.1.28).

Large parts or whole leaf eaten – Large parts or the whole leaf may be eaten although sometimes the main leaf vein and some hard parts of other veins may be left intact. This damage is commonly caused by the nymphs and adults of Orthoptera (Fig. 4.1.29), adults and larvae of Coleoptera (Fig. 4.1.30) and Hymenoptera, and the larvae of Lepidoptera (Figs 4.1.31-4.1.34). The damage caused by these insects with chewing mouthparts can be very similar and it is difficult to identify the cause in the field unless the insect is still present. Many of these insects feed at night.

Figure 4.1.29 Vine weevil *Otiorhynchus sulcatus* (Coleoptera: Curculionidae) adults have eaten at the leaf margins, Montenegro © C. Malumphy

Figure 4.1.30 Leafcutter ants *Acromyrmex* sp. (Hymenoptera: Formicidae) carrying a section of leaf back to their nest, Brazil © C. Malumphy

Figure 4.1.31 *Citrus* foliage eaten by grasshoppers or locusts (Orthoptera: Acridoidea), BVI © C. Malumphy

Figure 4.1.32 Proteaceae foliage showing feeding damage suspected to be caused by leaf beetles (Coleoptera: Chrysomelidae), South Africa © C. Malumphy

Figure 4.1.33 *Nerium oleander* completely defoliated by spotted oleander caterpillar *Empyreuma pugione* (Lepidoptera: Erebidae), BVI © C. Malumphy

Figure 4.1.34 Spotted oleander caterpillar *Empyreuma* pugione (Lepidoptera: Erebidae) is very common and widespread in the Caribbean, BVI © C. Malumphy

Figure 4.1.35 Herbaceous plant completely defoliated by *Spodoptera* sp. caterpillars (Lepidoptera: Noctuidae), BVI © C. Malumphy

Figure 4.1.36 *Spodoptera* species (Lepidoptera: Noctuidae) are very common and widespread in tropical regions and can be serious pests, BVI © C. Malumphy

Leaf mines

Leaf mines – Insect larvae may feed between the lower and upper epidermis forming a variety of linear and/or blotch shaped mines. The larvae of many Diptera (Agromyzidae) (4.1.35-4.1.36), Lepidoptera (Gracillaridae) (Figs 4.1.37-4.1.40), Hymenoptera and Coleoptera form leaf mines. The citrus leaf miner *Phyllocnistis citrella* is common and widespread throughout the Caribbean and can cause significant leaf deformation and die back of young citrus plants. It has less effect on mature citrus plants. High levels of leaf mining can cause complete desiccation of the foliage resulting in premature leaf fall (Fig. 4.1.38).

Figure 4.1.37 Leaf mining fly (Diptera: Agromyzidae) on unspecified leaf, BVI © C. Malumphy

Figure 4.1.38 Holly leaf miner *Phytomyza ilicis* (Diptera: Agromyzidae) mine on *Ilex aquifolium*, UK © C. Malumphy

Figure 4.1.39 Horse chestnut leaf miner *Cameraria ohridella* (Lepidoptera: Gracillariidae) mines on *Aesculus hippocastanum*, UK © C. Malumphy

Figure 4.1.40 Horse chestnut leaf miner causes severe necrosis and premature leaf fall to *Aesculus hippocastanum*, UK © C. Malumphy

Figure 4.1.41 Micro-moth (Lepidoptera: Gracillariidae) mines on *Coccoloba uvifera*, Tortola, BVI © C. Malumphy

Figure 4.1.42 Citrus leaf miner *Phyllocnistis citrella* (Lepidoptera: Gracillariidae) mine on orange *Citrus sinensis*, Canary Islands © C. Malumphy

Abnormal leaf growth

Galls – Galls are abnormal outgrowths of plant tissue or distorted plant growth which provide shelter for the causal organism and often other inquilines or 'guests'. They may affect the leaf lamina, vein or petiole (and other parts of the host plant). The shape, size and colour can vary greatly and are dependent on the organism causing the damage and the host. Galls are induced by the larvae of Diptera (Cecidomyiidae - Fig. 4.1.41), Hymenoptera (especially Cynipidae - Figs 4.1.42-4.1.44, Eulophidae and Thenthredinidae), Hemiptera (Aphididae - Fig. 4.1.45, Phylloxeridae – Fig. 4.1.46 and

Triozidae – Figs 4.1.49-4.1.51), Thysanoptera (Phlaeothripidae – Figs 4.1.52-4.1.55) and Trombidiformes (especially Eriophyidae – Figs 4.1.56-4.1.58).

Distorted leaf growth – Buds, growing tips and young leaves infested with sap sucking insects (Hemiptera, especially Aphididae) (Figs 4.1.59-4.1.60) can become wrinkled, puckered, and/or curled to various degrees.

Leaves spun together – Leaves may be spun together with silk to form nests (Hymenoptera: Formicidae – Figs 4.1.61-4.1.62) or to produce shelters in which the insect feeds (Lepidoptera, especially Crambidae, Pyralidae and Tortricidae – Figs 4.1.63-4.1.64).

Leaf rolling – Leaves can be strapped (pulled over) or cut in a certain way and then glued. This deformation of the leaf lamina creates a shelter where the insect continues to feed by cutting and folding/rolling. This type of shelter is produced by some Coleoptera (especially Attelabidae – Figs 4.1.47-4.1.48) and some Lepidoptera.

Figure 4.1.43 Leaf galling flies (Diptera: Cecidomyiidae) on *Coccoloba uvifera*, TCI © C. Malumphy

Figure 4.1.44 *Neuroterus numismalis and Neuroterus quercusbaccarum* (Hymenoptera: Cynipidae) on *Quercus robur*, UK © C. Malumphy

Figure 4.1.45 Oriental chestnut gall wasp *Dryocosmus kuriphilus* (Hymenoptera: Cynipidae) gall on *Castanea sativa*, UK © C. Malumphy

Figure 4.1.46 Oriental chestnut gall wasp *Dryocosmus kuriphilus* (Hymenoptera: Cynipidae) gall cut open to reveal the chamber containing a single larva © C. Malumphy

Figure 4.1.47 Oak leaf-roller *Attelabus nitens* (Coleoptera: Attelabidae) on *Quercus robur* leaf forming a protective covering, UK © C. Malumphy

Figure 4.1.48 Oak leaf-roller *Attelabus nitens* protective case, dorsal view, UK © C. Malumphy

Figure 4.1.49 Pistacia aphid galls *Forda marginata* (Hemiptera: Pemphigidae) on *Pistacia terebinthus*, Greece © C. Malumphy

Figure 4.1.50 Grape phylloxera *Daktulosphaira vitifoliae* (Hemiptera: Phylloxeridae) galls on the foliage of *Vitis vinifera*, Germany @ Fera

Figure 4.1.51 African citrus sucker *Trioza erytreae* (Hemiptera: Triozidae) galls on *Citrus*, South Africa © C. Malumphy

Figure 4.1.52 *Trioza* sp. (Hemiptera: Triozidae) galls on the upper-surface of *Ficus sur* foliage, South Africa © C. Malumphy

Figure 4.1.53 Foliar galls on *Laurus nobilis* formed by the bay sucker *Lauritrioza alacris* (Hemiptera: Triozidae), UK © C. Malumphy

Figure 4.1.54 *Tabebuia heterophylla* new growth severely galled by *Holopothrips tabebuia* (Thysanoptera: Phlaeothripidae), BVI © C. Malumphy

Figure 4.1.55 *Tabebuia heterophylla* new growth severely galled by *Holopothrips tabebuia* (Thysanoptera: Phlaeothripidae), BVI © C. Malumphy

Figure 4.1.56 *Ficus microcarpa* leaf galled by Cuban laurel thrips *Gynaikothrips ficorum* (Thysanoptera: Phlaeothripidae), BVI © C. Malumphy

Figure 4.1.57 *Ficus benjamina* new growth galled by *Gynaikothrips uzeli* (Thysanoptera: Phlaeothripidae), BVI © C. Malumphy

Figure 4.1.58 Close up of eriophyid mite galls (Trombidiformes: Eriophyidae) on the foliage of *Ehretia rigida* subsp. *nervifolia*, Pretoria © C. Malumphy

Figure 4.1.59 Hibiscus gall mite *Aceria hibisci* (Trombidiformes: Eriophyidae) forming galls on the foliage of *Hibiscus rosa-sinensis*, Jamaica © Crown Copyright

Figure 4.1.60 Lime nail galls *Eriophyes tiliae* (Trombidiformes: Eriophyidae) on *Tilia*, UK © Crown copyright

Figure 4.1.61 *Podocarpus henkelii* with severe leaf distortion due to an earlier aphid infestation, South Africa © C. Malumphy

Figure 4.1.62 Aphids *Aphis* sp. (Hemiptera: Aphididae) causing leaf distortion on the new growth of *Schefflera*, Canary Islands © C. Malumphy

Figure 4.1.63 Weaver ant *Oecophylla smaragdina* (Hymenoptera: Formicidae) nest, China © C. Malumphy

Figure 4.1.64 Weaver ants *Oecophylla smaragdina* (Hymenoptera: Formicidae) defending their nest, Australia © C. Malumphy

Figure 4.1.65 Leaf tip spun together by the caterpillar of a micro-moth (Lepidoptera), BVI © C. Malumphy

Figure 4.1.66 Leaf tip pulled apart to show the caterpillar frass, silk and feeding damage; the adult moth has already left, BVI © C. Malumphy

Leaf contamination

Insects with sessile stages and associated waxy deposits – Foliage in the tropics and subtropics is commonly smothered with large populations of insects with sessile stages, particularly in the order Hemiptera (Aphididae – Fig. 4.1.67, Aleyrodidae – Figs 4.1.68-4.1.73 and Coccoidea – Figs 4.1.74-4.1.82), and many of these species produce copious quantities of white wax.

Honeydew and associated moulds – Honeydew (Fig. 4.1.83) is excess plant sap egested by sap feeding bugs in the order Hemiptera (Aphididae, Psylloidea and Coccoidea). It serves as a medium for the growth of black sooty moulds (Fig. 4.1.84) and attracts ants, flies and wasps.

Foam or 'cuckoo spit' – This is a protective layer of foam produced by immature spittle bugs or frog hoppers (Hemiptera: Aphrophoridae) (Figs 4.1.85-4.1.86). The spittle may occur on foliage, petioles and stems.

Silk webbing and/or nests – Spider mites (Trombidiformes: Tetranychidae) (Fig. 4.1.87) cover their host with silk webbing and some caterpillars (Lepidoptera, for example Yponomeutidae) (Fig. 4.1.88) feed gregariously inside a silk tent that smothers foliage and branches. The silk tents can be extensive and cover large stretches of hedge and parts of trees.

Slime trails – Slugs and snails may leave shiny slime trails over the foliage and bark.

Figure 4.1.67 Palm aphid *Cerataphis* (Hemiptera: Aphididae) on coconut *Cocos nucifera*, South Africa © C. Malumphy

Figure 4.1.68 Solanum whitefly *Aleurotrachelus trachoides* (Hemiptera: Aleyrodidae) colony on tomato *Solanum lycopersicum*, BVI © C. Malumphy

Figure 4.1.69 Ixora whitefly *Asiothrixus antidesmae* (Hemiptera: Aleyrodidae) on *Ixora coccinea*, BVI © C. Malumphy

Figure 4.1.70 Coconut whitefly *Aleurodicus pulvinatus* (Hemiptera: Aleyrodidae) puparia on a palm, TCI © C. Malumphy

Figure 4.1.71 Coconut whitefly *Aleurodicus pulvinatus* (Hemiptera: Aleyrodidae) covering the lower surface of a palm frond, Bahamas © C. Malumphy

Figure 4.1.72 Spiralling whitefly *Aleurodicus dispersus* (Hemiptera: Aleyrodidae) on *Strelitzia*, Canary Islands © C. Malumphy

Figure 4.1.73 Spiralling whitefly *Aleurodicus dispersus* (Hemiptera: Aleyrodidae) on *Ficus microcarpa*, Canary Islands © C. Malumphy

Figure 4.1.74 Citrus ortheziid *Praelongorthezia praelonga* (Hemiptera: Ortheziidae) on *Coccoloba uvifera*, Saint Lucia © C. Malumphy

Figure 4.1.75 Boisduval scale *Diaspis boisduvalii* (Hemiptera: Diaspididae) on *Strelitzia*, BVI © C. Malumphy

Figure 4.1.76 Wax scales *Ceroplastes* sp. (Hemiptera: Coccidae) on *Schefflera*, attended by ants, Canary Islands © C. Malumphy

Figure 4.1.77 Aloe scale *Duplachionaspis* sp. (Hemiptera: Diaspididae) smothering an *Aloe marlothii,* turning the foliage completely white, South Africa © C. Malumphy

Figure 4.1.78 Close-up of *Aloe marlothii* foliage showing a 100% covering by Aloe scale *Duplachionaspis* sp. (Hemiptera: Diaspididae), South Africa © C. Malumphy

Figure 4.1.79 Cactus scale *Diaspis echinocacti* (Hemiptera: Diaspididae) on *Opuntia*, Canary Islands © C. Malumphy

Figure 4.1.80 Croton scale *Phalacrococcus howertoni* (Hemiptera: Coccidae) male scales on *Codaieum*, BVI © C. Malumphy

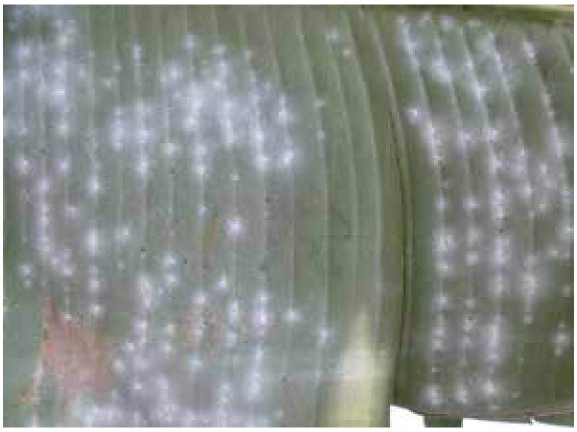

Figure 4.1.81 White powdery scale *Pseudocribrolecanium andersoni* (Hemiptera: Coccidae) on *Sterlitzia nicolai*, South Africa © C. Malumphy

Figure 4.1.82 Egyptian fluted scale *Icerya aegyptica* (Hemiptera: Monophlebidae) on *Ficus carica*, Egypt © C. Malumphy

Figure 4.1.83 Honeydew egested by brown soft scale *Coccus hesperidum* (Hemiptera: Coccidae) on *Schefflera*, UK © Crown copyright

Figure 4.1.84 Sooty mould growing on the honeydew egested by scale insects on the foliage of *Diospyros whyteana*, South Africa © C. Malumphy

Figure 4.1.85 'Cuckoo spit', the protecting foam produced by frog hopper (Hemiptera: Aphrophoridae) nymphs on *Bulbine natalensis*, South Africa © C. Malumphy

Figure 4.1.86 'Cuckoo spit' produced by common frog hopper *Philaenus spumarius* (Hemiptera: Aphrophoridae) nymphs on *Rosmarinus officinalis*, South Africa © C. Malumphy

Figure 4.1.87 Red spider mite *Tetranychus cinnabarinus* (Trombidiformes: Tetranychidae) feeding damage and layer of silk on *Solanum melongena*, Montenegro © C. Malumphy

Figure 4.1.88 Orchard ermine moth *Yponomeuta padella* (Lepidoptera: Yponomeutidae) caterpillars producing a network of silk, UK © Crown copyright

Premature leaf drop

Premature leaf drop can be caused by a range of abiotic (drought, climate, temperature, hurricane) and biotic causes. Leaves that have experienced high levels of insect feeding are often dropped prematurely (Fig. 4.1.89) and wood boring insects, particularly beetles (Coleoptera: Curculionidae and Buprestidae) that burrow under the bark can girdle the plant resulting in desiccation and leaf loss.

Abiotic factors, particularly climate (temperature and rain fall) can cause similar effects (Fig. 4.1.90).

Figure 4.1.89 *Codaieum* plant losing leaves due to large infestation of *Phalacrococcus howertoni*, Bahamas © C. Malumphy

Figure 4.1.90 *Plumeria* growing in tropical southern China showing complete defoliation and dieback due to unusually cold weather © C. Malumphy

4.2 Damage to fruit

Damage to fruit by invertebrate plant pests (chewing, mining, tunnelling, oviposition and emergence holes) is likely to result in secondary bacterial and fungal infections, rots, poor development and premature drop.

Fruit discoloured

Chlorosis and uneven ripening – Sap-sucking insects that feed on fruit, such as scale insects (Hemiptera: Coccoidea), and bugs (Hemiptera: especially Pentatomidae) can cause extensive chlorosis, uneven ripening and discolouration of fruit (Figs 4.2.1-4.2.4). Uneven ripening can also be caused by genetic chimera (Fig. 4.2.5).

Russeting – Russeting (Fig. 4.2.6) is often caused by mites feeding on the surface of the fruit.

Fruit surface damaged

Chewing – Adult wasps (Hymenoptera: especially Vespidae) (Fig. 4.2.7) and beetles (Coleoptera: especially Scarabaeidae) (Fig. 4.2.8) often chew the surface of mature fruit, and many groups of insects are attracted to the damaged fruit.

Mining – Caterpillars of some micro-moths (Lepidoptera: Gracillaridae) can mine under the surface of fruit leaving distinct linear tracks, for example the Citrus peel miner (Figs 4.2.9-4.2.10).

Figure 4.2.1 San Jose scale *Comstockaspis perniciosus* (Hemiptera: Diaspididae) on *Malus domestica* fruit, Montenegro © C. Malumphy

Figure 4.2.2 Citrus mealybug *Planococcus citri* (Hemiptera: Pseudococcidae) feeding damage on *Citrus sinensis* fruit, Montenegro © C. Malumphy

Figure 4.2.3 Armoured scale *Fiorinia proboscidaria* (Hemiptera: Diaspididae) causing chlorosis on *Citrus aurantifolia*, Saint Lucia © Crown copyright

Figure 4.2.4 Mango fruit *Mangifera indica* with yellow spotting due to being infested by yellow scale *Aonidiella citrina* (Hemiptera: Diaspididae), India © Crown copyright

Figure 4.2.5 Genetic chimera on *Citrus sinensis* fruit, Montenegro © C. Malumphy

Figure 4.2.6 Citrus fruit damaged by *Aculops pelekassi* (Trombidiformes: Eriophyidae), Montenegro © C. Malumphy

Figure 4.2.7 Plum *Prunus domestica* fruit with wasp feeding damage (Hymenoptera: Vespidae), Greece © C. Malumphy

Figure 4.2.8 Rose chafer *Cetonia aurata* (Coleoptera: Scarabaeidae) feeding on ripe *Ficus carica* fruit, Greece © C. Malumphy

Figure 4.2.9 Citrus peel miner *Marmara gulosa* (Lepidoptera: Gracillariidae) mine on *Citrus aurantifolia*, Dominican Republic © Fera

Figure 4.2.10 Citrus peel miner *Marmara* sp. (Lepidoptera: Gracillariidae) mine on *Citrus aurantium*, Peru © Crown copyright

Abnormal growth

Feeding on young fruit by adult and immature bugs (Hemiptera: especially Miridae and Pentatomidae) can induce the development of raised bumps or nipples on the mature fruit (Fig. 4.2.11). The feeding by some immature Coleoptera and Hymenoptera on young fruitlets can result in fruit becoming badly deformed as they mature (Fig. 4.2.12). Feeding by some mites, most notably the citrus bud mite *Aceria sheldoni* (Trombidiformes: Eriophyidae) on the developing fruit buds can result in badly deformed fruit (Figs 4.2.13-4.1.14).

External contamination of fruit

Insects, wax, honeydew and associated moulds – It is very common in the Caribbean for fruit to be heavily infested with insects, especially scale insects as these adhere firmly to the fruit and are difficult to remove and control. Fruit that is infested with insects and contaminated with wax, honeydew and associated sooty mould is often discoloured and exhibits uneven ripening, poor development, and may be dropped prematurely.

Insects that contaminate the fruit surface, in the adult and immature stages, include scale insects (Hemiptera: Coccoidea), mainly armoured scales (Diaspididae) (Figs 4.2.15-4.2.19), soft scales (Coccidae) (Fig. 4.2.20) and mealybugs (Pseudococcidae) (Figs 4.2.21-4.2.22). They latter two families egest excess plant sap as 'honeydew' and are often attended by ants (Hymenoptera: Formicidae) which feed on the honeydew.

Figure 4.2.11 Apple *Malus domestica* fruit with characteristic 'nipples' due to capsid bug (Hemiptera: Miridae) feeding damage, South Africa © Crown copyright

Figure 4.2.12 External damage to *Malus domestica* caused by the apple sawfly larva feeding on the young fruitlet, UK © Crown copyright

Figure 4.2.13 Citrus bud mite *Aceria sheldoni* (Trombidiformes: Eriophyidae) deformed orange *Citrus sinensis* fruit, Montenegro © C. Malumphy

Figure 4.2.14 Lemon fruit *Citrus limon* deformed by Citrus bud mite *Aceria sheldoni* © Giancarlo Dessi – Wikimedia Commons

Figure 4.2.15 San Jose scale *Comstockaspis perniciosus* (Hemiptera: Diaspididae) infesting *Prunus domestica*, Italy © Crown copyright

Figure 4.2.16 Grapefruit *Citrus paradisi* heavily infested with purple scale *Lepidosaphes beckii* (Hemiptera: Diaspididae), Jamaica © Crown copyright

Figure 4.2.17 Black parlatoria scale *Parlatoria ziziphi* (Hemiptera: Diaspididae) infesting orange *Citrus sinensis* fruit, Egypt © C. Malumphy

Figure 4.2.18 Oleander scale *Aspidiotus nerii* (Hemiptera: Diaspididae) infesting lemon *Citrus limon* fruit, Italy © C. Malumphy

Figure 4.2.19 Green spotting on banana *Musa* due to presence of Boisduval scale *Diaspis boisduvalii* (Hemiptera: Diaspididae), Costa Rica © Crown copyright

Figure 4.2.20 Sapodilla *Manilkara zapota* fruit and foliage covered in sooty mould growing on honeydew egested by green soft scale *Coccus viridis* (Hemiptera: Coccidae), TCI © C. Malumphy

Figure 4.2.21 Soursop *Annona reticulata* fruit badly infested with mealybugs (Hemiptera: Pseudococcidae), attended by ants, TCI © C. Malumphy

Figure 4.2.22 Sugar apple *Annona squamosa* fruit badly infested with mealybugs (Hemiptera: Pseudococcidae), Saint Lucia © C. Malumphy

Fruit with holes and/or bleeds

Oviposition punctures – Oviposition holes and scars are often tiny and difficult to detect although they may be associated with some discoloration and bleeds. In the Caribbean they are most commonly caused by adult fruit flies (Diptera: Tephritidae) (Fig. 4.2.23) and in some areas by mango seed weevil *Stenochetus mangiferae* (Coleoptera: Curculionidae).

Entrance and emergence holes – The eggs of some Lepidoptera may be laid on the surface of the fruit and on hatching the caterpillar burrows into the fruit leaving a small hole on the surface (Fig. 4.2.24). Mature fruit fly larvae tunnel out of the fruit, leaving an exit wound, to pupate in the soil (Fig. 4.2.25). Mature caterpillars of Lepidoptera (especially Tortricidae) also burrow out of infested fruit to pupate (Fig. 4.2.26). Mango seed weevil pupates in the seed and burrows out of the fruit as an adult and the resulting exit wound may bleed. The entrance and emergence holes often provide an opening for bacteria and fungi which cause the fruit to rot (Figs 4.2.25).

Figure 4.2.23 Mediterranean fruit fly *Ceratitis capitata* (Diptera: Tephritidae) oviposition scar on persimmon fruit, Montenegro © C. Malumphy

Figure 4.2.24 Tomato leaf miner *Tuta absoluta* (Lepidoptera: Gelechiidae) larval entrance hole in a tomato *Solanum lycopersicum* fruit, Spain © Crown copyright

Figure 4.2.25 Mediterranean fruit fly *Ceratitis capitata* (Diptera: Tephritidae) larval emergence hole in orange *Citrus sinensis* fruit with secondary rot, Montenegro © C. Malumphy

Figure 4.2.26 Emergence hole of a codling moth *Cydia pomonella* (Lepidoptera: Tortricidae) in a quince *Cydonia oblonga* fruit, Turkey © Crown copyright

Internal tunnelling

Tunnelling – The flesh of the fruit, the seed, or both may contain tunnels produced by immature insects, most commonly fruit fly maggots (Diptera: Tephritidae) (Figs 4.2.27-4.2.28), caterpillars (Lepidoptera) (Fig. 4.2.29), and in the case of mango seeds, with mango seed weevil larvae (Fig. 4.2.30). If you suspect a fruit is infested it is always advisable to cut it open to look for tunnelling, frass and the insect. Tephritidae larvae are most commonly found in mature, over ripe fruit.

Figure 4.2.27 *Carpomya vesuviana* (Diptera: Tephritidae) larva in a *Ziziphus jujubae* fruit cut open to show the feeding damage and frass, Montenegro © C. Malumphy

Figure 4.2.28 West Indian fruit fly *Anastrepha obliqua* (Diptera: Tephritidae) mature larva in a mango *Mangifera indica* fruit, Venezuela © Crown copyright

Figure 4.2.29 Bell pepper *Capsicum* fruit with feeding damage and frass of the false codling moth *Thaumatotibia leucotreta* (Lepidoptera: Tortricidae), Uganda © Crown copyright

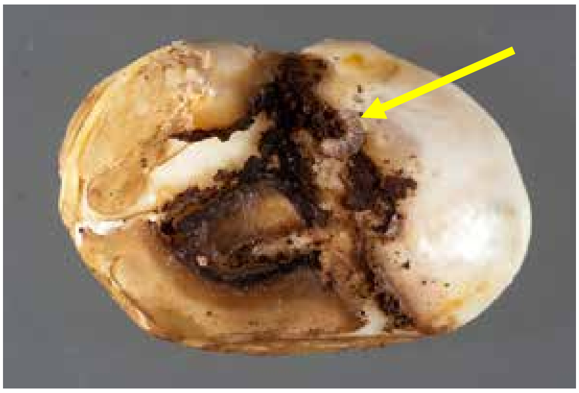

Figure 4.2.30 Mango *Mangifera indica* seed removed from the fruit and cut open to reveal mango seed weevil *Sternochetus mangiferae* (Coleoptera: Curculionidae) feeding damage, frass and a small larva (indicated with arrow), Kenya © Crown copyright

4.3 Damage to trunk, branches and stems

Contamination of bark

Silk and webbing – Apical twigs, branches, trunks and even whole sections of the plant may be covered in dense silk sheets that provide protection for feeding caterpillars (Lepidoptera: examples include Lymantriidae; Yponomeutidae) (Figs 4.3.1-4.3.2). Some species produce silk nests in which they rest during the day and emerge at night to feed (Lepidoptera: Thaumetopoeidae).

Figure 4.3.1 Brown tail moth *Euproctis chrysorrhoea* (Lepidoptera: Lymantriidae) communal nest on *Crataegus monogyna*, UK © Crown copyright

Figure 4.3.2 Brown tail moth *Euproctis chrysorrhoea* (Lepidoptera: Lymantriidae) caterpillar and communal nest on *Crataegus monogyna*, UK © Crown copyright

Soil trails and nests – Soil trails and soil nests covering bark are commonly seen in tropical climates. They are most frequently made by termites (Isoptera) (Figs 4.3.3-4.3.4) but some ants (Hymenoptera: Formicidae) may cover the base of a woody plant with soil, forming part of their nest, or to shelter aphids or scale insects which are being 'farmed' for honeydew.

Figure 4.3.3 Termite soil trails on the bark of a tree, TCI © C. Malumphy

Figure 4.3.4 Termite nest, made of soil and saliva which is remarkably tough, TCI © C. Malumphy

Insects, wax, honeydew and associated moulds and wax – Bark can be contaminated by many of the same insects found on the foliage and fruit discussed and illustrated above. The most common group of arthropods found are again the sap-feeding bugs (Hemiptera), especially the scale insects (Figs 4.3.5-4.3.7) which are often firmly attached to their host. Colonies of aphids (Aphididae) may be found feeding on bark and some are conspicuous due to a protective waxy coat (Fig. 4.3.8) or due to black mould growing on egested honeydew below the colony (Figs 4.3.9-4.3.10). Whiteflies (Aleyrodidae) are not found on bark. Waxy scale insect and aphid colonies can be easily mistaken for fungi (Figs 4.3.6 and 4.3.8).

Figure 4.3.5 A large infestation of scale insects *Lecanodiaspis* sp. (Hemiptera: Lecanodiaspididae) causing leaf loss and dieback to an ornamental *Hibiscus* plant, South Africa © C. Malumphy

Figure 4.3.6 Infestation of lesser snow scale *Pinnaspis strachani* (Hemiptera: Diaspididae) on *Hibiscus tiliaceus* resembles a fungus, BVI © C. Malumphy

Figure 4.3.7 Mature post-reproductive Nakahara wax scales *Ceroplastes nakaharai* (Hemiptera: Coccidae) feeding on the main trunk of a Rubiaceae tree, BVI © C. Malumphy

Figure 4.3.8 Infestation of woolly aphid *Eriosoma lanigerum* (Hemiptera: Aphididae) on apple *Malus* sp., Montenegro © C. Malumphy

Figure 4.3.9 *Peach Prunus persica* tree infested with peach trunk aphid *Pterochloroides persicae* (Hemiptera: Lachnidae). Note the dark patch on the ground due to mould growing on honeydew egested by the aphid colony, *Montenegro* © C. Malumphy

Figure 4.3.10 Colony of peach truck aphid *Pterochloroides persicae* (Hemiptera: Lachnidae) on peach *Prunus persica*, Montenegro © C. Malumphy

Holes, sap flows and bleeds

Emergence or exit holes – Adult insects that have developed inside wood create emergence or exit holes of various shapes and sizes in the bark of branches, twigs, stems and even the main roots. Removing the bark or cutting open the wood may reveal galleries or tunnels which are discussed below. Emergence holes can be produced by the adults of several families of Coleoptera including bark and ambrosia beetles (Curculionidae, Scolytinae) (Figs 4.3.11- 4.3.12), jewel beetles (Buprestidae) (Fig. 4.3.13), longhorn beetles (Cerambycidae) (Fig. 4.3.14); Lepidoptera, goat moths (Cossidae) and clear-wing moths (Sesiidae); and Hymenoptera, wood wasps (Siricidae).

Longhorn beetles are some of the largest wood boring insects and many species produce circular emergence holes 1 cm in diameter or larger. At the other extreme are the bark or ambrosia beetles which produce circular holes around 1 mm in diameter. Many jewel beetles produce emergence holes that are 'D' shaped or semi-circular. Lepidoptera usually produce emergence holes that are oval with coarse or uneven edges.

Figure 4.3.11 *Platanus* x *acerifolia* with emergence holes of an Asian ambrosia beetle *Euwallacea whitfordiodendrus* (Coleoptera: Curculionidae), a vector of a fungus that kills many tree species, South Africa © C. Malumphy

Figure 4.3.12 Adult bark beetle (Coleoptera: Curculionidae, Scolytinae) emergence holes in Scots pine *Pinus sylvatica*, UK © C. Malumphy

Figure 4.3.13 Emergence hole in oak *Quercus* of the gold-spotted oak borer *Agrilus auroguttatus* (Coleoptera: Buprestidae); note the 'D' shaped emergence hole, USA © C. Malumphy

Figure 4.3.14 Longhorn beetle (Coleoptera: Cerambycidae) emergence hole in the centre, South Africa © C. Malumphy

Sap flows or bleeds – Sap flows and bleeds from woody plants may be symptomatic of an insect infestation (Figs 4.3.15-4.3.17) or a pathogen, particularly fungi and bacteria (Fig. 4.3.18). Damaged trees and those stressed by abiotic factors may also exhibit bleeds and it can be difficult or impossible to determine the cause of these symptoms in the field. Removing the bark around the bleed may reveal galleries (discussed below) produced by an insect or stains produced by a pathogen. Bacterial infections can also have a distinctive unpleasant smell. Examples of beetle families that can cause bleeds include bark and ambrosia beetles (Curculionidae, Scolytinae and Platypodinae) (Figs 4.3.16-4.3.17) and jewel beetles (Buprestidae) (Fig. 4.3.15).

Figure 4.3.15 Resin bleed on the trunk of peach *Prunus persica* due to an infestation of *Capnodis tenebrionis* (Coleoptera: Buprestidae), Montenegro © C. Malumphy

Figure 4.3.16 Bleed caused by an infestation of an Asian ambrosia beetle *Euwallacea whitfordiodendrus* (Coleoptera: Curculionidae), USA © C. Malumphy

Figure 4.3.17 European beech *Fagus sylvatica* trunk with a bleed caused by large forest borer *Megaplatypus mutatus* (Coleoptera: Curculionidae, Platypodinae), Italy © C. Malumphy

Figure 4.3.18 *Celtis africana* tree exhibiting severe bleeds suspected to be due to a bacterial infection, South Africa © C. Malumphy

Frass and sawdust on the bark or at the tree base

Frass and sawdust – Many wood boring insects push frass (which looks like sawdust) out of their tunnels. The frass may appear as tubes coming out of the bark or it may fall and get caught on the bark or pile up at the base of the tree (Figs 4.3.19-4.3.20). The colour of the frass/dust varies with the tree and insect species, for example, *Prunus* frass appears reddish. These symptoms are often associated with bleeds, wilting, discoloured leaves, crown thinning, flagging, dieback and possibly mortality. The presence of frass/sawdust is usually indicative of adult and larvae of Coleoptera in the families, ambrosia and bark beetles (Curculionidae, Scolytinae); longhorn beetles (Cerambycidae) and other wood boring beetles); larvae of Hymenoptera, wood wasps (Siricidae); and larvae of Lepidoptera, goat and leopard moths (Cossidae) and clear wing moths (Sesiidae).

Figure 4.3.19 Saw dust/frass at the base of a cherry tree *Prunus cerasus* produced by the larva of a red-necked longhorn beetle *Aromia bungii* (Coleoptera: Cerambycidae), Italy © Don Walker

Figure 4.3.20 Saw dust is often the most easily seen symptom that a tree is infested by the larvae of *Aromia bungii* (Coleoptera: Cerambycidae), Italy © Don Walker

Oviposition slits

Oviposition slits in apical twigs – There are many bugs (Hemiptera) that oviposit into apical twigs. Some of the largest bugs belong to the family Cicadidae and these often form a series of oviposition slits in a longitudinal row that each contain a group of elongate ovoid eggs. These slits can cause shoot dieback.

Tunnelling

Tunnels in apical twigs – There are many beetle larvae (Coleoptera: especially Curculionidae, Scolytinae) (Figs 4.3.21-4.3.22) and caterpillars (Lepidoptera: Sesiidae) that tunnel into apical twigs causing shoot dieback. Infested coniferous plants often exude resin following the emergence of the adult beetles.

Tunnels under bark and in the heart wood – There are many species of ambrosia and bark beetles (Coleoptera: Curculionidae, Scolytinae) and jewel beetles (Buprestidae) whose larvae complete their development in the cambium layer beneath the bark. Removing the bark can reveal their galleries and tunnels (Figs 4.3.23-4.3.24). Ambrosia beetles infect the host with a fungus on which the larvae feed and the fungus can stain the tunnels black (Fig. 4.3.25). Other groups of wood boring beetle begin their development in the cambium layer but complete their development in the heart wood (Coleoptera: especially long horn beetles Cerambycidae) as do the caterpillars of some large moths (Lepidoptera: Cossidae) (Fig. 4.3.26).

Figure 4.3.21 Old oviposition slit made by a female cicada (Hemiptera: Cicadidae), South Africa © C. Malumphy

Figure 4.3.22 Cicada oviposition slits, USA © M. J. Raupp, University of Maryland

Figure 4.3.23 Black twig borer *Xylosandrus compactus* (Coleoptera: Curculionidae) causing dieback on *Magnolia*, Italy © C. Malumphy

Figure 4.3.24 Apical twig of *Pinus pinea* showing the tunnel produced by the larva of a pine shoot beetle *Tomicus destruens* (Coleoptera: Curculionidae), Italy © C. Malumphy

Figure 4.3.25 Bark beetle (Coleoptera: Curculionidae) galleries found under the bark, UK © C. Malumphy

Figure 4.3.26 Extensive tunnelling by the larvae of gold spotted oak borer *Agrilus coxalis* (Coleoptera: Buprestidae), USA © C. Malumphy

Figure 4.3.27 *Ricinus communis* stem cut open to reveal extensive mining and fungal infection (staining) caused by Polyphagous Shot Hole Borer *Euwallacea whitfordiodendrus* (Coleoptera: Curculionidae), South Africa © Trudy Paap

Figure 4.3.28 Leopard moth *Zeuzera pyrina* (Lepidoptera: Cossidae) caterpillar tunnelling in apple *Malus* sp., Italy © Crown copyright

4.4 Damage to whole plant and mortality

The introduction of invasive alien invertebrate plant pests can result in the rapid and catastrophic decline of native plants (see Chapter 1) although fortunately these dramatic events are uncommon. However, under the right conditions many invasive invertebrate plant pests can cause severe decline, dieback and mortality of individual or small groups of plants (Figs 4.4.1-4.4.4), which can become significant if the host plant is rare or endangered. Ornamental plants in urban environments are often stressed due to abiotic conditions such as under- or over-watering, pollution, root cramping, and are susceptible to plant parasites. For example, ornamental plants in urban parks in Saint Helena and Montenegro were observed showing severe dieback and mortality (Figs 4.4.1-4.4.4).

Some plant pests have natural cycles of epidemics such as the southern bark beetle *Dendroctonus frontalis* (Coleoptera: Curculionidae) in the Bahamas. Pathogens including fungi (honey fungus *Armillaria* spp., bracket fungus *Ganoderma* spp. and *Phytophthora* spp.), bacteria *(Xylella fastidiosa*) and phytoplasmas (Coconut Lethal Yellowing Disease) can also cause high levels of mortality. Islands in some areas are also vulnerable to natural disasters which can result in severe plant damage and mass mortality, most notably hurricanes (Fig. 4.4.5), tropical storms, tsunami and sea surges (Fig. 4.4.6).

Figure 4.4.1 Saint Helena gumwood *Commidendrum robustum* in an urban park exhibiting dieback due to white peach scale *Pseudaulacaspis pentagona* (Hemiptera: Diaspididae), Saint Helena © C. Malumphy

Figure 4.4.2 Ornamental Amaryllidaceae in an urban park dying due to large infestation of Amaryllus mealybug *Vryburgia amaryllidis* (Hemiptera: Pseudococcidae), Saint Helena © C. Malumphy

Figure 4.4.3 *Prunus* tree in an urban environment killed by huge infestation of globose scale *Sphaerolecanium prunastri* (Hemiptera: Coccidae), Montenegro © C. Malumphy

Figure 4.4.4 Canary Island date palm *Phoenix canariensis* killed by red palm weevil *Rhynchophorus ferrugineus* (Coleoptera: Curculionidae), Montenegro © C. Malumphy

Figure 4.4.5 Dry tropical forest severely damaged by Hurricanes Irma and Maria, BVI © C. Malumphy

Figure 4.4.6 Mass mortality of *Pinus caribbea* var. *bahamensis* due to a sea surge, Bahamas © C. Malumphy

5. Specimen collection and preservation

Insects, mites, and other invertebrates vary widely, as do their collection and preservation requirements. Methods are also often determined by the collecting conditions and the availability and cost of equipment.

This section will be a brief overview of general collecting techniques and preservation methods for the most commonly encountered invertebrate pests.

5.1 Collecting Methods

Basic collecting equipment

- A hand lense
- Fine soft forceps
- Fine paintbrush
- Killing bottle
- Notebook and pencil
- Bags for storing plant material
- Nets
- Sharp knife to cut into host fruits, twigs and seeds
- Beating sheet
- Vials containing alcohol or other preservatives
- Camera

Active collecting

Specimens can be collected directly from host material using a moistened paintbrush or soft forceps and then placed directly in a killing bottle or vial. Larger robust insects can be collected by hand but not when there is a risk of being stung or bitten. Ideally 15-20 individual specimens should be captured and preserved. If adults and immatures are present, specimens should be collected of all life stages.

Beating sheet/tray

Pests hiding in vegetation can be missed during casual inspections but can be easily collected by beating the plant with a stick or net handle while holding a beating sheet underneath. Take care to collect the insects quickly before they crawl or fly off.

Nets

Aerial nets - lightweight nets designed for collecting butterflies and other flying insects.
Sweep nets – stronger that aerial nets with a more durable bag, used for dragging and sweeping through vegetation.

Traps

A great variety of traps types are available to purchase commercially, and some can be easily home-made using plastic bottles and buckets. Most traps are used for monitoring insect populations, but some can also be used to for controlling pests. The most common types of trap used for monitoring plant pests are:

Sticky traps and rolls – A number of insect pests are attracted by the colours yellow (aphids, whitefly and some moths) and blue (leafminer flies and thrips) and can be caught on coloured sticky traps, the glue immobilizes and kills them. They are efficient at monitoring population densities of flying insects in the field and under protection and can also be used as a control measure using a large number of traps. Invertebrates can be removed from traps with drops of white spirit to dissolve the glue and then carefully teased off and placed in a preservative solution.

McPhail type traps – Used to catch pest flies, these robust plastic traps have an inverted funnel base and a transparent bell on top. The traps are used in combination with pheromone lures and a soap water solution to drown the pests that enter.

Delta traps – A triangular trap, made of glue-coated weatherproof card or plastic, often used with pheromone lures. They can be hung from trees to catch flying insects such as pest flies and moths.

Water/pan traps – Usually yellow, blue, white, or red and filled with dilute detergent, they are designed to capture and trap a range of flying pest insects in the field. They can be used in conjunction with pheromone lures. To collect the arthropods captured, the water is poured through a fine mesh net. It is then rinsed with water into a container 70% ethanol.

Pheromones and other attractants – Pheromones are substances naturally produced by insects to attract others of their own kind. They are often synthetically produced and used in traps to aid in controlling pest species. Most pheromones are highly specific, attracting only males of one species or a group of closely related species. Lures can be made from compounds found naturally in plants that are attractive to pest insects, they are invariably less selective than pheromones but catch both sexes. Baits can also be made up of natural ingredients that are attractive to target pests, usually made up with solutions of various combinations of fruits, sugars, yeasts, vinegars, and alcohol.

Rearing

Frequently insects and mites cannot be identified accurately from immature stages, and it is then necessary to rear them to the adult stage to obtain a precise identification. When only the immature stages are found, it is advisable to take a sample of their host material and attempt to rear them to adult before preserving them for study.

5.2 Preservation methods

Killing and temporary preservation for further study

Once collected, it is necessary to kill and preserve insects and mites for study or for them to be shipped to an expert for identification. Killing method is dependent on the technique with which they were collected and the invertebrate’s body structure.

Larvae of most insects (**caterpillars, grubs, maggots**) should be collected in alcohol and subsequently killed in boiling water to "fix" their proteins and prevent them from turning black. Larvae should be left in hot water for 1-5 minutes, depending on the size of the specimens, then transferred to 70 - 80 % percent alcohol. 70 - 80 % ethanol (ethyl alcohol) is the best general killing and preserving agent. Isopropanol (isopropyl alcohol) is generally easier to obtain than pure ethanol but isn’t suitable as a long-term preservative.

Other soft-bodied invertebrates such as **whitefly, mealybugs, scale insects, aphids, thrips** and **mites** can be killed in ethanol which will preserve them until they can be studied. It is preferable to take and preserve samples of whitefly puparia, scale insects and mealybugs in situ on host material as they can easily be damaged or lost when attempting to remove them. With larger leaves or stems it is necessary to change the preservative after 4-5 days as the plant material will dilute the ethanol and the invertebrates will begin to rot.

Adult **moths, butterflies, bees, mosquitoes** and other groups with scales or abundant hairs should not be collected into ethanol as they would become damaged and would probably be unidentifiable. Instead it would be best to capture them live and kill them by placing them in a freezer or a killing jar with ethyl acetate or chloroform. Once dead carefully place the insect in a small tube or box and cushion it or lightly wrap it with tissue (enough to stop it rattling around and becoming damaged). Almost any kind of container may be used for dry storage; however, airtight containers should be avoided because mould may develop on specimens if even a small amount of moisture is entrapped. You can often prevent this by puncturing a few holes in the tube or box. Moths and butterflies could be stored in paper or glassine envelopes but take care not to crush them.

Specimens collected in liquid traps are usually killed during the trapping process, they would need to be carefully filtered out and transferred to sample tubes or Wirl-pack sampling bags containing a preservative solution (70% ethanol) which will preserve them until they can be studied further and individually curated.

Permanent liquid preservation

Preservation methods for invertebrates in alcohol varies from one group to another and is often dependent on what chemicals are available and personal preference. 70 % Ethanol (ethyl alcohol) is the best general killing and preserving agent. For some kinds of insects and mites, other preservatives or higher or lower concentrations of alcohol may be better. For some groups, preservation is better if certain substances are added to the alcohol solution. Thrips are best collected in an alcohol- glycerin-acetic acid (AGA) solution.

Glass vials plugged by cotton or with polyethylene stoppers are recommended for long term storage. Stoppers made from cork and rubber are best avoided as they degrade and can leach chemicals into the alcohol.

Dry preservation

Hard-bodied insects such as beetles, moths and flies are best preserved dry. Large, robust insects are usually directly impaled with a pin, whereas smaller insects are indirectly pinned in a number of ways. Small beetles, for example should be glued to a card point or rectangle which is supported by a pin. Most can be pinned directly after removal from alcohol. Carter and Walker's (1999) *Care and Conservation of Natural History Collections* includes a chapter on insect curation and useful details on mounting techniques. The entire work is available through The Natural Sciences Collections Association website (www.natsca.org/care-and-conservation).

Microscope slide preservation

Smaller soft bodied insects and mites usually need to be slide mounted for examination with high power magnification. There are numerous permanent and temporary methods of slide preparation and most are quite technical and should be left to experienced person.

Labelling

Each specimen or sample must be clearly labelled indicating host plant, habitat, date collected, locality (as detailed as possible, include co-ordinates and altitude if relevant), collector's name, collecting method. Identification labels can later be added, and should include the name of the species, authority, identifiers name and date. Labels for specimens preserved in fluid should include the name and concentration of the preservative used.

Archival quality card and ink is most suitable for labels for dry specimens. Ordinary writing paper and pencil is useful to produce temporary labels when field collecting but is not suitable for permanent storage as it is known to disintegrate over time, instead use labels written with Indian ink on rag paper or a specialist coated paper.