Pest Identification

Many kinds of living organisms can damage plants or otherwise be undesirable occupants within the landscape. They become pests when they compete with, feed on, or infect desirable organisms. Pests reduce landscape quality and function, and range in severity from merely annoying or unattractive problems to those that threaten plant survival.

Common plant pests include insects, mites, snails and slugs, fungi, bacteria, nematodes and weeds. Disorders caused by adverse environmental conditions or inappropriate cultural practices (***abiotic*** or nonliving factors) and pest organisms often work in combination to damage plants. Fortunately, the great majority of living organisms in the landscape are valuable components of the ecosystem and perform beneficial functions.

Insects

Florida has more different kinds of insects than any other state. While most are not harmful to plants, there are more than enough kinds to damage plants by their feeding, breeding or shelter habits. The problems they cause are serious, and the damage is economically important. Obviously, there are too many different kinds of harmful insects to study and remember each kind individually. Therefore, the material presented in this manual will focus on beneficial insects and organisms defined as ***key pests*** of the horticulture and landscape industry.

Life Cycle

The insect life cycle and manner of feeding is an indicator of identity. Insects normally hatch from eggs that have been deposited on or near the food supply, while some, such as aphids, hatch within the female's body and emerge as living young. Most adult insects have fully developed wings, although a few species never develop wings.

Metamorphosis refers to the way insects develop, grow and change in form. Insects pass from an egg stage through immature stages to the adult stage during their life cycle. In immature stages, the insect ***molts*** periodically to shed its exoskeleton as it increases in size. Stages between molts are called ***instars***. The length of the life cycle varies greatly among insect species. Some develop from egg to adult in a few days or weeks, many require a year, and a few take two or more years to reach maturity.

Insects with ***gradual metamorphosis*** have three life stages: egg, nymph and adult. Plant

bugs, leafhoppers, thrips and grasshoppers hatch from eggs to a form known as a ***nymph***. This immature form resembles the full-grown insect, except it lacks wings and is smaller. Adults and nymphs usually feed on the same foods. Wings gradually develop externally during the final instars leading to the adult stage.

Insects with ***complete metamorphosis*** have four life stages: egg, larva, pupa and adult. Moths, beetles and flies hatch from eggs into a wormlike form (***larva***) much different in appearance from the adult. The larva of a moth or butterfly is commonly called a ***caterpillar***; the larva of a beetle is called a ***grub***; and the larva of a fly is known as a ***maggot***. Larvae molt periodically as they grow. After the last larval instar, the insect changes into a ***pupa***. In this stage, the insect does not feed or move around much and may be enclosed by a protective covering sometimes called a cocoon or chrysalis. Eventually the insect molts for the last time and emerges as an adult.

Identification

Although insect identification is one of the most basic elements of pest management, mistakes are still common, especially when many insects are similar in appearance or behavior. When the insect is correctly identified, information regarding its life cycle, food preference, habits and whether it is beneficial or harmful can be determined. When pest managers know how insects live, what they eat, and how they interact with their environment, safe and effective strategies can be used if needed.

Insects may be detrimental only during their immature stage (nymph or larva) or they may cause damage in both immature and adult stages. It is important for a pest manager to be able to recognize all life stages plus recognize typical damage symptoms to assess the need for control. Pest managers also must recognize the various stages of beneficial insects if they are to help conserve and protect them.

Figure 1. Illustrations of complete metamorphosis in beetles (top) and butterflies (middle). Illustration of incomplete metamorphosis in dragonflies (bottom). In dragonflies, the egg and nymph (known as a ***naiad***) stage occurs underwater.

A number of excellent manuals and guides are available to assist with insect identification from IFAS publications (***http://ifasbooks.ifas.ufl.edu***) or a local library. Online resources can be found at ***http://edis.ifas.ufl.edu***. Specimens may be sent to the UF/IFAS Insect Identification Service with the appropriate forms available at ***http://edis.ifas.ufl.edu/pdffiles/SR/SR02200.pdf***.

The Featured Creatures Website (***http://entnemdept.ifas.ufl.edu/creatures***) is another resource that provides in-depth profiles of insects, nematodes, arachnids and other organisms. The database is searchable by common name, scientific name, crop or habitat, higher classification and recent additions.

Beneficials

Only a small percentage (less than 0.5%) of all insects are plant pests. The remaining nonpest species may be considered beneficial because they feed on harmful ones. Most beneficial insects also perform functions directly or indirectly valuable to humans. These include pollination of crops, manufacture of medicines and pharmaceuticals, production of silk and textiles, production of honey and wax, and break down of organic matter.

Beneficial insects fall into two categories - predators and parasitoids (sometimes called parasites or parasitic insects). ***Predators*** kill and consume the entire insect pest. Some are predaceous only as larvae; other species are predaceous in both immature and adult stages. Predators may be generalists, feeding on a wide variety of prey, or specialists, feeding on only one or a few related species. ***Parasitoids*** lay eggs inside the host insect, on the insect, or somewhere in the host's habitat. The eggs hatch into larvae that slowly feed on the pest. The host remains alive during the early stages of the parasitoid's development. Late in development, the host dies and the parasitoid pupates inside or outside the host's body. The adult parasitoid later emerges from the dead host or from a cocoon nearby. Parasitoids are more specific in the insects they attack than predators.

Insects also suffer from diseases. Insect diseases, or ***entomopathogens***, act as parasites of insects and kill or seriously disable them. Many entomopathogenic organisms are host-specific and can be easily distributed without concerns about unwanted side effects on beneficial insects like bees and ladybugs. The disease-causing organisms most commonly used to manage insect pests in Florida include fungi, nematodes and bacteria such as *Bacillus thuringiensis*.

Assassin Bugs

Assassin bugs are named for the habit of attacking and ravenously feeding on insects with piercing-sucking mouthparts. Assassin bugs come in many shapes and sizes; they are generally black or brown, but many of them are brightly colored. Their length can vary from less than 1/4 inch to 1/2 inches, and they have only one generation per year. The head of all assassin bugs has a powerful, curved beak used to pierce its victim, inject venom and suck out dissolved tissues. These bugs are usually found on foliage, where they attack and feed on a wide variety of pests such as caterpillars, stinkbugs, aphids and beetles. Nymphs are just as effective in controlling pests as adults. While not a threat to humans, if not handled properly, assassin bug bites can cause a burning sensation with swelling that may last for several days. In some cases, the bite has been described as worse than stings from bees, wasps or hornets.

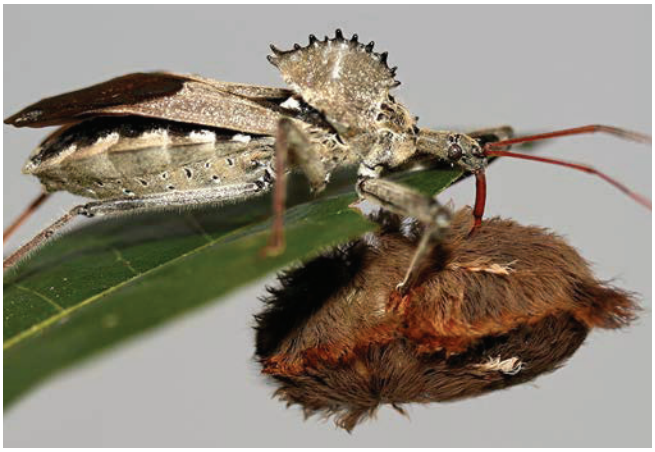

photo by donald w. hall, uf/ifas

Figure 2. Adult wheel bug, a type of assassin bug, feeding on puss caterpillar.

Two beneficial assassin bug species are found in Florida. The ***wheel bug*** adult usually measures from 1 to 1¼ inches long. This assassin bug is a dark brown, robust creature with long legs and antennae, a stout beak, large eyes on a slim head, and a prominent semicircular crest on the ***thorax*** (middle body section) that resembles a cog wheel. The ***longlegged assassin bug*** is distinctively orange and black in color. Adults and nymphs have a pear shaped head, constricted neck and long hairy legs. This assassin bug has a three-segmented beak which, when at rest, is bent and held under the thorax in a groove.

Figure 3. Longlegged assassin bug.

Figure 4. Big-eyed bug feeding on an insect using its piercing-sucking mouthpart.

photo by russ ottens, university of georgia, bugwood.org

Big-eyed Bugs

Big-eyed bugs are small, oblong-oval insects (approximately ⅙ to ¼ inch long) with a wide, almost triangular head and huge eyes that turn slightly backward. These features can be seen on nymphs as well as adults and serve to separate big-eyed bugs from similar bugs. They are generally regarded as beneficial because they prey on numerous turf, ornamental and agricultural crop pests, such as chinch bugs, small caterpillars and soft-bodied insects on the soil surface. The best time to spot these small insects is in the morning or evening when dew still clings to the leaves and blades of grass.

Lacewings

Lacewings are greenish or brownish and about ¾ inch in length. The wings are transparent with many veins. They are commonly found on weeds, cultivated row crops, and ornamental shrubs. The adults typically do not feed on insects, but some may feed on pollen. The larvae, often called ***aphid lions***, are voracious predators that feed on aphids, mealybugs, scale, whiteflies, thrips and insect eggs. Lacewing larvae are elongate and have large sickle shaped ***mandibles*** (a mouthpart used to grasp, crush, or cut food).

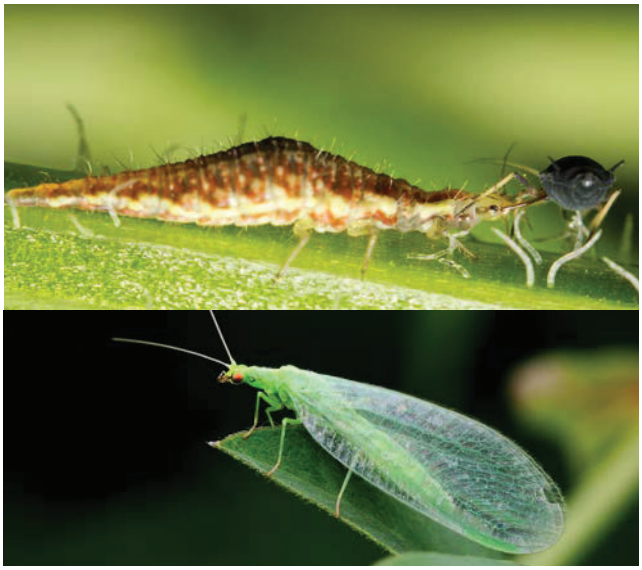

Figure 5. Lacewing larva feeding on aphids (above) and adult lacewing (below).

Lady Beetles

Lady beetles are among the best known and most beneficial insects. Adults are oval, orange or reddish with black markings, or black with yellow or red markings. Most species are about 1/4 inch long, but range from 1/16 to 1/2 inch. The larvae are elongated, with a cone shaped abdomen, somewhat flattened, usually dark or black with brightly colored spots or bands, and covered with small spines. Some larvae are white and resemble mealybugs. Both adults and larvae prey on aphids, scale, mealybugs, mites and other soft-bodied insect pests. Studies have found that 200 to 500 aphids can be consumed by lady beetle larva. The adults are usually even more voracious.

Figure 6. Lady beetle adult feeding on aphids (above) and lady beetle larva feeding on aphids (below).

Syrphid Flies

Syrphid flies are commonly found on flowers. They are also known as flower flies or ***hover flies***. The flies vary greatly in color and size, but most are yellow with brown or black bands on the abdomen and are about 1/4 inch long. The eyes of male hover flies actually meet at the top of the head. Many species resemble wasps, others closely resemble bees, but none sting. These flies are expert fliers and can hover or fly backward, an ability possessed by few insects.

Adults often visit flowers for nectar or may be seen around aphid colonies where they lay eggs and feed on the honeydew secreted by aphids. The adults are considered important agents in cross pollination of some plants. The full-grown larva is approximately 1/4 to 1/3 inches length, elongate oval in shape and pale green in color. The larvae are important predators, feeding primarily on aphids. High larval populations may reduce aphid populations by 70% to 100%.

Figure 7. Syrphid fly adult feeding on flower nectar (above) and syrphid fly larva feeding on aphids (below).

Parasitic Wasps

Parasitic wasps are very small; most species are less than 1/8 inch long making them practically unnoticeable. Adult females sting the host insect and lay eggs on or in the insect's body. The egg hatches and the larvae begins to consume the host's tissues, eventually immobilizing and killing it. Pupation may occur in or on the host. Some wasp larvae construct numerous small, white cocoons on the body of their hosts. Other species pupate inside their host and leave a small, circular hole when they emerge. Both characteristics are evidence of parasitism. These wasps parasitize and help control many harmful insects such as aphids, whiteflies, scales, leafminers and caterpillars.

photo by USDA ARS, bugwood.org

Figure 8. Female adult parasitic wasp inserting her ovipositor into a host fly pupa to lay a single egg. Once the egg hatches, the wasp larva feeds on the developing pupa.

Figure 9. Tomato hornworm with white cocoons (pupae) of a parasitic wasp attached to its back.

Spiders

Spiders are not true insects, but arachnids. They feed on a wide variety of insects, paralyzing their prey with venom. The majority of spiders capture their prey in webs, but some such as the jumping spider, pounce on victims. The latter are especially effective in capturing insects that inhabit the soil surface or plant foliage. Spiders rarely bite people and will usually move away when disturbed. Bites generally occur when a spider becomes accidentally pressed against the skin when putting on clothes or sticking hands in recessed areas or dark corners. Only a few species, such as the black, brown or red widow and the brown recluse are poisonous to humans.

Figure 10. Funnel weaver grass spider capturing a young grasshopper.

Figure 11. Green jumping spider.

Parasites and Predators

Common ornamental and turf pests and commercially available natural enemies	
Pest	***Natural Enemies***
Aphids	► Predatory flies ► Parasitic wasps
Beetles (grubs)	► Parasitic nematodes ► Predatory insects ► Microbial insecticides (*Bacillus thuringiensis var. tenebrionis*)
Caterpillars	► Predatory insects ► Parasitic wasps ► Microbial insecticides (*Bacillus thuringiensis*)
Fungus gnats	► Parasitic nematodes ► Predatory mites ► Predatory insects ► Microbial insecticides (*Bacillus thuringiensis var. israelensis*)
Leafminers	► Parasitic wasps ► Parasitic nematodes
Mealybugs	► Parasitic wasps ► Parasitic nematodes ► Predatory insects
Mites	► Predatory mites ► Predatory insects
Mole crickets	► Parasitic nematodes
Scales	► Predatory insects ► Parasitic wasps
Thrips	► Parasitic nematodes ► Predatory mites ► Predatory insects
Whiteflies	► Parasitic wasps ► Predatory mites ► Predatory insects

Adapted from Guidelines for Purchasing and Using Commercial Natural Enemies and Biopesticides in Florida and Other States, UF/IFAS EDIS

Figure 12. Key pests and generic commercially available biological control suggestions.

Key Insect Pests - Ornamentals

The diversity of plants in nurseries and the landscape is much greater than in typical agricultural systems that consist of few species or cultivars. This assortment of plant material and associated insects, diseases, weeds and other challenges complicate the process of pest management. Despite the diversity, most problems are confined to a few plants and pests that create those problems. One technique used to make monitoring, decision making and intervention more effective is the "Key Plant / Key Pest" concept.

Key plants are those commonly used landscape plants most likely to incur serious, continuous difficulties because of inherent problems or because they are not truly adapted to the location and site conditions. The identification of regional or local key plants can assist in the design of pest resistant landscapes by indicating which types are pest prone and should be avoided.

There are also common key plant species produced in Florida nurseries that are frequently infested with particular pests or diseases at definite times of the year. Often such key plants have ***key pests*** that dictate control practices; they can therefore serve as the focus for monitoring, intervention activities, and targeted as opposed to broad scale, sitewide pesticide applications.

Knowledge of the variations in pest movement, manner of feeding, life history and reproductive habits is a valuable aid in planning management programs. For example, insects feeding between the leaf surface layers require control methods different from those living on the leaf surface; those insects that lose the ability to move about during portions of their life cycle and secrete protective coverings require more thorough and repeated applications of insecticides than many of those that move about freely and unprotected.

A few of the key pests found in Florida nurseries and landscapes along with some of their common host plants follow.

Insects with Piercing-Sucking Mouthparts

Insects in this group have mouthparts with slender needlelike ***stylets*** that pierce the plant cell and suck up plant sap and the fluid inside cells. Insects with piercing-sucking mouthparts are also often able to transmit viruses. In some cases, their ability to act as a carrier or ***vector*** of diseases may be more harmful than the damage done by direct feeding.

Aphids

Aphids are soft bodied pear shaped insects generally less than 1/8 inch long. Species vary in color from green to reddish or black. The most distinguishing features of an aphid are the two short ***cornicles*** or tubes extending from the rear of the body. These structures are partly responsible for secretions of a fluid thought to be useful as a defense mechanism. Aphid legs and antennae are long and skinny. Most aphids are wingless but when colonies become overcrowded or the host plant becomes undesirable, winged forms are produced that migrate to establish new colonies. Temperature and photoperiod also affect the production of winged and wingless forms.

Aphids can reproduce rapidly with many generations occurring in a year. Unlike most insects, almost all aphids are female. They reproduce without mating and seldom lay eggs; instead they give birth to living young.

Figure 13. Aphids possess piercing-sucking mouthparts that act as feeding tubes for the fluids removed from the host plant. Distinctive cornicles extend from the rear of the body.

Aphids are commonly found on young, developing leaves and stems or flower buds in clusters or colonies. Their feeding deforms new growth and the leaves curl or crinkle as a result. Flower buds may become hardened, causing the flowers to be disfigured due to feeding damage. Most species of aphids are specialists that feed on one or a few closely related plants. A few aphids, such as the green peach and melon aphid, feed on a wide variety of plants. Some of the more frequently infested plants include camellia, crape myrtle, oleander, podocarpus, rose and viburnum.

Aphids excrete large amounts of ***honeydew***, a sugary liquid composed of unused plant sap and waste products. The excretion provides an excellent medium for the growth of ***sooty mold***, a black fungus that coats the top side of leaves. Sooty mold usually weathers away following control of the insect infestation.

Plants should be monitored during the growing season by examining the terminal stems and the undersides of leaves (especially the new growth). Tiny white cast skins (exoskeletons) found deposited on the upper leaf surface indicate an infestation. Molting aphids inhabiting the undersides of leaves immediately above such deposits are the source. Ants also feed on honeydew secretions. Consequently, when ants are observed, plants should be examined closely. The presence of hard, round aphid bodies with a small hole in the back is evidence of parasitism by tiny wasps.

Figure 14. Female aphids are ***viviparous***, meaning they give birth to live young, rather than laying eggs.

Figure 15. Aphid colony with ants "milking" aphids for honeydew and one winged member developed for migration.

Figure 16. Aphid colony with cast exosketons (shrunken white bodies) and parasitized aphids (round full bodies). The parasitized aphid is referred to as an "aphid mummy". The adult parasite may chew a hole in the rear of the mummy to escape.

Scales and Mealybugs

Scales and mealybugs are one of the most destructive groups of insects to ornamental crops. Some scales attack only a few species of closely related plants, while other species infest a wide variety of plants.

Scales feed by inserting a tiny threadlike beak into the plant and sucking juices from them. Heavily infested plants appear unhealthy and produce little new growth. Scales feeding on the undersides of leaves may cause yellow spots to appear on the top sides, and these spots progressively become larger as the scales continue to feed. If scales are not controlled, leaves will drop prematurely, sometimes killing portions of twigs and branches. Scales also feed on trunks and stems of plants.

Scales are divided into three groups: (1) armored scales, (2) soft scales and (3) mealybugs.

Armored scales secrete a waxy covering over their bodies. The scale lives and feeds under this covering; it resembles a plate of armor but is not an integral part of the body. Species vary in size from $^{1}/_{16}$ to $^{1}/_{8}$ inch in diameter and can be almost any color. Armored scales may be circular, oval, oblong, threadlike or pear shaped.

Eggs of armored scale are laid underneath the waxy covering and hatch in one to three weeks. The newly hatched scales (***crawlers***) move about over the plant until they locate succulent new growth. They insert their piercing-sucking mouthparts into the plant and begin feeding. Female scales lose their legs and antennae during the first molt. The exoskeletons cast from subsequent molts are incorporated in the scale cover. Adult males are tiny two-winged, gnatlike insects without mouthparts. In some armored scales, the adult stage is reached within six weeks and there are several generations per year. Common armored scales affecting woody plants include magnolia white scale, tea scale and the white peach scale.

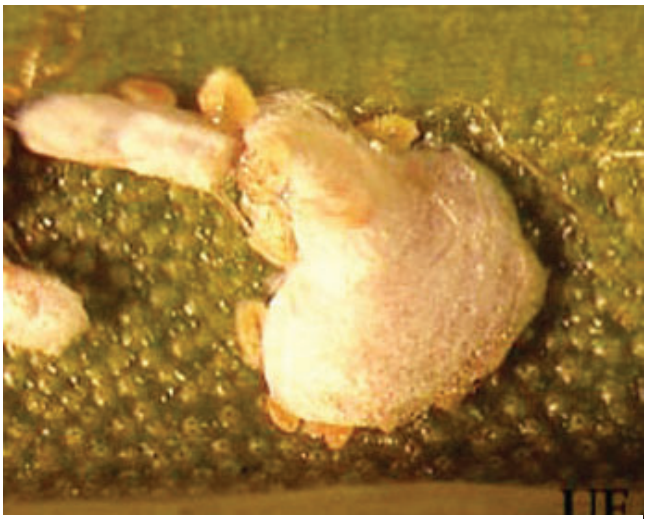

photo by f.w. howard, uf/ifas

Figure 17. Armored cycad aulacaspis scale with crawlers.

Figure 18. Severe infestation of armored cycad aulacaspis (Asian cycad) scale on sago palm frond.

Soft scales also secrete a waxy covering, which is an integral part of the body of this group. Soft scales vary widely in color, size and shape. They range from 1/8 to 2 inches in diameter and may be nearly flat to almost spherical.

Unlike armored scales, the antennae and legs are not lost in females after the first molt. Instead, their legs are reduced to such an extent that limited movement is possible but seldom occurs. When secreted, the waxy covering thickens on the back of the insect, forming a thick, fluffy mass for protection and to enclose eggs. Common soft scales found in Florida on woody plants include the brown soft scale, Florida wax scale, cottony cushion scale and the tulip tree scale.

Figure 19. Cottony cushion scale on a twig.

Mealybugs are soft-bodied insects covered with white, powdery or cottony, waxlike material. Short wax projections extend from the margin of the body, and some species have long filaments projecting from the rear of the body. They vary from 1/8 to 1/5 inch in length when mature. They tend to congregate together, appearing like fluffs of cotton on the foliage. The mealybug life cycle requires approximately 30 days at 80^{0}F.

Mealybugs are one of the major problems affecting plants grown in greenhouses and interiorscapes. Some common mealybug host plants are coleus, croton, cactus, rose, bedding plants and a large number of foliage plants.

Inspect plants closely at weekly intervals, especially plants where scale or mealybug problems have occurred in the past. These insects may be found on all plant parts, so every part of the plant must be checked. Leaves should be examined on both surfaces, particularly along the midrib of the underneath side. The waxy covering over scale and mealybug bodies makes them more difficult to control as they mature. Therefore, the crawler stage is the most ideal time to apply control measures.

Soft scales and mealybugs excrete large amounts of honeydew on which sooty mold forms. Armored scales do not excrete honeydew. A small hole in the wax covering of the scale or mealybug body indicates the presence of parasitic wasps.

Figure 20. Mealybug infestation on hibiscus.

Whiteflies

Whitefly adults resemble tiny white moths, but they are actually related to scale insects. Whiteflies are about 1/16 to 1/8 inch long and have four wings. The wings and body are covered with a fine, white powdery wax. The immature stages (nymphs), found on the underside of leaves, are flat, oval in outline, and slightly smaller than a pin head. They are light green to whitish and somewhat transparent.

Female whiteflies deposit eggs on the undersides of leaves. Eggs hatch into active six-legged nymphs (crawlers) that move a short distance seeking a suitable feeding site. Once a feeding site is selected, crawlers insert their long, threadlike mouthparts into the lower leaf surface and become immobile. They molt soon afterwards, lose their legs and antennae, and begin to resemble small scale.

Whitefly nymphs inflict the most foliar damage. They suck out large quantities of plant sap and excrete large amounts of honeydew causing sooty mold. The withdrawal of sap reduces plant vigor and the affected leaves display yellowing (chlorosis) or spotting. In heavy infestations, nymphs can be so numerous they almost cover the entire underside of the leaves. These infestations will cause the plant to wilt and eventually die. There are several generations per year, but the largest numbers occur in late summer and early fall.

Figure 21. Whitefly adults, eggs and nymphs on leaf underside.

The most common whiteflies impacting ornamentals in Florida are the silverleaf whitefly (formerly the sweet potato whitefly) and the citrus whitefly. Host range varies greatly with different species. The silverleaf whitefly feeds on numerous plant species, poinsettia being the most common host. The citrus whitefly commonly attacks citrus, allamanda, gardenia, ligustrum, poinsettia and many other annual, perennial and woody plants. Whiteflies can also transmit viruses among plants.

Monitor plants by observing for sooty mold. Tap plants to disturb adults that will fly and settle quickly. Inspect the undersides of leaves for nymphs. Observe for evidence of predators or parasites such as immature lady beetles, lacewings or tiny wasps. Ants may also be present feeding on honeydew secretions.

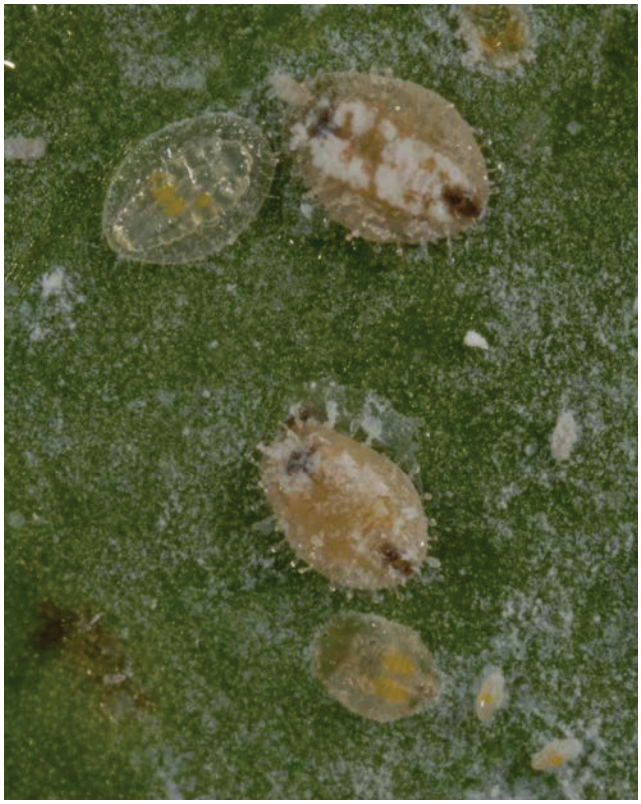

Figure 22. Pupae (tan colored individuals) and translucent nymphs (juveniles) of ash whitefly.

photo by lyle j. buss, university of florida, institute of food and agricultural sciences

Lacebugs

Lacebugs are small, broad, flat insects about 1/8 inch long. Their bodies are usually gray or brown and somewhat rectangular. A few species have a wide, hoodlike projection that extends over the head. The wings are clear with a fine, lacelike appearance. Immature lacebugs are black or brown, wingless and covered with spines.

Nymphs and adults withdraw plant sap with piercing-sucking mouthparts. Infested leaves are stippled with brown, yellow or white blotches on the upper surface. Lower surfaces are mottled by cast nymphal skins, shiny black stains from excrement, and from a brownish substance that is the protective covering for eggs. Severe infestations cause leaves to become almost white and drop from plants.

photo by james l. castner, uf/ifas

Figure 23. Adult azalea lacebug and excrement under leaves.

photo by gale allbritton

Figure 24. Lacebug damage on upper surface of azalea leaves.

Most lacebugs prefer sunny locations and often have very specific host preferences. The most prevalent species are the azalea lacebug, hawthorn lacebug, pyracantha lacebug and sycamore lacebug, so named because they are very common to these plants.

Lacebugs appear throughout the year, but are more prevalent in late summer and fall. Their host preferences aid in field identification. Examine the underside of leaves for adults and the spiny, dark nymphs. There will be dark-brown spots and stains present. When a leaf is pulled from a plant for observation, the disturbed lacebugs exhibit a peculiar bouncing movement. Lacebugs have several important natural enemies including egg parasites, lacewing larvae, assassin bugs, spiders and predatory mites.

Thrips

Thrips are very small, elongate and cylindrical insects ranging from 1/25 to 1/8 inch in length. Nymphs are frequently pale yellow with relatively short antennae and legs, and are highly active. Adults are usually black or yellow-brown, but may have red, black or white markings and often jump when disturbed. They may have long, narrow and fringed wings with hairs or be wingless. Stocky antennae often protrude in a V-shape at the front.

Female thrips deposit eggs in slits made with their sharp ovipositors in leaf tissue. The developmental period from egg to adult ranges from only 11 days to three weeks, so a population may increase quite rapidly under favorable conditions. ***Parthenogenesis*** (reproduction without mating) occurs in many species. When male thrips are present, they are usually smaller than the females.

Thrips feed on foliage, flowers and young tissues in shoot apexes where the leaves are expanding. They puncture the plant cells with their ***rasping-sucking*** mouthparts by first scraping the surface then withdrawing cell sap from the damaged area. Feeding activities produce bleached, silvered or deformed leaves and necrotic spots or blotches on flower petals.

photo by lance osborne, uf/ifas

Figure 25. Adult chilli thrips.

photo by bob cook

Figure 26. Chilli thrips damage to Indian hawthorn.

Eventually the damaged foliage becomes papery, wilts, and drops prematurely. Infested flower buds fail to open or the flowers are deformed. Damaged flowers become streaked and discolored. Thrips produce large quantities of varnishlike excrement that collects on leaves, creating an unsightly appearance.

Thrips attack an extremely wide variety of woody plants including azalea, avocado, ficus, gardenia, guava, hibiscus, magnolia, maple, palm, viburnum and many annual and perennial plants. Thrips occur throughout the growing season.

Monitor by shaking flowers or leaves suspected of being infested over a white sheet of paper to detect the insects. Thrips will fall onto the paper and can be more easily observed than when on the plant. Small spots of shiny, black excrement may also be found on the leaves.

Spider Mites

Spider mites are not insects but are closely related to spiders, ticks and scorpions with eight legs and no wings. Mature mites are usually less than $^{1}/_{50}$ inch in length and are generally found on the undersides of leaves. Eggs are attached to fine silk webbing and hatch in approximately three days. The length of time from egg to adult varies greatly depending on temperature. Under optimum conditions (about 80^{0}F), spider mites complete their development in five to twenty days. There are many overlapping generations per year.

Spider mites feed by penetrating the plant tissue with their mouthparts. Because of their small size, spider mites usually go undetected until severe infestations are present. Damage from light infestations appears as small chlorotic spots at the feeding sites. Continued feeding causes a stippled, bleached effect with leaves turning yellow, gray or bronze. The undersides of infested leaves usually have fine, silken webbing spun across them. Leaves will eventually drop off in heavy infestations. Webbing may be spun over entire branches, or in the case of small plants, over the entire plant.

The most common spider mites infesting ornamental plants in Florida are the two-spotted spider mite, southern red mite, six-spotted spider mite and the spruce spider mite.

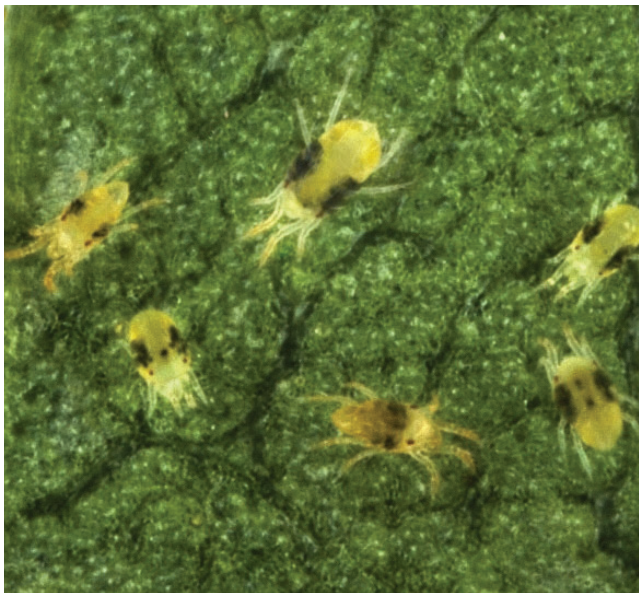

photo by university of georgia

Figure 27. Two-spotted spider mites.

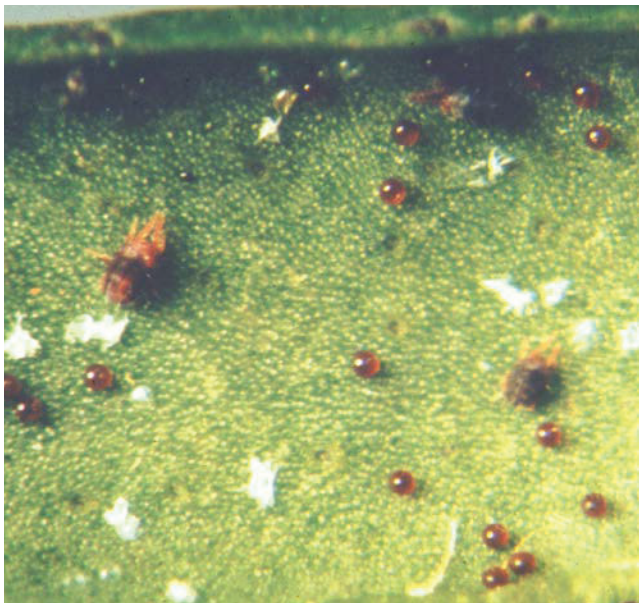

photo by john a. weidhass, virginia polytechic institute, bugwood.org

Figure 28. Southern red spider mite adults, nymphs and eggs.

photo by scot nelson, creative commons license

Figure 29. Spider mites on underneath side of leaf.

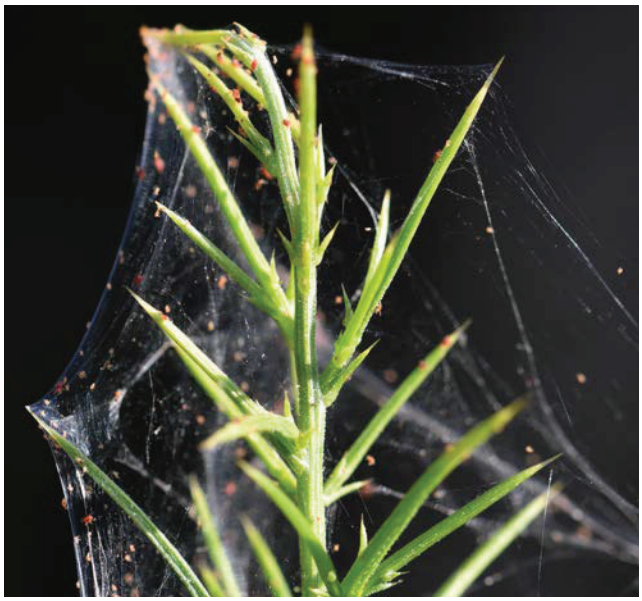

photo by scot nelson, creative commons license

Figure 30. Spider mites and webbing.

These species attack an array of foliage plants, bedding plants and woody plants.

The best mite detection technique is to place a sheet of white paper or a white paper plate beneath the leaves and strike the foliage sharply. The mites will fall onto the white surface and can be more easily observed than on the green foliage. Inspect plants frequently with the aid of a magnifying glass and treat promptly when damage begins to become evident.

Insect predators including lady beetles, praying mantis, assassin bugs and tiny parasitic wasps prey on harmful mites. Many mite species are actually predators, and do not damage plants. Every effort should be made not to destroy these beneficial organisms.

Chewing Pests or Foliage Feeding Insects

Insects with chewing mouthparts have ***mandibles*** that are jawlike structures with teeth. They tear off and chew plant tissue, or tunnel within stems and leaves. Chewing insects may feed on leaves, stems and flowers, or attack roots.

Caterpillars

Caterpillars are the immature or larval stage of moths and butterflies. Their bodies are usually cylindrical and either slender or robust. However, some are oval and others are flattened. They may be striped, marked with various color patterns or solid. They also may be naked or extremely hairy. Most mature larvae are about 1 inch long, but some are much smaller and some may be more than 4 inches long. Caterpillars have up to eight pairs of legs with adaptations that help them hold onto leaves and other plant parts.

Figure 31. Illustation of caterpillar leg adaptations for support.

Moths and butterflies go through a complete metamorphosis life cycle. In general, adult females lay several hundred eggs, singly or in clusters. The eggs hatch in two days to two weeks and larvae begin feeding immediately. The caterpillar molts as it grows in size; when full grown, it stops eating and becomes a pupa. Depending on the species, the pupa may be suspended under a branch, hidden in leaves, buried underground or protected inside a cocoon. Two to three weeks are spent in the pupal stage, where they transform to adults with distinctly different parts. After the adult emerges from the soil or cocoon, mating takes place and the female is ready to lay eggs. Under optimum conditions, three to six weeks are required for most moths or butterflies to develop from egg to adult.

Moths tend to fly at night, butterflies are usually active during the day, and both tend to feed on nectar and water. These adults are not damaging to plants. Some species in Florida have only one generation a year (for example, eastern and forest tent caterpillar, and hickory horned devil), whereas others may have multiple generations a year (for example, fall webworm, oleander caterpillar, and palm leaf skeletonizer). Caterpillar populations naturally fluctuate between periods of high and low abundance.

Caterpillars either partially or completely consume leaves or needles of host plants, or in some cases may also feed on flowers, buds and young shoots. Some species fold or roll leaves together with silk, and others make silken nests or tents for shelter. Still others may chew holes in leaves, feed selectively between the leaf veins (skeletonizers) or feed on only one surface of the leaf (window feeders). Initial infestations of newly hatched caterpillars are difficult to detect because they feed on the tissues of lower leaf surfaces. After feeding for several days, leaf skeletization begins to appear. Mature larvae chew holes or irregular areas in leaves or flowers.

During regular monitoring, observe plants for holes in leaves or on flower buds. If caterpillars are the problem, ***frass*** (small black dots or insect excrement) will be evident just beneath the affected leaves. The larger the caterpillar, the more frass will be apparent.

Knowing the caterpillar species and life cycle is important when trying to decide if control is needed. If the insect only has one generation a year, then it may be prudent to just wait it out until the larvae disappear or pupate.

The most environmentally friendly treatment against young caterpillars is *Bacillus thuringiensis* var. *kurstaki*, a commercially available insect pathogen. Other varieties or subspecies of *Bacillus thuringiensis (Bt)* are not effective on caterpillars. When infected with *Bt*, young caterpillars stop feeding within a day and usually die within a few days. The pathogen is not harmful to beneficial insects.

Figure 32. Caterpillar feeding on leaf with frass evident.

Figure 33. Eastern tent caterpillar nest.

Grasshoppers

Grasshoppers are medium to large insects ranging from 1/2 to almost 3 inches in length. Grasshoppers have chewing mouthparts, short antennae and may be winged or wingless. The hind legs are especially long and enlarged for jumping; they are also armed with spines for defense. Grasshoppers usually are brown, gray or green with large eyes. In some species, the males have bright colors on their wings that are used to attract females. Male grasshoppers also sometimes have special structures on their wings, which they rub together or with their hind legs to make sounds performed principally as a courtship ritual. Female grasshoppers are larger than the males, and have sharp points (***ovipositors***) at the end of their abdomen to help lay eggs underground.

Adult females produce eggs and deposit them in the soil clumped together in pods. When eggs hatch, young grasshopper nymphs dig to the surface and molt into an active form capable of walking, hopping and eating. Wings and sexual structures, such as the ovipositor in females, develop as the grasshoppers grow. Normally there is only one complete life cycle per year, but several species have more than one generation.

Grasshoppers can occasionally consume large quantities of foliage on ornamentals, leaving an ugly, irregular appearance. Feeding habits vary greatly. Some species feed only on grasses, some only on broadleaf plants, while others feed on a wide variety of plants. Many species will consume dried as well as green plant materials, and even exhibit cannibalism. Short-horned grasshoppers and the eastern lubber grasshopper are the most damaging grasshoppers in Florida.

Figure 34. Eastern lubber grasshopper feeding on leaves.

Grasshoppers are easy to see and should be controlled before they become numerous. Katydids are a type of grasshopper that is green and feeds at night; they are not commonly found in large numbers.

Beetles

Beetles are hard-shelled insects with chewing mouthparts ranging in size from 1/8 inch to over 6 inches in length. Adults possess hard, tough or horny ***forewings*** that serve as a protective covering for delicate ***hindwings***. The forewings are folded over the back and meet in a straight line over the abdomen; they are held stiffly out to the sides when the insect is in flight. The hard exoskeleton may be any color or combination of colors; however, most are black, brown or a shiny metallic.

Beetles have complete metamorphosis. The larvae (grubs) vary greatly in feeding habits, body shape, size and color. Some species feed on leaves while other species feed on roots. Some are elongate with relatively long legs and may be brightly colored, while others are plump, C-shaped and white with a brown head. Mature beetle larvae vary from 1/8 inch to more than 2 inches in length.

Figure 35. Adult lady beetle with forewings extended for flight (left). Characteristic forewings folded over the back meeting in a straight line (right).

Figure 36. Adult Colorado striped potato beetle feeding on foliage.

Beetles may have different feeding habits in different stages, but in many species the adult and larva share the same diet. Adult plant feeding beetles chew the foliage or flowers of many plants. Some are active at night and hide beneath the plant in debris or mulch during the day, while many feed during the day. Flower beetles are difficult to control, as they often fly in from adjacent areas in large numbers to feed on petals, nectar, or pollen. Beetle larvae are also destructive; they may feed on roots or bore through stems and branches. Some beetles feed on sap that flows from a tree wound.

As with other chewing insects, monitor for holes in the leaves and stems or missing roots. If present, search under leaves, along stems and below the mulch surface to locate larvae or adults that may be causing the damage.

Figure 37. Adult Japanese beetle damage.

Borers

Borers are the larvae of either moths or beetles. Most are whitish, elongate, cylindrical and legless with chewing mouthparts. Adults deposit eggs on bark, in crevices of bark or under bark at the edge of wounds. Larvae attack the trunk, stems, bark, buds and roots of woody ornamental plants. The life cycle usually requires one to three years; however, some species have several generations per year.

Borers can be placed into three main types: (1) borers that burrow in the inner bark and feed on the cambium; (2) borers that burrow in small limbs or twigs; and (3) borers that burrow deep into the trunk. Usually sawdustlike borings are noticed around the entrance holes and collect in bark crevices. Sap may flow from holes and form small "pitch tubes."

In most cases, borers are not the primary cause of trouble to trees, but rather attack trees first weakened by something else. A tree does not have to be badly weakened to make it susceptible to attack by borers. Injury or stress to the tree caused by drought, saltwater intrusion, soil added or removed above the roots, soil compaction, digging house foundations, septic tanks, underground utilities, lightning, and wounds to the trunk or roots caused by vehicles or machinery may mark the beginning of insect problems. The setback that trees receive following transplanting also increases the possibility that borers may attack them.

Figure 38. Illustration of the chewing mouthparts of a borer.

Monitor trees and woody plants for sap stains, holes in the bark, and blistered, peeling or spongy bark areas, especially on plants that are stressed or have been subjected to trunk injury.

Figure 39. Borer tunneling into pine wood.

photo by bob cook

Figure 40. Signs of a borer attack are often sawdustlike material (borer frass) being pushed out of small holes in tree trunks or branches. This produces a "soda straw" or toothpick-like appearance on the sides of the trunk.

Leafminers

Leafminers are very small larvae of flies, beetles or moths that tunnel or mine between upper and lower leaf surfaces as they feed. ***Serpentine leafminers*** leave winding trails in leaves. The adults are small, black flies about $^{1}/_{20}$ inch long and marked with yellow or gold patches. The larva is laterally compressed, legless and headless, and may have dark intestinal contents. ***Blotch leafminers*** are another important group of leafminers; they produce a blotch or blister instead of a serpentine mine. Adults are black or gray flies about the size of the common housefly.

In addition to mines, leaves may appear stippled due to the numerous feeding punctures made by the female fly's ovipositor. Adult flies feed on the sap exuding from these wounds. Feeding punctures occur particularly along the margin or at the leaf apex. Larvae feed singly but mines may be numerous and cross each other. The wounds in foliage also provide an entry site for fungal and bacterial pathogens.

The entire life cycle of most leafminer species can be completed in 21 to 28 days and even more rapidly if conditions are favorable. Adult females insert their eggs into leaf tissue. Once eggs hatch, the characteristic mine is made during larval growth and development. The mature larva usually cuts a hole at the end

Figure 41. Serpentine leafminer feeding damage.

photo by scot nelson, creative commons license

Figure 42. Blotch leafminer feeding damage.

of its mine, emerges and drops to the soil near the host plant to pupate with adults emerging in seven to fourteen days. There are many generations per year.

Leafminers are one of the most serious pests of commercial flower crops, especially chrysanthemums and bedding plants. With very few exceptions, azaleas and hollies for example, leafminers are not a serious problem on woody ornamentals. Infested leaves should be removed and discarded, and pruning may be required in the event of a heavy infestation. Populations are generally prevented from reaching especially damaging levels by a number of parasitic wasps that attack leafminers in Florida.

Leafminer populations can be monitored using several different methods. Observations of susceptible or key plants will indicate pest presence. Adults can be caught using sweep nets. Leafminer adults are also attracted to yellow sticky cards or cups placed over the top of the plant canopy. Early detection of adult leafminers can significantly improve population management.

Other Ornamental Pests

Sooty Mold

Sooty mold is a black fungus that grows on the honeydew excretion of aphids, mealybugs, many soft scales, and particularly of immature whiteflies. Besides being unattractive, sooty mold interferes with photosynthesis and somewhat slows plant growth. Sooty mold usually weathers or washes away following control of the causal insect infestation. Controlling the pests associated with sooty mold will prevent or reduce the problem.

photo by bob cook

Figure 43. Sooty mold fungus on gumbo limbo foliage.

Ants

Ants feed on honeydew excreted by sucking insects. They may protect and move these pests around from plant to plant. When ants are observed, plants should be examined closely for aphids, mealybugs or scale.

Ants are social insects that live in colonies. They are pests around the home because they feed on and contaminate human foods, infest structures, and build unsightly mounds in lawns. Ants have biting mouthparts and in some cases are able to inflict painful bites or stings. Most ant species are predatory, feeding on the larvae or pupae of harmful insects. However, some may cause plant damage by

injuring seedlings, cutting leaves, stealing seeds and building mounds of soil that disturb roots and cover stems or leaves.

Figure 44. Ants "nursing" aphids and feeding on honeydew as they "milk" them. When the host plant is depleted of nutrients, the ants carry their aphids to a new food source. Ants will also defend aphids aggressively if predatory insects or parasites attempt harm.

Snails and Slugs

Snails and slugs are mollusks with similar unsegmented gray to black or brown bodies covered by mucus. The head has two pair of tentacles, one pair bearing eyes and the other shorter pair for smelling. The mouth is at the center of the head, with a mucous gland below. Snails possess a hard, coiled outer shell used for extra protection.

Most snails and slugs are hermaphroditic (having male and female sex organs). This characteristic makes them particularly dangerous as invaders, because even a single individual can establish a new population through self-fertilization. Snails and slugs lay clusters of white or translucent spherical eggs in the soil or moist locations. Development time varies with weather conditions and among species, but several months or more are commonly required to reach maturity. Slugs can be long-lived and the adult size is quite variable.

Snails and slugs are most active at night and on cloudy or foggy days. They prefer damp and shady areas, so they hide under boards, stones, debris, leaf litter, dense ground covers and heavy mulch.

Snails and slugs feed on decaying plant matter and a variety of flowering and foliage plants by chewing on leaves, flowers and ripening fruits found close to the ground, such as strawberries. Most ornamental woody plants and ornamental grasses are not seriously affected. The nocturnal feeding habits and ability to burrow into the soil make snails and slugs difficult to detect. However, silvery mucous trails found near the damage confirms the presence of slugs or snails.

Snails and slugs have many natural enemies, including ground beetles, pathogens, snakes, toads, turtles and birds, but most are rarely effective enough to provide satisfactory control in the garden. Dense vegetation, deep mulch, and frequent irrigation favor slugs. Consequently, removing shelter that provides shade, minimizing irrigation or planting drought tolerant vegetation may reduce slug problems.

Figure 45. Slug and feeding damage.

Figure 46. Mucous trails left behind snails and slugs.

IPM Control Methods

Most pest management tools only eliminate a percentage of the pest population. To provide a higher level of success, more than one pest management method should be applied using an integrated approach. Different practices take on varying levels of significance depending on the pest, the plant type and the situation.

Control strategies for a particular pest of a certain host plant may not be the best strategies for another pest of the same or a different plant. Many are effective against one stage but ineffective against another stage. Likewise, some pest management tools may affect several different pests. For example, weed control may also result in fewer insect or disease problems because the host has been eliminated.

The pest manager must always keep in mind the effect of any management practice on other organisms, both pests and beneficials. An effective IPM program matches pest management practices and methods with the unique nature of the landscape or production environment. These programs can be designed by integrating biological, cultural, mechanical/physical and chemical management tools.

Biological Control

Biological control is the beneficial action of predators, parasites, pathogens, and other natural competitors in keeping pests and their damage at or below economically important thresholds. Biocontrol provided by these living organisms, collectively called natural enemies or ***biological agents***, is especially important for reducing the number of insects and mites. Plant pathogens and nematodes also have many natural enemies, but this biological control is often harder to recognize, less well understood, and/or more difficult to manage.

Biocontrol tactics include introducing or encouraging the development of predatory or parasitic insects (as eggs, larvae or adults), mites or nematode populations that attack certain pests. Microbiology also plays a role in pest management. For example, there are bacteria that kill caterpillars (*Bacillus thuringiensis*), beneficial fungi and bacteria that prevent root or leaf diseases and others that consume insects and mites. Products containing bacteria, such as *Bacillus* and *Streptomyces*, and fungi, such as *Trichoderma*, have reduced a variety of fungal plant pathogens in several experiments, especially when incorporated into transplant media or used as seed treatments.

It is important to understand that complete elimination of the target pest is not feasible when biological control measures are integrated into pest management schemes. A low pest population is necessary for the biological agent to have a continual food source. Ongoing research continues to evaluate and develop new biocontrols as well as expand the labeling of existing products.

A few of the currently labeled biocontrol products and reported applications on horticultural crops, including turf and ornamentals are found in the table on the next page.

The Biopesticide and Organic Database for Integrated Pest Management at ***http://ir4app.rutgers.edu/biopestPub/labelDb.aspx*** provides more information on available products and methods useful in an IPM program.

Figure 7. Lady beetles are natural enemies of aphids and voraciously consume them. The round, swollen bodies of several aphids also indicate parasitism by minute wasp larvae.

Biological Control Products		
Product	***Organism/Ingredient***	***Claimed Activity***
Actinovate®	*Streptomyces lydicus* (beneficial bacteria)	Controls soilborne diseases
Binab TF WP	*Trichoderma polysporum* and *T. harzianum* (beneficial fungi)	Controls a variety of fungal pathogens
BlightBan® A506	*Pseudomonas fluorescens* A506 (beneficial bacteria)	Controls fireblight
BotaniGard®	Pyrethrins (botanical extract) and *Beauveria bassiana* Strain GHA (beneficial fungi)	Controls whiteflies, aphids, thrips, spider mites, weevils and more
Companion®, Kodiak®	*Bacillus subtilis* (beneficial bacteria)	Soilborne diseases (*Rhizoctonia*, *Phythium*, *Fusarium*, *Phytophthora*, *Sclerotinia*, anthracnose, *Botrytis*)
Galltrol-A	*Agrobacterium radiobacter* 1026 (beneficial bacteria)	Prevents crown gall
Molt-X®	Azadirachtin (anti-feedant and insect growth regulator)	Controls foliar and soilborne pests
Mycostop®	*Streptomyces* spp. (beneficial bacteria)	Wilt and root rot caused by *Pythium*, *Fusarium*, *Botrytis*, *Alternaria*, *Phomopsis*, and to a lesser extent, *Phythophthora* and *Rhizoctonia*
Mycotrol®	*Beauveria* spores (beneficial fungi)	Controls adult and immature stages of whitefly, thrips, aphids and more
NemaShield®	*Steinernema feltiae* (beneficial nematode)	Controls fungus gnats and Western flower thrips
PlantShield® HC	*Trichoderma harzianum* (beneficial fungi)	Prevents foliar and root fungal diseases
Rhapsody® AS	*Bacillus subtilis* QST 713 strain (beneficial bacteria)	Anthracnose (*Colletotrichum* spp.), bacteria (*Erwinia*, *Pseudomonas*, *Xanthomonas*), black spot (*Diplocarpon rosae*), *Botrytis cinerea*, fungal leaf spots, and powdery mildew
RootShield®	*Trichoderma harzianum* T-22 strain (beneficial fungi)	Prevents root rot caused by *Pythium*, *Rhizoctonia*, and *Fusarium*
Soilgard® 12G	*Trichoderma virens* GL-21 (beneficial fungi)	Controls damping off and root rot organisms
SuffOil-X®	Mineral oil (biorational oil)	Suffocates and kills eggs, larvae, nymphs and adult soft bodied insects and mites, controls fungi including powdery mildew

Figure 8. Commercial biocontrol products and their claimed activity. This list is not a recommendation nor is it complete.

Cultural Control

Cultural pest control is the management of pests (insects, diseases, nematodes, weeds) by manipulation of the surrounding environment or implementation of preventive practices. The first line of defense in management of plant pest problems is providing the required conditions for optimal plant growth and development. Selecting plant species well adapted to soil type, soil porosity, sunlight exposure, soil pH, and microclimate avoids conditions that are not conducive to healthy growth. Planting in improper locations can increase plant stress and the likelihood of pest problems, thus leading to more frequent pesticide applications that may ultimately be ineffective and increase labor costs.

Reduction in damage caused by insects, mites, weeds, and other pests can be achieved through selection of pest resistant varieties, timing of planting, the use of traps, raising the mowing height of turf to shade out weeds, managing irrigation applications, etc. Even when cultural practices cannot be modified to control pests, it is important to understand their potential impact on future problems.

Plants should be thinned to permit free air circulation and allow sunlight to reach the lower parts of plants and the soil. Diseased branches and shoots should be removed and discarded before a disease can spread.

Adequate fertilization is needed to avoid nutrient deficiencies and keep plants healthy enough to resist and recuperate from disease or insect attacks. Too much nitrogen, however, can encourage excessive growth of new shoots, which may be more susceptible to plant pests than hardened mature growth.

To prevent root rot, avoid overwatering and persistent wetness of the soil. The lack of oxygen in waterlogged conditions cause many root cells to collapse, diminishing water and nutrient uptake and leading to decay. Excessive dryness between watering should also be avoided. Improper irrigation practices, insufficient aeration, and accumulations of soluble salts from overfertilization injure roots and favor root rotting pathogens. Further damage occurs from organisms known as ***facultative*** (happening in response to circumstances) parasites that are attracted to decaying tissue.

Disease infection can be prevented or reduced by keeping leaf surfaces dry. Adequate plant spacing promotes better air circulation, thereby decreasing periods of leaf wetness. Early morning irrigation or watering only around the roots using a drip system is also recommended. Keep in mind that water quality varies depending on the source and should be tested to ensure that pH and soluble salts are at acceptable levels for healthy plant growth.

photo by gale allbritton

Figure 9. Selection of resistant varieties, properly watered and fertilized foliage plants reduce the impact of pest infestations.

Figure 10. Management of irrigation and use of a drip system reduces disease infection potential.

Mechanical Control

Mechanical or physical control is sometimes practical for small numbers of larger insects such as caterpillars, grasshoppers and beetles. Frequently, insects can be picked or brushed off the plant and destroyed. Aphids and mites can be knocked off foliage by spraying plants with a water hose.

Sanitation methods are cleanliness strategies that can reduce the unintentional spread of plant pests from infested to healthy plants. Sanitation measures to keep the landscape or nursery area clean and free of scenarios that might attract insect pests include removing unwanted debris in contact with the ground, dead limbs, piles of decomposing organic matter and eliminating standing water that are not landscape design elements. Many nuisance pests are present due to physical characteristics of the local environment. Piles of rocks, deposits of leaf litter, and the presence of ground debris are favorable habitats of creatures like snails and slugs, sowbugs and pillbugs, centipedes and millipedes, and scorpions.

Other practices to accomplish sanitation include limiting the number of people handling stock plants in the propagation area, taking cuttings from the healthiest plants, avoiding splashing water from plant to plant whenever possible and if necessary, treating irrigation water to eradicate root rot pathogens. The spread of many pathogens can be prevented by disinfecting hands, pruning tools, equipment, potting benches, propagation areas, etc.

Cultivation for weed control is an important mechanical weed management practice, as is mulching soil surfaces to prevent weed seed germination. Weed suppression in landscapes, plant production areas, and if feasible, the surrounding space helps manage zones that often harbor pathogens and the insects that spread them. Weed control also reduces competition for water and nutrients plus it increases air circulation, all factors in keeping desirable plants healthy and resistant to disease.

Chemical Control

Chemicals used as pesticides are either natural or synthetic. ***Natural chemicals*** exist in the environment. ***Synthetic chemicals*** are made and introduced by humans. Many people mistakenly assume that "natural, organic chemicals" are less toxic than synthetic chemicals, but several poisons that come from nature are far more toxic than some synthetic chemicals. For that reason, chemical toxicity is not an accurate measure of "organic" or "botanical" toxicity. If chemical control is necessary, select a product that is safe and effective.

Figure 11. Good sanitation in greenhouse production.

Figure 12. Cultivation of soil for weed control.