Insects

Insects are the most abundant animals on earth. They exert important effects, both positive and negative, on our lives in ways we might not even think about. Although the vast majority of insects are either beneficial or harmless, we often are most familiar with those insects that cause problems. For example, the mosquito, because of diseases it transmits, has been responsible for more deaths than all of the wars in history.

On the whole, insects are enormously beneficial. Insects pollinate plants and provide food for birds, fish and other animals. Many beneficial insects prey on other insects that are pests. By studying insects, we gain a better understanding of their role in the web of life and as pollinators, indicators of environmental quality, predators of harmful species, and potential threats to crops, homes and health. Through applying what we learn from our study of insects, we help to preserve beneficial species by understanding their behavior patterns and conserving or enhancing their habitats. Our ultimate goal as Master Pollinator Stewards is to reduce the damage caused by insects in a sustainable and eco-friendly way.

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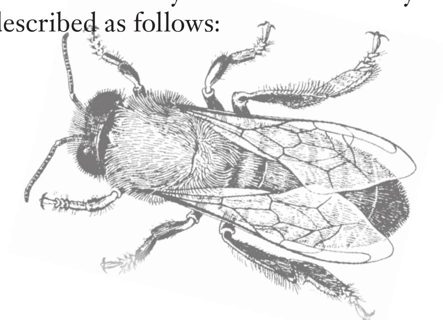
Insect basics

Insect classification

Insects are divided into categories using a standard classification system. Each insect is identified by a unique genus and specific epithet combination, which constitutes its species name. This system is known as binomial nomenclature, which means “naming with two names.” Common names differ from state to state and country to country. The binomial nomenclature system ensures that the scientific name of an organism is the same throughout the world in whatever language is prevalent. Binomial classification is just a filing system for information about organisms, organizing them within related groups based on shared common attributes such as structure, function and life history. To illustrate this system of classification, the honey bee can be described as follows:

Phylum: Arthropoda
Class: Insecta
Order: Hymenoptera
Family: Apidae
Genus: *Apis*
Specific epithet: *mellifera*
Common name: honey bee



The phylum Arthropoda — the highest level in this classification — includes all organisms with an external skeleton, jointed legs and a ventral nerve cord. The arthropods are then subdivided into smaller groups, each with its own unique features. This additional grouping based upon like features is known as a class, the largest of which is Insecta, which includes all insects.

The class Insecta refers to organisms with three pairs of legs; external mouthparts; three body regions of head, thorax and abdomen; and one pair of antennae (Figure 1). Several other types of arthropods — spider, ticks and mites —

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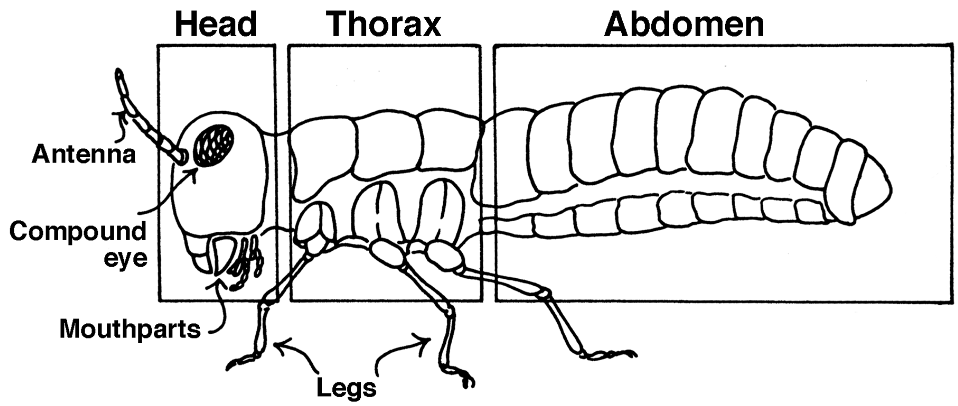


Figure 1. All insects have three main body segments: head, thorax and abdomen. The head contains the mouth and associated parts for food manipulation; the main sensory organs, including antennae and the compound eye; and the brain. The thorax contains the body parts used for locomotion: legs and wings. The abdomen contains the internal organs. On the abdomen of many females is an ovipositor for placement of eggs.

are commonly confused with insects. These organisms are in the class Arachnida, primary characterized by four pairs of legs and only two body regions.

Insects, like all other living organisms, are grouped into orders, often by characteristics such as physical appearance and behavior. Each insect order consists of any number of families, within which are genera (the plural of genus) and species.

Three main sections of an insect

Head

The head is the hardened region at the front of an insect's body. It includes the eyes, antennae and mouthparts. Most insects have two types of eyes: simple and compound. Compound eyes are the large eyes found on most adult insects. These eyes contain a few to several thousand eye units. Simple eyes are small eyes with a single structure used to detect light. They are located on top of the head of many adult insects.

Insects have one pair of antennae, which are jointed feelers that grow from the insect's head. Antennae can be short or long, and come in many forms (Figure 2). Knowledge of antennae is useful in insect identification. Antennae primarily function as sensors to detect the odors in the surrounding environment.

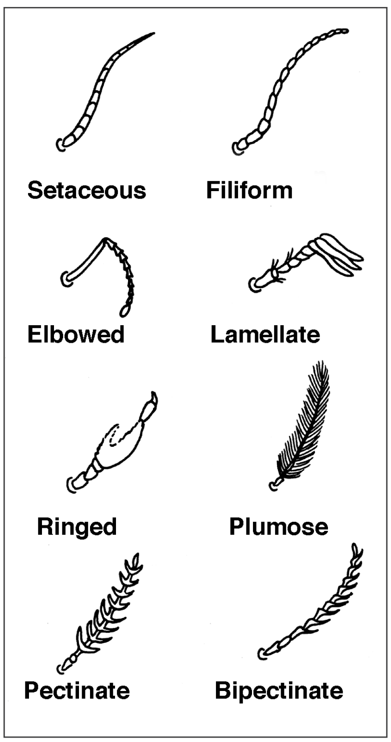


Figure 2. Insect antennae come in different forms, knowledge of which can aid in insect identification. Insects sense their environment through their antennae. They mainly sense smell, but also sound and vibration, finding food as well as mates by perception of chemicals.

Insect mouthparts and implications for control. Insect mouthparts are of two main types: chewing and piercing-sucking (Figure 3). Some insects have modifications of these two basic types. Mouthparts determine how an insect feeds and therefore play a role in the type of insect control that is most effective. Many insects feed on leaves, buds, stems, roots, fruits and seeds, as well as on plant tissue at various stages of decay. They feed on plants either externally on plant parts or internally on plant fluids. Insects that restrict their feeding to one type of plant are referred to as monophagous. Insects that are general feeders with a diversity of plants in their diet are said to be polyphagous. Insects that are moderately discriminating in their tastes are referred to as oligophagous. An example of an oligophagous insect is the Colorado potato beetle, which feeds only on plants in the genus *Solanum*.

Insects exhibit great variation in their mouthparts, which have evolved to fit the various diets on which insects feed. The most basic mouthparts, from which all other types have evolved, are for chewing. Predators such as the lady beetle have chewing mouthparts whose mandibles, or jaws, have evolved into long, pointed appendages that can also be used to grasp prey.

Chewing mouthparts allow an insect to bite or rasp off and swallow solid food. Signs of feeding damage caused by chewing insects include holes in plant tissue, missing leaves, "windowpane" leaves showing bared veins, and scraped areas. Insects with chewing mouthparts feed externally on the plant parts and have strong mandibles. The Japanese beetle, for example, is able to skeletonize the leaves of its preferred host plants. Caterpillars use their chewing mouthparts to consume many times their own weight in plant tissue during the course of their development. Much fibrous tissue passes through the caterpillar gut undigested and forms a major part of the large fecal pellets caterpillars leave behind. These pellets are a characteristic sign of caterpillar damage and serve to distinguish these pests from those with other kinds of mouthparts.

Many insects feed on liquid food for which chewing mouthparts are not effective. Many of these insects have a beak, called a proboscis, that is modified to suck up liquids. The piercing-sucking mouthparts of such insects have evolved into fine stylets that can pierce plant and animal tissue to extract fluid nutrients.

Insects with piercing-sucking mouthparts feed internally on plant sap by piercing plant tissue and extracting plant fluids. Their delicate stylets can penetrate leaves, fruit, stems and even tree bark, and are flexible enough to pass between fibrous plant elements and probe to find phloem or vascular bundles. Because these insects remove plant fluids, signs of feeding damage include spotting, curling, wilting and ultimately tissue death. Damage results from the removal of plant fluids, the toxicity of insect saliva to the plant, or diseases transmitted by the insect mouthparts. Insects with these mouthparts ingest primarily plant fluids, and their feces are watery and sticky (referred to as honeydew in some insects, such as aphids and scales).

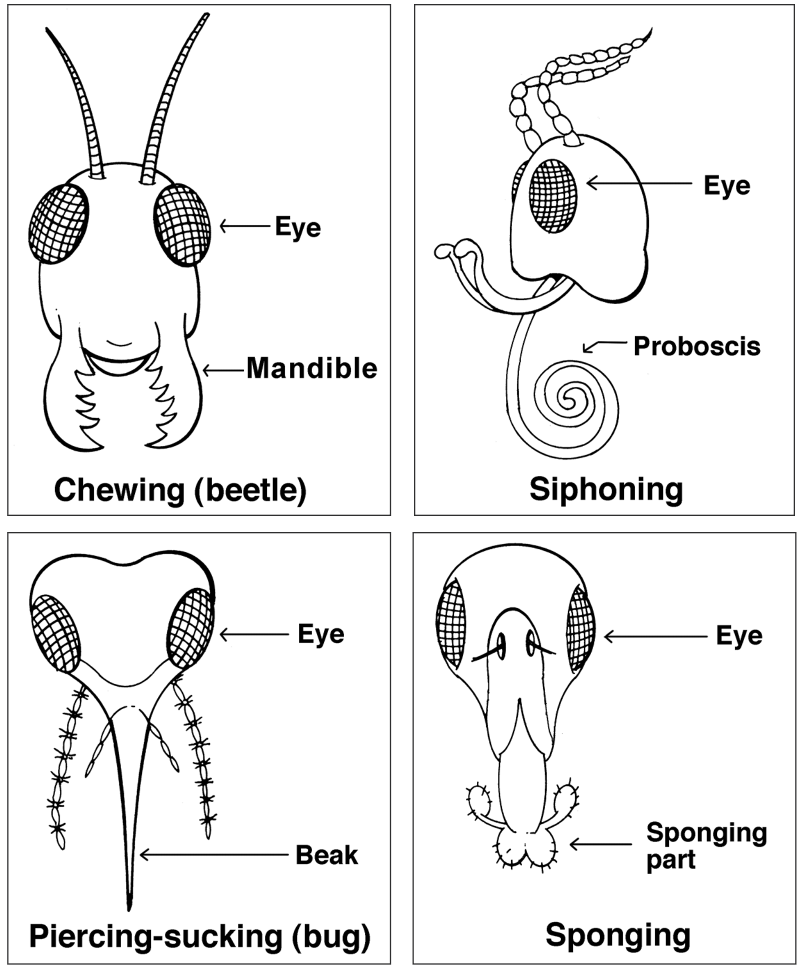


Figure 3. Insect mouthparts are highly variable, depending on how an insect feeds. Chewing mouthparts are the most general type. Piercing-sucking mouthparts have become modified for piercing the skin of animals or plants and sucking liquid food. Other common modifications enable particular insects to collect liquid food with long, coiled tubes or spongelike structures.

Butterflies and moths have a long, slightly coiled proboscis that serves to siphon plant nectar. House flies have a proboscis that has modified into a kind of sponge. House flies regurgitate salivary enzymes onto their food and then lap up the predigested, liquid food with their sponging mouthpart. Thrips have a short, stout proboscis and three stylets modified for rasping-sucking. It is thought that thrips scrape the surface of a plant to make the outer protective layer, called the epidermal layer, easier to penetrate. The stylets of mosquitoes are slender and needlelike to penetrate the skin of animals and suck blood. The itching sensation associated with mosquito bites is due to an anticoagulant that is injected into the skin to keep the blood flowing while mosquitoes feed.

Identification of mouthparts is key to correct diagnosis of insect damage, which in turn is crucial to selecting effective control tactics. An insect with chewing mouthparts will ingest a pesticide that is present on the surface — or as a systemic, in the tissue — of the plant. However, an insect with piercing-sucking mouthparts feeds internally within plant tissue and will not ingest pesticide that is on the surface of the plant. To kill insects with piercing-sucking mouthparts, an insecticide must either have contact toxicity, meaning it kills by just contacting the insect, or be systemic in nature. (See the *Integrated pest management* section for more information.)

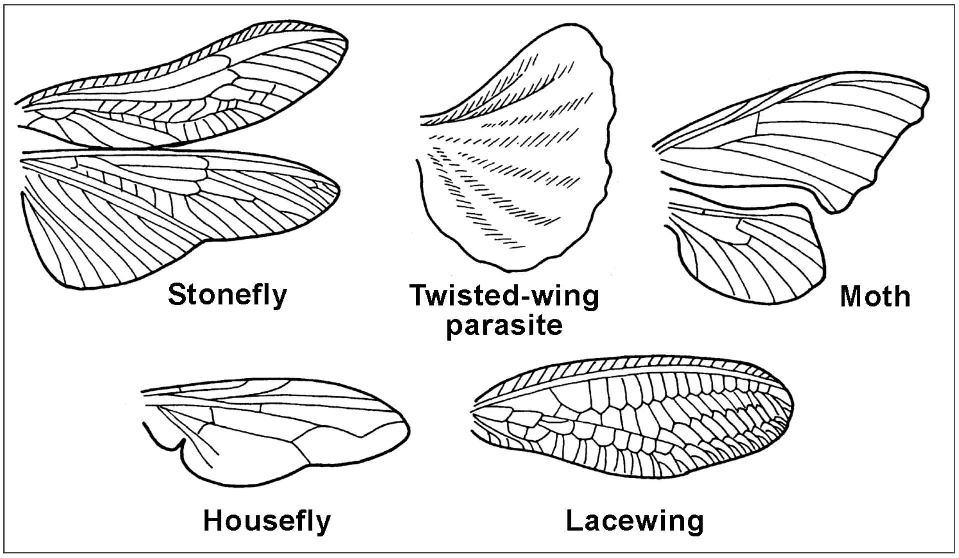


Figure 5. Insect wings are almost always found only on mature insects. Most insects have two pairs of wings. In several groups of insects, such as beetles, the front wings are more hardened and serve as protection for the hind wings. Some insects, such as fleas and lice, have no wings.

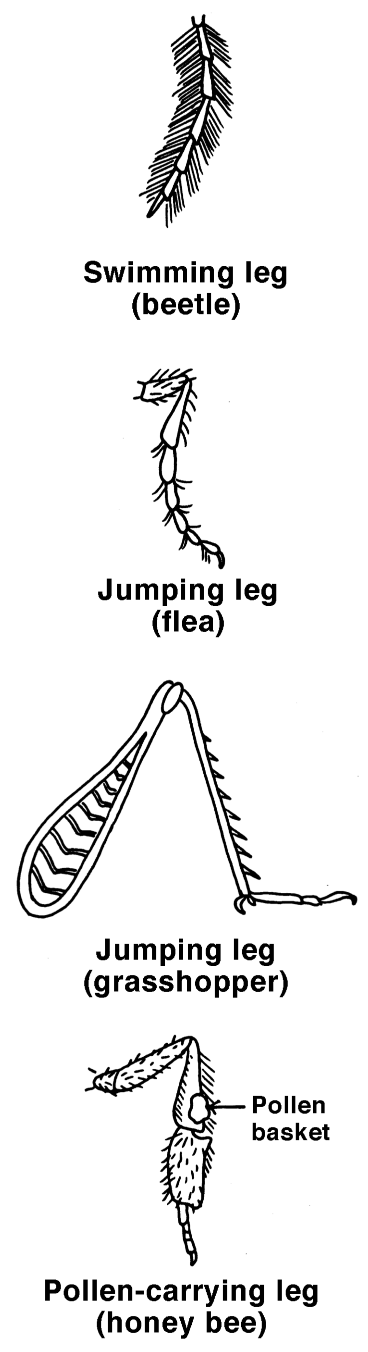


Figure 4. The thorax of an insect is specialized for locomotion and has three pairs of jointed legs. Each leg typically has six segments. Many insects have a pair of claws at the end of their legs, These claws enable insects to climb and hang upside down from surfaces.

Thorax

The thorax is the second section of an insect's body. It contains the muscles that control the insect's movement. Wings and legs are attached to the thorax. Adult insects have three pairs of legs, but not all adult insects have wings. The legs typically have six segments even though these can be hard to distinguish in many species. Legs come in many forms depending on their function, such as running, jumping, grasping or swimming (Figure 4). Insect wings also vary greatly in shape, size, color, thickness and vein pattern. The wing shape and pattern of veins are widely used in insect identification (Figure 5).

Abdomen

The abdomen is the third and final section of an insect's body. It may be visible or hidden under the wings. This body section contains the insect's internal organs, including the stomach and intestines, where food is digested and absorbed. The sexual organs are also in the abdomen. In addition, the abdomen has glands that secrete various fluids to mark the insect's trail, for example, or to drive enemies away, attract mates, or signal to others the location of food supplies. The abdomen may also have a needlelike projection for piercing or stinging.

Most female insects have an added appendage called an ovipositor at the end of their abdomen. The primary function of the ovipositor is for placing eggs in a protected location during egg-laying. Most insects with an ovipositor make a hole with this appendage and then place the egg inside the hole. In some insects, such as many bees and wasps, the ovipositor has been modified into a stinger for protection. Male bees and wasps cannot sting as they do not have an ovipositor. Parasitic wasps that lay their eggs on or in their hosts use the ovipositor to sting the prey, leading to paralysis, before placing the egg.

How insects grow and develop

Insect development occurs through changes not only in size but also in form. The series of changes that insects undergo as they grow and develop to the adult stage is known as metamorphosis (Figure 6). Almost all insects begin as eggs, although in a few cases the eggs hatch within the mother and they are born alive. The young insect develops through a series of distinct stages. As an insect develops, its exoskeleton, or cuticle, does not grow and must be shed and replaced. Insects are especially vulnerable during the period between the shedding of an old cuticle and the hardening of the new one.

Most insects undergo complete metamorphosis, which has four stages: egg, larva, pupa and adult (Figure 7). Adult females lay eggs that hatch into larvae (caterpillars in the case of moths and butterflies; maggots in the case of flies). The larva is the primary feeding stage, and it usually goes through four or five stages of larval development, called instars. The larva then becomes a pupa, which is the sedentary stage in which major transformation takes place, leading to an adult insect. The primary function of the adult stage is reproduction. Insects that exhibit complete metamorphosis include beetles, butterflies, moths, flies, bees and wasps. The life stage of an insect is an important consideration when deciding which control methods to use. For example, if insect damage is observed on the leaves of a tree, but the insect has already pupated, applying a pesticide is ineffective because the damage is done and the insect has moved on.

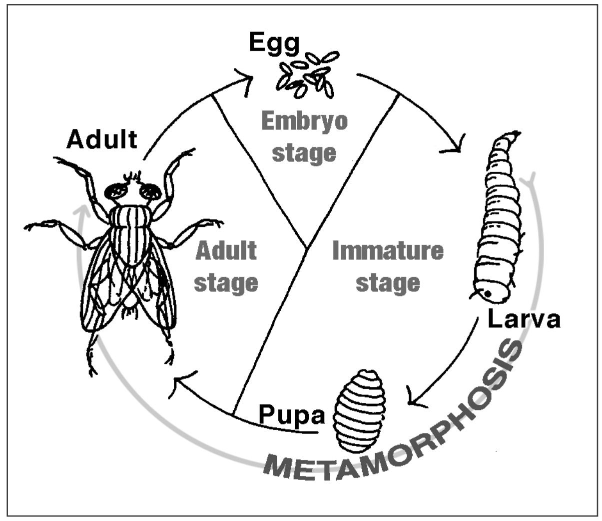


Figure 6. Insects pass through a series of stages as they develop, and these changes from one life stage to the next are called metamorphosis.

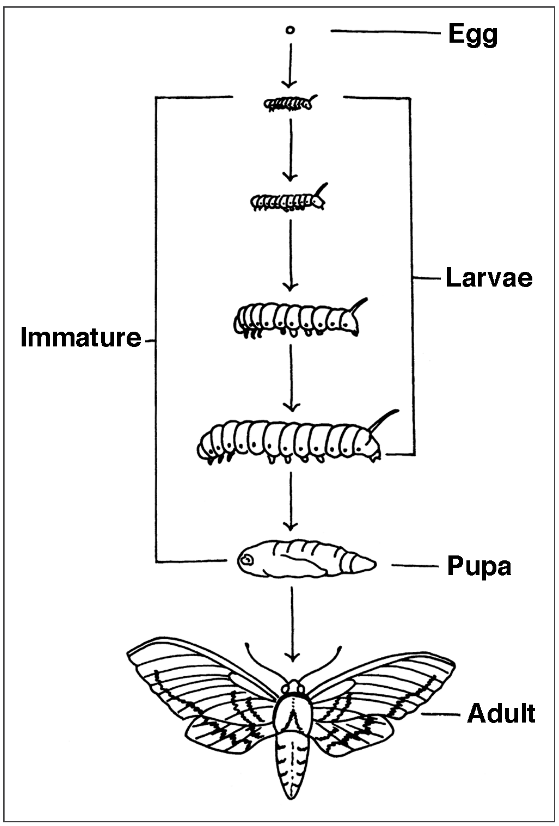


Figure 7. Most insects undergo complete metamorphosis with four primary stages: egg, larva, pupa and adult. Caterpillars pass through several stages, shedding their skin between them, as they feed and develop. Caterpillars of some insects, such as moths, spin silken cocoons to protect the pupa as it develops into an adult.

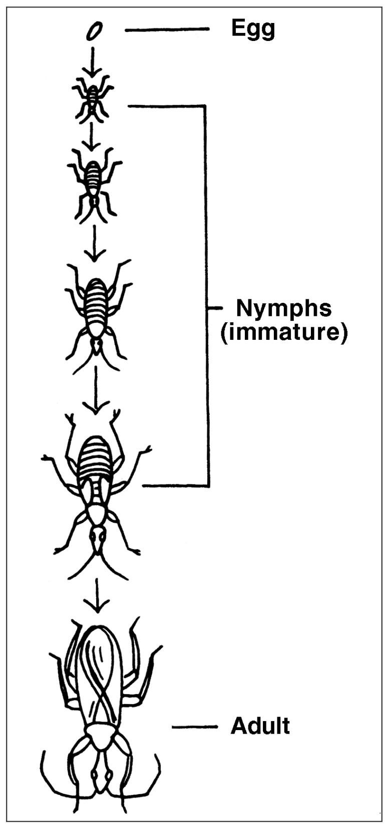


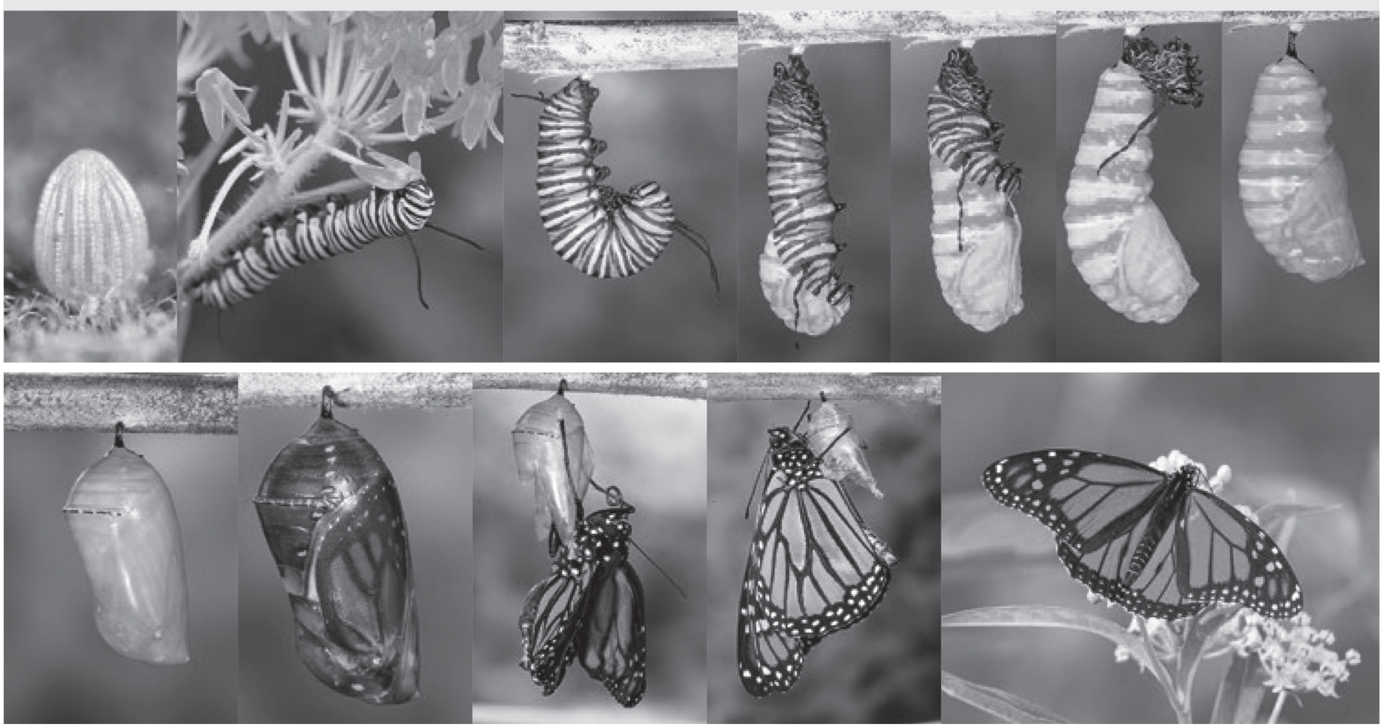
Figure 8. Immature insects that undergo incomplete metamorphosis are called nymphs, which resemble the adults. Growth from one nymph stage to the next occurs by shedding of its skin, or molting. A nymph's wings get larger with each successive molting, and by maturity as an adult, the wings are fully developed.

Incomplete metamorphosis has three stages: egg, nymph and adult (Figure 8). The immature stages are similar to the adult in appearance, feeding habits and habitat. Development is a gradual increase in size of the wing pads until the final molt, after which the wings and reproductive organs are fully formed. Insects that undergo incomplete metamorphosis include aphids, scales, true bugs, grasshoppers, katydids, crickets, cockroaches, mayflies, dragonflies and stoneflies. Having similar feeding habits in their nymph and adult stages, these insects have the potential for causing feeding damage to plants at both stages. For example, the squash bug feeds on plants in the family Cucurbitaceae, so if squash bugs are causing severe damage, control could be considered at any developmental stage.

Life cycle of the monarch butterfly

Like all species in the order Lepidoptera (moths and butterflies), monarchs undergo complete metamorphosis. This term indicates that there are four parts to the life cycle: egg, caterpillar, pupa and adult. A vital component of the monarch's life cycle is its host plant. Host plants are plant species that a moth or butterfly must have as food for the larvae (caterpillars). Caterpillars can only eat a select suite of plant species that are chemically compatible with that particular moth or butterfly species. In the case of the monarch, the host plants are milkweeds and a close relative called sand vine (*Cynanchum laeve*), native to Missouri. The butterfly lays its eggs on milkweed plants, and tiny caterpillars soon hatch. The caterpillars then begin eating the milkweed foliage, and they grow rapidly. The growth process involves five molts where the caterpillar sheds its skin and emerges slightly larger each time. Each stage between molts is termed an instar. After reaching the end of its fifth and final instar, the monarch caterpillar enters the pupa stage and forms a beautiful chrysalis, in which its tissues are transformed and reorganized into the adult butterfly. Once the transformation is complete, the butterfly forces its way from the chrysalis and fluid is pumped into the wings to make them expand. Once the wings harden, the butterfly is ready to take flight. The entire process, from egg to adult butterfly, takes four to five weeks.

Source: *Milkweeds and Monarchs*, Missouri Department of Conservation, 2016.



PHOTOS BY **NOPPADOL PAOTHONG**

Beneficial insects

The vast majority of insects visiting gardens are either neutral or beneficial. Many people spend a great deal of time and effort to destroy insects only to find out later that the insects they destroyed were beneficial. Hence, correct insect identification is important.

Insects as pollinators

Insects provide a huge benefit in the pollination of plants. Many plants require an insect to transfer the pollen needed to fertilize the flower and set fruit. Apple crops are not self-pollinated and rely almost exclusively on insects for pollination. Orchards now commonly have honey bee hives among the trees to promote pollination. The pollination activity of bees is suggested to annually provide benefits worth tens of millions of dollars to regional agriculture. Many native plants depend on insect pollination for their survival. Insects that pollinate plants include honey bees, flies, butterflies, moths, bumble bees and other native bees.

Insects and the natural recycling of nutrients

Insects play a key role as scavengers in recycling nutrients by feeding on decaying plant or animal material, thus hastening decomposition. Insects help break down organic matter they scavenge, and add organic matter to the soil as they live and breed. Dung beetles, for example, are usually found beneath cow dung, horse manure or carrion. Insects such as dung beetles help the manure of cattle and other animals break down more quickly. Fly maggots, which are the larvae of flies, play a vital role in the decomposition of animal material, especially carcasses. Termites, although considered pests when they destroy wooden structures, are extremely valuable scavengers that enhance the decomposition of wood materials in the environment.

Insects in the food webs of wildlife

Insects play a valuable role in the food chain of life as food for other species, including fish, birds and small mammals such as bats. Many game fish, such as trout, depend on insects as a major component of their diet, as do many songbirds. Mayflies, which are primarily aquatic insects, are reliable environmental indicators of water quality. If a water source has robust mayfly populations, the water quality can be assumed to be good. Declining populations of mayflies could indicate the water quality is declining.

Insects as biological control of pests

Biological control is any activity of one species that reduces the adverse effects of another species. Virtually every pest, whether weed or insect, has natural enemies that reduce its population under certain circumstances. The most important factor keeping the populations of many pest insects in check is the activity of other insects. There are two categories of insects used for biological control: phytophagous insects that feed on plants and act as biocontrol agents by destroying or limiting plant growth, and entomophagous insects that feed on other insects and keep pest populations in check.

For example, the Klamathweed beetle is one of at least 268 species of insects — mostly flies, beetles and moths — that have been introduced in attempts to control various noxious weeds. Klamathweed beetles have virtually eliminated Klamathweed (also called common St. Johnswort) from millions of acres of rangeland in the western United States, Australia, Canada, Chile, New Zealand and South Africa. Introduced insects have significantly reduced puncturevine, musk thistle, tansy ragwort and waterlettuce. There is reason to hope that insects can also help control leafy spurge and purple loosestrife.

Insects that feed on plant-feeding insects are the single most important factor keeping these pest populations in check. Insects that feed on other insects are

Revitalizing the health of pollinators

The Million Pollinator Garden Challenge (MPGC) is a nationwide program initiated to establish gardens and landscapes that help revitalize the health of bees, butterflies and other pollinators. Pollinator gardens contain plants that provide pollen and nectar as well as a source of water for pollinators. Additionally, they are managed with an attempt to minimize the impact of pesticides on beneficial species. More information can be found online at ***http://millionpollinatorgardens.org/about***.

considered either predators or parasites. Predators actively hunt for insect prey. The prey is typically smaller than the predator, but not always. Lady beetles can consume up to several hundred aphids during the two or three weeks that they are growing and many more after becoming adults. Parasites live on or in the bodies of their hosts and get their food from them. Parasitic wasps or flies lay eggs on certain kinds of insects, and their young feed inside the host, killing it and emerging in adult form. Hosts are typically larger than the parasites and are not killed immediately but continue to live in close association with the parasite.

Insect ecology

Knowledge of some ecological concepts can greatly enhance your understanding of insects and their management. Simply put, insect ecology is the scientific study of how insects — individually or as a community — interact with the surrounding environment, or ecosystem. Of the vast amount of information covered by this definition, some of the key issues are whether the insect overwinters in Missouri or migrates, and the effects of temperature on the insect's development and reproduction. Also important is knowing if the pest in considered invasive.

Insect overwintering. Some insects overwinter in Missouri in a resting state called diapause. Insects can enter diapause in any stage but most commonly do so in the adult and larval stages. Lady beetles, mourning cloak butterflies and fertilized queen bumble bees are examples of insects that overwinter as adults. Insects that overwinter as larvae include woolly bear (*Pyrrharctia isabella*) caterpillars, dragonflies and cicada killer wasps. Some insects cannot overwinter in Missouri. Populations of some insects seen in Missouri in the summer actually originate in the south and move north each year.

Insect migration. Insect migration is the seasonal long-distance movement of some species of dragonflies, beetles, butterflies and moths. The distance can

Monarch migration

The annual migration of North America's monarch butterfly is a unique and amazing phenomenon. The monarch butterfly is the only butterfly known to make a two-way migration, as birds do. Unlike other butterflies that can overwinter as larvae, pupae or even as adults in some species, monarchs cannot survive the cold winters of northern climates. The monarch butterfly migrates from southern Canada and the eastern United States to sites in central Mexico where they spend the winter. In the early spring, the same adult monarchs that migrated to Mexico travel north. Mating occurs, and the females seek out milkweed on which to lay their eggs, usually first in northern Mexico and southern Texas. The caterpillars hatch and develop into adults that move north, where more offspring can go as far as central Canada until the next migratory cycle. The entire annual migration cycle involves five generations.

Map source: *Milkweeds and Monarchs*, Missouri Department of Conservation, 2016.

vary with species, and in most cases, these migrations involve large numbers of individuals. In some cases, the individuals that migrate in one direction may not return, but instead, the next generation will migrate in the opposite direction. One example of a pest that exhibits long-distance, one-way migration is the tomato fruitworm. Because this pest can feed on many different plants, it has been given many different common names, including cotton bollworm and corn earworm. Most populations enter Missouri as migrating swarms of moths from the southern states.

Effects of temperature. Insects cannot regulate their body temperature; they rely on external sources of heat. Temperature has a direct effect on the growth and development of insects. Each species has a temperature range in which it develops. Within this range, the higher the temperature, the faster the insect develops and grows. But at very low or very high temperatures, insect development stops. The insect may die at such times, or it may resume development when the temperature returns to its normal range. Knowing the temperature ranges of an insect can help you to predict pest development and thus to determine the best time to scout and to use control measures.

Invasive insects. Insects, plants, animals and other life forms can be considered invasive species. An invasive species is one that is not native to a specific location, but has been introduced. Invasive species have a tendency to spread to a degree believed to cause damage to the environment, human economy or human health. Invasive insects are generally difficult to control because the ecology in their new location lacks the ability to control their population or limit their spread. In their native environment, they are often much less of a threat. Pesticides might be more effective against invasive insects because naturally occurring biological controls, such as parasites, predators or fungal pathogens, aren't present to help control the population. Eventually, the ecology may rebalance, which is what seems to have occurred with Japanese beetles (*Popillia japonica*) when they have been in an area long enough (see the *Invasive pests* box). In other instances, devastating damage may occur, as with the emerald ash borer (*Agrilus planipennis*). This pest has decimated ash trees where it is active, and no biological control is yet effective for widespread control. It originated from eastern Russia, northern China and Korea, and arrived in Missouri in 2008 from states to the east. Another well-known invasive insect from Eurasia is the gypsy moth (*Lymantria dispar*), which is currently established in the northeastern U.S. states and parts of the Upper Midwest. In 2013, an Asian fruit fly called the spotted wing drosophila (*Drosophila suzukii*) swept through Missouri. It is more difficult than other fruit flies to control because it can insert its eggs through the skin of berries, whereas other fruit flies need a skin break or split. Two other pests of concern are the brown marmorated stink bug (*Halyomorpha halys*) and Asian longhorned beetle (*Anoplophora glabripennis*). The former has been found in Missouri, but as of 2016, the latter had not been.

Insects as pests

The term pest refers to any organism that adversely affects humans, crops, livestock or anything considered to be of value. By this definition, not only insects but also diseases, weeds, nematodes (small unsegmented worms that live in the soil), arthropods other than insects, and vertebrates can be considered pests. Less than 1 percent of insects are pests, but that small fraction can do expensive damage. Insects cause damage in a variety of ways.

Chewing insects

Some insects feed by biting off and chewing the external parts of a plant. This type of injury can weaken the plant and cause it to be less productive or to die. Many pests, such as grasshoppers, feed on many different plants, whereas other

How many plant types does an insect feed on?

- Monophagous insects feed on one type of plant.
- Oligophagous insects feed on a few types of plants.
- Polyphagous insects feed on a wide variety of plants.

insects, such as cabbageworm and Colorado potato beetle, feed on only a few types of plants.

Piercing-sucking insects

Insects such as aphids and scales feed on plant sap by piercing the epidermal layer of the plant and sucking the sap from the cells. In this process, they damage the plant cells and remove valuable nutrients. Plant damage may include distorted leaves; curled leaves; chlorotic-looking, or yellow, tissue; deformed fruit; and even death of the entire plant. Some insects inject a salivary toxin into the plant that does additional damage. Common insects with piercing-sucking mouthparts include aphids, scales, leafhoppers, squash bugs and plant bugs.

Internal feeders

In addition to insects that feed internally by way of a proboscis, many insects actually make their way into a plant to feed internally on plant tissue, which makes control difficult or impossible. These insects enter the host plant either in the egg stage when the female adult lays eggs within the plant tissue, or they hatch and immediately eat their way into the plant tissue. Internal feeders include wood borers, codling moth in apples, leaf miners, seed weevils and gall insects. Perhaps the most widely noticed internal feeders are those that cause galls. These unusual growths on plants can be caused by many different insects, including wasps and flies. Most internal feeding insects emerge from their feeding structure as adults. Control must be aimed at the immature stage before it enters the plant or at the emerging adult to reduce the population in later generations by reducing the number of females available to lay eggs.

Insects as disease vectors

Many insects pick up plant viruses and bacteria as they feed, and then later transmit diseases to healthy plants. Insects that transmit diseases are known as vectors. They may carry a disease from plant to plant on their body, or transmit the disease through plant injection as they feed. The diseases they carry can result in severe damage or death to plants. Insects can spread plant diseases either directly, via active feeding such as in thrips, aphids and cucumber beetles; or indirectly, when their feeding or boring into plants creates openings through which pathogens — bacteria, fungal spores or viruses — enter the plant. Insects that transmit plant diseases include the bark beetles that move fungi that cause Dutch elm disease, and the aster leafhopper that injects the bacteria that cause aster yellows. Another example is cucumber beetles, which can carry a bacterial disease called bacterial wilt. Cucurbit plants infected with these bacteria are destined to die. In addition to spreading disease to plants, insects can spread diseases to humans. For example, mosquitoes can transmit malaria, dengue and other diseases to humans. To control such diseases, one needs to control the insect vector.

Types of insecticides

Keep in mind that the way an insect pest feeds, which is determined by the type of mouthparts it has, will dictate which insecticide option will be most effective at controlling it. For example, Sevin, a well-known garden pesticide with the active ingredient carbaryl, is formulated as both a dust to sprinkle or spread and a liquid to spray. The dust is a stomach poison that must be ingested to be effective and therefore provides good control against insects with chewing mouthparts. It does not, however, provide control of insects with piercing-sucking mouthparts because they do not chew external plant material and therefore would not ingest the dust. The spray is a contact poison with some residual activity. It kills most insects on contact and does not need to be ingested to be effective. As a spray, Sevin kills insects with piercing-sucking mouthparts as well as others. Another common insecticide is Dipel, which is a microbial insecticide with the active ingredient

Invasive pests: Missouri's ongoing saga with Japanese beetles

In 1934, Japanese beetles (*Popillia japonica*) made it to St. Louis, after being accidentally introduced in the U.S. in 1916. They have since migrated across much of the state, with some areas having extremely high numbers. As of the late 2010s, these beetles are still scarce in north Missouri and Kansas City, but are abundant in the southwest and central areas of the state. For some reason, they don't seem to have become as troublesome in southeast Missouri, despite its favorable weather. In areas with extremely high numbers, the populations may drop and stabilize at lower numbers due to natural controls, as seems to have occurred in St. Louis (see below).

In general, Japanese beetles are considered a nuisance pest. They do not devastate plant communities, as does the emerald ash borer (*Agrilus planipennis*); or challenge cropping systems, as does the hemlock woolly adelgid (*Adelges tsugae*). Plus, unlike the red imported fire ant (*Solenopsis invicta*), humans do not find them difficult to coexist with.

The feeding of the adult beetles is the primary damage associated with this pest. The adults chew on a variety of annuals, including asparagus, green beans, okra, soybeans and zinnias. Their heavy clipping of corn silks will keep the corn from setting kernels. They also feed on rhubarb, grape, raspberry, elderberry and blackberry, some tree fruits and hundreds of ornamental plants and trees. Grapes are such a preferred food that beetles feeding on wild grapes might be an early indicator of their presence. Commercial traps are available and used by farmers of field corn and soybean to determine when to spray their field edges, where the pest can be killed after flying in from adjoining pastures or hay fields.

Grubs, the larvae of the beetles, feed on the roots of corn, beet, beans, asparagus, tomato and onion, as well as many grasses. Japanese beetles overwinter as a partially grown grub in the soil below the frost line. After pupating in the soil, the adult emerges in early summer. Feeding activity lasts four to six weeks. The adults mate after emerging and then lay eggs in the soil, usually in grass, where they hatch in mid- to late summer. Larvae feed on roots until the soil cools in the fall.

Climatic occurrences that harm natural controls will cause the population to rebound. For example, beetle populations have been lower in the years following a severe drought, but have been known to recover their previous numbers.

Several insecticides are labeled for Japanese beetle control, but control is made difficult because of their continued emergence over several weeks. Trapping may attract more beetles than it kills, so unless you are doing mass trapping to reduce numbers, place the traps away from produce and landscaping areas.

St. Louis's Japanese beetle population

In 2016, people in rural central Missouri were distressed by what seemed like a large increase in the numbers of Japanese beetles in the area. Horticulture professionals to the east, where Japanese beetles had been around for a couple of decades, were asked for advice based on their experiences. This telling reply was received from Elizabeth Wahle, a horticulture educator with University of Illinois Extension:

> The St. Louis Metro East experienced the worst of the Japanese beetle front in the early 2000s, particularly in Clinton County where we had a lot of dairy farms. You would be driving along and see this black cloudlike haze, which turned out to be a large group of Japanese beetles. [It was] like being inside a large popcorn popper when driving through [them]. I have not really even thought about Japanese beetles for at least the last eight years. [They] just have not been at levels that have been problematic. Levels have gradually leveled out to where they can be found, but not at devastating levels.

Adapted from *Japanese beetles plagued some parts of rural Missouri in 2016. What's their outlook?* a November 21, 2016, Missouri Produce Growers Bulletin article by Patricia Miller and James Quinn.

Bacillus thuringiensis, or Bt. It also comes in both dust and liquid formulations, but it is not a contact pesticide and must be ingested to provide control in either form. Some contact insecticides work with a physical action, instead of causing a chemical disruption as does Sevin. Insecticides that contain oil or soaps are examples. They can smother an insect by plugging its air supply. Air enters an insect's body through valve-like openings in the exoskeleton. These tiny openings, called spiracles, are located laterally along the thorax and abdomen of most insects — usually one pair of spiracles per body segment. Soaps might also cause the skin of soft-bodied insects to deteriorate, thus causing the insect to dry out. Yet other insecticides are systemic, meaning they can be absorbed by plants and move around in plant tissues. These are sometimes applied as a drench to the soil and then taken up by the roots. Systemic insecticides applied as a drench need to be ingested and can be highly effective on insects with piercing-sucking mouthparts as the insecticide is moving in the plant sap.

Does a cold winter kill off insect pests?

There is a common perception among farmers and gardeners that a hard winter will reduce insects — specifically, some insect pests — the next growing season. This idea may be based on the migration habits of several insect pests, such as corn earworms and sunflower head moths, that migrate to Missouri from southern environments. The thinking is that if the weather were milder in Missouri, these insects could overwinter here and establish earlier. But, is this true? And, if so, is it predictable? Unfortunately, the answers aren't clear.

One might think that relatively warm weather would favor insect survival. However, many factors contribute to insect population dynamics. Spring and summer weather patterns, an abundance of an insect's natural enemies, and crop growth and development each influence insect populations as much as winter weather does. For insects that overwinter above ground, mild winter weather could actually increase death rates due to a lack of insulating snow cover to protect the insects on days when temperatures drop below freezing. In contrast, insects that overwinter below ground — such as Japanese beetle grubs, which can overwinter up to 10 inches deep in the soil — will not likely be affected by a mild winter because soil temperatures are more constant than air temperatures.

Another factor to consider is that insects develop based on the air temperature in their surroundings. A warm winter day could cause some insects, such as woolly bear caterpillars, to become active when they normally should be dormant. This activity uses up stored fats they depend on to survive until spring. And because they won't have access to food during winter, these active insects could starve to death before food does become available.

Even if high winter survival occurs, these insect pests may cause few, if any, significant problems if spring weather is not favorable, natural enemy populations are high, or crop growth isn't favorable. Likewise, a small surviving population could cause damage if conditions are good. Therefore, careful crop scouting for the insect, its damage and its natural enemies is necessary and will remain an important component of an integrated pest management (IPM) program. The University of Missouri maintains a pest-monitoring website, where the most significant insect pest populations and occurrences can be followed, at ***https://ipm.missouri.edu/pestmonitoring***.

Adapted from *What does this warm weather mean for insects?* a March 2012 Missouri Produce Growers Bulletin article by Jaime Piñero.

Integrated pest management

Integrated pest management (IPM) is a science-based decision-making process that identifies and reduces risks from pests and pest management-related strategies. IPM coordinates the use of pest biology, environmental information and available technology to prevent unacceptable levels of pest damage by the most economical means, while minimizing risk to people, property and the environment. IPM provides an effective strategy for managing pests in all arenas, including agricultural, residential and natural areas. Although the concept of IPM was originally developed to combat insect pests, it was subsequently expanded to include all pests.

The pioneers of IPM used the term "integrated" because they recognized that biological control as a stand-alone strategy was rarely economically practical — but when combined with ecologically based tactics, such as cultural control, it could be. IPM assumes a good understanding of the life cycle and behavior of the pest, and the ecological interactions between pests, the ecosystem (for example, crops and livestock in agricultural settings), natural enemies and human decision-making.

The need for IPM was recognized shortly after World War II, when it became apparent that the indiscriminate use of the new synthetic insecticides that were developed by that time, including DDT, would create serious problems. Some of those problems actually became a reality due to the overuse of pesticides:

- Pest resistance — the pesticide no longer kills the pest
- Target pest resurgence — the target pest becomes more abundant than before because pesticides killed its natural enemies
- Secondary pest outbreaks — a secondary pest (that is, a pest that was not targeted) reaches damaging levels after pesticides applied against the target pest kill the secondary pest's natural enemies
- Environmental contamination — chemicals accumulate to levels that can cause damage to a variety of life forms, possibly even humans

Many people now recognize the importance of IPM because it focuses on long-term prevention of pests or their damage through a combination of techniques. These could include biological control, habitat manipulation, modification of cultural practices, and use of resistant crop varieties, leaving the use of pesticides as a last resort. A combination of controls is often more effective than one method by itself. The goal of IPM is to minimize the abundance of insect pests and their damage, not to kill every insect in the treated area. The mere presence of a few insect pests in a garden does not justify the application of insecticides, as they might kill natural enemies that otherwise would control pest populations.

Common goals of IPM and organic agriculture

Integrated pest management and organic agriculture share many of the same goals. Both IPM and organic methods for pest management address environmental and human health concerns. Further, both emphasize pest management based on preventive tactics.

Identifying and monitoring pest insects

Before deciding whether control of an insect is necessary, the pest needs to be correctly identified and its population monitored. As detailed earlier in this chapter, a variety of characteristics can be used to identify an insect, including the length and form of its antennae, and the shape and vein pattern of its wings. The type of plants affected and the damage caused also provide clues to the pest's identity.

Because insects can reproduce rapidly, prompt detection of infestations is crucial. Insect populations can be monitored through scouting or with traps. Both methods provide early warning of pest presence and hot spots. Scouting involves looking closely at your plants for pests and signs of pest damage. When you notice a problem, factors to consider include which plants are affected, how quickly they were affected, their age, and what area of the garden or field they are located in. You also can use traps to detect the present of a pest and monitor its population. Many types of insect traps are available, but yellow sticky cards can be used to monitor many insect pests. Sticky cards provide a relative measure of insect density and indications of whether the pest density is changing or remaining relatively constant over the long term.

IPM control measures

Cultural controls

Cultural controls are preventive and comprise the first line of defense when controlling insects in the garden. The range of cultural controls is wide.

Resistant varieties. Resistant crop varieties have innate resistance or tolerance to attack by certain pests. The degree of resistance can vary from slight to almost complete. Unfortunately, fewer plants are resistant to insects than to diseases. When present, insect resistance often is based on plant morphology. The suppression of leaf hoppers and aphids on beans because of fuzzy or hairy leaf surfaces is an example of natural resistance.

Keeping plants healthy. Proper watering and fertilization regimes and good general care will provide plants the extra edge they need to overcome insect feeding. Healthy trees, for example, are not as easily attacked by wood-boring insects.

Sanitation. Sanitation helps to decrease pest pressure by removing or preventing access to sources of infection or sources of food and shelter. Practices include removing infected crop material from the garden, turning over or burning crop residues, and eliminating unharvested plant material. For example, twigs with insects inside them may fall from an infested tree; these insects can be controlled by simply removing the infected material. Pruning tent caterpillar egg cases from tree limbs removes the insect from the area. Removing unharvested squash eliminates an overwintering site for squash bugs from the garden or farm.

Crop rotation. Growing a single crop year after year in the same area of a garden or farm gives insect pest populations time to become established and build up to damaging levels. Rotating the crop to a different location each year can break this cycle by starving pests that cannot adapt to a different host plant. This practice was originally developed to produce higher yields by replenishing soil nutrients and breaking disease and insect pest cycles. In a garden, for example, crops in the potato family, which includes tomatoes and peppers, should be planted in one area; crops in the cucumber family, which includes squash, zucchini, watermelon, cantaloupe, etc., in another area; and crops in the carrot family in yet another area. Each year, change the area in which you plant each of these crop families. Many gardening books contain specific examples of crop rotations.

Trap cropping. Insects have a preference for certain types of foods just as most animals do. Given a choice, insects will likely select their preferred plant. But if they cannot find their favorite plant in the area, they will feed on the plants that are available. Trap cropping is done by growing plants that are attractive to the insect pest along the edges of a garden or cucurbit field. These attractive plants pull the pest away from the cash crop. Insects congregated on trap crop plants can be more easily killed with insecticides or by other means. For example, Blue Hubbard squash can be used as trap crop to pull squash bugs and cucumber beetles away from the cash crop. Two-week-old Blue Hubbard squash seedlings can be transplanted to the field at the same time you sow the seeds of your cucurbit cash crop. If you grow your cash crop from transplants, then you will need to transplant the Blue Hubbard seedlings at least two weeks before you transplant the cash crop.

Keep invasive insects out of Missouri

As of 2017, the following insect pests had been introduced to Missouri or were a potential threat:

- Asian longhorned beetle
- Brown marmorated stink bug
- Emerald ash borer
- European wood wasp
- Gypsy moth
- Pine shoot beetle

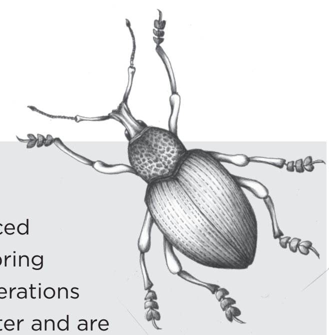
To avoid introducing invasive pests, inspect your vehicle and outdoor equipment for signs of pests when you are returning home from a location where one of these pests lives. Also, do not take firewood from one location to another, even within the state.

Mechanical and physical controls

Mechanical and physical controls either directly remove or kill a pest, make the environment unsuitable for it, or physically block it from reaching its host. Handpicking insects and spraying them off plants with a water hose are two effective mechanical controls. Soil cultivation is a physical control method that kills some pests by burying them and others by exposing them to the soil surface where they face drying conditions and greater potential to become food for birds or other predators. Soil cultivation also buries potential food sources for insect pests and kills weed seedlings. Other methods include trapping insects and subjecting insects to freezing temperatures, for example, by placing food items infested with grain insects in a freezer.

Biological control

The populations of pests' natural enemies can be enhanced by either attracting them to the garden using insectary plants, or buying and releasing predators or parasitoids. The use of insectary plants is much cheaper and sustainable than the second approach. Establishing flowering plants in and around a garden to provide pollen and nectar resources for natural enemies can enhance biological control of insect pests. Beyond providing effective natural pest control, the friendly insects also assist in pollination. For example, the larvae of hover flies are predators of small insects such as aphids, and the adults assist with pollination. Female hover flies need to consume pollen to develop their eggs; therefore, a garden that does not provide pollen due to a lack of flowering plants may have fewer hover flies. Lady beetles can feed on plant nectar if prey is scarce and therefore also can be attracted to gardens with insectary plants. Garden plants that are highly attractive to beneficial insects include sweet alyssum, buckwheat, dwarf sunflower, basil, anise and dill. Perhaps the most important single step toward improving the survival of beneficial insects in a garden is to reduce the use of insecticides.



Boll weevil eradication: An integrated pest management success

The National Boll Weevil Eradication Program ranks close to Eli Whitney's invention of the cotton gin as one of the greatest advancements ever for the U.S. cotton industry. This federal-state-grower cost-share program has helped thousands of U.S. cotton farmers become more competitive and has been a plus for the environment.

History at a glance. In the 1890s, the boll weevil (*Anthonomus grandis*) migrated from Mexico to the U.S. and spread rapidly throughout the Cotton Belt. Since then, it has cost America's cotton producers more than $23 billion, from yield losses and costs to control the insect pest.

A federal research program initiated in the late 1950s demonstrated that the boll weevil could be eradicated by using a combination of traps, well-timed insecticide treatments, and (pest) habitat management.

In the late 1970s, the National Boll Weevil Eradication Program was launched by the U.S. Department of Agriculture along the Virginia–North Carolina border.

The program's success led to financial support from producer groups as well as state and federal sources. As of 2013, the boll weevil had been eradicated from more than 98 percent of the U.S. cotton acreage in 15 southeastern and southwestern states, as well as significant portions of three others. The pest has also been eradicated in several parts of northern Mexico.

How to eliminate the pest in a given area. Boll weevil eradication relies on three main techniques:

- Pheromone traps to detect the weevil's presence
- Cultural practices of modifying habitat to decrease its food supply
- Chemical treatments to reduce weevil populations

In most areas, in addition to the cultural controls, the program begins with a series of treatments in the fall. In subsequent years, traps are placed around all cotton fields in the spring as cotton is planted. Control operations begin about five to six weeks later and are based on trap captures. Continuous, season-long trapping pinpoints areas of infestation and triggers necessary treatments until all weevils are gone. This process usually takes about four to five years in each area.

Benefits to farmers. Farmers benefit from the eradication of boll weevils in two main ways: by eliminating the crop damage and losses caused by the pest, and by significantly reducing the cost of production. Once the weevil is gone from an area, farmers typically see an increase in cotton yield of at least 10 percent — and significantly more in some areas. Moreover, as weevil populations become smaller, insects that prey on other cotton pests rebound. Their presence further reduces the need to use pesticides on cotton crops and brings even more cost savings to the grower. After eradication, the grower's cost of production is significantly lower, yield is often greater, land value increases, and integrated control programs for other cotton pests become much more feasible.

Benefit to the general public. As the weevil and its damage are eliminated from an area, the local cotton industry becomes more stable, and cotton acreage tends to increase. Reduced production costs make cotton more profitable, allowing growers to spend more in the local community for equipment, goods and services. In Georgia, for instance, the economic benefits of boll weevil eradication have been dramatic, with average gross crop revenues increasing from $70 million per year before eradication to $400 million per year afterward. This increased profitability results in stronger rural and, ultimately, statewide economies.

For further information

MU Extension publications

G7185–G7424, entomology guides, ***http://extension.missouri.edu/insects***

Integrated Pest Management publications, ***http://extension.missouri.edu/ipm***

Related reading

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Chemical control

The use of chemicals to control insects is necessary in many situations. For example, termites can infest structures, fleas want to live on our pets, mosquitoes may transmit deadly diseases, grain pests (such as weevils, beetles and moths) can cause vast spoilage, and a range of agricultural plant pests can cause crop failure or yield losses. In antiquity (around 1000 BC), people used naturally occurring compounds in the struggle against pest insects. Inorganic sulfur, via fumigation, was one of these natural chemicals that helped get rid of lice. The use of arsenics, cryolite and borax followed. In the mid-19th century, Colorado potato beetle was controlled with Paris green, which is the common name for copper acetoarsenite. This chemical's use was expanded to control mosquitoes to suppress the spread of malaria. The modern era of synthetic insecticides began with the synthesis of DDT in 1874 and the understanding of its lethality to insects in 1939. While an excellent insecticide, DDT was also dangerous for many other groups of organisms, such as mammals, birds and reptiles. Other chemicals were discovered to be effective insecticides, and by the mid-20th century, three chemical classes were in wide use: organochlorines, carbamates and organophosphates.

Environmental problems developed for several reasons. First, insects developed resistance to several of these insecticides, and a common initial response was to apply increasingly greater amounts. Second, several of the insecticides were extremely stable (that is, they didn't break down) and would accumulate in the environment, including in animal tissues. Fish, reptiles or birds would eat treated insects and then be eaten by predators themselves. These predators, including bald eagles, would further concentrate the active ingredient and suffer devastating consequences, such as thin egg shells. This problem was recognized and brought to light in 1962 by Rachel Carson's impactful book *Silent Spring*, the title of which refers to the silence resulting from the presence of fewer songbirds. This book essentially ushered in the modern environmental movement.

Newer chemical classes that would be less harmful to the environment were sought. The first was the synthetic pyrethroid group, which was based on a naturally occurring compound in chrysanthemums called pyrethrin. By the 1970s, these were in widespread use and several other chemical classes were either developed or being discovered. By 2015, more than 25 chemical classes had been defined as registered insecticides. These newer chemistries are often environmentally safer. Several have been modeled after naturally occurring compounds. The best example is the neonicotinoid group, whose chemistry is based on nicotine, the same compound as in tobacco, which was understood as being harmful to many insects.

Rotating between different chemical classes was determined to be an excellent way to prevent insects from developing resistance to an insecticide. Using different insecticides from the same chemical class is less effective because the insects have often developed genetic resistance to a chemical's mode of action — the way it kills. All chemicals within a class have the same mode of action. Gardeners and others who commonly use insecticides (for example, pet owners) are encouraged to rotate between chemical classes, especially if using the insecticide repeatedly to control the same pest.

Insecticides for home garden use as of 2015

Chemical class	Active ingredients commonly available to gardeners
Carbamates	Carbaryl
Organophosphates	Malathion
Pyrethroids	Bifenthrin, cyhalothrin, permethrin, pyrethrins
Neonicotinoid	Acetamiprid, imidacloprid
Spinosyns	Spinosad

For information about the Missouri Master Pollinator Steward program, go to ***http://extension.missouri.edu/pollinator***.

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