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Issued in furtherance of Cooperative Extension Work, Acts of May 8 and June 30, 1914, in cooperation with the U.S. Department of Agriculture, Donald L. Uchtmann, *Director*, Cooperative Extension Service, University of Illinois at Urbana-Champaign.

Beneficial Insects and Mites

MANY INSECTS AND RELATED ARTHROPODS perform functions that are directly or indirectly beneficial to humans. They pollinate plants, contribute to the decay of organic matter and the cycling of soil nutrients, and attack other insects and mites that are considered to be pests. Only a very small percentage of over one-million known species of insects are pests. Although all the remaining nonpest species might be considered beneficial because they play important roles in the environment, the beneficial insects and mites used in pest management are natural enemies of pest species. A natural enemy may be a predator, a parasitoid, or a competitor.

PREDATORS, PARASITOIDS, AND COMPETITORS

Predators

Predaceous insects and mites function much like other predaceous animals. They consume several-to-many prey over the course of their development, they are free living, and they are usually as big as or bigger than their prey. Some predators, including certain syrphid flies and the common green lacewing, are predaceous only as larvae; other lacewing species, lady beetles, ground beetles, and mantids are predaceous as immatures and adults. Predators may be generalists, feeding on a wide variety of prey, or specialists, feeding on only one or a few related species. Common predators include lady beetles, rove beetles, many ground beetles, lacewings, true bugs such as *Podisus* and *Orius*, syrphid fly larvae, mantids, spiders, and mites such as *Phytoseiulus* and *Amblyseius*.

Parasitoids

Parasitoid means parasitlike. Although parasitoids are similar to true parasites, they differ in important ways. True parasites are generally much smaller than their hosts. As they develop, parasites usually weaken but rarely kill their hosts.

In contrast, many parasitoids are almost the same size as their hosts, and their development always kills the host insect. Although parasitoids are sometimes called parasites or parasitic insects, these terms are not completely accurate. In contrast to predators, parasitoids develop on or within a single host during the course of their development.

The life cycles of parasitoids are quite unusual. In general, an adult parasitoid deposits one or more eggs into or onto the body of a host insect or somewhere in the host's habitat. The larva that hatches from each egg feeds internally or externally on the host's tissues and body fluids, consuming it slowly; 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 of the host's body. The adult parasitoid later emerges from the dead host or from a cocoon nearby. (See Figure 1.)

Most parasitoids are highly host-specific, laying their eggs on or into a single developmental stage of only one or a few closely related host species. They are often described in terms of the host stage(s) within which they develop. For example, there are egg parasitoids, larval parasitoids, larval-pupal parasitoids (eggs are placed on or into the larval stage of the host, and the host pupates before it dies), pupal parasitoids, and a few species that parasitize adult insects.

The vast majority of parasitoids are small-to-minute wasps that do not sting humans or other animals. Certain species of flies and beetles also are parasitoids. *Trichogramma*, *Encarsia*, *Muscidifurax*, *Spalangia*, and *Bracon* are some of the more important parasitoids studied or used in agricultural systems.

Competitors

Competitors are often overlooked in discussions of natural enemies, perhaps because many competitors of common crop pests also are pests

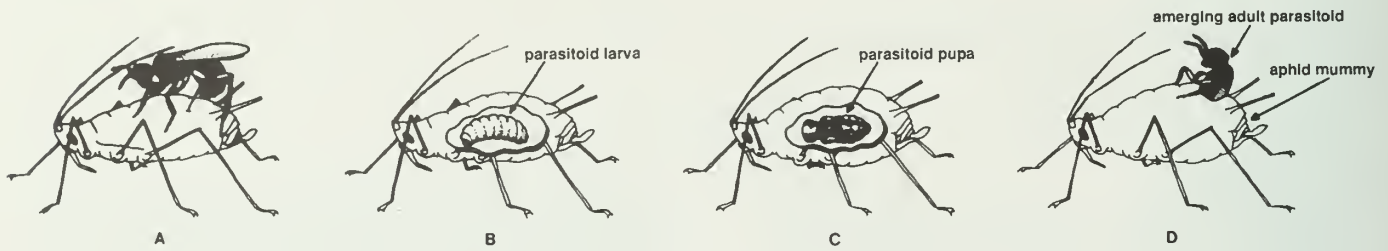


Figure 1. Generalized life cycle of an aphid parasitoid. A) Adult parasitoid wasp injects an egg into a live aphid. B) The parasitoid larva feeds within the aphid; late in the parasitoid's development the aphid dies. C) The parasitoid pupates within the enlarged, dry shell of the dead aphid. D) The new adult parasitoid cuts an exit hole in the back of the aphid and flies away, leaving behind the empty "aphid mummy."

themselves. Competitors can be beneficial, however, in instances where they compete with a nondamaging stage of a pest species. For example, dung beetles in the genera *Onthophagus* and *Aphodius* break up cow pats in pastures as they prepare dung to feed their larvae. This action speeds the drying of dung and makes it less suitable for the development of the larval stages of horn flies, face flies, and other pest flies. Some nonpest flies also develop in pasture dung and compete with pest species for the resources it provides. Despite these and a few other examples, the use of competitors in pest management is not common.

TYPES OF BIOLOGICAL CONTROL

Biological control, sometimes referred to as biocontrol, is the use of predators, parasitoids, competitors, and pathogens to control pests. In biological control, natural enemies are released, managed, or manipulated by humans. Without human intervention, however, natural enemies exert some degree of control on most pest populations. This ongoing, naturally occurring process is termed biotic natural control. Applied biological control produces only a small portion of the total benefits provided by the many natural enemies of pests.

There are three basic approaches to the use of predators, parasitoids, and competitors in insect management. These approaches are (1) **classical biological control**—the importation and establishment of foreign natural enemies; (2) **conservation**—the preservation of naturally occurring beneficials; and (3) **augmentation**—the inundative or inoculative release of natural enemies to increase their existing population levels. Broad definitions of biological control sometimes include the use of *products* of living organisms (such as purified microbial toxins, plant-derived chemicals, pheromones, etc.) for pest

management. Although these products are biological in origin, their use differs considerably from that of traditional biological control agents.

Classical Biological Control

Importing natural enemies from abroad is an important step in pest management in part because many pest insects in the United States and elsewhere were originally introduced from other countries. Accidental introductions of foreign pests have occurred throughout the world as a result of centuries of immigration and trade. Although the foreign origins of a few recently introduced pests such as the Asian tiger mosquito, Russian wheat aphid, and Mediterranean fruit fly are often noted in news stories, many insects long considered to be serious pests in this country are also foreign in origin. Examples of such pests include the gypsy moth, European corn borer, Japanese beetle, several scale insects and aphids, horn fly, face fly, and many stored-product beetles. In their native habitats some of these pests cause little damage because their natural enemies keep them in check. In their new habitats, however, the same set of natural enemies does not exist, and the pests pose more serious problems. Importing and establishing their native natural enemies can help to suppress populations of these pests.

Importation typically begins with the exploration of a pest's native habitat and the collection of one or several species of its natural enemies. These foreign beneficials are held in quarantine and tested to ensure that they themselves will not become pests. They are then reared in laboratory facilities and released in the pest's habitat until one or more species become established. Successfully established beneficials may moderate pest populations permanently and at no additional cost if they are not

eliminated by pesticides or by disruption of essential habitats.

Importation of natural enemies has produced many successes. An early success was the introduction of the Vedalia beetle, *Rodolia cardinalis*, into California in 1889 for the control of cottony cushion scale on citrus. For over 100 years this predaceous lady beetle from Australia has remained an important natural enemy in California citrus groves. In Illinois, populations of *Coccinella septempunctata*, an introduced lady beetle, have become increasingly widespread in recent years. This beetle feeds on a variety of aphids, including such pests as the green peach aphid and the pea aphid. Efforts to introduce and establish natural enemies of several important Midwestern pests are ongoing.

Although the importation of new natural enemies is important to farmers, gardeners, and others who practice pest management, the scope of successful introduction projects (involving considerable expertise, foreign exploration, quarantine, mass rearing, and persistence through many failures) is so great that only government agencies commonly conduct such efforts. Introducing foreign species is not a project for the commercial farmer or home gardener.

Conservation

Conserving natural enemies is often the most important factor in increasing the impact of biological control on pest populations. Conserving or encouraging natural enemies is important because a great number of beneficial species exist naturally and help to regulate pest densities. Among the practices that conserve and favor increases in populations of natural enemies are the following:

(1) **Recognizing beneficial insects.** Learning to distinguish between pests and beneficial insects and mites is the first step in determining whether or not control is necessary. This circular provides general illustrations of several predators and parasitoids. Picture sheets available from the University of Illinois Office of Agricultural Entomology feature common pests of many crops and sites. Insect field guides are useful for general identification of common species (see Borror and White, 1970).

(2) **Minimizing insecticide applications.** Most insecticides kill predators and parasitoids along with pests. In many instances natural enemies are more susceptible than pests to commonly used insecticides. Treating gardens or crops only when pest populations are great enough to cause appreciable damage or when levels exceed established

economic thresholds minimizes unnecessary reductions in populations of beneficial insects.

(3) **Using selective insecticides or using insecticides in a selective manner.** Several insecticides are toxic only to specific pests and are not directly harmful to beneficials. For example, microbial insecticides containing different strains of the bacterium *Bacillus thuringiensis* (Bt), are toxic only to caterpillars, certain beetles, or certain mosquito and black fly larvae. Other microbial insecticides offer varying degrees of selectivity. (See University of Illinois Extension Circular 1295 for more information on microbial insecticides.)

Other insecticides that function as stomach poisons, such as the plant-derived compound ryania, do not directly harm predators or parasitoids because these compounds are toxic only when ingested along with treated foliage. Insecticides that must be applied directly to the target insect or that break down quickly on treated surfaces (such as natural pyrethrins or insecticidal soaps) also kill fewer beneficials. Leaving certain areas unsprayed or altering application methods can also favor survival of beneficials. For example, spraying alternate middles of orchard rows, followed by treating the opposite sides of the trees a few days later, allows survival and dispersal of predatory mites and other natural enemies and helps to maintain their impact on pest populations.

(4) **Maintaining ground covers, standing crops, and crop residues.** Many natural enemies require the protection offered by vegetation to overwinter and survive. Ground covers supply prey, pollen, and nectar (important foods for certain adult predators and parasitoids), and some degree of protection from weather. Most studies show greater numbers of natural enemies in no-till and reduced tillage cropping systems. In addition, some natural enemies migrate from woodlots, fencerows, and other noncrop areas to cultivated fields each spring. Preserving such uncultivated areas contributes to natural biological control.

Maintaining standing crops also favors the survival of natural enemies. Where entire fields of alfalfa are cut, natural enemies must emigrate or perish. Alternate strip cutting (with time for regrowth between the alternate cutting dates) allows dispersal between strips so that natural enemies remain in the field and help to limit later outbreaks of pests.

INSECT METAMORPHOSIS

Understanding biological control requires a general knowledge of insect biology. One of the key features of insect growth and development is the process of metamorphosis.

The insect cuticle (skin) is a rigid or semi-rigid body covering that provides protection and support but limits growth. In order to increase in size or change form, an insect must shed its old skin and replace it with a new one through a process known as molting. Immature insects undergo two to several molts (the number differs among species) that mainly result in increases in size. Once an immature insect is fully grown, it undergoes one or two final molts to become an adult possessing wings and mature reproductive organs. The process of development from immature to adult is known as **metamorphosis** (meaning change in form).

There are two main types of insect metamorphosis, complete and gradual. In **complete metamorphosis**, the change in form from the immature stage (known as a **larva**) to the adult is extreme and occurs abruptly. In most cases larvae differ greatly from adults in both

physical form and life style. Because the massive changes involved in complete metamorphosis cannot be accomplished in a single molt, the fully grown larva molts first to an intermediate stage known as a **pupa**. Wings, reproductive structures, and other adult features begin to develop during the pupal stage. When development is complete and environmental conditions are appropriate, the pupa molts and emerges as an adult. Beetles, flies, lacewings, ants, bees, wasps, butterflies, and moths undergo complete metamorphosis. (See Figure 2a.)

In **gradual metamorphosis**, the change from immature form (in most cases known as a **nymph**) to adult occurs gradually from molt to molt. Nymphs differ from adults mainly in their smaller size and lack of wings and reproductive maturity. Little rearrangement of tissues is required during the last molt from nymph to adult, and there is no pupal stage. Grasshoppers, cockroaches, mantids, true bugs, and aphids are among some of the insects that undergo gradual metamorphosis. (See Figure 2b.)

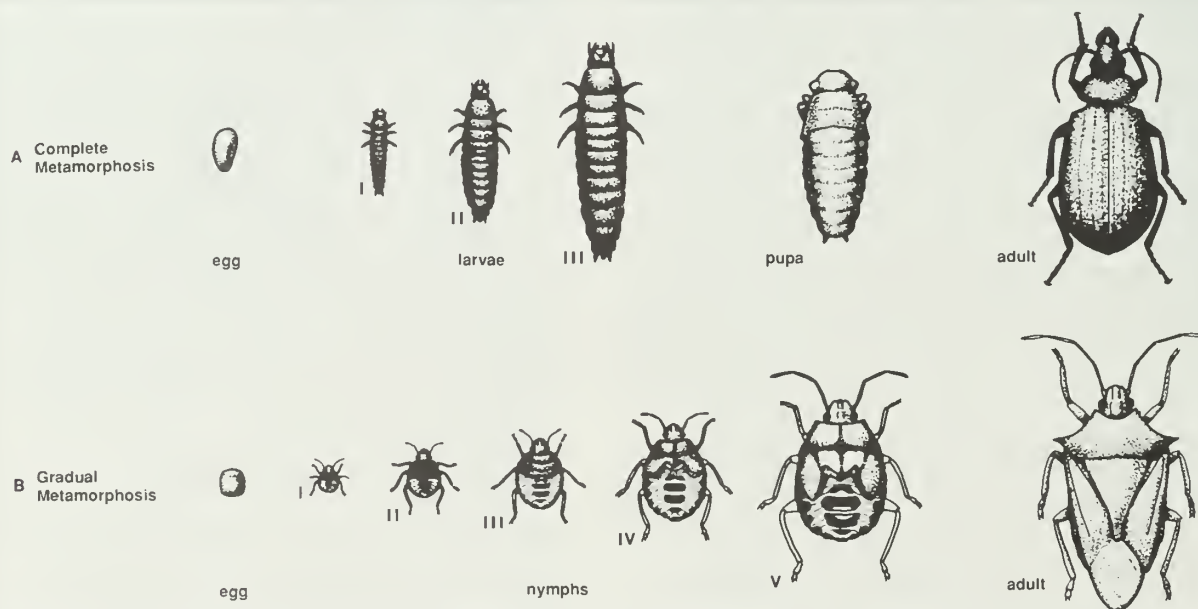


Figure 2. Insect metamorphosis. A) Complete metamorphosis. The ground beetle, *Calosoma scrutator*, passes through four life stages (egg, larva, pupa, and adult) in the course of its development. Larvae are wingless and reproductively immature; in addition, their legs, mouthparts, antennae, eyes, and general body form differ from those of the adult. B) Gradual metamorphosis. The spined soldier bug, *Podisus maculiventris*, passes through three life stages (egg, nymph, and adult). Nymphs have the same form as adults in most respects, differing mainly in their smaller size, winglessness, and reproductive immaturity.

(5) **Providing pollen and nectar sources or other supplemental foods.** Adults of certain parasitic wasps and predators feed on pollen and nectar. Plants with very small flowers (such as some clovers, Queen Anne's lace, and other plants in the family Umbelliferae) are the best nectar sources for small parasitoids and are also suitable for larger predators. Seed mixes of flowering plants intended to attract and nourish beneficial insects are sold at garden centers and through mail order catalogs. Although no published data document the effectiveness of particular commercial mixes, these flower blends probably encourage a variety of natural enemies. The presence of flowering weeds in and around fields may also favor natural enemies.

Artificial food supplements containing yeast, whey proteins, and sugars may attract or concentrate adult lacewings, lady beetles, and syrphid flies. As adults these insects normally feed on pollen, nectar, and honeydew (the sugary, amino acid-rich secretions from aphids or scale insects), and they may require these foods for egg production. Lady beetles are predaceous as adults, but some species eat pollen and nectar when aphids or other suitable prey are unavailable. The proteins and sugars in artificial foods provide enough nutrients for some species to produce eggs in the absence of abundant prey. Wheast®, BugPro®, and Bug Chow® are a few of the artificial foods available from suppliers of natural enemies.

The practices listed above must be judged according to their impacts on pest populations as well as their effects on natural enemies. Practices that favor natural enemies may or may not lessen overall pest loads or result in acceptable yields. For example, reduced tillage favors beneficials but also contributes to infestations of such pests as the common stalk borer and European corn borer in corn. Moreover, tillage decisions may be influenced more by soil erosion and crop performance concerns than by impacts on pests or natural enemies. Flower blends and flowering weeds can serve as nectar sources for moths (the adult forms of cutworms, armyworms, and other caterpillar pests) as well as beneficials. The ultimate goal of conserving natural enemies is to limit pest problems and damage to

crops, rather than simply to increase numbers of predators or parasitoids. Pest densities and crop performance are factors that must be included in any evaluation of the effectiveness of natural enemy conservation efforts.

Augmentation

Augmentation involves releasing natural enemies into areas where they are absent or exist at densities too low to provide effective levels of biological control. The beneficial insects or mites used in such releases are usually purchased from a commercial insectary (insect rearing facility) and shipped in an inactive stage (eggs, pupae, or chilled adults) ready for placement into the habitat of the target pest. Augmentation is broadly divided into two categories, inoculative releases and inundative releases.

Inoculative releases involve relatively low numbers of natural enemies, and are intended to inoculate or "seed" an area with beneficial insects that will reproduce. As the natural enemies increase in number, they suppress pest populations for an extended period. They may limit pest populations over an entire season (or longer) or until climatic conditions or a lack of prey results in population collapse. Generally only one or two inoculative releases are made in a single season.

In contrast, inundative releases involve large numbers of natural enemies that are intended to overwhelm and rapidly reduce pest populations. Such releases may or may not result in season-long establishment of natural enemies in the release area. Inundative releases that do not result in season-long establishment are the most expensive way to employ natural enemies because the costs of rearing and transporting large numbers of insects produce only short-term benefits. Such releases are usually most appropriate against pests that undergo only one or two generations per year.

The distinction between inoculative and inundative releases is not absolute. Many programs attempt to blend long-term establishment with short-term results. In addition, conservation and augmentation may be used together in a variety of ways to produce the best results.

SOME BASIC PRINCIPLES OF BIOLOGICAL CONTROL

The actions of natural enemies can be manipulated by the timing and magnitude of releases and by habitat management. Unlike insecticides, however, natural enemies are living organisms with biological needs and behavioral traits that may conflict with the goals or constraints of pest management programs. Success with natural enemies depends on understanding and accommodating their biological and evolutionary limitations.

Natural Enemies Survive Better in Stable Environments

Many pests colonize annual crops or temporary habitats rapidly. In contrast, most natural enemies colonize such habitats slowly. Where crop residues are frequently removed and soil is disturbed by tillage, or where insects are nearly eliminated by the use of insecticides, the rebuilding of natural enemy populations tends to lag behind the regrowth of pest populations. Consequently, naturally occurring predators and parasitoids are more prevalent and more easily maintained in perennial crops (such as alfalfa, pasture grasses, and orchard crops) than annual crops.

Providing a more stable environment by using reduced tillage, ground covers, or strip harvesting contributes to the survival of a range of natural enemies, both naturally occurring and introduced. These practices may also favor certain pests, however, and each must be evaluated according to its overall benefits and drawbacks.

Natural Enemies Usually Leave a Moderate Pest Residue

As natural enemies reduce pest population densities, it becomes increasingly difficult for them to locate and attack the few surviving pests. When pest population densities become too low, natural enemies often leave the pest residue (the remaining pest population) and disperse in search of more abundant hosts or prey. In the absence of predators or parasitoids, the remaining pest population

rebuilds, providing hosts or prey for subsequent generations of natural enemies. This cycling of populations allows the natural enemies and their hosts to avoid extinction. Exceptions to this rule occur in greenhouses, for example, where natural enemies are confined with their hosts or prey and cannot disperse when pest population densities fall.

The occurrence of moderate pest residues may or may not limit the use of biological control. Where nearly 100 percent control is necessary, natural enemies alone usually do not provide sufficient control. This is the case with certain pests of commercial fruits and vegetables, cut flowers, ornamentals, and other commodities for which current cosmetic or grade standards are very strict. In many situations, however, moderate levels of pest infestation are acceptable. This is true for most pests of gardens, lawns, and field crops. In these settings natural enemies may provide acceptable levels of control.

Control by Natural Enemies Takes Time

Unlike insecticides, which are uniformly applied and have nearly immediate effects on pest populations, natural enemies require time to disperse from release sites, search for hosts or prey, and handle (consume or lay eggs into) each host or prey individually. In some cases, the natural enemies that are released must reproduce before a significant degree of control occurs. Consequently, where commodities must be rapidly disinfested or protected from a pest that is already causing serious losses, predators and parasitoids do not (or only rarely) provide sufficiently rapid control.

Determining the correct timing for releases is one of the most important steps in the implementation of biological control. Because natural enemies do not provide immediate control, they usually must be released before severe damage is imminent. Preventive releases, however, are almost never appropriate or effective because natural enemies die or disperse in the absence of hosts or prey. In

general, releases should begin when pest populations are substantial enough to sustain the natural enemy but low enough to allow the natural enemy time to catch up and provide an adequate degree of control. Knowledge of pest development and careful monitoring of pest populations are key factors in determining when to make releases.

Natural Enemies Are Products of Evolution, Not Manufacturing

In evolutionary terms, the success of a natural enemy is defined by its ability to survive as a species. This survival depends on the continued availability of the natural enemy's host or prey. In pest management terms, however, the success of a natural enemy is defined by the degree to which it controls its host or prey. Where high levels of control are required, naturally selected behaviors that result in moderate pest residues and guarantee species survival may prevent predators and parasitoids from "succeeding" in pest management terms. Rearing and releasing greater numbers of natural enemies does not always overcome these limitations.

Traits such as host or prey preferences, host finding behaviors, dispersal thresholds, climatic dependencies, habitat preferences, and sensitivity to insecticides are genetically determined. Some of these traits--climatic tolerances and insecticide resistance, in particular--can be manipulated through selective breeding. In addition, some trait selection may occur unintentionally during mass rearing. Continuous rearing of natural enemies in insectaries can select for undesirable traits such as a preference for hosts other than the target pests or a lack of vigor under field conditions. Many traits, however, are difficult to alter and must be accommodated when developing biological control programs.

Rearing and releasing natural enemies is much more complicated than spraying an insecticide. Consequently, attempts to use natural enemies without understanding their behavior often result in failure and disappointment. However, when natural enemies are used in ways that accommodate their strengths and weaknesses, they can become effective components of integrated pest management programs.

INSECTS AND MITES AVAILABLE FOR PURCHASE AND RELEASE: A SELECTED LIST

The beneficial insects and mites discussed below may be purchased from insectaries or gardening and farming supply outlets. *Suppliers of Beneficial Organisms in North America*, a booklet available from the California Department of Food and Agriculture (see References), contains a list of suppliers.

Predators

The convergent lady beetle, *Hippodamia convergens*

The convergent lady beetle is one of the best known of all insect natural enemies. The adult beetle has orange wing covers, usually with 6 small black spots on each side. The beetle's pronotum (the shieldlike plate often mistaken for the head) is black with white margins and two diagonal white dashes. These "convergent" dashes give this lady beetle its common name. The immature convergent lady beetle is a soft-bodied, alligator-shaped larva. It is grey and orange and is covered with rows of raised black spots (Figure 3).

Larval and adult convergent lady beetles feed primarily on aphids. Where aphids are not available, they may feed on scale insects, other small, soft-bodied insect larvae, insect eggs, and mites. Adults also feed occasionally on nectar, pollen, and honeydew (the sugary secretions of aphids, scales, and other sucking insects). Development from egg to adult takes 2 to 3 weeks, and adults live for several weeks to several months, depending on location and time of year.

The convergent lady beetle occurs naturally throughout much of North America. In the Midwest adult beetles overwinter in small groups beneath bark or in other protected sites. In California, adult beetles overwinter in huge aggregations in the foothills of the central and southern

mountain ranges. These California beetles are harvested from their overwintering sites, stored at cool temperatures to maintain their dormant state, and shipped to customers in the spring and summer for release in gardens or crops.

A common problem that limits the usefulness of convergent lady beetles is that they fly away soon after being released. In California, when convergent lady beetles emerge from their overwintering sites in the foothills, they disperse, seeking feeding and reproduction sites where aphids or some other suitable prey are abundant. Convergent lady beetles harvested in California and released in Midwest gardens retain this natural tendency to disperse, making them poorly suited for small-scale releases. Field-scale or community-wide releases of convergent lady beetles for control of heavy aphid outbreaks are likely to be more useful than backyard garden releases for control of minor pest problems.

Convergent lady beetles provide long-term, adequate aphid control in a release area only if they reproduce. Several factors influence reproduction. Adult female beetles harvested from overwintering sites cannot produce eggs until they have fed on prey. In addition, they lay their eggs only where prey are abundant enough to sustain the resulting larvae. Because adults are able to fly, they tend to disperse in search of more abundant prey when aphid populations fall below a critical threshold. If they disperse without laying eggs, the aphids that are left behind may build up to damaging levels. If the lady beetles lay eggs before dispersing, the resulting larvae continue to control aphids when the adults are gone. Larvae provide better aphid control than adults because they cannot fly away when aphid populations are low.

Despite problems with dispersal, the convergent lady beetle is widely advertised in gardening supply catalogs for small-scale releases. Suppliers recommend release rates ranging from 1 pint to 1 quart of beetles per home garden, and from 1 gallon of beetles per acre to 1 gallon per 15 acres for field scale releases. The basis for these release rates is unclear.

Making releases at dusk (lady beetles do not fly at night) and watering the release site so that plenty of moisture is available may increase the chances that the lady beetles will remain in the area. Some distributors recommend spraying the beetles with a dilute soft drink solution to glue their wing covers down temporarily (to prevent flying), or providing the beetles with artificial foods such as Bug Chow®, BugPro®, or Wheast®. Whether

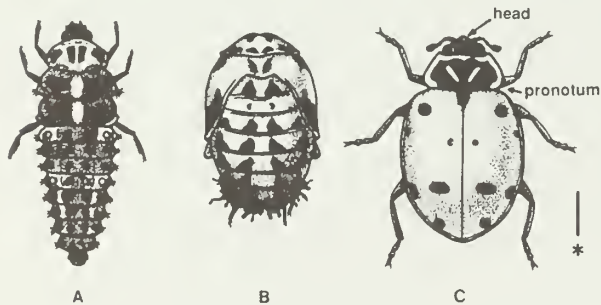


Figure 3. The convergent lady beetle, *Hippodamia convergens*. A) Larva. B) Pupa. C) Adult.

*Actual insect size.

or not these approaches help to keep lady beetles near the site of release is not clear.

The Mealybug Destroyer, *Cryptolaemus montrouzieri*

The mealybug destroyer is an Australian lady beetle. The adult is a small (about 4 mm), round, black beetle with an orange pronotum and orange wing tips. The larva is covered with a shaggy, white, waxy material, and resembles its mealybug hosts when small (Figure 4). As its common name implies, the mealybug destroyer feeds on all species of above-ground mealybugs including the citrus mealybug (*Planococcus citri*), which is a serious pest of ornamental plants in greenhouses and interior plantscapes. If mealybugs are not available, the mealybug destroyer may feed on aphids and immature scale insects. Both larvae and adults are predaceous.

Adult mealybug destroyers lay several hundred eggs, depositing them singly in mealybug egg masses. Each beetle larva may consume more than 250 immature mealybugs in the course of its development. The mealybug destroyer requires high mealybug populations and optimum environmental conditions in order to reproduce and is most effective when used for quick reductions of heavy mealybug infestations.

Development and reproduction of the mealybug destroyer occur most rapidly at temperatures between 22° and 25°C (72° and 77°F), and relative humidities of 70-80%. Temperatures below 20°C (68°F) and short days slow the reproductive rate of this predator but do not have as much effect on mealybug reproductive rates. As a result, the mealybug destroyer is often unable to control mealybug infestations during winter months in greenhouses or other facilities where temperature and daylength are reduced.

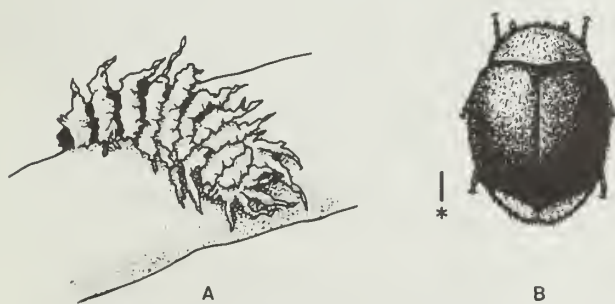


Figure 4. The mealybug destroyer, *Cryptolaemus montrouzieri*. A) Larva. B) Adult.

Suppliers recommend releases of 1 beetle per 2 square feet of planted area or 2 to 5 beetles per infested plant. Mealybug populations should not be reduced insecticidally prior to beetle releases. Although the mealybug destroyer is widely advertised, supplies are often limited due to difficulties in maintaining colonies.

The Green Lacewings, *Chrysoperla* (formerly *Chrysopa*) *carnea* and *Chrysoperla rufilabris*

Green lacewings occur naturally throughout North America and are widely available for purchase and release. Adult green lacewings have delicate, light green bodies, large, clear wings, and bright golden or copper-colored eyes. The larvae are small, greyish brown, and elongate and have pincerlike mandibles. Green lacewing eggs are found on plant stems and foliage. They are laid singly or in small groups on top of fine, silken stalks which reduce predation and parasitism by keeping the eggs out of reach (Figure 5).

Green lacewing larvae are generalist predators of soft-bodied insects, mites, and insect eggs, but they feed primarily on aphids and are commonly known as "aphid lions." Lacewing larvae are also cannibalistic, feeding readily on other lacewing eggs and larvae if prey populations are low. Larvae feed for about 3 weeks before pupating inside silken cocoons that are usually attached to the undersides of leaves.

Although adults of some lacewing species are predaceous, *Chrysoperla carnea* adults feed only on nectar, pollen, and aphid honeydew. *Chrysoperla carnea* females cannot produce eggs if these foods are not available. Green lacewing adults make long dispersal flights soon after emerging from the pupal stage; this dispersal takes place regardless of whether or not ample food is present when the

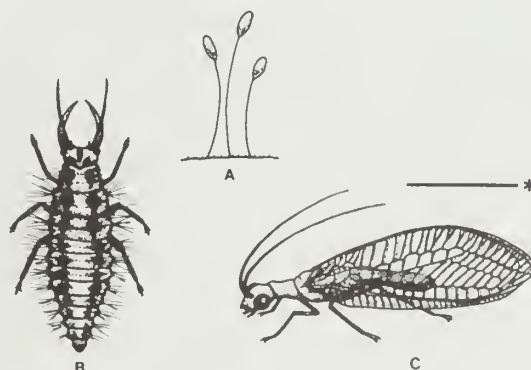


Figure 5. The common green lacewing, *Chrysoperla carnea*. A) Eggs. B) Larva, commonly known as an "aphid lion." C) Adult.

adults emerge. Lacewings are night fliers and may travel many miles before mating and starting to produce eggs. Females are mobile throughout their egg-laying period, although they concentrate where nectar and honeydew are abundant. They tend to lay eggs wherever they land to feed or rest.

Artificial foods, such as Bug Chow®, BugPro®, or Wheast®, can be used in place of natural foods (nectar and honeydew) to attract and concentrate adult lacewings. The presence of artificial foods does not keep newly emerged adults from dispersing, but such foods may attract older adults that are in the area. Food sprays are useful only when a substantial population of lacewings is present in the area.

Lacewings are usually purchased as eggs. They are shipped in a mixture of rice hulls and frozen (killed) caterpillar eggs. The caterpillar eggs provide food for the larvae that hatch during shipment, and the rice hulls keep the larvae separated to minimize cannibalism. Lacewings shipped in this manner are meant to be released as soon as hatching begins. Some insectaries offer lacewing eggs in sufficient quantities for aerial application to fields or orchards.

For small-scale gardens, suppliers recommend release rates of 1 to 5 lacewing eggs per square foot of garden space. For field crop or orchard releases, recommendations range from 50,000 to 200,000 lacewing eggs per acre. Releases are made singly or sequentially at 2-week intervals, depending on the pest to be controlled. In field trials for control of various caterpillar and aphid pests in cotton, corn, and apples, lacewing releases at these rates have provided high levels of control and significant increases in yields in some cases. However, the costs of purchasing and releasing such high numbers of lacewing eggs may be prohibitive for commercial use.

Lacewing larvae are naturally tolerant of low rates of several insecticides, including azinphos-methyl (Guthion), dimethoate (Cygon), trichlorfon (Dylox), carbaryl (Sevin), permethrin, pyrethrin, rotenone, and ryania. Larvae are highly susceptible to many other insecticides, however, and adults tend to be more susceptible than larvae in all cases.

Chrysoperla carnea, the common green lacewing, is the most widely available lacewing species. It is sold for general field and garden releases. *Chrysoperla rufilabris* is an eastern lacewing species that is better adapted for use in tree crops. *Chrysoperla rufilabris* adults are predaceous to a limited extent.

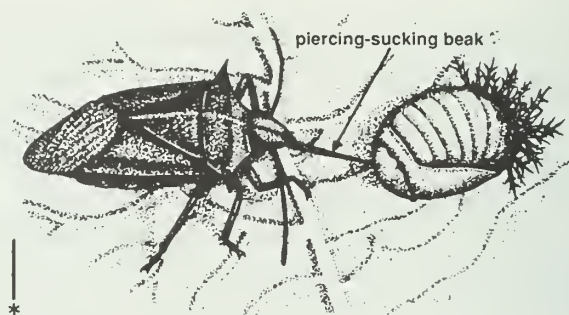


Figure 6. An adult spined soldier bug, *Podisus maculiventris*, feeding on a Mexican bean beetle pupa.

The Spined Soldier Bug, *Podisus maculiventris*

The spined soldier bug is the only predaceous "true bug" (Order Hemiptera) available for purchase. It occurs naturally throughout the Midwest and is one of the most common predatory stink bugs throughout much of the country. The adult spined soldier bug is greyish brown with sharply pointed "corners" on its pronotum. Nymphal soldier bugs are various shades of orange with black markings. They are round bodied and wingless. Nymphs and adults stab their prey with long, pointed "beaks" that are held folded under their bodies while not feeding. (See Figures 1b and 6.)

Although the spined soldier bug is sold mainly as a predator of Mexican bean beetle (*Epilachna varivestis*) larvae, it is a generalist that feeds readily on many soft-bodied insects and larvae. Spined soldier bug nymphs and adults feed on the same kinds of prey, and if ample prey is available these predators may provide some degree of control for several weeks after the initial release (they are sold as nymphs). At this time there are no adequate guidelines for release rates.

Praying Mantids

Although several mantid species occur naturally in the southern U.S., many of the species found commonly in the Midwest were originally introduced from the tropics. In the fall, adult female mantids produce egg cases that may contain up to two hundred eggs. These eggs remain dormant until early summer when tiny mantid nymphs hatch and begin to search for prey. Only one generation of mantids develops each year.

Mantid nymphs and adults are indiscriminate generalist predators that feed readily on a wide variety of insects, including many beneficial insects



Figure 7. The Chinese praying mantid, *Tenodera aridifolia sinensis*. A) Egg case with newly hatched nymphs. B) Adult.

and other mantids. Older mantids feed on medium-sized insects such as flies, honey bees, crickets, and moths. They are not effective predators on aphids, mites, or most caterpillars. Most of the mantids that hatch from an egg case die as young nymphs as a result of starvation, predation, or cannibalism. In addition, mantids are territorial, and by the end of the summer often only one adult is left in the vicinity of the original egg case.

Although mantids are fascinating to watch in action, they are nearly useless for pest control in home gardens because of their indiscriminate appetites and poor survival rate. Nevertheless, they are widely advertised for sale to home gardeners. Mantids are sold as egg cases, and prices vary greatly from one supplier to the next. The Chinese praying mantid, *Tenodera aridifolia sinensis*, is the species that is most commonly available for purchase. (See Figure 7.)

The Predatory Mites, *Phytoseiulus persimilis* and Other Species

Predators of twospotted spider mites. Mites in the genera *Phytoseiulus* and *Amblyseius* are fast-moving, pear-shaped predators with short life cycles (from 7 to 17 days, depending on temperature and humidity) and high reproductive capacities. They are pale to reddish in color and can be distinguished from twospotted spider mites by their long legs, lack of spots, and rapid movement when disturbed. The eggs of predatory mites are elliptical and larger than the spherical eggs of spider mites (see Figure 8). Predatory mite nymphs feed on spider mite eggs, larvae, and nymphs. Adult predators feed on all developmental stages of spider mites.

Several species of predatory mites are sold by U.S. distributors, but the only species that has been studied extensively for use on a commercial scale is

Phytoseiulus persimilis. This mite develops, reproduces, and preys on spider mites most effectively in a temperature range of 21° to 27°C (70-80°F), with relative humidities of 60-90%. Above and below these ranges, *Phytoseiulus persimilis* is less able to bring twospotted spider mite populations under control.

Most of the scientific literature on the use of *Phytoseiulus persimilis* in greenhouses deals with commercial production of tomatoes and cucumbers in Great Britain and the Netherlands. Evaluating European research results and biological control programs for use in U.S. greenhouses is difficult. In the U.S., many greenhouses are used to produce flowers or ornamental plants rather than vegetables. The degree of spider mite control needed for ornamentals is generally much higher than it is for vegetables. In addition, production practices in U.S. greenhouses differ from those in Europe. (See Osborne et al., 1985).

In the U.S., insectaries generally recommend releasing *Phytoseiulus persimilis* when there are 1 or fewer spider mites per leaf throughout a greenhouse. If spider mite populations exceed that level, application of an insecticidal soap or other nonresidual insecticide is recommended to reduce the infestation before the predatory mites are released. Some insectaries recommend spot introductions to control patchy spider mite infestations, while others recommend systematic uniform introductions. The best method depends on the distribution of the twospotted spider mite. Release rate recommendations range from 2 to 30 *Phytoseiulus persimilis* per plant, depending on the stage and susceptibility of the crop. Some experimentation may be necessary to determine the appropriate release rate and method for specific situations. (See Table 1 for further information.)

In Europe, twospotted spider mites are often introduced intentionally to greenhouse crops at a low, even rate soon after planting; this is followed some days later by a uniform release of *Phytoseiulus persimilis*. This "pest-in-first" method allows the predatory mites to become established throughout the greenhouse before natural spider mite outbreaks occur in isolated spots. Another alternative is to introduce spider mites and *Phytoseiulus persimilis* simultaneously at the start of the growing season. These techniques have been more consistently successful than attempts to introduce the predatory mite only after natural infestations have been detected.

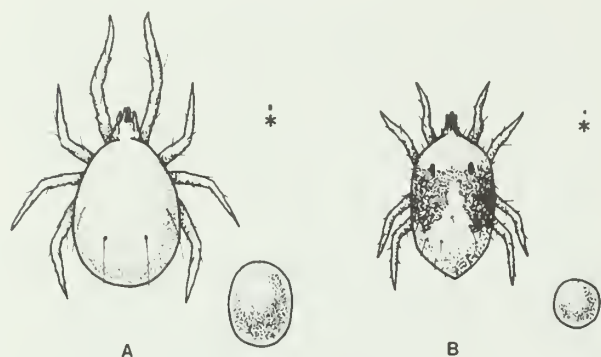


Figure 8. A) A predatory mite, *Phytoseiulus persimilis*, adult and egg. B) The twospotted spider mite, *Tetranychus urticae*, adult and egg.

Phytoseiulus longipes and *Amblyseius californicus* are also sold in the U.S. for control of twospotted spider mites. *Phytoseiulus longipes*, an African species, tolerates temperatures up to 38°C (100°F) if humidity is high; it can tolerate low relative humidities (down to 40%) at 21°C (70°F). *Amblyseius californicus* occurs naturally in California, the Mediterranean, and several other regions of the world. It is an important predator of pest mites in California strawberry fields and is used extensively for greenhouse releases. *Amblyseius californicus* also tolerates higher temperatures (up to 32°C/90°F). It consumes mites at a slower rate than *Phytoseiulus* species, but is able to tolerate short periods of starvation when spider mite densities are low. Mixed releases of *Phytoseiulus persimilis* and *Amblyseius californicus* function well in greenhouses where conditions and pest mite population densities are variable.

Thrips predators. In addition to spider mite predators, two species of predatory mites feed primarily on thrips. *Amblyseius cucumeris* and *Amblyseius mckenziei* (also known as *Amblyseius barkeri*) feed on the western flower thrips (*Frankliniella occidentalis*) and the onion thrips (*Thrips tabaci*), both of which may be serious pests in greenhouses. If introduced early in an infestation, these mites can eliminate thrips populations in greenhouses.

Amblyseius cucumeris and *Amblyseius mckenziei* can subsist for short periods on pollen, fungi, or spider mite eggs when thrips are not available. These mites require high relative humidities and are not tolerant of insecticides. Short days inhibit egg production by predatory mites, making thrips control difficult during winter months.

U.S. suppliers recommend high release rates of *Amblyseius cucumeris* and *Amblyseius mckenziei* for control of thrips. For control of *Thrips tabaci* on

sweet peppers, suppliers recommend releasing 10 predatory mites per plant plus an extra 25 mites per infested leaf throughout the greenhouse. For cucumbers, the recommended rate is 50 predatory mites per plant plus an extra 100 per infested leaf. For both crops, distributors recommend that introductions be made weekly until there is 1 predatory mite for every 2 thrips. The efficacy of these release rates is difficult to evaluate because very little published research on *Amblyseius cucumeris* or *Amblyseius mckenziei* exists. Literature from Europe indicates that control may be possible with lower release rates.

PARASITOIDS

Encarsia formosa, A Parasitoid of the Greenhouse Whitefly

Encarsia formosa, a tiny parasitic wasp, has been used to control greenhouse whiteflies on tomatoes and cucumbers in Europe for over fifty years. *Encarsia* adults lay their eggs into the scalelike third and fourth nymphal stages of whiteflies (see Figure 9a). Parasitized whitefly nymphs blacken and die as the parasitoid larva develops inside. Adult wasps provide additional whitefly control by feeding directly on early and late nymphal stages.

Encarsia performs best when greenhouse temperatures are maintained between 21 and 26°C (70 and 80°F), with relative humidities of 50-70%. In these conditions, *Encarsia* reproduces much faster than the whitefly. At lower temperatures the whitefly reproduces more rapidly than the parasitoid, and *Encarsia* may not provide adequate control. In addition, *Encarsia* requires bright light for optimum reproduction and development. This dependence on light intensity further limits the parasitoid's effectiveness during winter months when daylength is shorter and light intensities are lower.

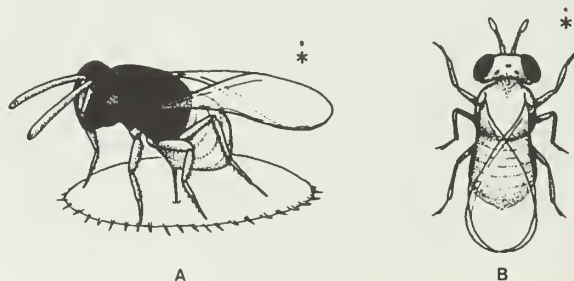


Figure 9. A) An adult female *Encarsia formosa* depositing an egg into the scalelike fourth nymphal stage of the greenhouse whitefly. B) An adult *Trichogramma* wasp.

Numerous release schedules have been developed for *Encarsia*. As with predatory mites, most of the research and practical information on *Encarsia* has come from Great Britain and the Netherlands and involves commercial tomato and cucumber production. In these countries the "pest-in-first" method (introducing the pest at low levels before releasing the natural enemy) is commonly used for whitefly control. Where this approach is not used, *Encarsia* must be released at the very first sign of whitefly infestation. As with releases of predatory mites for spider mite control, the degree of whitefly control provided by *Encarsia* is not likely to be sufficient for production of commercial ornamentals.

Most U.S. *Encarsia* suppliers recommend that releases be made when there is an average of less than 1 adult whitefly per upper leaf (regardless of plant species) on all plants throughout the greenhouse. Introductions should be made sequentially (usually at 2-week intervals) for several weeks in order to control immature whiteflies as they hatch. Release rates range from 1 to 5 wasps per square foot or from 1 to 8 per plant, depending on plant species and the severity of the infestation. Evidence of parasitism by *Encarsia* (presence of blackened whitefly scales) becomes apparent 2 to 3 weeks after the initial release, and whitefly populations are usually reduced to low levels within 2 to 3 months. After *Encarsia* has become established in a greenhouse, it continues to reproduce and control whitefly populations as long as conditions are favorable and the whitefly is present. (See Table 1 for further information.)

***Trichogramma* Wasps, Egg Parasitoids**

The *Trichogramma* wasps are the most commonly used parasitoids worldwide. They are released extensively in Europe and Asia for the control of many species of caterpillar pests in various crops. *Trichogramma* wasps are extremely small, averaging about 0.7 mm in length as adults (the size of the period at the end of this sentence; see Figure 9b).

Most *Trichogramma* species lay their eggs into the eggs of moths and butterflies. A few species parasitize eggs of other kinds of insects. *Trichogramma* larvae develop within host eggs, killing the host embryos in the process. Instead of a caterpillar hatching from a parasitized egg, one or more adult *Trichogramma* wasps emerge. Because the caterpillar pests are killed in the egg stage, no feeding damage occurs. This makes *Trichogramma* an especially important natural enemy for control of pests such as codling moth larvae, European corn borers, and

corn earworms, all of which bore into plant tissues and cause economic damage soon after hatching.

There are many species of *Trichogramma*, and each prefers different hosts. Although several *Trichogramma* species are generalist parasitoids, many parasitize only one or a few related species. Three species are commonly available for purchase and release in the U.S. *Trichogramma pretiosum*, sold for control of caterpillar pests in field crops, vegetables, and stored grain, is capable of parasitizing over 200 species of caterpillar eggs (although it is not equally effective against all of those species). *Trichogramma minutum* is sold for control of orchard and forest caterpillars. The third species, *Trichogramma platneri*, parasitizes a caterpillar pest of avocados and is not useful in the Midwest. *Trichogramma nubilale*, a species currently under research, shows promise as an effective parasitoid of the European corn borer; it is not yet available for purchase.

Success with *Trichogramma* is extremely variable. In research trials, it has been used in single or sequential releases at rates of 50,000-300,000 wasps per acre per release. *Trichogramma* wasps are usually released as mature pupae inside host eggs. Adult wasps emerge within 1 to 3 days of release and are active for about 9 days. If a mixture of larval-stage and pupal-stage parasitoids is released, activity is extended by several days. Releases are usually timed to correspond with the start of egg laying by the pest, as determined by pheromone trapping or other monitoring methods. (See Table 1.)

The size and host-finding ability of *Trichogramma* wasps are partially dependent on the species of host egg within which the wasps are reared. Most insectaries rear *Trichogramma* in the eggs of the Angoumois grain moth, *Sitotroga cerealella*, because this moth is easy to rear inexpensively in large numbers. Angoumois grain moth eggs are very small, however, and the resulting parasitoids may also be small and not well suited to locating and parasitizing eggs of other target pest species when released in the field. Locally collected species or strains of *Trichogramma* reared on the intended target host are more likely to be successful for field releases than exotic species; however, rearing facilities do not provide customized regional production.

Filth Fly Parasitoids, *Muscidifurax* and *Spalangia* Species

Most parasitoids sold for use in the biological control of filth flies around livestock and poultry are wasps in the genera *Muscidifurax* and *Spalangia*.

Adult wasps in these genera are less than 2.5 mm long. They deposit their eggs in or on fly pupae located in manure or other breeding sites. These wasps parasitize both house fly and stable fly pupae, but different species exhibit different host or habitat preferences.

Studies of the effectiveness of releasing parasitoids for fly control have produced mixed results, and the use of parasitoids for the control of filth flies must be considered somewhat experimental. Nonetheless, several key findings can serve as guidelines for release programs.

The parasitoid species most likely to contribute to the control of house flies in cattle feedlots are *Muscidifurax raptor* and *Muscidifurax zaraptor*. For the control of stable flies in feedlots, *Spalangia nigroaenea* and *Spalangia cameroni* are most likely to provide benefits. (These two *Spalangia* species also parasitize house flies, but not as frequently as the *Muscidifurax* species.) Two commonly sold parasitoids are very unlikely to provide any benefit in feedlots; neither *Nasonia vitripennis* nor *Spalangia endius* parasitized a significant percentage of house flies or stable flies when released in large numbers in studies conducted in Midwest (Kansas and Nebraska) feedlots. Because these two parasitoids are distributed by several companies but are unlikely to provide any significant fly control in feedlots, cattle producers are cautioned not to purchase "generic" fly parasitoids that are not identified by species.

Available data indicate that release rates recommended by suppliers of fly parasitoids are probably too low to provide much fly control in feedlots. Although suppliers often recommend weekly releases of 5 to 20 parasitoids per animal, significant control of stable flies requires releases of 50 to 100 *Spalangia nigroaenea* or *Spalangia cameroni* per animal per week. Simultaneous weekly releases of 50 to 100 *Muscidifurax raptor* or *Muscidifurax zaraptor* per animal are necessary for house fly control. Although these release rates exceed the recommendations of most suppliers, they still can be economically feasible.

Parasitoids can be used effectively for house fly control in poultry facilities, especially those with concrete floors. *Muscidifurax raptor*, *Muscidifurax zaraptor*, *Spalangia cameroni*, *Spalangia nigroaenea*, and *Spalangia endius* parasitize house fly pupae in poultry buildings. *Pachycrepoideus vindemiae*, also shown to be useful in poultry buildings, is available from some insectaries. Release rates for the use of these parasitoids in poultry depend upon house

construction and manure management, but a general recommendation is the weekly release of 1 parasitoid per 2 birds. Practices that minimize moisture problems (fixing leaks and improving drainage) help to lower the moisture content of manure accumulations and contribute to parasitoid buildup and fly control. Removing only a portion of the manure (for example, under alternate rows of cages) at any one time also favors parasitoid success.

SOME COMMON NATURALLY OCCURRING BENEFICIAL INSECTS AND MITES

Few guidelines exist for monitoring populations of natural enemies and determining their likely impacts on pest infestations. Nonetheless, recognizing the beneficials that are present in any situation and understanding their roles are useful steps in deciding on appropriate pest management practices. Some common, naturally occurring species include:

Predators

Lady Beetles (Family Coccinellidae)

Beetles in the family Coccinellidae are known as lady beetles, though they are commonly referred to as "ladybugs." There are over 400 species of lady beetles in North America, ranging in color from the familiar orange with black spots to various shades of red and yellow, to jet black. The vast majority of lady beetles are beneficial predators of soft-bodied insects (aphids and scale insects in particular), mites, and insect eggs. In each species, adults and larvae consume similar prey and generally can be found together where their prey is abundant. Most species of lady beetles are not available for purchase and release, but many of them provide significant levels of pest control if they are not eliminated by insecticides, tillage, or other land-use practices.

Coccinella septempunctata, referred to as "C-7" for its seven spots, is a Eurasian lady beetle that was introduced into the U.S. several times in the 1970s and 1980s. Now common throughout Illinois, it is a significant natural enemy of several important aphid species, including the pea aphid and the green peach aphid. (See Figure 10a.)

Other common aphid-feeding lady beetles found in Illinois include the convergent lady beetle (*Hippodamia convergens*, Figure 3), the two-spotted lady beetle (*Adalia bipunctata*, Figure 10b), and the spotted lady beetle (*Coleomegilla maculata*, Figure 10c). The twice-stabbed lady beetle (*Chilocorus*



Figure 10. Some important Illinois lady beetles. A) C-7, *Coccinella septempunctata*. B) The twospotted lady beetle, *Adalia bipunctata*. C) The spotted lady beetle, *Coleomegilla maculata*. D) The twice-stabbed lady beetle, *Chilocorus stigma*.

stigma, Figure 10d) is a predator of many species of scale insects.

Stethorus punctum, an important predator of spider mites in apple orchards throughout Michigan, Pennsylvania, and western New York, is found sporadically in Illinois. Adults are tiny (3 mm), round, shiny, black beetles. Both adults and larvae feed on mites, and they are most often found where spider mite populations are high (15 or more mites per leaf). Adults overwinter in debris at the base of apple trees or in fields or wooded areas near orchards. Although *Stethorus punctum* is susceptible to standard rates of most orchard insecticides and miticides, adults are mobile and can fly into orchards after spray residues have declined.

Ground Beetles (Family Carabidae) and Rove Beetles (Family Staphylinidae). Adult and larval ground beetles and rove beetles prey on a wide range of insects and are especially important as predators of caterpillars and other soft-bodied insects in field crops, forests, and many other habitats. Together these two families of beetles include nearly 5,000 species that are widely distributed throughout North America. (See Figure 11.)

Both ground beetles and rove beetles are commonly found under plant debris and beneath

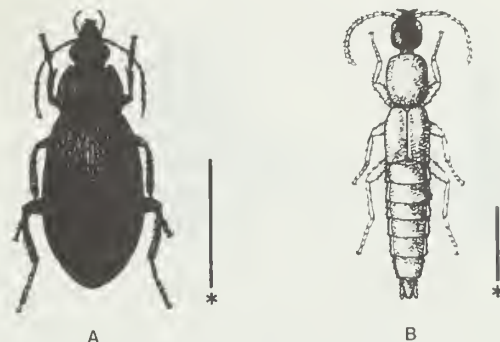


Figure 11. A) A ground beetle, Family Carabidae. B) A rove beetle, Family Staphylinidae.

the soil surface. Many species are nocturnal (active at night) and as a result are not as apparent as other natural enemies. Some of the larger species of ground beetles can be found in trees, where they prey on various caterpillar pests, including tent caterpillars, tussock moth larvae, and gypsy moth larvae (see Figure 1a). Ground beetles and rove beetles, along with spiders, are the most common predators found in many field crops.

Syrphid, Flower, or Hover Flies (Family Syrphidae). Syrphid flies are common in many habitats. The small, wormlike larvae of many species are found on foliage where they prey on aphids. Adult syrphid flies feed on pollen and nectar. The adults of many species closely resemble bees or wasps but do not sting or bite. See Figure 12.

True Bugs (Order Hemiptera). Many species of true bugs are predaceous, and several play important roles in the control of agronomic pests. The minute pirate bug (*Orius insidiosus*, Figure 13a) feeds on the eggs of caterpillar pests in corn and other crops; it also feeds on many other small soft-bodied insects. The big-eyed bugs (*Geocoris* species, Figure 13b) also prey on caterpillar eggs and other small insects. Damsel bugs (*Nabis* species, Figure 13c) are common in gardens and crops, where they feed on aphids and many other pests.

Predatory Mites (Family Phytoseiidae). Several very important predatory mites prey on pest mites in apple orchards. In some areas integrated mite management programs have been developed to take advantage of these naturally occurring predators.

Amblyseius fallacis, sometimes called the "fallacis mite," is the most important predatory mite in Illinois apple orchards. It overwinters along with twospotted spider mites in ground cover and debris

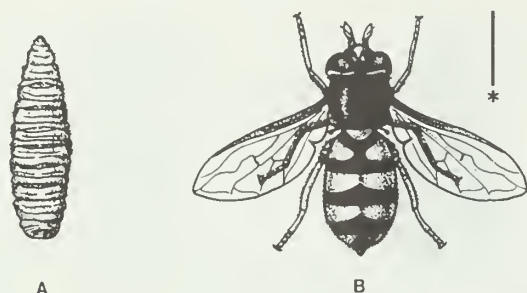


Figure 12. A syrphid fly. A) Larva. B) Adult.

beneath apple trees. In early summer *Amblyseius fallacis* follows the movement of the two-spotted spider mite up into the apple tree canopy. Once in the canopy, *Amblyseius fallacis* feeds on all species of pest mites (the European red mite and the apple rust mite, as well as the twospotted spider mite).

Mite management programs call for early season oil sprays to control the European red mite (as well as San Jose scale and apple aphids) when necessary. They recommend that oil sprays be discontinued during summer months after *Amblyseius fallacis* and the twospotted spider mite have moved up into the canopy. These programs include guidelines for sampling pest and predatory mite populations to determine whether or not populations of *Amblyseius fallacis* are sufficient to control pest mites adequately. (See Croft, 1975, and van Driesche et al., 1989.) Some populations of *Amblyseius fallacis* have developed resistance to low levels of azinphos-methyl (Guthion) and phosmet (Imidan), two organophosphate insecticides commonly used in apple orchards for control of the codling moth.

Parasitoids

Parasitoids are by far the most numerous naturally occurring biological control agents, with more than 8,500 species of parasitic wasps and flies occurring in North America. Despite their prevalence and importance, parasitoids go largely unnoticed because of their small size and inconspicuous behavior. A detailed discussion of individual, naturally occurring parasitoid species is beyond the scope of this circular. For useful background information and specific details on selected parasitoids, see Askew (1971), Clausen (1940), and Debach (1964).

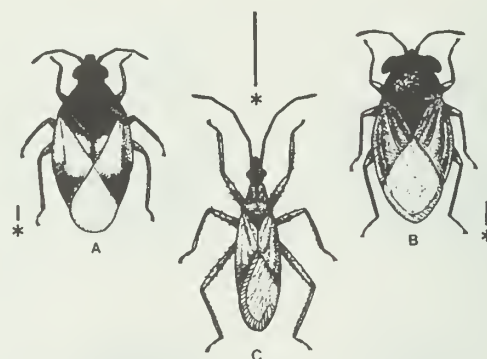


Figure 13. Some important Illinois predaceous bugs. A) The minute pirate bug, *Orius insidiosus*. B) A big-eyed bug, *Geocoris* species. C) The common damsel bug, *Nabis americanoferus*.

SUMMARY

Biological control is a complex subject that can be presented only superficially in a publication of this length. Successful use of natural enemies in pest management requires detailed understanding of insect biology and pest management techniques. In addition, it requires realistic expectations. The possibilities are not endless; there are real limitations that result from biological constraints and from current agricultural production and marketing practices. Nonetheless, biological control utilizing beneficial insects and mites represents an effective alternative for insect management in some situations. In almost all settings, encouraging or conserving naturally occurring populations of beneficial insects and mites is possible. Conservation may be aided greatly by the development and use of more selective, rapidly degrading insecticides and by the use of insecticides in a more selective manner. The greatest promise for biological control may lie in such conservation efforts.

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RELATED EXTENSION PUBLICATIONS*

The following publications are available for purchase from the Office of Agricultural Communications and Education, 69 Mumford Hall, 1301 West Gregory Drive, Urbana, IL 61801:

C897 Insect Pest Management Guide: Commercial Vegetable Crops

C898 Insect Pest Management Guide: Livestock and Livestock Buildings

C899 Insect Pest Management Guide: Field and Forage Crops

C900 Insect Pest Management Guide: Home, Yard, and Garden

C1242 Insect Pest Management Guide: Stored
Grains

C1292 Midwest Tree Fruit Handbook

C1295 Alternatives in Insect Management:
Microbial Insecticides

C1296 Alternatives in Insect Management:
Botanical Insecticides and Insecticidal Soaps

C1297 Alternatives in Insect Management: Insect
Attractants and Traps

**Titles available as of March 1990.*

Table 1. *Uses of Natural Enemies. This table presents biological control guidelines adapted from scientific literature and suppliers' recommendations. These guidelines should be viewed only as suggestions rather than as established recommendations. Refer to the text for more detailed information.*

COMMODITY/ SITE	PEST	NATURAL ENEMY	NOTES
General			
various field and vegetable crops, gardens, orchards, ornamentals and shade trees	aphids, caterpillars, mites, and many other small, soft-bodied pests	<i>Chrysoperla carnea</i> or <i>Chrysoperla rufilabris</i>	The larval stages of the green lacewings, <i>Chrysoperla carnea</i> and <i>Chrysoperla rufilabris</i> , are generalist predators of aphids, caterpillar eggs, mites, and small soft-bodied insects. Green lacewing larvae may contribute significantly to insect control when used with other tactics in integrated pest management programs. Specific release rates have not been determined for most crops; however, research indicates that 2-3 releases of 50,000-100,000 eggs per acre per release, made at intervals of 10-14 days, may provide significant control. Experimentation may be necessary to determine optimum release rates and timing for specific crops. <i>Chrysoperla carnea</i> is used in field and vegetable crops and gardens; <i>Chrysoperla rufilabris</i> is used in orchards and shade trees.
Field Crops			
field corn	European corn borer	<i>Trichogramma pretiosum</i>	<i>Trichogramma pretiosum</i> may be effective in controlling European corn borer when released at rates of 50,000-300,000 (total) per acre per generation. Three releases of 100,000 <i>Trichogramma</i> per acre per release should be made at 7-10 day intervals during corn borer egg laying. Releases should begin as soon as corn borer moths are captured in pheromone or light traps. Control of second generation corn borers may require higher release rates or a longer release period because egg laying usually occurs over an extended period. <i>Trichogramma nubilale</i> may be more effective against corn borers than <i>Trichogramma pretiosum</i> , however <i>T. nubilale</i> is not yet available commercially. BT (<i>Bacillus thuringiensis</i> , a microbial insecticide approved by most organic certification programs) is easier to apply, more effective, and more economical than <i>Trichogramma</i> , for control of European corn borer in corn.

COMMODITY/ SITE	PEST	NATURAL ENEMY	NOTES
small grains and forage crops	various pests	- -	Naturally occurring predators, parasitoids, and pathogens often contribute significantly to suppression of pests in small grains and forage crops. Natural enemy populations (species and numbers) should be monitored when scouting for pests; however, specific management decisions based on natural enemy populations have not been developed for most crops. Conservation practices may help increase natural populations of beneficial insects (see text), but purchase and release of natural enemies is not economically feasible for many of these crops.
Orchards			
apples	spider mites: European red mite, twospotted spider mite, and apple rust mite	<i>Amblyseius fallacis</i>	<i>Amblyseius fallacis</i> is a naturally occurring predatory mite that is not available for purchase. Populations can be encouraged and conserved by maintaining orchard ground covers and carefully timing oil sprays. Early oil sprays for control of European red mite and San Jose scale should be discontinued as soon as <i>Amblyseius fallacis</i> moves up onto apple foliage sometime in June. Spraying "alternate middles" preserves natural enemies during the season.
	codling moth	<i>Trichogramma minutum</i>	Success with <i>Trichogramma</i> species for control of codling moth in apple orchards has been variable. Release rates of 50,000-100,000 wasps per acre per release at weekly intervals during egg laying (as determined by pheromone trapping) may provide some control. Releases should be made evenly throughout the orchard rather than at a single site. <i>Trichogramma</i> is most effective in orchards during warm, sunny weather.
peaches	various pests	- -	Little information is available concerning biological control of peach pests. The major insect pests of peaches in Illinois include the oriental fruit moth, plum curculio, green stink bug, and tarnished plant bug. Because the oriental fruit moth has 4 generations per year, it is very difficult to control with <i>Trichogramma</i> (constant releases of parasitoids would be needed to control overlapping generations). There are no natural enemies available for control of plum curculio, green stink bug, or tarnished plant bug in peaches.

COMMODITY/ SITE	PEST	NATURAL ENEMY	NOTES
Commercial Vegetables (for Fresh Market or Processing)			
sweet corn	European corn borer	<i>Trichogramma pretiosum</i>	See field corn. Limited data indicate substantial control of corn borer in sweet corn at release rates of 40,000-50,000 <i>Trichogramma</i> per acre per release and 3 releases at 7-10 day intervals.
tomatoes, cole crops, squash, peppers, and snap beans	various pests	- -	Because of the high degree of insect control required for fresh market or processing vegetables, and because many vegetable crops are susceptible to damage by several key pests, there are few biological control alternatives that are economically feasible on a commercial scale. <i>Trichogramma</i> or <i>Chrysoperla</i> may provide some control of caterpillar pests, but timing and release rates have not been determined.
Commercial Greenhouses			
vegetables (tomatoes and cucumbers)	greenhouse whitefly	<i>Encarsia formosa</i>	<i>Encarsia</i> should be released at the first sign of whitefly infestation. Releases should be made 4 times at 10-14 day intervals (or until black scales appear). Release rates and methods vary considerably depending on initial infestation and cropping system. For very low initial infestations (less than 1 whitefly adult per 50-100 plants), rates of 1 parasitoid per 4-7 square feet are recommended for each release. For higher initial infestations (still less than 1 whitefly adult per upper leaf), releases of 1-5 parasitoids per square foot should be made at 10-14 day intervals. If the initial whitefly population is higher than 1 adult per upper leaf, it should be reduced with a nonresidual insecticide, such as an insecticidal soap or natural pyrethrins (NOT pyrethroids; see Extension Circular 1296), before releasing <i>Encarsia</i> . Maintaining greenhouse temperatures at 23-27°C (75-80°F) and relative humidities at 50-70% and providing high light intensity favors the survival of <i>Encarsia</i> .
	twospotted spider mites	<i>Phytoseiulus persimilis</i> , <i>Phytoseiulus longipes</i> , and/or <i>Amblyseius californicus</i>	Predatory mites should be released at the very first sign of spider mites. Release rates and methods vary, depending on crop and levels of infestation. If the infestation is low and uniform throughout the greenhouse, releasing 2 predatory mites per small plant is recommended. If the infestation is high or patchy, releases of 10-30 predatory mites per plant are recommended. Mites should be placed on individual leaves (predatory mites will not move from leaf to leaf if spider mite populations are high). See text for discussion of temperature and humidity requirements for each strain or species.

COMMODITY/ SITE	PEST	NATURAL ENEMY	NOTES
greenhouse vegetables (continued)	western flower thrips, onion thrips	<i>Amblyseius cucumeris</i> or <i>Amblyseius mckenziei</i> (=barkeri)	Repeated releases of high numbers of <i>Amblyseius cucumeris</i> are required for adequate protection of peppers or cucumbers. High release rates are economically feasible with this predatory mite, however, because it is very easy to rear in large quantities. For peppers, suppliers recommend releasing 10 predatory mites per plant plus an additional 25 per infested leaf. For cucumbers, releases of 50 predatory mites per plant plus an additional 100 per infested leaf are recommended. In both cases, releases should be made weekly until there is 1 predatory mite per 2 thrips.
	serpentine leafminers	<i>Dacnusa sibirica</i> and/or <i>Diglyphus isaea</i>	<i>Dacnusa sibirica</i> and <i>Diglyphus isaea</i> are parasitoids of the serpentine leafminer (<i>Liriomyza trifolii</i>). Release rates for tomatoes are not well established. Research suggests the release of 1 parasitoid per every 10 new mines per week for the first 6 weeks of an infestation. Greater than 90% parasitism must occur for control to be sufficient. High cost and limited availability limit the usefulness of these parasitoids.
commercial flowers and ornamentals	various pests	- -	Commercially produced flowers and ornamental plants are sold on the basis of appearance, and little or no insect damage is tolerated. In general, biological control alone cannot maintain sufficiently low levels of insect damage and is usually not economical for commercial operations. One exception is the control of leafminers in chrysanthemums.
chrysanthemums	serpentine leafminers	<i>Dacnusa sibirica</i> and/or <i>Diglyphus isaea</i>	Experimental evidence indicates that the release of 3 <i>Dacnusa</i> adults per 1,000 plants early in the growing season can provide control of first-generation leafminers. <i>Diglyphus</i> may be more effective for controlling subsequent generations, especially if temperatures are high. An alternate approach involves the release of 500 <i>Dacnusa</i> adults per acre every 2 weeks, beginning when the first signs of adult leafminer feeding are detected.

COMMODITY/ SITE	PEST	NATURAL ENEMY	NOTES
botanical gardens or conservatories	whitefly	<i>Encarsia formosa</i>	Where many different plant species are maintained together in a permanent collection for public display or for research or educational purposes, biological control poses few risks and can provide adequate protection. Careful monitoring of populations of pest insects and natural enemies and the development of complex management programs may be necessary. Experimentation may be required to determine the best release rates and timing for each situation. Because the yield or marketability of conservatory plants is not a factor, tolerance for injury may be higher, and lower release rates than those that are recommended for commercial production may be adequate.
	spider mites	<i>Phytoseiulus</i> and <i>Amblyseius spp.</i>	
	mealybugs	<i>Cryptolaemus montrouzieri</i>	
	aphids	<i>Aphidoletes aphidimyza</i> (predatory midge)	
	soft scales	<i>Metaphycus helvolus</i> (parasitoid)	
	armored scales	<i>Aphytis melinus</i> (parasitoid)	

Home, Yard, and Garden

vegetable gardens flowers, shrubs, and trees lawns	various pests	- -	Problems of dispersal, timing of releases to coincide with the susceptible stage(s) of specific pests, and patchy or limited distribution of pests often reduce the effectiveness of natural enemies when released in home gardens. For the degree of control needed in home gardens, such readily available alternatives as insecticidal soaps, BT, and various row covers are easier to use and more dependable than natural enemies. Conservation of naturally occurring beneficial insects and mites (by reduced use of broad spectrum insecticides, providing nectar and pollen sources, use of artificial foods such as Wheat [®] , etc.) may be more effective than purchasing and releasing predators and parasitoids. For home gardeners wishing to experiment with natural enemies, generalist predators such as green lacewings (<i>Chrysoperla carnea</i>) and spined soldier bugs (<i>Podisus maculiventris</i>) are probably the best choices. Lady beetles and praying mantids are seldom effective (see text).
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COMMODITY/ SITE	PEST	NATURAL ENEMY	NOTES
Livestock and poultry			
feedlot and dairy cattle	stable flies	<i>Spalangia nigroaenea</i> and/or <i>Spalangia cameroni</i>	Releases of 50-100 <i>Spalangia</i> per animal per week may help limit fly populations. Suppliers' recommended rates are much lower and are not likely to reduce fly numbers substantially. Purchases of "generic" filth fly parasitoids should be avoided because these mixtures often do not include <i>Spalangia nigroaenea</i> or <i>Spalangia cameroni</i> , the two species shown to parasitize stable fly pupae effectively. These species also parasitize house fly pupae, but not as frequently. <i>Spalangia endius</i> and <i>Nasonia vitripennis</i> are sometimes sold, but neither species has been shown to be effective for the control of flies in Midwest feedlots.
	house flies	<i>Muscidifurax raptor</i> and/or <i>Muscidifurax zaraptor</i>	Releases of 50-100 <i>Muscidifurax</i> per animal per week may help limit fly populations. Some parasitism of house flies may also be achieved with <i>Spalangia nigroaenea</i> and <i>Spalangia cameroni</i> .
poultry	house flies	<i>Muscidifurax</i> species, <i>Spalangia</i> species, and/or <i>Pachycrepoides vindemiae</i>	All of these parasitoids can be used for house fly control in poultry houses (especially those with concrete floors). Release rates depend on manure management and poultry-house construction. A general recommendation is to make weekly releases of 1 parasitoid per 2 birds. Fly control is improved where moisture problems are minimized.
Stored Products			
raw grains	Indianmeal moth	<i>Trichogramma pretiosum</i> and/or <i>Bracon hebetor</i>	<i>Trichogramma</i> and <i>Bracon</i> can provide moderate levels of control of Indianmeal moth eggs and larvae. This degree of control is not adequate in most cases, however, due to very stringent regulations on levels of insect infestation in grains. Dependable release rates have not been determined.
	weevils and grain beetles	<i>Xylocorus flavipes</i> and <i>Anisopteromalus calandreae</i>	<i>Xylocorus</i> feeds on the eggs of grain weevils and the eggs and larval stages of grain beetles and the Indianmeal moth. <i>Anisopteromalus</i> is a parasitoid of weevil larvae. Both of these natural enemies provide some control of the immature stages of stored grain pests but do not attack adults. Because adult grain weevils and beetles may live and reproduce for 3-6 months or longer in stored grain, <i>Xylocorus</i> and <i>Anisopteromalus</i> are not able reduce pest infestations to the low levels required by grain regulations. Release rates have not been determined.



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