UF UNIVERSITY of FLORIDA
IFAS Extension

Beneficial Insects and Mites[1]

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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 non-pest 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 or bigger than their prey. Some predators, including certain syrphid flies and the common green lacewing, are predaceous only as larvae; other lace wing species, lady beetle, 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 parasitelike. 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 (Figure 1). In general, an adult parasitoid deposits one or more eggs into or onto the body of a host

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insect or somewhere in the host 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.

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.

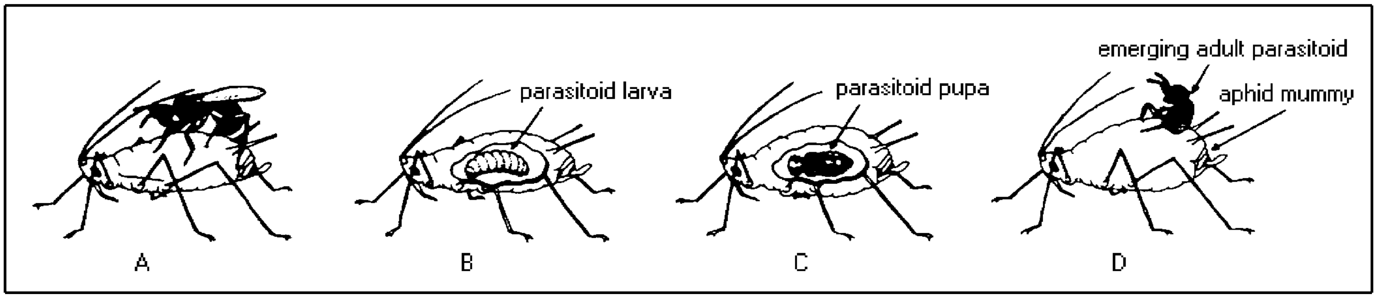

Figure 1. Generalized life cycle of an aphid parasitoid. A) Adult parasitoid wasp injects an egg into a live aphid. B) The parasitoid larva feeds within the aphid; late in the parasitoid's development the aphid dies. C) The parasitoid pupates within the enlarged, dry shell of the dead aphid. D) The new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

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 place 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 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

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.

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 Florida 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 exeed 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.

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 grove 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 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 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. (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 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 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.

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 (Figure 2) 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.

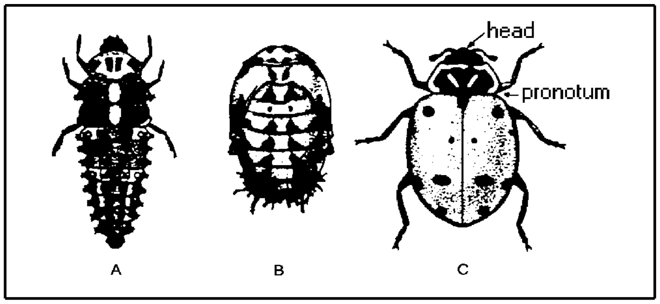

Figure 2. The convergent lady beetle, *Hippodamia convergens*. A) Larva. B) Pupa. C) Adult.

These "convergent" dashes give this lady beetle is a soft bodied, alligator-shaped larva. It is grey and orange and is covered with rows of raised black spots.

Larval and adult convergent lady beetle 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. 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 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 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 (Figure 3) 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. 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.

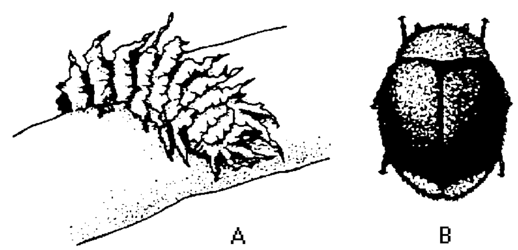

Figure 3. The mealybug destroyer, *Cryptolaemus montrouzieri*. A) Larva. B) Adult.

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 day length are reduced.

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, *Chrysoperia* (formerly *Chrysopa*) *carnea* and *Chrysoperia rufilabris*

Green lacewings (Figure 4) 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. The 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.

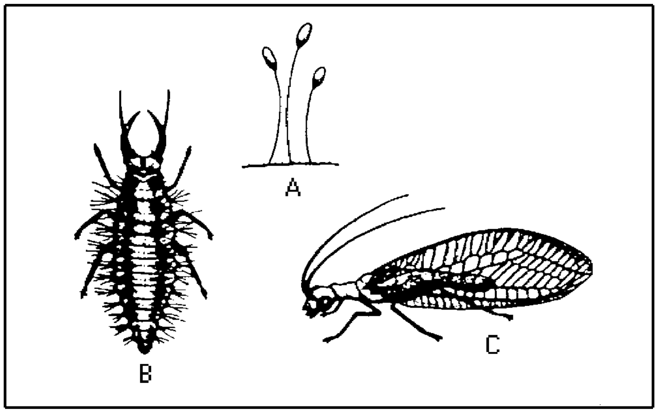

Figure 4. The common green lacewing, *Chrysoperia camea*. A) Eggs. B) Larva, commonly known as an "aphid lion." C) Adult.

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, *Chrysoperia carnea* adults feed only on nectar, pollen, and aphid honeydew. *Chrysoperia 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 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.

For small-scale gardens, suppliers recommend release rates of 1 to 5 lacewing eggs per square foot of garden space. For field crops 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. Larvae are highly susceptible to many other insecticides, however, and adults tend to be more susceptible than larvae in all cases.

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

The Spined Soldier Bug, *Podisus maculiventris*

The spined soldier bug (Figure 5) is the only predaceous "true bug" (Order Hemiptera) available for purchase. It occurs naturally in the United States and is one of the most common predatory stink bugs. 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 that are held folded under their bodies while not feeding.

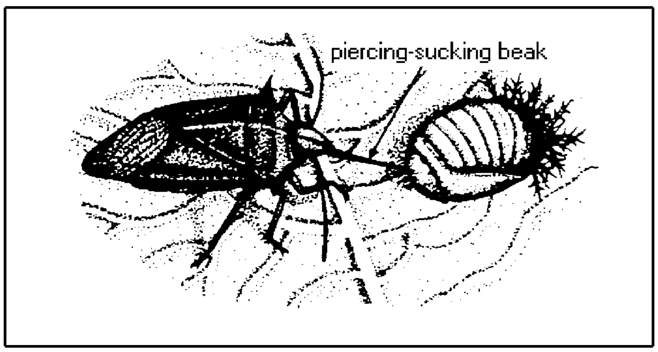

Figure 5. An adult spined soldier bug, *Podisus maculliventris*, feeding on a Mexican bean beetle pupa.

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 bodies 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

Several mantid species occur naturally in the southern U.S. 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 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 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 the prices vary greatly from one supplier to the next. The Chinese praying mantid (Figure 6), *Tenodera aridifolia sinesis*, is the species that is most commonly available for purchase.

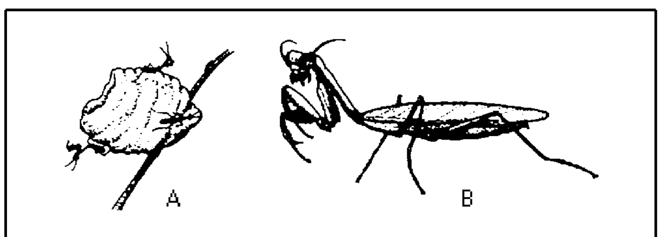

Figure 6. The Chinese praying mantid, *Tenodera aridfollia sinensis*. A) Egg case with newly hatched nymphs. B) Adult.

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 two spotted 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. 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* (Figure 7). 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.

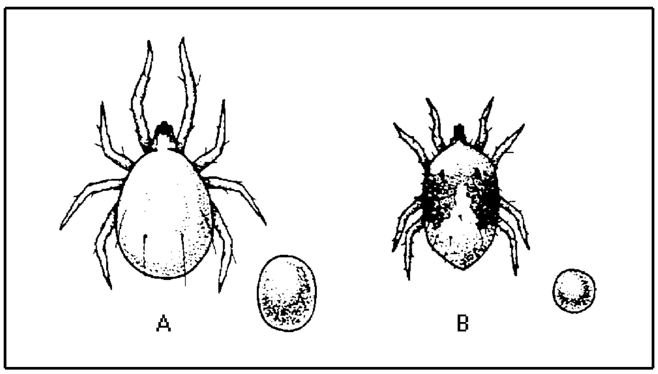

Figure 7. A) A predatory mite, *Phytoseiulus persimilis*, adult and egg. B) The twospotted spider mite, *Tetranychus urticae*, adult and egg.

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.

In the U.S., insectaries generally recommend releasing *Phytoseiulus persimilis* when there are 1 or fewer spider mites per leaf throughout the 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 releases. 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.

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 allow 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.

Phytoseiulus longipes and *Amblyseius californicus* are 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. *Amblyseiulus 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 ebbs 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 *Thripstabaci* 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 (Figure 8), a tiny parasitic wasp, has been used to control greenhouse whiteflies on omatoes 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 8). 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.

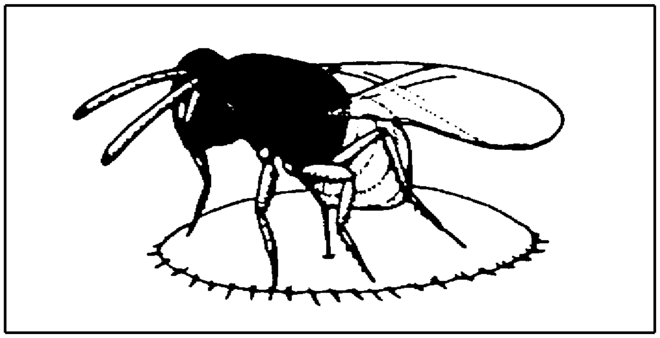

Figure 8. An adult female *Encarsia formosa* depositing an egg into the scalelike fourth nymphas stage of the greenhouse whitefly.

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 day length is shorter and light intensities are lower.

Numerous release schedules have been developed for *Encarsia*. As with predatory mites, most or the research and practical information on *Encarsia* has come form 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 provided by *Encarsia* is not likely to by 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 rate 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.

Trichogramma Wasps, Egg Parasitoids

The *Trichogramma* wasps (Figure 9) 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).

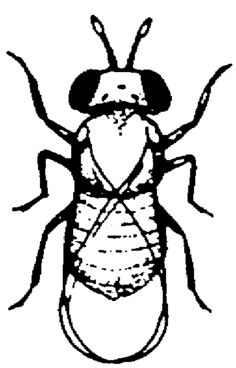

Figure 9. Adult *Trichogramma* wasp.

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 presotiosum*, 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 forest caterpillars. The third species, *Trichogramma platerni*, parasitizes a caterpillar pest of avocadoes and is not. *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.

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 strain 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 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 nigroanea* 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 bird. 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 Occuring 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 bodies 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" (Figure 10) for its seven spots, is a Eurasian lady beetle that was introduced into the U.S. several times in the 1970s and 1980s. It is a significant natural enemy of several important aphid species, including the pea aphid and the green peach aphid.

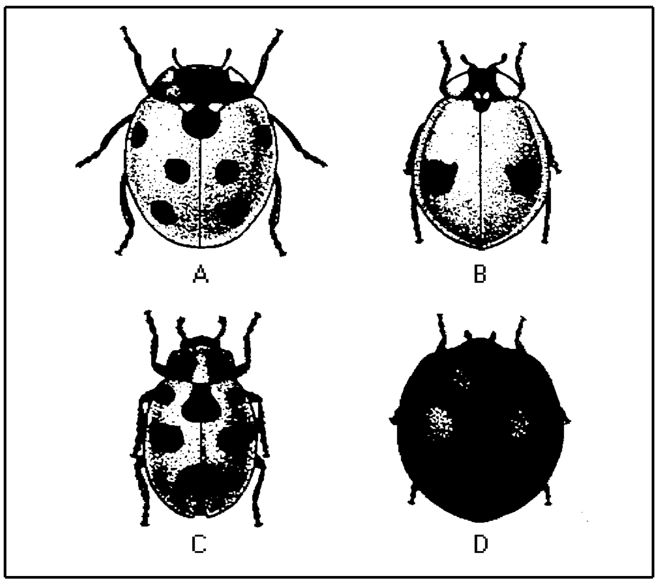

Figure 10. Some important lady beetles. A) C-7, *Coccinella septempunctata*. B) The twospotted lady beetle, *Adalia bipunctata*. C) The spotted lady beetle, *Coleomegilla maculata*. D) The twice-stabbed lady beetle, *Chilocorus stigma*.

Other common aphid-feeding lady beetles include the convergent lady beetle (*Hippodamia convergens*), the two-spotted lady beetle (*Adalia bipunctata*), and the spotted lady beetle (*Oleomegilla maculata*). The twice-stabbed lady beetle (*Chilocorus stigma*) is a predator of many species of scale insects.

Ground Beetles (Family Carabidae) and Rove Beetles (Family Staphylinidae)

Adult and larval ground beetles and rove beetles (Figure 11) prey on a wide range of insects and are especially important as predators of caterpillars and other soft-bodies insects in field crops, forests, and many other habitats. Together these two families of beetles include nearly 5,000 species.

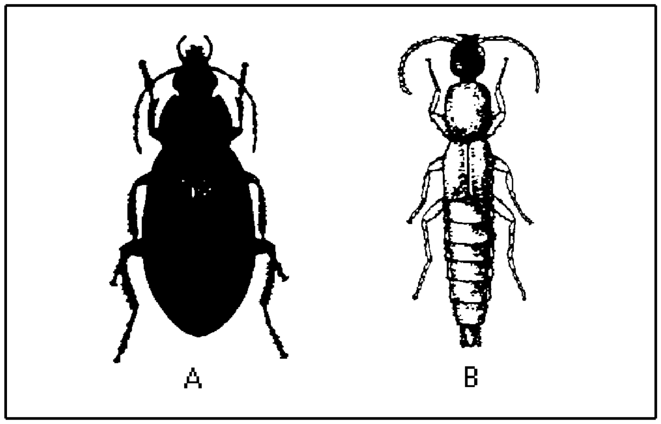

Figure 11. A) A ground beetle, Family Carabidae. B) A rove beetle, Family Staphylinidae.

Both ground beetles and rove beetles are commonly found under plant debris and beneath 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. 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 (Figure 12) 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 and wasps but do not sting or bite.

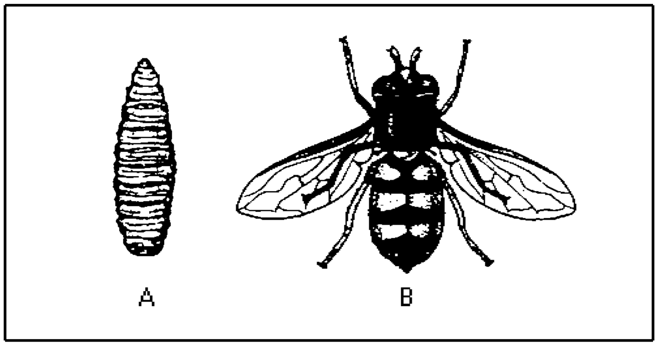

Figure 12. A syrphid fly. A) Larva. B) Adult.

True Bugs (Order Hemiptera)

Many species of true bugs are predaceous (Figure 13), and several play important roles in the control of agronomic pests. The minute pirate bug (*Orius insidiousus)* 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,) also prey on caterpillar eggs and other small insects. Damsel bugs (*Nabis* species) are common in gardens and crops, where they feed on aphids and many other pests.

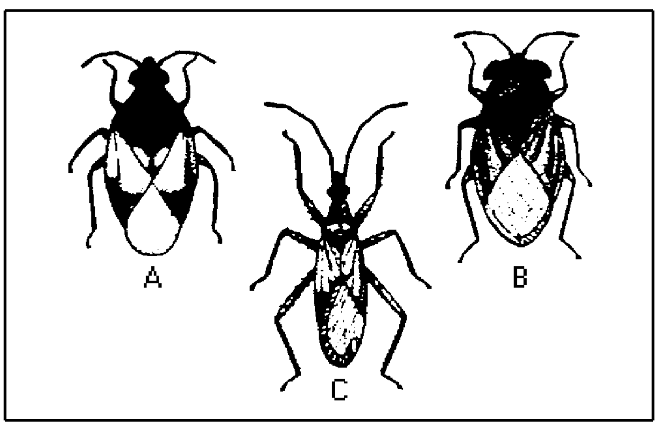

Figure 13. Some important predaceous bugs. A) The minute pirate bug, *Orius insidious*. B) A big-eyed bug, *Geocoris species*. C) The common damsel bug, *Nabis americoferus*.

Predatory Mites (Family Phytoseiidae)

Several very important predatory mites prey on pest mites. In some areas integrated mite management programs have been developed to take advantage of these naturally occurring predators.

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).

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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