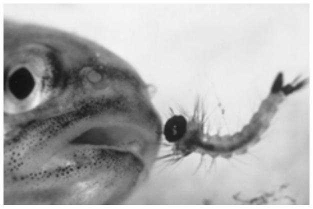
Section 10: Biological control

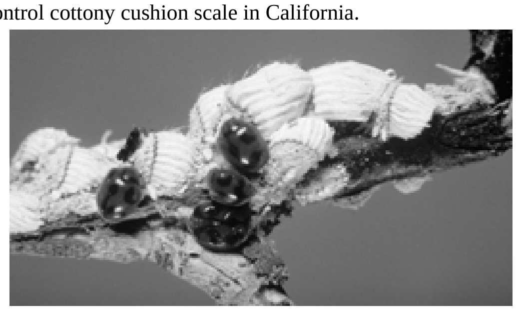


A mosquito fish about to enjoy lunch.

Biological control in action!

- Biological control (BC) involves the use of “animals” to reduce pest numbers. In many texts, the concept is treated more broadly, and includes use of microbial pathogens, or even host resistance.

Use of poultry to control insects predates historical records, but for practical purposes, BC began in 1887 when a lady beetle, Rodolia cardinalis, was imported from Australia to control cottony cushion scale in California.



Vedalia beetles, Rodolia cardinalis, feeding on cottony cushion scales.

Success of biological control

- There are reported to be perhaps 500 examples of successful BC involving 150 pest species.
- Relatively small number of successes. Only about 1 in 8 BC attempts are successful.
  - Not possible to implement in annual crops, elsewhere?
  - Not enough effort? Misdirected efforts?
  - Too easy to use insecticides?
- Most examples involve exotic pests and agriculture or forestry; few with med/vet or plant disease vectors.

Advantages of biological control

- Selectivity - few side effects, not broad-spectrum. Not totally without impacts when generalists used.
- Non-polluting - no chemical involved, though sometimes beneficials get too abundant.
- Cost - can be inexpensive if permanent establishment (important for low-value crops); expensive if frequent augmentation.
- Duration - may be long-lasting or permanent
- Resistance - development of resistance unlikely as beneficials also can evolve.

Disadvantages of biological control

- Constrains management options - may limit use of insecticides
- Speed of action - may require considerable time
- Pest elimination - rarely is pest eliminated; problem for pests causing damage at low densities
- Specificity - may limit commercial potential and use for minor pests
- Predictability - may be concern about reliability
- Production - for inoculation, availability of BC agents may be concern

Types of BC agents

- Predators
  - Both vertebrates and invertebrates
  - Major taxa are beetles, bugs, lacewings, flies, wasps, ants, spiders, mites
  - Capture, kill, and consume numerous prey during development
  - Usually have broad feeding habits
  - Searching abilities not very developed
  - Development times relatively long
  - Often cannibalistic
  - Useful, but not most efficient, for BC

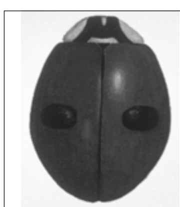
Lacewing larva

Overview of common insect predators

Order	Family	Predator	Prey
Mantodea	Mantidae	mantids	various insects
Dermaptera	Labiduridae	earwigs	caterpillars, others
Thysanoptera	Alelothripidae	predatory thrips	spider mite eggs
Hemiptera	Anthocoridae	pirate bugs	eggs, small insects
	Lygaeidae	big-eyed bugs	eggs, small insects
	Miridae	plant bugs	eggs, small insects
	Nabidae	damsel bugs	eggs, small insects
	Reduviidae	assassin bugs	various insects
	Pentatomidae	stink bugs	caterpillars and grubs

Overview of common predators, continued

Order	Family	Predator	Prey
Neuroptera	Chrysopidae	lacewings	various insects
Coleoptera	Coccinellidae	lady beetles	eggs, small insects
	Carabidae	ground beetles	eggs, various insects
	Staphylinidae	rove beetles	small insects
	Melyridae	soft-winged flower beetles	eggs, small insects
Diptera	Cecidomyiidae	midges	aphids
	Syrphidae	flower flies	aphids
Hymenoptera	Formicidae	ants	eggs, small insects
	Sphecidae	digger wasps	caterpillars, others
	Vespidae	paper wasps	caterpillars and grubs



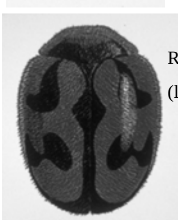
Some ladybird beetles

Adalia bipuntata

(upper left)

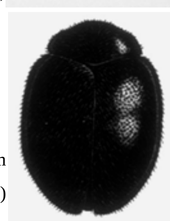
Coccinella septempunctata

(upper right)



Rodolia cardinalis

(lower left)



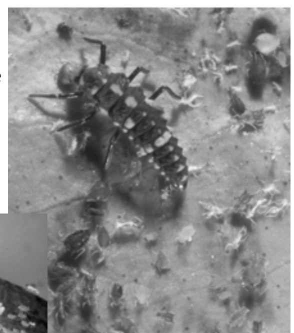
Stethorus punctillum

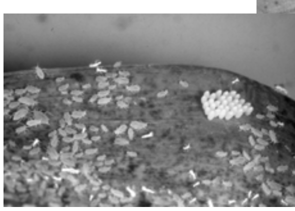
(lower right)

Lady beetles (Coccinellidae)

- Among best known predators: colorful, abundant
- Consume many pests, particularly aphids and mites, but usually general feeders and cannibalistic
- Other less obvious (small maggots or nocturnal species) predators sometimes more important
- Color patterns is not a very reliable method of ID
- Larvae and eggs often overlooked

Lady beetle egg mass (below) inserted among aphids on heavily infested leaf. One of the problems with ladybirds is that often pest densities must be quite high before ovipositing adults are attracted. Larva (right) feeding on aphids.

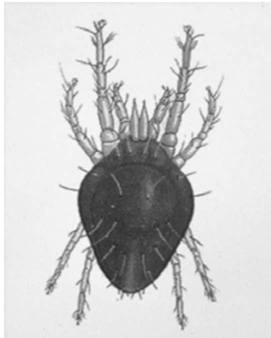




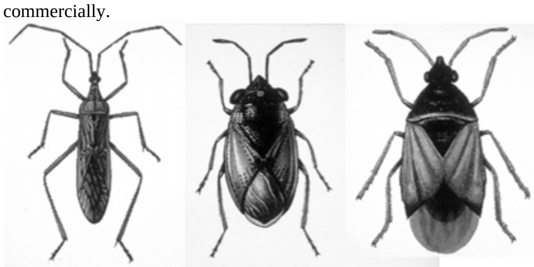
Nymph of predaceous stink bug (Pentatomidae) feeding on caterpillar (top right). Not all stink bugs are predatory, but those that are tend to have stout beaks.

Ground beetles (Carabidae) feed on and below the soil surface but also climb vegetation to reach prey. They can be quite important in agricultural systems.

A predatory mite, Neoseiulus sp. (formerly Amblyseius) (family Phytoseidae). These mites feed mostly on plant-feeding spider mites (Tetranychidae) and can be effective predators. They are available commercially, and sometimes released to affect mite suppression.

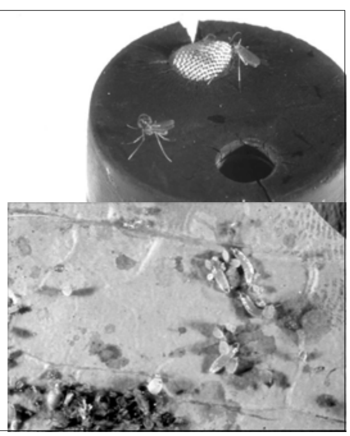


Some important predatory bugs (Hemiptera): left, a damel bug, Nabis; center, a big-eyed bug, Geocoris; and right, a minute pirate bug, Orius. These are worthy of conservation, and some are available commercially.



Note, these images are not to scale; they are quite different in size. Can you determine their biology by examining the literature?

One of the most under-appreciated aphid predators is the midge Aphidoletes aphidimyza (Cecidomyiidae) (adults in top photo). The small orange larvae (bottom photo) are commonly overlooked because of their small size, or misidentified as small flower fly (Syrphidae) larvae. These are available commercially. The similar aphid flies (Chamaemyiidae) also are overlooked.



Flower flies (family Syrphidae) are common predators of aphids and some other sedentary insects. The larva (left photo) is the beneficial stage; they usually bear a pointed head, though their body color varies considerably. To the uniformed observer, the adults (right) are readily mistaken for bees as they forage for nectar and pollen..

Bee fly (Bombyliidae) adults (left) are fuzzy and commonly seen hovering in the air. They are best known as predators of grasshopper egg pods, but some develop internally in other insects

Adults of robber flies (Asilidae) (shown at right) are ferocious predators, often capturing large insects in flight. The larvae, which usually are soil dwelling, also are predatory.

Adult green lacewings (Chrysopidae) (left) may or may not be predatory, though larvae always feed on insects. They are good generalist predators, and commonly sold by biocontrol companies.

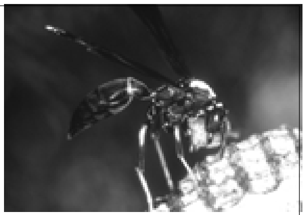
Brown lacewings (Hemerobiidae) (right) are less common, though normally found earlier in the year and favoring wooded areas. Like green lacewings, they feed mostly on aphids and mealybugs, and related insects.

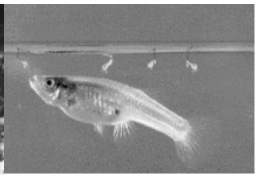
Typical lacewing larva (right) and eggs (below). Below right is a lacewing species that attaches debris, usually dead prey, to its back; hence it is called a "trashbug." Presumably the disguise help it avoid predation.

Mantids (Mantodea) are among the most easily recognized insect predators, but unfortunately they are not very effective. Shown below is an adult; to the right is an egg mass with hundreds of young hatching. The young likely will feed on each other initially, then eventually search for other food.

Earwigs (Dermaptera), like many other insects, sometimes are overlooked as predators. However, Doru taeniatum (shown below) is an important predator in southern crops and a major predator of fall armyworm.

Though wasps often are thought of as parasitoids, some wasps are important predators instead. Both colonial and solitary wasps are important. Photo at top shows paper wasp (Vespidae) carrying a portion of a caterpillar to its nest, where it will feed its developing brood. These wasps are especially effective as caterpillar hunters. Photo below shows a thread-waisted wasp (Sphecidae) dragging prey to its below-ground burrow it stock it with food for its young. These wasps vary greatly in their prey items. (photos, Kevin O'Neil)

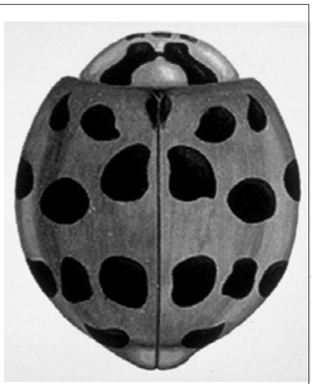




Mosquito fish, Gambusia spp. are native to the United States. They tolerates warm, shallow water very well, and feed on mosquito larvae, so they been used to inoculate temporary and permanent pools of water for biocontrol of these pests in many parts of the world. Like some other generalist predators, however, Gambusia have been accused of displacing native fauna; so now, for ecological reasons, they are in less favor (photos, USGS and San Diego Co. Environmental Health).

Asian lady beetle, Harmonia axyridis, was imported to the United States and released several times by USDA before it successfully established. It now has largely displaced some native lady beetle species and become so numerous at times that it is considered to be a nuisance. The nuisance factor stems from its tendency to overwinter in the attics of homes.

What lessons can be derived from this experience, and that of mosquitofish?



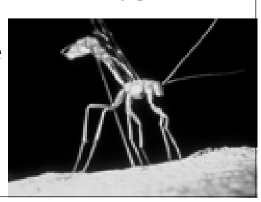
Cattle egrets flocking in a pasture. These and other birds, and vertebrates in general, can be important predators locally.

In general, are vertebrates more important for low or high density pest regulation?

Spiders have been shown to be important predators in many studies. The web-building species are most often seen, but not necessarily the most important from the perspective of insect population regulation and management.

Types of BC agents

- Parasitoids (parasites that kill their host)
  - Invertebrates
  - Mostly small wasps, some flies, a few others
  - Require only single host; sometimes many per host
  - Endo- and ecto-parasitic
  - Selective in host preference
  - Good searching abilities
  - Often good for BC



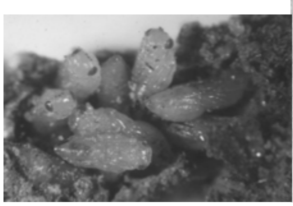
Megharyssa sp.

Overview of common parasitoids

Order	Family	Host	Internal/ external
Diptera	Tachinidae	beetles, caterpillars	I
	Nemestrinidae	grasshoppers, beetles	I
	Phoridae	ants, caterpillars, flies, etc.	I
Hymenoptera	Chalcididae	flies, caterpillars	I, E
	Encyrtidae	various	I
	Eulophidae	various	I, E
	Aphelinidae	aphids, whiteflies, scales	I, E
	Trichogrammatidae	moth eggs	I
	Scelionidae	bug and moth eggs	I
	Ichneumonidae	caterpillars, grubs, etc.	I, E
	Braconidae	caterpillars, grubs, etc.	I

Wasps sting their hosts, sometimes paralyzing their victim but most often depositing an egg within (sometimes on the outside) the host insect's body. Above is a caterpillar being attacked, below is a fly puparium.

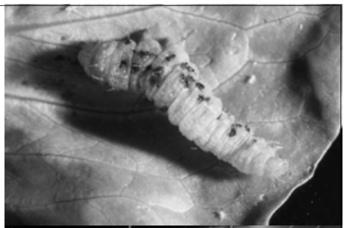
Endoparasites develop in the host until they near maturity. Right is a whitefly-parasitic wasp, ready to emerge as an adult. Below is a cluster of asparagus beetle parasites still in the pupal stage; the below-ground pupal cell was broken to observe these gregarious wasps.



Most parasitoids are endoparasitic. Above is a cluster of parasitoids that have completed their larval development in a looper and are preparing to pupate externally.

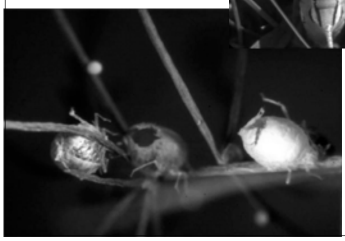
Below the parasites of this saddleback caterpillar have completed their development and formed pupal cases (cocoons) on the back of the host.

The black spots on the body of this looper (above) are the breathing pores (respiratory funnels) formed by tachinid fly larvae developing internally. In most cases, it is not apparent when insects are parasitized.



The webworm below is being attacked by ectoparasites, which live on the outside of the host. Like endoparasites, they feed on the blood of the host. (photo W. Cranshaw)

Tachinids often deposit their eggs externally, in this case on the thorax of a hornworm (right). The hornworm cannot chew off the eggs when they are so positioned.



Parasitized aphids typically assume a swollen appearance (left), and when the wasp matures the adult cuts a hole or doorway and escapes. Parasitized aphids are referred to as “mummies.”

Tachinid flies (Tachinidae) are difficult to recognize as beneficial insects. As you can see here with Myiopharus doryphorae, a Colorado potato beetle parasite, the fly is fairly nondescript. Tachinids bear stout hairs, however, and some are quite spiny. Some species scatter their eggs, which are consumed accidentally by plant-feeding insects; others deposit larvae instead of eggs.

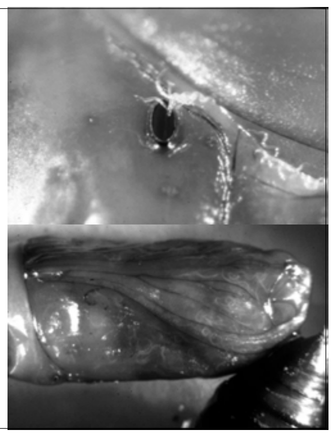
The nature of parasitism is variable. In the photo above you can see a single tachinid larva that emerged from the grasshopper nymph shown. Obviously this grasshopper cannot support more than one such large parasitoid. In contrast, the cutworm shown below is packed with polyembryonic wasp parasitoid larvae. Not surprisingly, the adult wasps are quite small.

Types of BC agents

- Nematodes
  - Like parasitoids, many develop per host
  - Lethality varies; some transmit lethal symbiotic bacteria
  - Especially useful in inundative BC
  - Most effective are Steinernematidae, Heterorhabditidae, and Mermithidae
  - Often have wide host range.

Steinernematid and Heterorhabditid nematodes have small infective stages (shown at top left next to a caterpillar) and larger reproductives. They develop internally in the hemolymph of insects, and also release a lethal bacterium. The nematodes serve mostly as a transport mechanism for the nemas, and then feed on the bacteria growing in the insect. When infected by Heterorhabditis, the host insect turns red (bottom right); this does not happen with Steinernema.

The Steinernema and Heterorhabditis spp. enter the insect through natural openings. At the top right you can see hair-like, minute white infective stage of the nematode trying to enter an insect spiracle (brown oval structure); the mouth and anus are other entry points. At the bottom right, if you look closely at the cuticle, you can seen that this pupa is packed with infective stage juvenile nematodes ready to escape and search for a new host.

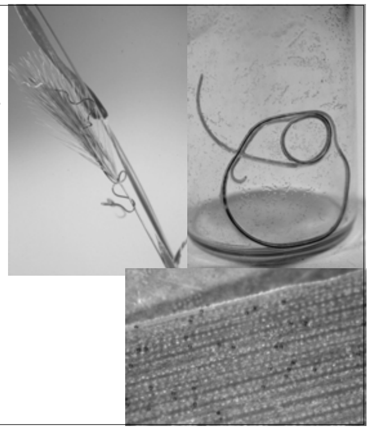


Steinernema and Heterorhabditis spp. have many attributes that make them suitable for commercialization:

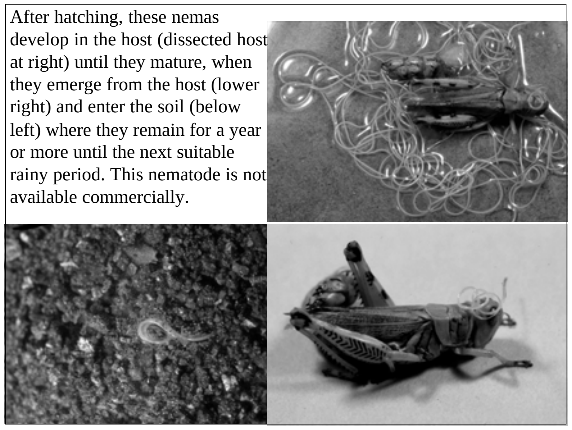
- economic production,
- longevity,
- (in some cases) wide host range,
- safety,
- ability to apply them with standard pesticide application equipment, and
- freedom from EPA registration requirements.

Their principal constraint is their susceptibility to sunlight and dryness, so they are used for insect pests occupying cryptic environments such as soil and burrows.

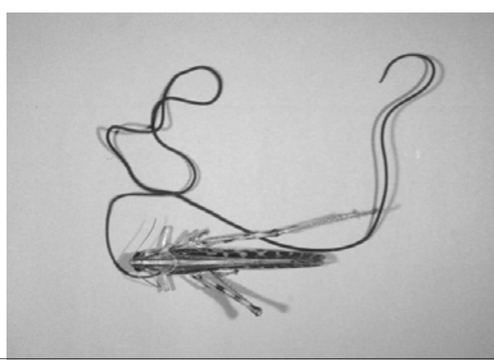
The mermithid nematode Mermis nigrescens parasitizes grasshoppers. Here it is shown climbing vegetation during a prolonged rainy period. The nema in the vial (far right), typical of the ascending nemas, is packed full of thousands of eggs (the dark "stripe"). The eggs are deposited on the foliage (lower photo), and then inadvertently consumed by insects, initiating an infection in the host.



After hatching, these nemas develop in the host (dissected host at right) until they mature, when they emerge from the host (lower right) and enter the soil (below left) where they remain for a year or more until the next suitable rainy period. This nematode is not available commercially.



This large dark-bodied "worm" is a nematomorph, not a nematode. What is the difference between a nematode and a nematomorph?

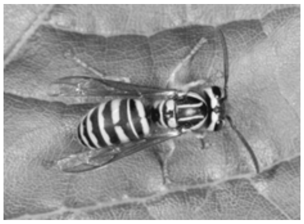


Where can you find information on natural enemies?

- It can be surprisingly difficult to find detailed, practical information on natural enemy biology and use. Some biocontrol suppliers treat their information as proprietary, seeking to sell service as well as product.
- Some potential sources of information are:
  - Natural Enemies Handbook. Univ. California Pub 3386 by Flint, Dreistadt and Clark (1998)
  - Biological Control: A guide to Natural Enemies in North America. By Weeden, Shelton, Li and Hoffman (eds.) http://www.nysaes.cornell.edu/ent/biocontrol/
  - Association of Natural Biocontrol Producers http://www.anbp.org/

Techniques in Biological Control (BC)

- Inoculative or classical BC
- Inundative or Augmented BC
- Conservation BC



The yellowjacket Vespula squamosa is often thought of as a nuisance, but also feeds on pests such as caterpillars.

Inoculative or Classical BC

- Approach used for accidentally introduced pests
- Works best on islands (geographic or ecological), for perennial crops, sedentary pests, crops tolerant of damage
- Requires quarantine and regulatory oversight to avoid mistakes
- Search center of origin of pest for effective beneficial (may be at low density); assumes that there is ecological “balance” there.
- Goal is permanent establishment of beneficial.

Some terminology related to BC

- Terminology concerning the origin/distribution of animals is confusing, and sometimes misapplied
  - Indigenous = native (sometimes but incorrectly called endemic)
    - Precinctive = indigenous, and the organism is restricted to the area specified
    - Indigenous but not precinctive = native to the area specified and elsewhere
  - Adventive = non-native; arrived from elsewhere
    - Immigrant = not native and arrived by hitchhiking or by its own powers
    - Introduced = not native and arrived by purposeful introduction

Inoculative BC

- Sometimes it is difficult to determine which natural enemy to introduce; may be rare in natural environment
- Good to study in native environment, but may be necessary to use quarantine
- In quarantine, beneficials evaluated for: freedom from disease and parasites, biological traits such as reproductive rate, adaptability to temperatures, host range, etc.

Inoculative BC

- Several separate introductions of different genetic material from separate portion of the insect's range may be needed to provide diversity, and adaptability to new climate.
- Also, repeated attempts at introduction are fairly common.
- Sometimes there is a period of adaptation and poor results, after which the introduced agent becomes more effective.

Inoculative BC

- In special cases “disturbed” areas freed of beneficials may require seasonal re-inoculation.
- Atriums, livestock feedlots, and temporary mosquito-producing pools are good examples of areas requiring annual or seasonal inoculation, but annual food crops and flower beds also sometimes are inoculated.
- Sometimes inoculative and inundative approaches overlap.

Inundative or Augmented BC

- Use of a BC agent as a biopesticide, with pest population flooded by releases of lab-reared/cultured beneficials.
- Don’t rely on in-field propagation of beneficials.
- Requires that beneficial be easily and economically cultured, and services may be provided with product.
- Careful monitoring to maintain correct ratio of beneficial to pests is important, and protection of the beneficials is a consideration.
- Greenhouses and feedlots are common sites for inundative releases, but nearly any pest targeted by steinernematid or heterorhabditid nematodes is an inundative process.

Conservation BC

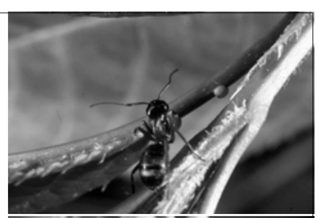
- Two complementary approaches:
  - Avoid destruction of natural enemies by insecticides
  - Improve environmental conditions to enhance survival and activities of BC agents
- Selectivity of insecticides is based on timing, placement, or differential toxicity.
  - Timing difficult to manage.
  - Placement easier if natural enemies occupy refugia or zones different from the pests
  - Differential toxicity relatively easy to implement

Improving the Environment for Conservation BC

- Alternative prey is sometimes helpful in maintaining predator and parasite population in the absence of the primary host, though specific natural enemies are preferred.
- Flowers seem to be important food resources for adult predators and parasites, so crop edges, ground cover or strips managed.

Larra bicolor is a sphecid ectoparasitoid of mole crickets (above right). It was imported to Florida to suppress invading mole crickets. The distribution of Larra is limited by availability of adult food resources, largely the flowering plant Spermacoce verticillata (below right). Where planted, such as around golf courses, this plant boosts the population of parasitic wasps.

Flowers are not only source of nectar, as many plants possess extrafloral nectaries. The nectaries are highly attractive to predators and parasites, and can be found on some crops and many weeds. Reservation of such plants enhances activity of beneficials. At right you can see ants feeding at the extrafloral nectar-producing glands on Passiflora. The glands take many shapes.



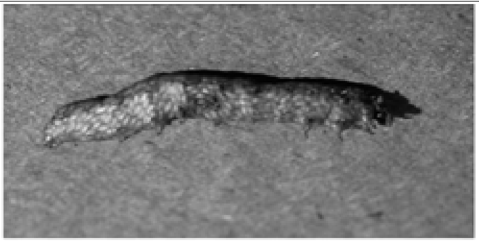
Earwigs can be important predators, but often are overlooked because they are nocturnal. By placing shelters in an orchard (right and below) earwig survival increases, affording better biological control.

Failures in BC

- Principal reasons involve:
  - Climatic mismatching.
  - Absence of flowers or alternative prey.
  - Selection of poor natural enemies, or species affected by disease or parasites.
  - Habitat or cultural conditions unsuitable for BC.
  - Cultural practices disruptive.
  - Insecticides disruptive.

Practice Quiz

- On the next slide, there is an interactive quiz based on the information and photographs in this section. Use it to test your comprehension of this lesson.
- The questions are randomly generated, so take the quiz more than once for more questions!



Question #1
This cutworm is "lumpy" appearing because:

Questions

- How widespread is biological control (BC)? Why is it not more widespread?
- Can you describe the advantages and disadvantages of BC?
- What are the principal characteristics of predators? Parasitoids? Nematodes?
- Can you list 10 families of insects that are important predators? 5 families of parasitoids? 3 families of nematodes?
- Damsel, big-eyed, and pirate bugs are common in agricultural environments. How can you distinguish them?

More questions

- Can you name 3 families of flies in which the larvae are important aphid predators?
- Are wasps predators or parasitoids? Document your position with examples.
- Is introduction of predators always beneficial? Why or why not?
- How do steinernematid nematodes enter their host? What makes them so suitable for commercialization?
- Distinguish between inoculative, inundative, and conservation BC.
- What can be done to enhance conservation BC?

Questions from supplementary readings

- Reading 23, Release of Bemisia parasitoids
  - What were the problems that confronted biological control of Bemisia? Do you think this is very different than what confronts us with other invaders?
  - Why were collections of biocontrol agents made in various parts of the world?
  - Why would transplants containing Bemisia be introduced into the field? What is this practice called?
  - Did native parasitoids adapt and become more important over time?

Questions from supplementary readings

- Reading 25, Classical BC in 21st century
  - If classical biocontrol has been “oversold,” why is there continuing interest in this approach?
  - What benefits accrue from effective biocontrol besides economic benefits?
  - What is a “rogue” biocontrol agent?
  - Is importation of exotic flora and fauna adequately regulated?
  - Explain the importantance of host specificity in biocontrol.

Questions from supplementary readings

- Reading 27, Augmentation in orchards
  - Why are orchards considered a good site for biocontrol?
  - Are all Trichogramma species equivalent with respect to pest suppression?
  - How does distribution of released Trichogramma affect parasitism rates?
  - How does Trichogramma longevity affect releases?

View a Short Video on Biological Control