Biological pest control

The current scope of this article does not include composting techniques. For these see Composting: Destroying pathogens, seeds, or unwanted plants or Mulch: Mulching (composting) over unwanted plants.

Biological control is a bioeffector-method of controlling pests (including insects, mites, weeds and plant diseases) using other living organisms.[1] It relies on predation, parasitism, herbivory, or other natural mechanisms, but typically also involves an active human management role. It can be an important component of integrated pest management (IPM) programs. There are three basic types of biological pest control strategies: importation (sometimes called classical biological control), augmentation and conservation.

Natural enemies of insect pests, also known as biological control agents, include predators, parasitoids, and pathogens. Biological control agents of plant diseases are most often referred to as antagonists. Biological control agents of weeds include seed predators, herbivores and plant pathogens.

1 Types of biological pest control

There are three basic types of biological pest control strategies: importation (sometimes called classical biological control), augmentation and conservation.[2]

1.1 Importation

Importation (or "classical biological control") involves the introduction of a pest's natural enemies to a new locale where they do not occur naturally. This is usually done by government authorities. In many instances the complex of natural enemies associated with a pest may be inadequate, a situation that can occur when a pest is accidentally introduced into a new geographic area, without its associated natural enemies. These introduced pests are referred to as exotic pests and comprise about 40% of the insect pests in the United States.

The process of importation involves determining the origin of the introduced pest and then collecting appropriate natural enemies associated with the pest or closely related species. Selected natural enemies are then passed through a rigorous assessment, testing and quarantine process, to ensure that they will work and that no unwanted organisms (such as hyperparasitoids) are introduced. If these procedures are passed, the selected natural enemies are mass-produced and then released. Follow-up studies are conducted to determine if the natural enemy becomes successfully established at the site of release, and to assess the long-term benefit of its presence.

To be most effective at controlling a pest, a biological control agent requires a colonizing ability which will allow it to keep pace with the spatial and temporal disruption of the habitat. Its control of the pest will also be greatest if it has temporal persistence, so that it can maintain its population even in the temporary absence of the target species, and if it is an opportunistic forager, enabling it to rapidly exploit a pest population.[3] However an agent with such attributes is likely to be non-host specific, which is not ideal when considering its overall ecological impact, as it may have unintended effects on non-target organisms.

There are many examples of successful importation programs, including:

- Joseph Needham noted a Chinese text dating from 304AD, *Records of the Plants and Trees of the Southern Regions*, by Hsi Han, which describes mandarin oranges protected by biological pest control techniques that are still in use today.

- One of the earliest successes in the west was in controlling *Icerya purchasi*, the cottony cushion scale, a pest that was devastating the California citrus industry in the late 19th century. A predatory insect *Rodolia cardinalis* (the Vedalia Beetle), and a parasitoid fly were introduced from Australia by Charles Valentine Riley. Within a few years the cottony cushion scale was completely controlled by these introduced natural enemies.

- Damage from *Hypera postica* Gyllenhal, the alfalfa weevil, a serious introduced pest of forage, was substantially reduced by the introduction of several natural enemies. 20 years after their introduction the population of weevils in the alfalfa area treated for alfalfa weevil in the Northeastern United States was reduced by 75 percent.

- A small wasp, *Trichogramma ostriniae*, was introduced from China to help control the European corn borer (*Ostrinia nubilalis*), one of the most destructive insects in North America, making it a recent example of a long history of classical biological control efforts for this major pest.

- The population of *Levuana iridescens* (the Levuana moth), a serious coconut pest in Fiji, was brought under control by a classical biological control program in the 1920s.

Classical biological control is long lasting and inexpensive. Other than the initial costs of collection, importation, and rearing, little expense is incurred. When a natural enemy is successfully established it rarely requires additional input and it continues to kill the pest with no direct help from humans and at no cost. However importation does not always work. It is usually most effective against exotic pests and less so against native insect pests. The reasons for failure are not often known but may include the release of too few individuals, poor adaptation of the natural enemy to environmental conditions at the release location, and lack of synchrony between the life cycle of the natural enemy and host pest.

1.2 Augmentation

Augmentation involves the supplemental release of natural enemies, boosting the naturally occurring population. Relatively few natural enemies may be released at a critical time of the season (inoculative release) or millions may be released (inundative release). An example of inoculative release occurs in greenhouse production of several crops. Periodic releases of the parasitoid, *Encarsia formosa*, are used to control greenhouse whitefly, and the predatory mite *Phytoseiulus persimilis* is used for control of the two-spotted spider mite. Lady beetles, lacewings, or parasitoids such as those from the genus *Trichogramma* are frequently released in large numbers (inundative release). Recommended release rates for Trichogramma in vegetable or field crops range from 5,000 to 200,000 per acre (1 to 50 per square metre) per week depending on level of pest infestation. Similarly, entomopathogenic nematodes are released at rates of millions and even billions per acre for control of certain soil-dwelling insect pests.

Hippodamia convergens, the convergent lady beetle, is commonly sold for biological control of aphids.

The spraying of octopamine analogues (such as 3-FMC) has been suggested as a way to boost the effectiveness of augmentation. Octopamine, regarded as the invertebrate counterpart of dopamine plays a role in activating the insects' flight-or-fight response. The idea behind using octopamine analogues to augment biological control is that natural enemies will be more effective in their eradication of the pest, since the pest will be behaving in an unnatural way because its flight-or-fight mechanism has been activated. Octopamine analogues are purported to have two desirable characteristics for this type of application: (1) they affect insects at very low dosages (2) they do not have a physiological effect in humans (or other vertebrates).[4]

1.3 Conservation

The conservation of existing natural enemies in an environment is the third method of biological pest control. Natural enemies are already adapted to the habitat and to the target pest, and their conservation can be simple and cost-effective. Lacewings, lady beetles, hover fly larvae, and parasitized aphid mummies are almost always present in aphid colonies.

A turnaround flowerpot, filled with straw to attract Dermaptera-species

Cropping systems can be modified to favor the natural enemies, a practice sometimes referred to as habitat manipulation. Providing a suitable habitat, such as a shelterbelt, hedgerow, or beetle bank where beneficial insects can live and reproduce, can help ensure the survival of populations of natural enemies. Things as simple as leaving a layer of fallen down leaves or mulch in place provides a suitable food source for worms and provides a shelter for small insects, in turn also providing a food source for hedgehogs and shrew mice. Compost pile(s) and containers for making leaf compost also provide shelter, as long as they are accessible by the animals (not fully closed). A stack of wood may provide a shelter for voles, hedgehogs, shrew mice, some species of butterflies, ... Long grass and ponds provide shelters for frogs and toads (which themselves eat snails). Not cutting any annual or other non-hardy plants before winter (but instead in spring) allows many insects to make use of their hollow stems during winter.[5] In California prune trees are sometimes planted in grape vineyards to provide an improved overwintering habitat or refuge for a key grape pest parasitoid. The prune trees harbor an alternate host for the parasitoid, which could previously overwinter only at great distances from most vineyards. The provisioning of artificial shelters in the form of wooden caskets, boxes or flowerpots is also sometimes undertaken, particularly in gardens, to make a cropped area more attractive to natural enemies. For example, the stimulation of the natural predator *Dermaptera* is done in gardens by hanging upside-down flowerpots filled with straw or wood wool. Green lacewings are given housing by using plastic bottles with an open bottom and a roll of cardboard inside of it.[5] Birdhouses provide housing for birds, some of whom eat certain pests. Attracting the most useful birds can be done by using a correct diameter opening in the birdhouse (just large enough for the specific species of bird that needs to be attracted to fit through, but not other species of birds).

Besides the provisioning of natural or artificial housing, the providing of nectar-rich plants is also beneficial. Often, many species of plants are used so as to provide food for many natural predators, and this for a long period of time (this is done by using different types of plants as each species only blooms for a short period). It should be mentioned that many natural predators are nectivorous during the adult stage, but parasitic or predatory as larvae. A good example of this is the soldier beetle which is frequently found on flowers as an adult, but whose larvae eat aphids, caterpillars, grasshopper eggs, and other beetles. Letting certain plants (as Helianthus spp, Rudbeckia spp, Dipsacus spp, Echinacea spp) come into seed is also advised, to supply food for birds. Having some trees or shrubs in place that carry berries is also practiced and provide a source of food for birds. Often, trees/shrubs are used that do not produce berries fit for human consumption, avoiding food competition. Examples are Sorbus spp, Amelanchier spp, Crataegus spp, Sambucus nigra, Ilex aquifolium, Rhamnus frangula. Obviously for this to work, these trees can not be pruned/trimmed until after the birds and other animals have eaten all of the berries.

Also, the providing of host plants (plants on which organisms can lay their eggs) may also be necessairy. These organisms for which host plants can be foreseen can be certain natural predators, caterpillars, and even a limited amount of host plants for pests can be tolerated. The latter ensures that natural predators remain in the vicinity and tolerating a certain amount of loss to pests would be needed anyhow since no chemical pesticides can be used (organic pesticides can be used but often can, on itself, not eliminate all pests during an infestation). This, as natural predators are susceptible to the same pesticides used to target pests. Plants for caterpillars are optional and only ensure that sufficient amounts of moths are produced which form a source of food to bats. Bats may be wanted as they also consume large amounts of mosquitoes, which despite not targeting any plants, can still be a nuisance to people in areas where there is much standing water nearby (i.e. pond, creek, ...).

Conservation strategies such as mixed plantings and the provision of flowering borders can be more difficult to accommodate in large-scale crop production. There may also be some conflict with pest control for the large producer, because of the difficulty of targeting the pest species, also refuges may be utilised by the pest insects as well as by natural enemies. Some plants that are attractive to natural enemies may also be hosts for certain plant diseases, especially plant viruses that could be vectored by insect pests to the crop.

2 Biological control agents

2.1 Predators

Lacewings are available from biocontrol dealers.

Predators are mainly free-living species that directly consume a large number of prey during their whole lifetime.

Ladybugs, and in particular their larvae which are active between May and July in the northern hemisphere, are voracious predators of aphids, and will also consume mites, scale insects and small caterpillars.

The larvae of many hoverfly species principally feed upon greenfly, one larva devouring up to fifty a day, or 1000 in its lifetime. They also eat fruit tree spider mites and small caterpillars. Adults feed on nectar and pollen, which they require for egg production.

Predatory Polistes wasp looking for bollworms or other caterpillars on a cotton plant

Dragonflies are important predators of mosquitoes, both in the water, where the dragonfly naiads eat mosquito larvae, and in the air, where adult dragonflies capture and eat adult mosquitoes. Community-wide mosquito control programs that spray adult mosquitoes also kill dragonflies, thus reducing an important biocontrol agent.

Several species of entomopathogenic nematode are important predators of insect pests.[6] *Phasmarhabditis hermaphrodita* is a microscopic nematode that kills slugs, thereafter feeding and reproducing inside. The nematode is applied by watering onto moist soil, and gives protection for up to six weeks in optimum conditions.

Other useful garden predators include lacewings, pirate bugs, rove and ground beetles, aphid midge, centipedes, spiders, predatory mites, as well as larger fauna such as frogs, toads, lizards, hedgehogs, slow-worms and birds. Cats and rat terriers kill field mice, rats, June bugs, and birds. Dachshunds are bred specifically to fit inside tunnels underground to kill badgers.

More examples:

- *Phytoseiulus persimilis* (against spider mites)
- *Amblyseius californicus* (against spider mites)
- *Amblyseius cucumeris* (against spider mites)[7]
- *Typhlodromips swirskii* (against spider mites, thrips, and white flies)
- *Feltiella acarisuga* (against spider mites)
- *Stethorus punctillum* (against spider mites)
- *Macrolophus caluginosus* (against spider mites)

2.2 Parasitoid insects

Parasitoids lay their eggs on or in the body of an insect host, which is then used as a food for developing larvae. The host is ultimately killed. Most insect parasitoids are wasps or flies, and usually have a very narrow host range.

Four of the most important groups are:

- Ichneumonid wasps: (5–10 mm). Prey mainly on caterpillars of butterflies and moths.
- Braconid wasps: Tiny wasps (up to 5 mm) attack caterpillars and a wide range of other insects including greenfly. A common parasite of the cabbage white caterpillar- seen as clusters of sulphur yellow cocoons bursting from collapsed caterpillar skin.
- Chalcid wasps: Among the smallest of insects (<3 mm). Parasitize eggs/larvae of greenfly, whitefly, cabbage caterpillars, scale insects and Strawberry Tortrix Moth (*Acleris comariana*).
- Tachinid flies: Parasitize a wide range of insects including caterpillars, adult and larval beetles, true bugs, and others.

Examples of parasitoids:

Encarsia formosa was one of the first biological control agents developed.

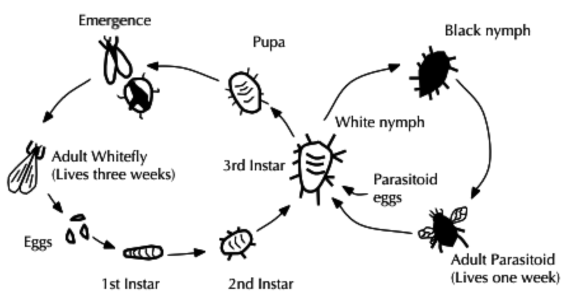

Diagram illustrating the life cycles of Greenhouse whitefly and its parasitoid wasp Encarsia formosa

- *Encarsia formosa* A small predatory chalcid wasp which is a parasitoid of whitefly, a sap-feeding insect which can cause wilting and black sooty moulds. It is most effective when dealing with low level infestations, giving protection over a long period of time. The wasp lays its eggs in young whitefly 'scales', turning them black as the parasite larvae pupates.

- *Eretmocerus* spp. (against white flies)[8]

- *Aphidius colemani* (against aphids)

- *Gonatocerus ashmeadi* (Hymenoptera: Mymaridae) has been introduced to control the glassy-winged sharpshooter *Homalodisca vitripennis* (Hemipterae: Cicadellidae) in French Polynesia and has successfully controlled ~95% of the pest density.[9]

Parasitoids are one of the most widely used biological control agents. Commercially there are two types of rearing systems: short-term daily output with high production of parasitoids per day, and long-term low daily output with a range in production of 4-1000million female parasitoids per week.[10] Larger production facilities produce on a yearlong basis, whereas some facilities will produce only seasonally.

Rearing facilities are usually a significant distance from where the agents will be used in the field, and transporting the parasitoids from the point of production to the point of use can pose problems. Shipping conditions can be too hot, and even vibrations from planes or trucks can disrupt the parasitoids.[10]

2.3 Micro-organisms

Further information: biopesticide

Pathogenic micro-organisms include bacteria, fungi, and viruses. They kill or debilitate their host and are relatively host-specific. Various microbial insect diseases occur naturally, but may also be used as biological pesticides. When naturally occurring, these outbreaks are density-dependent in that they generally only occur as insect populations become denser.

2.3.1 Bacteria

Bacteria used for biological control infect insects via their digestive tracts, so insects with sucking mouth parts like aphids and scale insects are difficult to control with bacterial biological control.[11] *Bacillus thuringiensis* is the most widely applied species of bacteria used for biological control, with at least four sub-species used to control Lepidopteran (moth, butterfly), Coleopteran (beetle) and Dipteran (true flies) insect pests. The bacteria is available in sachets of dried spores which are mixed with water and sprayed onto vulnerable plants such as brassicas and fruit trees. Bacillus thuringiensis has also been incorporated into crops, making them resistant to these pests and thus reducing the use of pesticides.

2.3.2 Fungi

Fungi that cause disease in insects are known as entomopathogenic fungi, including at least fourteen species that attack aphids.[12] *Beauveria bassiana* is used to manage a wide variety of insect pests including: whiteflies, thrips, aphids and weevils. A remarkable additional feature of some fungi is their effect on plant fitness. *Trichoderma* species may enhance biomass production promoting root development, dissolving insoluble phosphate containing minerals.

Examples of entomopathogenic fungi:

- *Beauveria bassiana* (against white flies, thrips, aphids and weevils)

- *Paecilomyces fumosoroseus* (against white flies, thrips and aphids)

- *Metarhizium* spp. (against beetles, locusts and grasshoppers, Hemiptera, spider mites and other pests)

- *Lecanicillium* spp. (against white flies, thrips and aphids)

- *Cordyceps* species (includes teleomorphs of the above genera: that infect a wide spectrum of arthropods)

- *Trichoderma* species are used to manage certain plant pathogens. *Trichoderma viride* has been used against Dutch Elm disease, and to treat the spread of fungal and bacterial growth on tree wounds. It may also have potential as a means of combating silver leaf disease.

Several members of Chytridiomycota and Blastocladiomycota have been explored as agents of biological control. From Chytridiomycota, *Synchytrium solstitiale* is being considered as a control agent of the yellow star thistle (*Centaurea solstitialis*) in the United States.[13] *Synchytrium minutum* occasionally parasitizes kudzu and was considered as a control agent against this weed outside of its native range, but *S. minutum* parasitizes agricultural crop plants more frequently than it parasitizes kudzu.[14] Batrachochytrium dendrobatidis was briefly considered and soundly rejected as a means of controlling invasive frog populations in Hawaii.[15] From Blastocladiomycota, certain members of Coelomomyces were explored as possible agents of biological control of mosquitoes.[16]

The European Rabbit (Oryctolagus cuniculus) is seen as a major pest in Australia and New Zealand.

2.3.3 Viruses

- A viral biological control that can be introduced in order to control the overpopulation of European rabbit in Australia is the rabbit haemorrhagic disease virus that causes the rabbit haemorrhagic disease.

2.4 Combined use of parasitoids and pathogens

In cases of massive and severe infection of invasive pests, techniques of pest control are often used in combination. An example being, that of the emerald ash borer (*Agrilus planipennis* Fairmaire, family Buprestidae), an invasive beetle from China, which has destroyed tens of millions of ash trees in its introduced range in North America. As part of the campaign against the emerald ash borer (EAB), American scientists in conjunction with the Chinese Academy of Forestry searched since 2003 for its natural enemies in the wild leading to the discovery of several parasitoid wasps, namely *Tetrastichus planipennisi*, a gregarious larval endoparasitoid,*Oobius agrili*, a solitary, parthenogenic egg parasitoid, and *Spathius agrili*, a gregarious larval ectoparasitoid. These have been introduced and released into the United States of America as a possible biological control of the emerald ash borer. Initial results have shown promise with *Tetrastichus planipennisi* and it is now being released along with *Beauveria bassiana*, a fungal pathogen with known insecticidal properties.[17][18][19]

2.5 Plants

The legume vine *Mucuna pruriens* is used in the countries of Benin and Vietnam as a biological control for problematic *Imperata cylindrica* grass. *Mucuna pruriens* is said not to be invasive outside its cultivated area.[20] *Desmodium uncinatum* can be used in push-pull farming to stop the parasitic plant, *Striga*.[21]

2.6 Indirect control

Pests may be controlled by biological control agents that do not prey directly upon them. For example the Australian bush fly, *Musca vetustissima*, is a major nuisance pest in Australia, but native decomposers found in Australia are not adapted to feeding on cow dung, which is where bush flies breed. Therefore the Australian Dung Beetle Project (1965–1985,) led by Dr. George Bornemissza of the Commonwealth Scientific and Industrial Research Organisation, released forty-nine species of dung beetle,[22] with the aim of reducing the amount of dung and therefore also breeding sites of the fly.[23]

3 Effects of biological control

3.1 Effects on native biodiversity

The cane toad, Bufo marinus

Biological control can potentially have positive and negative effects on biodiversity.[3] The most common problems with biological control occur via predation, parasitism, pathogenicity, competition, or other attacks on non-target species.[24] Often a biological control agent is imported into an area to reduce the competitive advantage of an exotic species that has previously invaded or been introduced there, the aim being to thereby protect the existing native species and ecology. However the introduced control does not always target only the intended species; it can also target native species.[25] In Hawaii during the 1940s parasitic wasps were introduced to control a lepidopteran pest and the wasps are still found there today. This may have a negative impact on the native ecosystem, however, host range and impacts need to be studied before declaring their impact on the environment.[26]

Over the past 15 years with the rise in biological control interest there has become a greater focus on the non-target impacts that could occur.[3] In the past many biological control releases were not thoroughly examined and agents of biological control were released without any consideration. When introducing a biological control agent to a new area, a primary concern is its host-specificity. Generalist feeders (control agents that are not restricted to preying on a single species or a small range of species) often make poor biological control agents, and may become invasive species themselves. For this reason potential biological control agents should be subject to extensive testing and quarantine before release into any new environment. If a species is introduced and attacks a native species, the biodiversity in that area can change dramatically. When one native species is removed from an area, it may have filled an essential ecological niche. When this niche is absent it may directly affect the entire ecosystem.

Vertebrate animals tend to be generalist feeders, and seldom make good biological control agents; many of the classic cases of "biocontrol gone awry" involve vertebrates. For example the cane toad, *Bufo marinus*, was intentionally introduced to Australia to control the introduced French's Cane Beetle and the Greyback Cane Beetle,[27] pests of sugar cane. 102 toads were obtained from Hawaii and bred in captivity to increase their numbers until they were released into the sugar cane fields of the tropic north in 1935. It was later discovered that the toads could not jump very high and so they could not eat the cane beetles which stayed up on the upper stalks of the cane plants. However the toad thrived by feeding on other insects and it soon spread very rapidly; it took over native amphibian habitat and brought foreign disease to native toads and frogs, dramatically reducing their populations. Also when it is threatened or handled, the cane toad releases poison from parotid glands on its shoulders; native Australian species such as goannas, tiger snakes, dingos and northern quolls that attempted to eat the toad were harmed or killed.[28] This example shows how small mis-introduced organisms can alter the native biodiversity in large ecosystems. If native species are reduced or eradicated, a domino effect can take place until a new equilibrium is reached.

Other examples of biological control agents that subsequently crossed over to native species are:

- *Rhinocyllus conicus*, a seed-feeding weevil, was introduced to North America to control exotic thistles (Musk and Canadian). However the weevil does not target only the exotic thistles; it also targets native thistles that are essential to various native insects which rely solely on native thistles and do not adapt to other plant species.
- The mongoose was introduced to Hawaii in order to control the rat population. However it preyed on the endemic birds of Hawaii, especially their eggs, more often than it ate the rats. (Note, however, that the introduction of the mongoose was not undertaken based on scientific—or perhaps any—understanding of the consequences of such an action. The introduction of a generalist mammal for biocontrol of anything would be unthinkable by any reasonable standards today.)
- 5 cats brought to the subantarctic Prince Edward Islands to catch mice in 1949 multiplied to 3,400 in about two decades and started to threaten local extinction of birds. They had to be infected with feline distemper virus. The rest were shot and completely eliminated by the 1990s.
- The sturdy and prolific mosquito fish was introduced from around the Gulf of Mexico to around the world in the 1930s and 40s to combat malaria; however, it was found to cause the decline of local fish and frogs through competition of other food source as well as eating their eggs.[29] (See Mosquitofish in Australia)

Living organisms, through the process of evolution, may achieve increased resistance to biological, chemical, and physical methods of control over time. In the event the target pest population is not completely exterminated or is still capable of reproduction (were the pest control means a form of sterilization), the surviving population could acquire a tolerance to the applied pressures - this can result in an evolutionary arms race with the control method. Successful biological control reduces the population density of the target species over several years, thus providing the potential for native species to re-establish. In addition, regeneration and reestablishment programs can aid the recovery of native species. To develop or find a biological control that exerts control only on the targeted species is a very lengthy process of research and experiments.

3.2 Effects on invasive species

The invasive species Alternanthera philoxeroides *(alligator weed) was controlled in* Florida *(U.S.) by the introduction of* Agasicles hygrophila *(alligator weed flea beetle)*

Biological control programs aim to reduce or eliminate populations of ecologically and agriculturally harmful invasive species. Examples where this has been achieved include:

- The alligator weed[30] was introduced to the United States from South America. This aquatic weed spreads rapidly and causes many problems in lakes and rivers. The weed takes root in shallow water causing major problems for navigation, irrigation, and flood control. The alligator weed flea beetle and two other biological controls were released in Florida. Because of their success, Florida banned the use of herbicides to control alligator weed three years after the controls were introduced.[31]
- *Galerucella calmariensis*, a leaf beetle, has been introduced in North America as a control agent for purple loosestrife (*Lythrum salicaria*).
- In the late 19th century cottony cushion scale was discovered in the Californian citrus industry, and it was feared that severe economic losses would result. However the vedalia beetle and, subsequently, *Cryptochaetum iceryae*, a parasitoid fly, were introduced to control the pest. Within a few years the cottony cushion scale was controlled and the citrus industry suffered little financial loss.
- *Salvinia molesta* is a major aquatic weed. It covers many waterways causing damage to water flow and the ecosystem. This weed was incorrectly identified at first. Scientists found weevils eating this weed. They named this species of weevils *C. salviniae*. The weevils have become a great biological control success for all countries.[32]
- Prickly pear cacti, Opuntia spp., were introduced into Queensland, Australia as an ornamental plant. It quickly spread to cover over 25 million hectares of Australia. Two control agents were used to help control the spread of the plant. These were *C. cactorum*, a Lepidopteran species, and Dactylopius spp., a Hemipteran species.[33]

4 Grower education

A potential obstacle to the adoption of biological pest control measures is growers sticking to the familiar use of pesticides, particularly since it has been claimed that many of the pests that are controlled today using pesticides, actually became pests because pesticide use reduced or eliminated natural predators.[34] A method of increasing grower adoption of biocontrol involves letting growers learn by doing, for example showing them simple field experiments, having observations of live predation of pests, or collections of parasitised pests. In the Philippines, early season sprays against leaf folder caterpillars were common practice, but growers were asked to follow a 'rule of thumb' of not spraying against leaf folders for the first 30 days after transplanting; participation in this resulted in a reduction of insecticide use by 1/3 and a change in grower perception of insecticide use.[35]

5 See also

- Association of Natural Biocontrol Producers
- Beneficial insects
- Biological pesticide
- Chitosan (Natural Biocontrol for Agricultural & Horticultural use)
- Companion planting
- Insectary plants
- International Organization for Biological Control
- Inundative application
- Japanese beetle (article includes information on biological control methods)
- Mating disruption
- Nematophagous fungus
- Organic gardening
- Organic farming
- Pest control
- Permaculture zone 5: leaving an environment as is also sparks the creation of natural predators for areas that *are* under cultivation
- Sterile insect technique
- Sustainable farming
- Sustainable gardening

6 References

[1] Flint, Maria Louise & Dreistadt, Steve H. (1998). Clark, Jack K., ed. *Natural Enemies Handbook: The Illustrated Guide to Biological Pest Control*. University of California Press. ISBN 978-0-520-21801-7.

[2] "Biological control: Approaches and Applications". University of Minnesota. Retrieved 3 September 2012.

[3] Follett PA, Duan JJ (2000) 'Nontarget effects of biological control.' (Kluwer Academic Publishers).

[4] "the only biogenic amines whose physiological significance is presumably restricted to invertebrates, pharmacologists have focused their attention on the corresponding receptors, which are still believed to represent promising targets for new insecticides" TYRAMINE AND OCTOPAMINE: Ruling Behavior and Metabolism T Roeder - Annual Review of Entomology, 2005 - Annual Reviews

[5] HDRA Encyclopedia of Organic Gardening by Pauline Spears

[6] Kaya, Harry K. et al. (1993). "An Overview of Insect-Parasitic and Entomopathogenic Nematodes". In Bedding, R.A. *Nematodes and the Biological Control of Insect Pests*. CSIRO Publishing. ISBN 978-0-643-10591-1.

[7] Spider mites and their natural enemies

[8] White flies and their natural enemies

[9] Hoddle M.S., Grandgirard J., Petit J., Roderick G.K., Davies N. (2006). "Glassy-winged sharpshooter Ko'ed - First round - in French Polynesia". *Biocontrol News and Information* **27** (3): 47N–62N.

[10] Smith SM (1996) Biological control with Trichogramma: advances, successes, and potential of their use. In 'Annual Review of Entomology' pp. 375–406.

[11] L.A. Swan. 1964. Beneficial Insects. 1st ed. page 249.

[12] I.M. Hall & P.H. Dunn, Entomophthorous Fungi Parasitic on the Spotted Alfalfa Aphid, Hilgardia, Sept 1957.

[13] Voigt K., A.V. Marano, & F.H. Gleason. 2013. Ecological & Economical Importance of Parasitic Zoosporic True Fungi. *in*: The Mycota: A Comprehensive Treatise on Fungi as Experimental Systems for Basic & Applied Research Vol. 11 Agricultural Applications. 2nd edition Eds: K. Esser & F. Kempken. Springer: New York pg. 243–270.

[14] Li Z., Q. Dong, T.P. Albright, & Q. Guo. 2011. Natural and human dimensions of a quasi-natural wild species: the case of kudzu. Biological Invasions 13:2167–2179.

[15] Beard, Karen H., and Eric M. O'Neill. "Infection of an invasive frog *Eleutherodactylus coqui* by the chytrid fungus *Batrachochytrium dendrobatidis* in Hawaii." Biological Conservation 126.4 (2005): 591-595.

[16] Sparrow FK. 1960. Aquatic Phycomyetes. The University of Michigan Press:Ann Arbor. 2nd edition

[17] Gould, Juli; Bauer, Leah. "Biological Control of Emerald Ash Borer (*Agrilus planipennis*)". *Animal and Plant Health Inspection Service (APHIS) website* (United States Department of Agriculture). Retrieved 28 April 2011

[18] Bauer, L.S.; Liu, H-P; Miller, D.; Gould, J. (2008). "Developing a classical biological control program for Agrilus planipennis (Coleoptera: Buprestidae), an invasive ash pest in North America". *Newsletter of the Michigan Entomological Society* **53** (3&4): 38–39. Retrieved 29 April 2011.

[19] "Biocontrol: Fungus and Wasps Released to Control Emerald Ash Borer". *Science News*. ScienceDaily. 26 April 2011. Retrieved 27 April 2011.

[20] "Factsheet - Mucuna pruriens". www.tropicalforages.info. Retrieved 2008-05-21.

[21] Khan, Z.; Midega, C. A. O.; Amudavi, D. M.; Hassanali, A.; Pickett, J. A. (2008). "On-farm evaluation of the 'push–pull' technology for the control of stemborers and striga weed on maize in western Kenya". *Field Crops Research* **106** (3): 224–233. doi:10.1016/j.fcr.2007.12.002.

[22] Bornemissza, G. F. (1976), The Australian dung beetle project 1965–1975, *Australian Meat Research Committee Review* 30:1-30

[23] http://www.csiropedia.csiro.au/display/CSIROpedia/Dung+beetle+program

[24] Council NR (1996) 'Ecologically Based Pest Management:New Solutions for a New Century.' (The National Academies Press)

[25] Society for Conservation Biology (2002), "Biocontrol backfires again," http://www.scienceblog.com/community/older/2002/C/20025043.html, accessed July 31, 2009.

[26] Wright MG, Hoffmann MP, Kuhar TP, Gardner J, Pitcher SA (2005) Evaluating risks of biological control introductions: A probabilistic risk-assessment approach. Biological Control 35, 338-347.

[27] "Cane Toad". *Exotic Animals - Major Pests*. Northern Territory Government, Australia. Retrieved 14 March 2011.

[28] http://fdrproject.org.au/pages/toads.htm

[29] National Research Council (U.S.). Board on Agriculture and Natural Resources (June 2000). *Incorporating science, economics, and sociology in developing sanitary and phytosanitary standards in international trade: proceedings of a conference*. National Academies Press. p. 97. ISBN 978-0-309-07090-4. Retrieved 12 August 2011.

[30] "Alternanthera philoxeroides information from NPGS/GRIN". www.ars-grin.gov. Retrieved 2008-08-09.

[31] Cofrancesco (2007)

[32] http://www.environment.gov.au/biodiversity/invasive/weeds/publications/guidelines/wons/pubs/s-molesta.pdf

[33] http://www.daff.qld.gov.au/documents/Biosecurity_EnvironmentalPests/IPA-Prickly-Pear-Control-PP29.pdf

[34] Thacker, J.R.M. 2002. An Introduction to Arthropod Pest Control. Cambridge University Press.

[35] Heong, K.L. and Escalada, M. M. 1998, Int. J. Pest Management 44: 191-197

7 Further reading

General

- Wiedenmann, R. (2000). Introduction to Biological Control. Midwest Institute for Biological Control. Illinois. Available from http://www.inhs.uiuc.edu/research/biocontrol
- Cowie R. H. (2001) "Can snails ever be effective and safe biocontrol agents?". *International Journal of Pest Management* **47**(1): 23-40. PDF
- Cooksey D. 2002. Biological Control in Pest Management Systems of Plants. Western Regional Committee, Riverside, CA.
- R. James Cook (September 1993). "Making Greater Use of Introduced Microorganisms for Biological Control of Plant Pathogens". *Annual Review of Phytopathology* **31**: 53–80. doi:10.1146/annurev.py.31.090193.000413. PMID 18643761.
- U.S. Congress, Office of Technology Assessment (1995). "Biologically based technologies for pest control" (PDF). *OTA-ENV-636* (US Government Printing Office, Washington, DC).
- Felix Wäckers, Paul van Rijn and Jan Bruin (2005). "Plant-Provided Food for Carnivorous Insects - a protective mutualism and its applications". Cambridge University Press, UK, 2005. ISBN 978-0-521-81941-1.

Effects on native biodiversity

- Pereira, M.J. et al. (1998) Conservation of natural vegetation in Azores Islands. Bol. Mus. Munic. Funchal 5, 299–305
- Weeden, C.R., A. M. Shelton, and M. P. Hoffman. Biological Control: A Guide to Natural Enemies in North America. Available from (accessed December 2007)
- Cane toad: a case study. 2003. Available from (accessed December 2007)
- Humphrey, J. and Hyatt. 2004. CSIRO Australian Animal Health Laboratory. *Biological Control of the Cane Toad Bufo marinus in Australia*
- Cory, J. and Myers, J. 2000. Direct and indirect ecological effects of biological control. Trends in Ecology & Evolution. 15, 4, 137-139.
- Johnson, M. 2000. Nature and Scope of Biological Control. *Biological Control of Pests*

Effects on invasive species

- Cofrancesco, A. 2007. U.S. National Management Plan: An Action Plant for the Nation- Control and Management. Army Corps of Engineers. Available from

Economic effects

- Griffiths, G.J.K. 2007. Efficacy and economics of shelter habitats for conservation. Biological Control: in press. doi:10.1016/j.biocontrol.2007.09.002
- Collier T. and Steenwyka, R. 2003. A critical evaluation of augmentative biological control. Economics of augmentation: 31, 245-256.

8 External links

- Biological Pest Control, National Invasive Species Information Center, United States National Agricultural Library. Lists general information and resources for biological pest control.
- Biological fight applied to the South countries - 10 minute video
- Biological Control: A Guide to Natural Enemies in North America
- Construction of a garden and implementation of natural pest control
- Educational movies about biological pest control of white flies, aphids and spider mites in greenhouses
- Association of Natural Biocontrol Producers Trade association of biological pest control industry
- International Organization for Biological Control
- Use of ionizing radiation in biological control

9 Text and image sources, contributors, and licenses

9.1 Text

- **Biological pest control** *Source:* http://en.wikipedia.org/wiki/Biological%20pest%20control?oldid=648162385 *Contributors:* Bryan Derksen, Tarquin, Nonenmac, Hephaestos, Quercusrobur, Kku, Menchi, Skysmith, Stan Shebs, Miocp, Milkfish, Nikai, Jengod, Pollinator, JorgeGG, Roscoe x, Sunray, Alan Liefting, Bobblewik, Toytoy, Williamb, Onco p53, JoJan, Heegoop, Discospinster, Cacycle, ESkog, Barfooz, Femto, Bobo192, Stesmo, Sendai, Storm Rider, Plumbago, Spangineer, Wtmitchell, Lerdsuwa, Kazvorpal, Ceyockey, Dwiki, CranialNerves, Woohookitty, Yansa, Rjwilmsi, Bhadani, Gumboot, Nihiltres, DVdm, WriterHound, Gwernol, Debivort, YurikBot, Wavelength, Waitak, Dialectric, Snek01, Cquan, Trollderella, Nick C, Zwobot, IceCreamAntisocial, Extraordinary, Shyam, Smurrayinchester, Sparkyboy, SmackBot, FocalPoint, Rex the first, KVDP, Cacuija, Ohnoitsjamie, Hmains, Hectorguinness, Chris the speller, Tree Biting Conspiracy, DHN-bot, Tamfang, Jefffire, Glloq, Decltype, Richard001, Just plain Bill, Kuzaar, Valfontis, Khazar, Jidanni, SilkTork, Mgiganteus1, Mr Stephen, Bendzh, Odedee, Hu12, Iridescent, Paul venter, Joseph Solis in Australia, Jsorens, CmdrObot, Philiptdotcom, AshLin, Outriggr, Meodipt, Alfirin, Vanished user vjhsduheuiui4t5hjri, Thijs!bot, Nick Number, Danielfolsom, Raupp, Prolog, Smartse, MER-C, Aderksen, Wasell, DerHexer, JaGa, Peter coxhead, Adriaan, CommonsDelinker, Nono64, Wiki Raja, Trusilver, Anandcv, All Is One, Mike Cherim, Dan bioline, Cobi, Biglovinb, Juliancolton, Raggz, Wakawakawakawaka, Agrihouse, Qbert203, Giancarlodessi, Falcon8765, Breghan, Bob Blaylock, SieBot, Funkamatic, Bugguyak, Yerpo, Bob98133, Lightmouse, Emesee, Beastinwith, Denisarona, ClueBot, Botanybob, Trfasulo, The Thing That Should Not Be, MikeVitale, Jboltonnal, Nkershner, Lumenos, Kjcamper, Addbot, Polinizador, DOI bot, Roy Bateman, Ka Faraq Gatri, MrOllie, LaaknorBot, Legobot, Luckas-bot, Amirobot, Nallimbot, AnomieBOT, Teratyke, Materialscientist, Furor1, Bob Burkhardt, ArthurBot, TheAMmollusc, Capricorn42, Nickkid5, Dr Oldekop, J04n, Anhydrobiosis, Sternmusik, Eugene-elgato, Thomasfutureco, FrescoBot, Alarics, Theowoo, Citation bot 1, Intelligentsium, Dickalan, Pinethicket, AQUIMISMO, Notedgrant, Jacarandatree, Missylisa153, Joeyn64, TobeBot, Animalparty, Vrenator, Çalıştay, Tbhotch, Andychuck, TjBot, Androstachys, EmausBot, Look2See1, Set theorist, Ezekiel.golan, Wikipelli, PhyllisWeintraub, Kingofaces42, Willyrubin, JTor, Rcsprinter123, Wikiproject1400, Donner60, ClueBot NG, PaleCloudedWhite, Mesoderm, Vibhijain, Helpful Pixie Bot, Vantado, BG19bot, Mohamed CJ, Think kittens, MKar, Northamerica1000, Lawrencehaynes, ILoveurmum, ChrisGualtieri, Khazar2, Tamarixia, Annie236, Lugia2453, Sidelight12, Lmile61, Jshi9908, Redddbaron, Ginsuloft, Dekayem, Gemeaiodorakk, Pdhruv755, TelosCricket, Monkbot, Vieque and Anonymous: 197

9.2 Images

- **File:Alternanthera_philoxeroides_NRCS-1.jpg** *Source:* http://upload.wikimedia.org/wikipedia/commons/c/ce/Alternanthera_philoxeroides_NRCS-1.jpg *License:* Public domain *Contributors:* http://en.wikipedia.org/wiki/Image:Alligator-Weed1web.jpg / http://plants.usda.gov *Original artist:* National Plant Data Center, Baton Rouge, LA 70874-4490 USA.
- **File:Bufo-marinus-1.jpg** *Source:* http://upload.wikimedia.org/wikipedia/commons/e/ee/Bufo-marinus-1.jpg *License:* GFDL *Contributors:* http://www.allemaal-beestjes.nl/cpg145/index.php *Original artist:* Patrick Gijsbers
- **File:Chrysopidae_3035.jpg** *Source:* http://upload.wikimedia.org/wikipedia/commons/5/56/Chrysopidae_3035.jpg *License:* CC-BY-SA-3.0 *Contributors:* Originally from en.wikipedia; description page is/was here. *Original artist:* Original uploader was Pollinator at en.wikipedia
- **File:Dermaptera_flowerpot.jpg** *Source:* http://upload.wikimedia.org/wikipedia/commons/4/47/Dermaptera_flowerpot.jpg *License:* Public domain *Contributors:* Own work *Original artist:* KVDP
- **File:Encarsia_formosa,_an_endoparasitic_wasp,_is_used_for_whitefly_control.jpg** *Source:* http://upload.wikimedia.org/wikipedia/commons/a/a7/Encarsia_formosa%2C_an_endoparasitic_wasp%2C_is_used_for_whitefly_control.jpg *License:* CC BY-SA 3.0 *Contributors:* Own work *Original artist:* Dekayem
- **File:France_Loiret_La_Bussiere_Potager_05.jpg** *Source:* http://upload.wikimedia.org/wikipedia/commons/f/f0/France_Loiret_La_Bussiere_Potager_05.jpg *License:* CC-BY-SA-3.0 *Contributors:* ? *Original artist:* ?
- **File:Hazardous-pesticide.jpg** *Source:* http://upload.wikimedia.org/wikipedia/commons/e/e7/Hazardous-pesticide.jpg *License:* Public domain *Contributors:* USDA – http://www.usda.gov/oc/photo/94cs3568.htm *Original artist:* Unknown
- **File:Lady_bugs_are_a_beneficial_insect_commonly_sold_for_biological_control_of_aphids..jpg** *Source:* http://upload.wikimedia.org/wikipedia/commons/f/f5/Lady_bugs_are_a_beneficial_insect_commonly_sold_for_biological_control_of_aphids..jpg *License:* CC BY-SA 3.0 *Contributors:* Own work *Original artist:* Dekayem
- **File:Organic-agriculture_biocontrol-cotton_polistes-wasp3.png** *Source:* http://upload.wikimedia.org/wikipedia/commons/a/ae/Organic-agriculture_biocontrol-cotton_polistes-wasp3.png *License:* CC-BY-SA-3.0 *Contributors:*
- Organic-agriculture_biocontrol-cotton_polistes-wasp.JPG *Original artist:* Wikipedia editor Pollinator
- **File:Oryctolagus-cuniculus-and-carrot.png** *Source:* http://upload.wikimedia.org/wikipedia/commons/e/ed/Oryctolagus-cuniculus-and-carrot.png *License:* CC-BY-SA-3.0 *Contributors:*
- Rabitt-and-carrot3.jpg *Original artist:* User:ElC
- **File:Question_book-new.svg** *Source:* http://upload.wikimedia.org/wikipedia/en/9/99/Question_book-new.svg *License:* Cc-by-sa-3.0 *Contributors:*

  Created from scratch in Adobe Illustrator. Based on Image:Question book.png created by User:Equazcion *Original artist:*

  Tkgd2007
- **File:Veranotrigo.jpg** *Source:* http://upload.wikimedia.org/wikipedia/commons/4/4f/Veranotrigo.jpg *License:* CC BY 2.0 *Contributors:* http://www.flickr.com/photos/soilscience/2513807337/ *Original artist:* Soil-Science.info
- **File:Waspcycle.png** *Source:* http://upload.wikimedia.org/wikipedia/commons/e/e5/Waspcycle.png *License:* CC-BY-SA-3.0 *Contributors:* Originally from en.wikipedia; description page is/was here. *Original artist:* Original uploader was Quercusrobur at en.wikipedia Later versions were uploaded by Pmcm at en.wikipedia.

9.3 Content license