Chapter 15
ANALYSIS OF BC SUCCESSES AND CASE HISTORIES

I. Successes in Classical Biological Control

A. Successes may be divided into 3 categories based on an economic scale:

1. **Complete BC**: biological control obtained and maintained against a major pest of a major crop over a fairly extensive area so that insecticidal treatment becomes rarely, if ever, necessary.

Example: Cottony cushion scale, *Icerya purchasi*, controlled by the vedalia beetle, *Rodolia cardinalis*, in Hawaii.

2. **Substantial BC**: cases where economic savings are somewhat less pronounced by reason of the pest or crop being less important, by the crop area being restricted (such as a small island), or by the control being such that occasional insecticidal treatment is indicated.

Example: *Liriomyza* leafminers on watermelon controlled by various natural enemies introduced into Hawaii

3. **Partial BC**: cases where chemical control measures remain commonly necessary but either the intervals between applications are lengthened or results are improved when the same treatments are used or outbreaks occur less frequently.

Example: Lebbeck mealybug, *Nipaecoccus vastator*, on various plants controlled by *Anagyrus dactylopii* (hymenopterous parasitoid) imported into Hawaii from Hong Kong.

B. Analysis of worldwide attempts at biological control of insect pests shows:

1. More than 1,300 cases of BC have resulted in either partial, substantial or complete control of target species
2. More than 135 species of insect pests and weeds have been substantially to completely controlled by introduced natural enemies
3. During the last 100 years there have been 1.4 BC successes per year
4. **Ranking of insect orders with regards to successes in BC**

1st - Homoptera	5th - Hymenoptera
2nd – Lepidoptera	6th - Orthoptera
3rd - Coleoptera	7th - Heteroptera
4th - Diptera	8th - Dermaptera

Table 20.1. Success in biological control of arthropods and weeds in Hawaii.

Pest Organism	Number of projects	Projects with substantial to complete control
Weeds	9	6
Scales	3	3 (Homoptera)
Mealybugs/Whiteflies	6	4 (Homoptera)
Aphids	1	1 (Homoptera)
Leaf- and Planthoppers	3	3 (Homoptera)
Heteroptera	1	1
Orthoptera	5	3
Lepidoptera	5	2
Diptera	4	3
Coleoptera	4	2
Thysanoptera	1	1
Spiders	1	1
Snails	1	1
TOTAL	44	30

C. Rough analysis of BC successes in Hawaii (Substantial to Complete) With respect to biological control in Hawaii:
1. Most of the successes have occurred in the Homoptera (11)
2. Successes with introduced weeds have been high
3. California and Hawaii lead the world in the number of complete BC successes. The world leaders in BC are:
1st - California 27 successes
2nd - Hawaii 25
3rd - Rest of U.S.A. 23
4th - Canada 17
4th - Australia 17
5th - New Zealand 10
6th - Fiji 7
6th - Chilie 7
6th - South Africa 7
6th - Peru 7

D. Correlations with successful BC projects:

1. Over a period of time, the number of successes attained will be proportional to the amount of research and importation work carried out
2. Worldwide there are 4 times as many successes with parasitoids as with predators
3. Majority of the successes have been with scale insects
4. In the biological control of weeds, there have been a great number of successes against *Opuntia* sp.

II. Case Histories - See supplements provided and reading material

The following case histories will be examined in lecture:
Sugarcane Leafhopper in Hawaii - 1920
Citrus Whitefly - 1967
Spiny Blackfly (Orange Spiny Whitefly) - 1925
Coconut Scale - 1928
Citrophilus Mealybug - 1928
Citrus Blackfly - 1930
Citriculus Mealybug - 1940

Citrus Blackfly - 1948
Rhodesgrass Scale - 1957
Dictyospermum Scale - 1962
Green Vegetable Bug - 1963
Prickly Pear Catus - 1925
Klamath Weeds - 1944

SIGNIFICANT EVENTS OF CASE HISTORIES OF BIOLOGICAL CONTROL PROJECTS

Sugar-cane Leafhopper, *Perkinsiella saccharicida*
Use of an insect predator belonging to an insect family predominantly composed of plant feeding species.
Citrus whitefly, *Dialeurodes citri*
Biological control projects should be carried on when there is any chance of success. This project was terminated due to difficulties in importation of natural enemies. Fifty-five years later, importations of natural enemies were resumed.
Spiny blackfly (Orange spiny whitefly), *Aleurocanthus spiniferus*
Costs of biological control importations can be extremely low when there is good cooperation among research scientists.
Prickly pear cactus, *Opuntia* spp.
Outstanding successes throughout the world. Analogous to the successes with the cottony cushion scale.
Eucalyptus snout beetle, *Gonipterus scutellatus*
1) Project showed that an egg parasitoid can be an effective biological control agent.
2) Effective natural enemies will become established within 3 years at or near the release sites, but it may take many years to obtain complete biological control throughout the pest's ecological range.
Coconut scale, *Aspidiotus destructor*
Parasitoids may not always be the most effective natural enemies. This pest was controlled by a predatory coccinellid within nine months following its release.
Citrophilus mealybug, *Pseudococcus fragilis*
Ranks second only to the cottony cushion scale in success in California.
Citrus blackfly, *Aleurocanthus woglumi*
1) Work in Cuba showed that *Eretmocerus serius* was the best parasitoid for this pest in the Caribbean area.
2) Work in Mexico showed that *Amitus hesperidum* was a generally effective parasitoid in dry areas but it did not work well when it was hot. *Prospaltella opulenta* was dominant in hot areas and *Prospaltella clypealis* was good in humid areas.
3) For many situations, there may be no one "best" natural enemy. In order to obtain complete biological control in some areas, one may need a complex of parasitoids, each with different ecological requirements.
Citriculus mealybug, *Pseudococcus citriculus*
1) Identification of the pest species targeted for biological control is just as important as accurate identifications for the natural enemies. Misidentification can result in foreign exploration being carried out in the areas where suitable natural enemies are lacking.
2) Personal initiative is extremely important in carrying out biological control projects. Two of the main participants in this project were not professional entomologists.
Klamath weed (St. Johnswort weed), *Hypericum perforatum*

Some problems may arise when bringing insects from one hemisphere to the other (insects have to make adjustments in yearly cycles).

Rhodesgrass scale, *Antomina graminis*

1) Parasitoids which control a pest in one location may not be suitable in a second location with significantly different ecological parameters.

2) A parasitoid with low dispersal abilities may be effective as a biological control agent, especially when aided by Man (parasitoids distributed by plane).

California red scale, *Aonidiella aurantii*

1) Longest active project against a pest (since 1889).

2) Classical example of competitive displacement among parasitoids.

3) The search continues for parasitoids to control this pest in the harsher inland areas of the San Joaquin Valley, California.

Dictyospermum scale, *Chrysomphalus dictyospermi*

1) Project completed for a few hundred dollars.

2) Natural enemies transported from near Los Angeles, CA, to Athens, Greece, in 24 hours.

3) Fastest dispersal of *Aphytus melinus* recorded in a year's time: 124 miles (remember *A. melinus* is ca. 1 mm in length).

Green vegetable bug (Southern green stink bug), *Nezara viridula*

1) Good evaluations are important to the science of biological control.

2) The introduced natural enemy may not always be the one reducing the pest numbers.

Walnut aphid, *Chromaphis juglandicola*

1) More than one strain of the same natural enemy species may be required for complete biological control over a widely varying ecological area.

2) Complete control of an aphid species (aphids were originally thought to be uncontrolable by natural enemies due to their high reproductive capacities).

Chapter 16
CONSERVATION OF NATURAL ENEMIES

I. Conservation of natural enemies:

A. Absolutely essential if biological control is to work at all. This process involves manipulation of the environment to favor natural enemies, either by removing or mitigating adverse factors or by providing lacking requisites.
B. Conservation of natural enemies works best in insect habitats which may lack only certain key requisites and it is with these habitats that adversity may be favorably modified for effectual action by natural enemies.
C. To a large extent, the efficacy of natural enemies depends upon the degree of permanence, stability, and general favorability of environmental conditions. Departures from the natural environment, whether intentional or incidental, by influencing entomophagous species, are often reflected in the degree of depredation caused by injurious arthropods.

II. Environmental modifications may be made to increase natural enemy effectiveness.

These modifications include:

A. Construction of artificial structures;
B. Provision of supplementary food;
C. Provision of alternative hosts;
D. Improvement of pest-natural enemy synchronization;
E. Control of honeydew-feeding ants; and
F. Modification of adverse agricultural practices.

III. Construction of artificial structures.

A. This has been done to increase the densities of predaceous insects, birds, and insectivorous vertebrates such as shrews, mice, squirrels, etc.
B. The best known example of using artificial structures to enhance predaceous insect populations was that of using "nesting shelters" for protection of *Polistes* wasps around tobacco fields in North Carolina for control of the tobacco hornworm, *Manduca sexta*.

IV. Provision of supplementary food.

A. Adult natural enemies often need nectar and pollen as a source of nourishment and moisture.
B. In nature these requisites are provided by a variety of plants. However, in agro-ecosystems many of these plants are considered weeds and are removed.
C. Interplanting of certain crops has been used to provide nectar and pollen sources for natural enemies. It is known that coccinellid species such as *Hippodamia* shift over to pollen when aphids become scarce. Unfortunately they cannot reproduce on a diet of only pollen. The late Kenneth Hagen, University of California, Berkeley, conducted many studies on providing supplementary food sources by spraying solutions of sugar/honey and yeast hydrolysate directly on crops.

V. Provision of alternative hosts.

A. Fundamentally, alternate hosts reduce conditions of asynchrony between preferred hosts and their non-specific parasites and predators.
B. The secondary manifestations of this function are:
1. Damping of extreme oscillations in natural enemy and host densities;
2. Maintaining functional natural enemy populations during low density periods of preferred hosts;

3. Providing suitable overwintering hosts;
4. Facilitating maximum natural enemy distribution; and
5. Reducing natural enemy cannibalism and combat.

C. In many cases this has been attempted through the concept of intercropping host plants of the pest and/or alternate hosts thus preventing total destruction of the habitat at harvest time. In New Jersey, intercropping of peaches and strawberries leads to better control of the oriental fruit moth, *Grapholitha molesta*, by the braconid parasite *Macrocentrus ancylivorus*. The parasite normally overwinters in alternative hosts such as the strawberry leaf roller which occurs on strawberries.

VI. Improvement of pest-natural enemy synchronization.

A. Occasionally, the effectiveness of an entomophagous species is reduced or lost because it becomes partially or wholly separated from its host in time or space. Usually this can only be rectified by manipulation of the environment.

B. In control of scale pests in California achieving synchronization of natural enemies and parasites has been a great difficulty. When citrus orchards are fumigated for control of the black scale, *Saissetia oleae*, all parasitoids are eliminated. This problem is reduced by the growth of pepper and olive trees around the orchards which act as a host for the black scale and provide a safe environment for the effective parasites. Use of English ivy as a ground cover in citrus provides an alternative plant host for the California red scale and Oleander scale and allows *Aphytis* spp. to build up in orchards.

VII. Artificial infestation or inoculation of crops with pests has been used to augment effective natural enemies.

A. The best example was with the cyclamen mite, *Steneotarsonemus pallidus*, on strawberry. Early inoculation of this species allowed its predator (*Typhlodromus reticulatus*) to build up prior to it reaching economic levels.

VIII. Control of Honeydew-feeding ants.

A. Ants often protect honeydew producing organisms such as aphids, mealybugs, and scales from attack by natural enemies. Control of ants (usually with pesticides) often leads to more effective biological control.

B. In Hawaii, an excellent example of this is with the *Dysmicoccus* mealybugs (the pink and gray pineapple mealybugs) that infest pineapple and that are tended by the big-headed ant, *Pheidole megacephala*. Use of ant baits eliminate the ants, and allow the mealybugs' natural enemies to attack them.

K. Modification of adverse agricultural practices.

A. This involves an extremely large area. Some of the main areas where modifications may take place are in:

1. Cultivation and Dust Buildup. Many natural enemies which overwinter in the soil or pupate there may be destroyed through cultivation practices. Dust accumulation on foliage can interfere with the searching activities of natural enemies. Small amounts of dust can kill parasites such as *Aphytis* spp.

2. Use of Clean Culture (elimination of weeds). This can result in the elimination of valuable alternative hosts and supplementary sources of nourishment for natural enemies. Elimination of cruciferous weeds in cabbage-growing areas in South Africa reduces alternate hosts for the Diamondback Moth. The weeds serve to maintain the pest for the natural enemies and thus maintain the natural balance in the area. In some areas burning of harvest residue (i.e., sugarcane, wheat) can destroy natural enemies which develop on hosts remaining in the residue.

3. Mowing (harvest). Mowing of large contiguous acreages of alfalfa in California adversely affects most of the beneficial insects inhabiting the fields. Use of strip farming can reduce destruction of natural enemies of the spotted alfalfa aphid.
4. Chemical pesticides. Use of pesticides can result in the disruption of favorable natural enemy-pest balances. Resulting outbreaks of pests may be classified as to the mechanism of increase. **These are**:

a. Pest Resurgences: characterized by an abnormally rapid return of a pest to economic abundance after initial suppression by a pesticide this also destroyed the pest's natural enemies (which provided only partial control).

b. Pest Upsets (Secondary Pest Outbreaks): characterized by the rise to economic prominence of an insect which is relatively unaffected by a pesticide treatment for another insect pest, but whose normally efficient natural enemies are affected.

5. Usually the best way to improve these situations is by employing a selective pesticide which kills the pest but not the natural enemies.

Selectivity may be derived several ways:

a. Physical (= Ecological) Selectivity: results from differential exposure of pests and natural enemies to a pesticide.

- Preservation of natural enemy reservoirs outside of treated areas
- Differential susceptibility of developmental stages of natural enemies
- Distinctive seasonal life histories and habits of natural enemies
- Distinctive physical features of pesticides and their applications

b. Physiological Selectivity: results from physiological differences in susceptibilities of pests and associated natural enemies to a pesticide. Such physiological differences in the natural enemy may be inherent or a product of laboratory or field selection.