Chapter 13
ENVIRONMENTAL IMPACTS OF BIOLOGICAL CONTROL

I. Is Biological Control Safe?

A. Answer to the question depends on whom you ask. It is a controversial area…without much data.

B. What is the record? See Table 19.1.

1. The *frequency* of non-target impacts: it is not uncommon for an introduced natural enemy to attack a non-target host (or prey) species.

2. The *strength* of non-target impacts: data are minimal. Painstaking and expensive research is required. Duan *et al*. (1998) quantified impact on lantana gall flies. A few other studies showed impact of weed biocontrol agents on non-target plants. But these are mostly "snapshots."

3. See Stiling & Simberloff (2000) [page 39, paragraph 1] for an example of faulty logic based on preconceptions. *[always read scientific papers with a critical or questioning eye*]

C. What is the perception? Perceptions are important because policy makers, politicians, and regulators are usually not scientists.

1. Early biocontrol specialists: "*biocontrol is benign*"… generally thought to be safe, and to be one the most cost effective and environmentally sound methods of pest control, especially compared to the broad-spectrum pesticides often used.

2. The post-Howarth era: "*biocontrol is dangerous*" a backlash against the *laissez faire* attitude of earlier practitioners. "*Absence of evidence is not evidence of absence*" but many charges were leveled without substantiation.

3. Factors impinging on the perception of BC safety:

a. Development and release of genetically modified organisms (GMOs): public often lumps new biocontrol agents with new genetically modified organisms, in terms of risk and regulation.

b. Focus on biological invasions. It is a hot topic now in the field ecology (invasive species).

c. Concern about rates of extinction. the focal point of environmentalism around the world. A real concern, but is any of it attributable to biocontrol?

4. Current status: struggling for a balanced approach. Scientists, regulators, and informed voters must weigh risk from natural enemies vs. value of agriculture and native ecosystems.

D. The joys of bureaucracy

1. Federal (USDA APHIS, EPA, U.S. Fish and Wildlife Service), NEPA.

2. State Hawaii Dept. of Agriculture, committees

Table 19.1. "Data" from Stiling & Simberloff (2000), citing previous studies on non-target impacts.

Type of Natural Enemy	Area	No. species released	No. attacking non-targets	Percentage attacking non-targets
Parasitoids	USA	313	50	16.0
Arthropod herbivores	World	33	7	21.2
All biocontrol agents	Hawaii	243	33	13.6
Parasitoids & predators	Canada	40	15	37.5

II. What Types of Environmental Impact are Possible?

A. Direct parasitism/predation/herbivory of non-target species *Rhinocyllus* weevils on thistles — an introduced herbivore biocontrol agent moves from feeding on the target weed to feed on native plants.
B. Competition with extant species
1. *Interference* (i.e., host access, microhabitats, mates). Some herbivores can actually block access to a weedy plant by other herbivores. Parasites can kill each other, or use up available oxygen, in side a host.
2. *Exploitation* (i.e., phenology important). Phenological synchrony between parasite and host is often important in successful BC…one natural enemy may disturb synchrony between another (better) enemy and its prey (or host). Predators (i.e., coccinellids) may just consume most prey.
3. "Vaccination" (theoretical consideration). One herbivore may trigger plant defenses, and make a plant more resistant to a second (potentially more effective) herbivore species.
C. Hyperparasites and diseases commercially produced aphid parasites — even supposedly clean cultures of biocontrol agents can be contaminated with hyperparasitoids. Hyperparasitoids can really interfere with successful biocontrol. We know very little about diseases.
D. Simberloff's "*invasional meltdown*" hypothesis: new species can have synergistic effects
1. Ants and homopterous
2. Bees and weeds
3. Pigs and guava
4. Lantana gall flies and associates

III. The Value of Retrospective Studies…

A. Why bother? We can learn from the past, develop some level of prediction, and avoid mistakes in the future
B. Case histories:
1. Fruit fly parasites — plenty of species imported to Hawaii, some attack non-target flies, but impact is minimal.
2. Stinkbug parasites — accused of contributing to decline of Koa bug in Hawaii — but the data are inconclusive
3. *Opuntia* and *Cactoblastis* - a moth that was spectacularly successful in controlling pest cacti in Australia now threatens a native cactus in Florida (where it jumped from the Caribbean)

IV. Perspectives:

A. Biocontrol of arthropods vs. weeds — different historical development, different levels of testing.
B. Arthropod BC agents vs. vertebrate (& snail) agents: vertebrates and snails have a bad record: think of mongoose, cane toad, predatory snails.
C. Earlier introductions vs. more recent introductions: new laws and regulations have led to improved record of safety.
D. Island ecosystems vs. mainland ecosystems: often island flora and fauna (especially in very isolated places like Hawaii) have not evolved defenses to common herbivores/parasites/predators. Islands may be more susceptible.
E. Impacts of pathogens and nematodes: *Nosema locustae* against rangeland grasshoppers, *Baccillus thuringiensis* against forest Lepidoptera.

V. Methods: How to Measure Environmental Impacts:

A. Long term monitoring (at a minimum) — historically hard to obtain funding for long term studies. It's the least we should do.
B. Experimental methods — the same as used for assessing success of BC agents against the target pest. Physical exclusion, chemical exclusion, serological, behavioral, etc.
C. Life table or recruitment studies — perhaps the best data, but also the most difficult to obtain. and usually too late to remedy.

VI. How to Minimize Risk:

A. Conduct preliminary cost/benefit analyses — doesn't make sense to conduct a project if the projected benefits are minimal. (but often hard to know)
B. Know your species! (the importance of taxonomy) — much can be learned about host range and potential risk by studying the biology of congeners.
C. Conduct studies in home area, when possible. This makes sense and is often demanded by BC critics, but the logistics are usually daunting.
D. Quarantine is critical — must be treated seriously. hypers, diseases, other contaminants must be removed.
E. Host range testing — must be done in quarantine, which precludes ecological realism.
1. Define the list — centrifugal phylogeny. Parasitoids often choose hosts based on microhabitat.
2. No-choice tests — most conservative. can the agent even develop on the non-target (in the face of starvation)?
3. Choice tests — a bit more realistic. Does the agent hit the non target if more suitable host is available?
4. Limitations — lab conditions can never truly predict the field outcome.
F. Post-release monitoring — mitigation plans? In some cases it may be possible to "recall" a natural enemy once released, especially if in field cages or other isolated situation, perhaps using pesticides. There may be an intermediate step between quarantine study and full field release. But…bugs are smart and adaptable.
G. Documentation and voucher specimens — important both for morphological and genetic examination, especially when groups of sibling species or host biotypes occur.

VII. Risk / Benefit Analysis

A. What currency shall we use? How does one weigh the value of a subspecies of a rare non-economic native insect? How does one compare that with the dollar value of a given crop?

B. Ecological and evolutionary time frames — natural enemies can evolve. Can they expand their host range over time? Can we ever predict safety with absolute certainty?
C. All pest control tactics entail risk- biocontrol should not be judged in a vacuum. It is only one alternative to pest control, and the risk must be weighed against the alternatives
1. Compare with pesticides — longevity, mobility, diversity of species affected.
2. Compare with doing nothing — this has risk, too.
D. The role of the scientist — we are not the decision makers. We can only try to provide information and the knowledge necessary to make predictions. After that, an informed citizenry has to decide on social and political priorities.

Chapter 14
THEORIES OF BIOLOGICAL CONTROL

I. Probability of Biological Control Success Correlated With Geographical Area.

A. "Island Theory" - Islands vs. Continental areas Analysis of successes to date - ca. 67% of BC successes which occurred on islands later occurred in continental areas.

B. Tropical Areas vs. Temperate Areas. Successes in tropical areas were reinforced by the fact that initial BC successes occurred on tropical islands. Success was probably a product of the latitude. Successes in tropical areas are supported on a physiological basis. Comparison of Heterodynamous insects vs. Homodynamous insects:

1. Heterodynamous

a. Unable to reproduce year round.

b. Usually have discrete generations

c. Require synchrony between natural enemy and pest

2. Homodynamous

a. Capable of continuous reproduction

b. Have overlapping generations with all stages present at any one time

c. Easiest species to control with BC

II. Introduction Strategies

A. Pros and Cons of Multiple Introductions

1. Pemberton & Willard (1918) hypothesized that multiple parasitism was detrimental. Other natural enemy species thought to be decimated by inherently superior natural enemies when in competition as larvae. Ideas developed from work on *Biosteres humilis* and *Biosteres tryoni* on the Med Fly, *Ceratitis capitata* in Hawaii.

2. H. S. Smith refuted idea through analysis of data of Pemberton & Willard. Concluded that:

a. Inherent reproductive capacity alone is rarely if ever an indication of the success of a parasitoid

b. Competition between parasitoids for the same host resulted in more host mortality than produced by either natural enemy individually.

3. Two theoretical situations in which multiple parasitism could be detrimental:

a. Parasitization of host (with overlapping generations) results in discrete generations due to elimination of a given host stage.

b. Parasitization of host by inefficient parasitoid which results in reduced "intraspecific" competition between individuals of the host species at high densities.

4. Advantages of multiple parasitism

a. Increased probability for BC over entire geographical range of host

b. Increased host mortality than expected with a single natural enemy alone

c. Increased probability of natural enemy that can utilize alternative hosts when primary host population is low

d. Potential attack of all host stages (sequence theory)

5. Intra-Guild Predation

J.A. Rosenheim, University of California, Davis, discovered that among predators in cotton (in California), resulting levels of biological control could be manipulated by adding and subtracting predators. Also in papaya (in Hawaii), he found the presence of spiders in the spring eliminated staphylinid beetles that suppressed tetranychid spider mite populations before predatory mites excerted control. If spiders were present during the spring time, spider mite outbreaks would occur.

6. *Liriomyza* parasitoids may interfere with each other when larval ectoparasitoids (e.g., *Diglyphus* spp.) and larval-pupal endoparasitoids (e.g., *Chrysocharis oscinidis*, *Ganaspidium utilis*) are present in a cropping system. Larval ectoparasitoids adults are able to parasitize leafminers that already contain a living endoparasitoid larva, resulting in the death of the endoparasitoid. Endoparasitoids do not parasitize leafminers with ectoparasitoids because the parasitized hosts will not pupate so the endoparasitoids can complete their life cycles. On the other hand, there is no 'silver bullet' leafminer parasitoid, so many species are needed to control leafminers across different crop systems (e.g., tomatoes, cucumber, onions, celery, etc.)

B. Single introductions vs. multiple introductions

1. Turnbull and Chant (1961) again advanced the idea that the single "best" species should be introduced for BC
2. Currently, no way exists to totally evaluate successful natural enemy's performance in the field prior to release.
3. Effective BC may depend on a 2nd or 3rd natural enemy species to achieve a desirable level of BC
4. A major problem in biological control is the lack of predictive theory that permit one to predict the outcomes of natural enemy introductions for new exotic pest problems with no prior history of classical biological control efforts

C. The "Sequence Theory"

1. Howard and Fiske (1911) advanced the theory that control of an insect would be inefficient if only one developmental stage of the pest species was attacked. BC should be achieved through a variety of natural enemies attacking several developmental stages of the host
2. In general, successful BC has been the result of a single "best" natural enemy
3. When satisfactory control is lacking, attempts should be made to complete the "sequence" of natural enemies

D. Time Factor with respect to expected results from introduced BC agent

1. Curtis P. Clausen (1951) concluded from worldwide analysis of BC projects that an effective natural enemy might be expected to show evidence of control *at the point of release* within a period of 3 host generations or 3 years.

2. Conclusions drawn from the theory:

a. A fully effective natural enemy is always easily and quickly established

b. Failure of a parasitoid/predator to become established easily and quickly is an indication that it will not be fully effective after establishment is achieved

c. Colonization of an imported BC agent may well be discontinued after 3 years if there is still no evidence of establishment

3. An exception to the rule: the eucalyptus snout beetle, *Gonipterus scutellaris* and the mymarid egg parasitoid *Anaphoidea nitens* in South Africa. Twenty-five years were required for total success.

E. Elimination of hyperparasites prior to parasitoid introduction

1. Primary consideration in introduction phase of BC agent
2. DeBach's study indicates hyperparasitism can significantly reduce parasite's ability to control host
3. Host preference change of some parasitoids may reduce effective BC agents used in weed control

F. Geographic races

1. Must not be neglected

2. Refer to class notes on Walnut Aphid.

III. Characteristics of Biological Control Agents

A. Predaceous vs. parasitic (parasitoid) in nature

1. Ca. two-thirds of BC successes have been with parasitoids
2. Food requirements of parasitoids allow them to maintain a balance with their hosts at lower host densities as compared to predators
3. Importance of predators is just being realized and evidence indicates that they may be a great stabilizing influence in many situations

B. Specific vs. General natural enemies

1. BC agents which are specific to a given host are inherently closely attuned to the host species and are responsive to changes only in the host species
2. Problems may be encountered by a specific BC agent at low host densities when a less specific agent can switch over to other hosts to maintain its numbers
3. A high degree of specificity may be correlated with less adaptability to environmental change or spread
4. Recent concerns among nature conservationists are pressuring biological control researchers to introduce only natural enemies with very limited host / prey ranges to avoid non-target impacts on desirable species (e.g., Kamehameha butterfly, endemic species)

C. Which make the best BC agents, "r" or "K" strategists???

1. "r" strategists may be better BC agents in "disturbed" ecosystems such as short term crops (i.e., vegetables)
2. "K" strategists may be better BC agents in long term ecosystems (i.e., orchard crops and forests)

D. Egg Parasitoids - can they effectively reduce hosts to low densities???

1. Usually egg parasitoids are not considered to be effective parasitoids
2. Eggs parasitoids such as *Anaphoidea nitens* which attacks the eucalyptus snout beetle prove that egg parasitoids can effectively control their hosts as low densities

IV. Characteristics of Pests that affect BC efforts

A. Exotic pests vs. indigenous pests

1. Usually introduced pests are not a problem in their native home and are quite amenable to BC by introduced natural enemies
2. Evidence suggests that there is potential for controlling some indigenous pests with the introduction of exotic natural enemies. Hokkanen and Pimentel (Cornell University) call this phenomenon ‘new associations.’ Given a lack of prior co-evolution between the host and new natural enemy, a newly associated natural enemy may have an advantage over a natural enemy that evolved with the host. With respect to insect pests, closely related exotic hosts should be examined for their effective natural enemies.

Example: Control of the coconut leafmining beetle, *Promecotheca reichei*, in Fiji by *Pleurotropis parvulus*, a parasitoid of another species of *Promecotheca* spp. from Java.

3. Potential is also good in the field of BC of weeds.

Example: Native Bermuda cedars decimated by introduced diaspine scales, *Carulaspis visci* and *Lepidosaphes newsteadi*

B. Possibilities of effective biological control of those pests causing direct damage to crops as opposed to indirect damage.

1. Indirect damage is that damage caused to any part of the plant or animal that is not valued (i.e., leaves of an apple tree, skin covering head of beef cattle).

2. Direct damage is that damage to the part of the plant or animal that is valued (i.e., apple fruit, meat derived from beef cattle).
3. Usually economic injury levels are so low for plant products that biological control is not effective enough to contain the injury below the economic threshold.
4. Exceptions to the norm: Control of the olive scale, *Parlatoria oleae*, by multiple parasitism by *Aphytis maculicornis* and *Coccophagoides utilis* .

C. Control of sedentary pests vs. mobile, active pests

1. Many successes in biological control have been with sedentary pests such as scales, aphids and mealy bugs.
2. Sedentary insects are easy to transport from location to location.
3. Sedentary insects are usually associated with stable ecosystems (i.e., orchard crops).
4. A great proportion of time and money in BC has been directed at the control of sedentary pests.

V. Types of Ecosystems - Short term crops vs. long term crops.

A. Short term crops include vegetables, cotton, and grains.
B. Long term crops include most fruits and nuts and lumber products.
C. Many short term crops are too "short" with respect to time for biological control to be depended on to regulate all pests associated with the crop.
D. Short term crops are the most unstable due to the growing season length, thus natural enemy populations are disturbed quite often by crop destruction practices.
E. Orchard crops are long term and natural enemy complexes remain within a stable environment.
F. Usually extremely low economic injury levels are associated with short term crops (i.e., high cosmetic standards for produce in the market place). Remember a parasitized larva in a tomato is just as bad as a healthy larva to a health inspector or produce manager.