Chapter 3
RELATIONSHIP OF SYSTEMATICS TO BIOLOGICAL CONTROL

I. The Problem of Identification

A. Identification of both the pest and known associated natural enemies is the first step in a biological control effort.

1. A correct name provides a link with the work carried out in the past and represents a key to information in the scientific literature on ecology of a species.
2. Species identification is usually first based on dead specimens (Morphological Species Concept) submitted to a professional taxonomist whose main activity concerns identification and classification of organisms. Generally, the professional taxonomist works in a museum, is a specialist in a relatively high systematic category, and has a good knowledge of the order containing that category.
3. Identification of all organisms associated with a problem (pests and natural enemies) is part of the initial evaluation of available information (Fig. 3.1) in the overall scheme of foreign exploration program (classical biological control).

B. Determination of native habitats of the target species (pest).

1. The search for natural enemies of a pest species in the pest's native habitat is a first priority matter in biological control.
2. Correct identification may help direct biological control workers to the area of origin of a pest.
a. The successful search for natural enemies of the cottony cushion scale, *Icerya purchasi* Maskell, was initiated in Australia (1888) based on the systematic work of W. M. Maskell which suggested that Australia was the native home of the scale.
b. Misidentifications of the California red scale, *Aonidiella aurantii* (Maskell), as belonging to the genus *Chrysomphalus* (believed to originated in South America) led to importations of South American parasitoids of scale species other than *A. aurantii* which did not attack the pest.
c. Misidentification of the coffee mealy bug, *Planococcus kenyae* (LePelley), in Kenya (Africa) resulted in unsuccessful searches for natural enemies on 4 continents until it was realized the pest was an undescribed species from East Africa. Following, natural enemies were found in the neighboring countries of Uganda and Tanzania (Tanganyika).
d. Misidentification of the citriculus mealy bug, *Pseudococcus citriculus* Green, a citrus pest in Israel, as the Comstock mealy bug, *Pseudococcus comstocki* (Kuwana), resulted in foreign exploration being carried out in the Japan where the citriculus mealy bug did not originate. Luckily. natural enemies were found by accident on the Comstock mealy bug in Japan.
e. Locating the area of origin of a pest is not always easy, especially if it has widely dispersed.
3. In the future, researchers may use molecular biology techniques to determine the origin of the pest species they are targeting for control, but it may be an expensive endeavor with plenty of logistical problems. If specimens of the pest can be obtained

from museums or by routine collecting from various locations, then comparison of DNA sequences from the targeted pest population and the collections outside the newly infested area, may reveal where the new pest population originated. Molecular biology work by Judith Brown, University of Arizona, Tucson, on *Bemisia tabaci* (Biotye A. B. *et al*.) populations provided insights into where the whitefly some call the silverleaf whitefly (*Bemisia argentifolii* or *Bemisia tabaci* Biotype B) originated.

C. Identification of natural enemies.

1. Taxonomists of entomophagous species are relatively rare, and are becoming more rare as time passes due to the reluctance of many academic institutions (e.g., University of Hawaii at Manoa) to maintain a strong systematics research program. A 1992 survey by Daly (1995) indicated that there were 28% fewer systematic doctoral students in 1992 compared with 1982. If the trend continues, by the year 2017, there would be no students being trained in systematics.
2. With the initiation of many biological control projects, taxonomic problems have extended beyond the pest and natural enemy species concerned (little known about species or confusion exists).
a. Classical examples of these problems include the efforts to utilize natural enemies in the genus *Aphytis* (scale parasitoids) and *Trichogramma* (parasitoids of lepidoptera eggs).
b. Potential success in biological control of California red scale in California was delayed >50 years because the effective natural enemies *Aphytis lingnanensis* and *A. melinus* were not introduced because they were thought to be *A. chrysomphali* which existed in California.
3. Once natural enemies and pests are established in cultures, it is important that species identification be monitored to insure that contaminants have not entered the cultures.
a. Some natural enemy species may be highly competitive in culture, but highly ineffective natural enemies in the field.
b. During a biological control project for the San Jose scale, *Quadraspidiotus perniciosus* (Comstock) (Homoptera: Diaspididae) in Europe, 4 million individuals of the ineffective parasitoid *Prospaltella fasciata* Malenotti (Aphelinidae) where accidentally released because they were though to be the effective parasitoid *Prospaltella perniciosi* Tower (Aphelinidae). *P. fasciata* never became established where it was released.
c. Molecular markers are now developed in some projects so that different species and strains (e.g., *Encarsia*) can be tracked in culture and contaminates more easily discovered via a routine monitoring program.

II. Limitations of the Morphological Species Concept

A. Definitions.

1. Morphological Species Concept (Typological Species Concept): the concept that two species may be differentiated based on morphological and chromatic characters. The assumption is made that the characters are static in time (no change) and species display little variation.
2. Biological Species Concept (BSC): the concept that species consist of groups of actually or potentially interbreeding populations that are reproductively isolated from other groups. Species have been described as the largest and most inclusive reproductive community of sexual and cross fertilizing individuals sharing a common gene pool. Populations may be assumed to be the same species when one population

interbreeds with another population and the resulting offspring are of normal number, viable and fertile.

B. Reference collections and descriptions of dead adult stages.

1. The professional insect and mite taxonomist deals mainly with reference collections and keys based on morphological characters of dead specimens.
2. Systematic research has suffered from the lack of appreciation of intraspecific variation in morphological characters.
a. No allowance is made for the natural range of variation. Specimens exhibiting insignificant morphological variation may be assumed to be distinct species. Example: Individuals within a species of the genus *Aphytis* exhibiting differences in the number and relative lengths of certain setae (which varies with specimens) were thought to represent more than one species, but did not in reality.
b. If intraspecific variation is not thoroughly understood, valid diagnostic characters may be overlooked. Example: In the genus *Aphytis*, it was eventually discovered that the pattern of pigmentation could be an important species diagnostic characteristic.
3. ***New techniques in molecular biology are contributing to the systematics of entomophagous species. Using techniques such as the Polymerase Chain Reaction (PCR) and Randomly Amplified Polymorphic DNA (RAPD), researchers can get a better idea of what constitutes a species and strains of organisms. These techniques are now being used to verify specimen identifications.***

C. More definitions.

1. Systematics: the field of biology which includes a) biosystematics which is concerned with speciation and phylogeny; and b) classification of organisms.
2. Biosystematics: the investigational field of systematics based on any scientific information that can be brought to bear on the problems of the evolution of species, whether they concern speciation or phylogeny. Aids used in biosystematics to differentiate species include data on biology, physiology, habits, sound–production, pheromone production, host or prey relationships, host plants, and micro–habitat preferences.
3. Alpha–taxonomy: the description of new species based on morphological characteristics within an already existing classification (framework).

D. Problems with identifications based on morphological parameters alone.

1. Identifications based on morphological traits do not allow one to differentiate *sibling species* and *cryptic species*.
a. Sibling species: sister species arising from the same ancestral species. Differentiation may be possible by conventional means.
b. Cryptic species: those species that cannot be differentiated from each other by conventional means. They may not be *sibling species*.
2. Biological parameters used to differentiate *sibling species* and *cryptic species* include host and habitat specificity; number of generations within a given area; diapause's habitat; and different tolerances to climatic factors.
3. The validity of a species must be verified by reproductive isolation.
4. Molecular biology techniques are helping to address these problems now, but the answers are not always 100% clear cut. Use of different makers may indicate different lines of phylogeny.

E. Below the species level: *strains* & *semi species.*

1. Morphologically identical populations of a given species may represent a set of strains or semi species.

2. Some strains of a given natural enemy may be biparental, others uniparental (e.g., some *Encarsia* spp.) One strain may be a more effective natural enemy than another strain within the same species.
3. Semi species represent conspecific populations of an organism which exhibit only partial reproductive isolation. Work on *Aphytis lingnanensis* provides an illustration of this reproductive isolation (Fig. 3.2).
4. Some semi species possess distinct host preferences and other biological characteristics which may be of utmost importance in biological control projects.

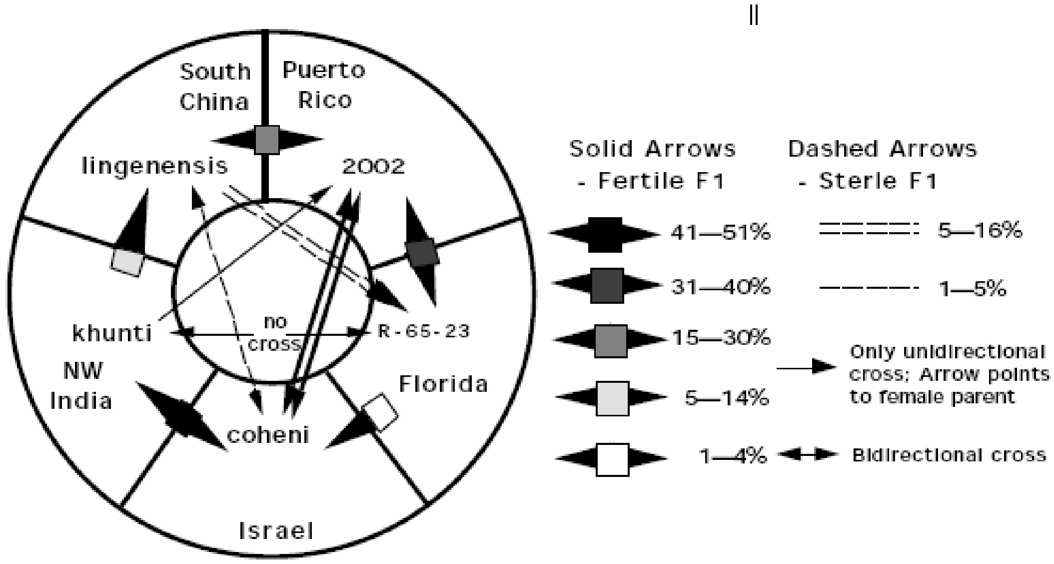

Fig. 3.2. The crossing relationships of some geographical forms of the *Aphytis lingnanensis* complex. These forms are indistinguishable on a morphological basis one from another, yet all degrees of reproductive isolation are evident (modified from Rao & DeBach 1969).

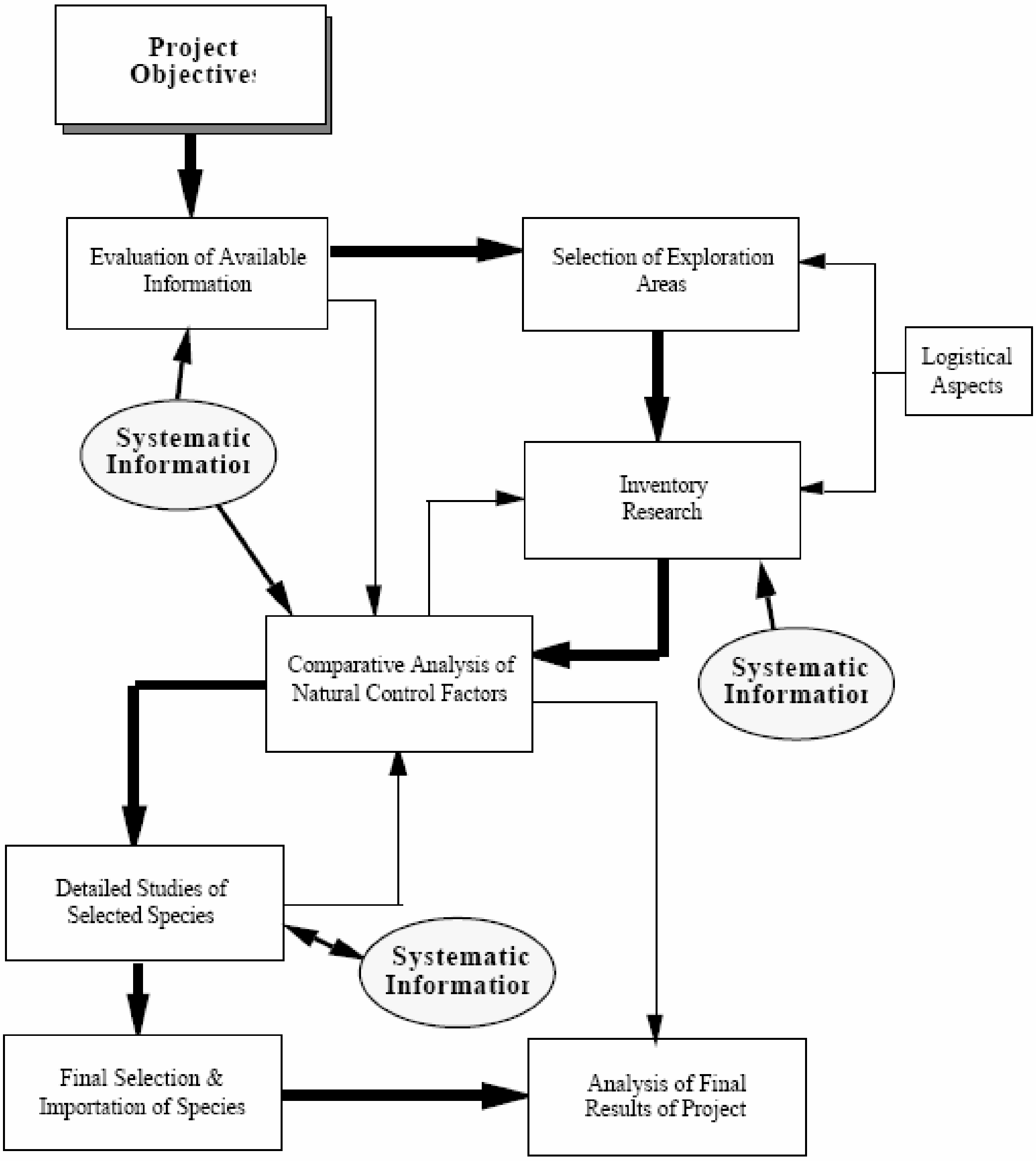

Fig. 3.1. Information flow in foreign exploration programs (modified from Zwölfer et al. 1976).

Chapter 4
BIOLOGY AND IMPACT OF PREDATORS

I. Definitions of Predator and Prey

A. Predator: An animal that feeds upon other animals (prey) that is either smaller or weaker than itself
B. Prey: Those animals fed upon by predators

II. Characteristics of Predators

A. An immature predator will consume a number of preys in the process of completing development to the adult stage.
B. The predator is free living in all life stages except the egg.
C. The eggs are usually laid in the vicinity of the prey.
D. Upon hatching from the egg, predator nymphs or larvae actively seek out, capture, kill, and consume prey.
E. Many predators are carnivorous in both the immature and adult stages (but there are exceptions [e.g., syrphid flies]).

III. Feeding Habits

A. Predators may be categorized based on feeding mechanisms:
1. Those with chewing mouth parts which simply chew up and swallow their victims. This includes ladybugs, ground beetles and preying mantis; and
2. Those with piercing-sucking mouthparts which stick the mouthpart into the prey and suck out the body contents. These predators often have powerful toxins and digestive enzymes that immobilize the prey. This group includes the assassin bugs, lacewing larvae, and syrphid larvae.
B. Predators may be grouped with respect to host range:
1. Monophagous: those species that are highly restricted in their host range. Sometimes limited to one species of prey (e.g., the vedalia beetle);
2. Oligophagous: those species with a somewhat restricted host range. Limited to a few species (e.g., aphid-feeding coccinellids and syrphids);
3. Polyphagous: those species with a broad host range (e.g., green lacewing, preying mantis).
C. Predators may be grouped with respect to the stage of prey attacked which can either be egg, larval (or nymphal), pupal, adult, or a combination of these.

IV. Orders of Insecta which include Predators:

A. All orders include predators except for the Protura, Embioptera, Zoraptera, Isoptera, Mallophaga, Anoplura, Homoptera, and Siphonaptera.
B. List of orders including predators is provided in handout along with the predatory stage (immature and/or adult) and prey attacked (from Hagen *et al.* 1976). The list is provided for your information only.

V. Predatory Araneae and Acari

A. Research conducted on effectiveness of spiders as predators is limited. However, many studies indicate that spiders have not adapted to the fluctuations in the numbers of specific pest species. They are considered a stabilizing influence on the invertebrate community due to their shifts from one prey species to another when the prey is numerous. Recent work by Cerruti R. R. Hooks, University of Hawaii at Manoa, indicates that the spider, mostly *Nesticodes* (=*Theridion*) *rufipes* (Araneae: Theridiidae), may be contributing substantially to the control of lepidopterous pests within the broccoli habitat.

B. The most attention has been given to the phytoseiid mites as predators of tetranychid mites. This attention has only been during the last 30 years. Because of their relatively small size they can survive on low populations of prey and thus have the potential to regulate spider mites at low densities. Some of the well known phytoseiids include *Phytoseiulus persimilis* and *Amblyseius fallacis*. The predator *Phytoseiulus macropilus* may be found in Hawaii's papaya plantings where it preys upon the carmine spider mites, *Tetranychus cinnabarinus*, on the foliage.

VI. Biological aspects of predatory insects

A. Life stages

1. **Eggs** - diversity of eggs carries more genotypic characteristics than the phenotypic adaptive modifications found among parasitic insects
2. **Nymphs or larvae** - body parts are modified compared with phytophagous cousins. Mouthparts may be held horizontally, anterior legs may be more raptorial, or smeared with resin for capturing prey. Internally the alimentary tract may be longer and the salivary glands may produce alkaline secretions for injection into prey to cause paralysis. In some the mouthparts have evolved into effective tools for sucking out body juices.
3. **Adults** - in the holometabolous predators the mouthparts may be similar in both the larvae and adults, but usually they are quite different (e.g., syrphid flies).

B. Phenology

1. Diapause
2. Thermal thresholds

C. Relationships of Predators to Prey

1. Searching ability - Predators respond to a sequence of environmental cues to locate prey.

a. Habitat selection
b. Prey finding
c. Prey acceptance
d. Prey Suitability

2. Most adult stage predators require a *minimum* number of preys to produce eggs and oviposit. A minimum number must be consumed by immature stages to provide energy for maintenance, searching, growth and development. Number of prey required depends upon:

a. Size of predator
b. Extent of its searching and other energy consuming activities
c. Size and nutritional quality of prey

3. Ease with which prey can be found depends on:

a. Predator's searching efficiency
b. Prey's population size
c. Prey's spatial distribution
d. Obstructions in habitat (e.g., plant hairs)

4. Ovipositional sites and predatory stages

a. Eggs deposited in immediate vicinity of prey

i. Immature stages only are predatory aculeate

- Hymenoptera (i.e., Sphecidae); Diptera: Cecidomyiidae, Syrphidae

ii. Immature and adult stages are predatory on similar types of
prey (e.g., Neuroptera: Chrysopidae, Hemerobiidae, Coniopterygidae; Thysanoptera; Coleoptera: Coccinellidae)

iii. Immature and adult stages predatory on different types of prey (e.g., Diptera: Anthomyiidae)

b. Eggs deposited only in the general environment of the prey

i. Immature stages only are predatory (e.g., usually aquatic: Plecoptera, Trichoptera, some Neuroptera [i.e., Corydalidae]; Some Diptera species: Families: Culicidae, Tipulidae, Chironomidae, Tabanidae, Bombyliidae)

ii. Immature and adult stages are predatory on different types of prey (e.g., Odonata, Diptera (Asilidae, Dolichopolidae)

c. Eggs deposited independent of prey

i. Immature stages only are predatory (e.g., Meloidae)

ii. Immature and adult stages are predatory on similar types of prey (e.g., Orthoptera, Thysanura, and some Hemiptera)

iii. Immature and adult stages are predatory on different types of prey (e.g., Mantispidae & Raphidoidea)

iv. Adult stage only is predatory (e.g., Mecoptera, Diptera & Hymenoptera [host feeding])

VII. Impact of Predators

A. Classical biological control projects

1. Only about 11% of the successful BC projects have utilized predators as the major BC agent.
2. A number of pest species have been controlled by relatively few predator species.
3. Types of pests successfully controlled by predators are usually essentially sessile, nondiapausing, non-migratory species associated with evergreen perennial plants or crops (e.g., scale insects, mealybugs, eggs of leafhoppers).
4. Attributes of successfully introduced predators include multivoltinism (nondiapausing), narrow prey specificity (monophagus or oligophagus), high searching efficiency by long-lived adults, and thermal thresholds for activity close to those of the prey.
5. Successful introduced predators include the vedalia beetle, *Rodolia cardinalis* and *Cryptognatha nodiceps*. The latter beetle is a predator of the coconut scale.
6. Reasons for failure of introduced predators include poor climate fit between origin and release areas, lack of high prey specificity, absence of symbiotic microorganisms in certain predators or in the target release area, and lack of ecological diversity in release area (agro-ecosystems).

B. Indigenous predator's agro-ecosystems

1. It is very difficult to show impact of predators in agricultural habitats due to the difficulty in isolating their action among a complex of natural control factors in field situations.
2. DeBach considered general predators "as sort of a balance wheel in the pest-natural enemy complex". They tend to feed upon whatever pest is present in abundance. Even though they don't achieve complete natural control, they slow down the rate of increase of many pests.
3. Predators are especially important in cotton where general predators often prevent damaging outbreaks of certain noctuids (e.g., beet armyworm, cabbage looper). Controlling predators include *Geocoris*, *Orius*, *Nabis*, and *Chrysopa* spp.

4. Generalist predators may feed on both pest and beneficial species. This has been referred to as “intrguild predation” in which specific predators which attack the same pest organism may also feed upon each other. In Hawaii, during the early spring months (primarily April and May), two specialist beetles, *Stethorus siphonulus* and *Oligota* sp. are associated with carmine mites on papaya. The beetles feed upon the mites, thereby suppressing them. However, if the spider *Nesticodes rufipes*, is present, it feeds on the beetles and the spider mite populations increase (Jay Rosenheim, unpublished data).

C. Augmentation of predators

1. Supplementary foods have been provided in plantings to retain, arrest, or attract predators and to increase their oviposition. Compounds used include sucrose, yeast products with sugar ("artificial honeydew), and pollen (for augmentation of predatory mite populations).
2. Inundative releases of predators include *Cryptolaemus montrouzieri* (mealybug destroyer), *Chrysopa* spp., and predatory mites such as *Phytoseiulus persimilis*. These predators may be purchased from commercial insectaries.