Enhancing Biological Control

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Habitat Management to Promote Natural Enemies of Agricultural Pests

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Enhancing Biological Control

Preface

Refuges have long been used to maintain flora and fauna that could not exist otherwise. Today, the preservation of wetlands, rainforests and other sensitive habitats has become a major priority of environmentalists throughout the world. Field biologists know that without certain habitat, migratory waterfowl and other threatened species will disappear. Farmers in the United States have planted hedges and maintained ponds for the purpose of attracting game birds. Rarely, however, do farmers consider setting aside land for aiding in pest management, although certain kinds of habitat can increase the diversity and abundance of natural enemies.

Over the last ten years an increasing number of field entomologists and farmers have recognized that conservation of natural enemies is important to effective biological control in many agricultural systems. Researchers and extension entomologists in the United States and Europe are studying the roles of non-crop vegetation and natural enemies on organic farms. Farmers in these areas grow a diversity of crops within a small area and often maintain a mix of non-crop vegetation to increase the diversity of natural enemies. Growers on small farms in developing countries have traditionally intercropped when growing food crops. Both types of growers know through practical experience that diversity within their farming system reduces pest problems and provides other benefits, e.g. enhanced soil quality. However, conventional agriculture in the United States has never relied on such practices because of the widespread use of pesticides and fertilizers and the lack of well-understood alternatives.

Biological control through importation of new natural enemies has been used to reduce arthropod pest problems for 100 years. However, the full potential of introduced and native natural enemies has rarely been realized in conventional agricultural because most crops are treated with broad-spectrum pesticides. Furthermore, annual crops are continually rotated or replanted, thus disrupting predator–prey associations. In these systems, lack of habitat, hosts, or prey may prevent natural enemies from persisting. Permanent strips of vegetation within a field may allow for the year-round presence of important natural enemies. These plantings can provide the continuity seen in forests and orchard systems where "successes" in classical biological control have been most frequent.

Most research efforts in biological control concern the importation, establishment and evaluation of new biological control agents, not the enhancement or maintenance of resident natural enemies. Only recently have there been sufficient, especially ongoing, field studies using habitat modification to warrant a book on the subject. This book, however, does not present habitat management as a panacea for pest control. Non-crop vegetation and intercrops may compete or otherwise interfere with economic crops. The same vegetation may support key pests or serve as a source of plant pathogens.

We include contributions from the United States, Finland, Germany, Great Britain, New Zealand, People's Republic of China, and Switzerland. Chapters summarize recent findings on aspects of habitat management, with an emphasis on regional perspectives. The introductory chapter by Bugg and Pickett provides a historical overview of the field of habitat modification to enhance natural enemies. That field is discussed in relation to other aspects of biological control, conventional pest control, integrated pest management, and integrated farming. Subsequent chapter topics include habitat modification in the following settings: (1) within fields (Chaney; Coll; Helenius; Riechert; Schoenig et al.), orchards (Häni and Keller), or vineyards (Häni and Keller; Roltsch et al.); (2) along or near the perimeters of fields (Bugg et al.; Murphy et al.; Nentwig; Wratten et al.); (3) distant from fields, including hedges or other non-cultivated areas (Beane and Bugg; Corbett; Häni et al.). Generalist and specialist natural enemies are discussed, as are both theoretical and practical issues. Whereas most of the chapters emphasize vegetational diversification, those by Beane and Bugg and by Olkowski and Zhang also detail the use of human-constructed arthropod nesting and overwintering sites. Schoenig et al. discuss issues of experimental design, analysis, and interpretation. Corbett presents a computer analysis of natural enemy movement that has important implications for both experimental and practical enhancement schemes. Häni et al. discuss "The Third Way," a constantly evolving technique that is intermediate between conventional and organic farming, compatible with biological control, and driven in part by public policy.

At a time when agricultural practices are changing rapidly, we hope that this book helps researchers, agricultural advisers, and progressive farmers alike to design and implement appropriate systems for enhancing biological control of agricultural pests.

We thank the following individuals for assisting in the development of this book: Larry Bezark of the California Department of Food and Agriculture; Ray Gill and Fred Hrusa of the California Department of Food and Agriculture for providing valuable taxonomical expertise; Lyndon Hawkins and Kathy Brunetti of the California Department of Pesticide Regulation; Darle E. Tilly and M. Christine Sparks of The Publications Department for their dedication to finalizing this book; Timothy A. Rice for page design and typesetting.

Charles H. Pickett and Robert L. Bugg
Davis, California, March, 1998

The editors dedicate this book to their parents:
Marion N. and Morris J. Pickett
Elizabeth B. and Sterling L. Bugg

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Introduction: Enhancing Biological Control—Habitat Management to Promote Natural Enemies of Agricultural Pests

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Definitions

DeBach (1964) narrowly defined biological control as "the action of parasites, predators, or pathogens in maintaining another organism's population density at a lower average than would occur in their absence." DeBach outlined three categories: importation, augmentation and conservation of natural enemies (Table 1). In our usage, "habitat management to enhance biological control" means the provision of resources to natural enemies to improve their effectiveness at controlling pests. This represents a subcategory for conservation of natural enemies. The latter term includes both modification of the environment and careful use of pesticides to protect natural enemies. Our concept includes the former but not the latter aspect. Here we consider this concept in some of its complexity, including the basis and origin of the practice; complications in research and implementation; integration with other aspects of biological control and with cultural control; the importance of vegetational diversification, diets and movement patterns of biological control agents; and reducing pesticide dependency through integrated farming.

Basis and Origin of the Practice

Habitat management can enhance biological control of arthropod pests by providing various environmental requisites to natural enemies, including: (1) supplementary foods (alternate hosts or prey, or in some cases pollen); (2) complementary foods (honeydew, pollen, nectar); (3) modified climate (e.g., windbreaks, Reed et al. 1970; Pickett et al. 1990); or (4) overwintering or nesting habitat (Janvier 1956; Huang & Yang 1987; Olkowski & Zhang this volume). This general approach is not new. Chinese citrus

Table 1. Components of biological control according to DeBach 1964.

Term	*Original Definition*
Biological Control	The action of predators, parasites, or pathogens in maintaining the densities of pests at a level lower than would occur in their absence.
Augmentation of Natural Enemies	Manipulation of natural enemies in order to make them more efficient in regulating pests: achieved through either inundative or inoculative releases of mass reared natural enemies.
Biological Control	The use of predators, parasites, and pathogens to reduce a pests density to a level lower than would occur in their absence.
Classical Biological Control	The importation and establishment of exotic natural enemies for control of pests (usually exotic).
Conservation of Natural Enemies	Modification of environment and judicious use of pesticides in order to conserve natural enemies.
Naturally-occurring Biological Control	The maintenance of a population density of an organism within certain upper and lower limits by action of both biotic and abiotic environmental factors; permanent control.
Inoculative Release of Natural Enemies	Release of mass reared enemies to control a pest by action of released individuals and progeny.
Inundative Release of Natural Enemies	Releases of mass reared enemies to control a pest, primarily by the released individuals, not their progeny.

growers have for centuries promoted the activity of the predaceous ant *Oecophylla smaragdina subnitida* Emery (Hymenoptera: Formicidae) by placing bamboo poles between trees previously inoculated with ant colonies (McCook 1882; Yang 1982; Huang & Yang 1987; Way & Khoo 1992). *Oecophylla smaragdina subnitida* Emery is an important natural enemy of a coreid pest of coconuts in the Solomon Islands (O'Connor 1950). Despite its demonstrated value, the theory and practice of enhancing natural enemies has been relatively neglected. This neglect is understandable, because biological control is seldom simple to document, and habitat management to enhance ongoing biological control leads to further complications.

Complications in Research and Implementation

Biological control in its simplest manifestations is nonetheless complex. Natural enemy effectiveness has been evaluated by many workers. For example, the late George Tamaki and co-workers explored qualitative and quantitative dimensions of "predator power and efficacy." In Tamaki's view, predator effectiveness depended on numerous interactive factors, including issues of temporal and spatial synchrony and colonization/dispersal dynamics of populations, as well as thermal activity patterns, voracity, relative reproductive rates, and availability of alternative foods (Tamaki et al. 1974; Tamaki & Long 1978; Tamaki 1981; Tamaki et al. 1981). In assessing successful classical biological programs, Huffaker (1974) found that effective imported parasites and predators shared the following traits:

1. High searching capacity (ability to find host or prey when these exist at low densities);
2. Host specificity;
3. High potential rate of increase (high fecundity, short developmental time);
4. Ability to occupy the same niche as the host or prey.

In evaluating the role of habitat modification, we must add the following complicating issues:

1. Inadvertent direct or indirect effects of the habitat management scheme on crop plants;
2. Variable effects of scale (including plot size and proximity) (Corbett and Plant 1993); distance that a natural enemy must travel between overwintering and summer habitat may affect its abundance and impact (Kido et al. 1984; Pickett et al. 1990; Thomas et al. 1991, Nentwig this volume);
3. Year-to-year variation in populations of pests and natural enemies;
4. Intra-guild interactions among natural enemies (Rosenheim & Wilhoit 1993; Rosenheim et al. 1993);
5. Differential performance of pests or natural enemies in various farming systems and plot configurations (Coll & Bottrell 1994; Kruess & Tscharntke 1994), crops (Braimah & Van Emden 1994; Coll & Ridgway 1995), cultivars (Obrycki & Tauber 1985; Barbour et al. 1993, 1997; Stoner 1996), or microhabitats (Wilson and Gutierrez 1980; Coll & Bottrell 1992).

From the above, it may be obvious that evaluation of enhancement of biological control is a daunting problem, far different from "spray-and-count" entomology or even from the incremental advance to the "count-and-spray" approach of conventional "integrated pest management." Such complexity is likely to deter many scientists. Nonetheless, habitat management to enhance biological control has proven valuable in many settings, and it may be more expensive to ignore the concept than to fund the relevant research and development.

Integration with Other Aspects of Biological Control

Although conceptually distinct from various other categories of biological control (Table 1), habitat management may in practice interrelate with these. Practitioners of classical biological control, the introduction of natural enemies against pests of exotic origin, have long been aware of the importance of physical environmental requisites. Typically, the first consideration in foreign exploration for new natural enemies is the degree of climatic similarity between the native and target regions. Even if physical environmental requisites are met, however, biological requisites may remain unfulfilled, leading to failed importations (Drea & Hendrickson 1986; Rose & DeBach 1990). Habitat management could be used in conjunction with classical biological control, to enhance the establishment of introduced natural enemies (De Charmoy 1917; Shahjahan 1968; Pickett et al. 1996).

Habitat management may also be used to support "augmentative biological control," which involves repeated releases of natural enemies, usually purchased from a commercial insectary. In fact, some habitat-management schemes effectively create field insectaries that could enable released natural enemies to better control pests. In California, related scenarios are currently being explored with the use of cover crops or "nursery plants" to promote build-up following inoculative release of the generalist predatory mite *Euseius tularensis* (Congdon) (Acari: Phytoseiidae) in California citrus orchards (Ouyang et al. 1992; E.E. Grafton-Cardwell & Y. Ouyang personal communication 1997) and *Anaphes iole* Girault (Hymenoptera: Mymaridae), an egg parasite of *Lygus hesperus* Knight (Hemiptera: Miridae) in strawberries (*Fragaria xannanassa*) (Norton et al. 1992; S. Udayagiri & S.C. Welter personal communication1997).

Integration with Cultural Control

Habitat management to enhance biological control may also interrelate with aspects of cultural control, which involves farming practices that make the environment less favorable to pests. In some cases, the same practices that favor natural enemies may interfere directly with pest survival, reproduction, dispersal, or colonization. In such instances, habitat management can represent the dovetailing of biological and cultural controls. This could occur in the use of trap crops (Hokkanen 1991) that arrest movement by the pest *Lygus hesperus* into California strawberry fields (S. Udayagiri & S.C. Welter personal communication1997). Experimental trap crops include such nectar-bearing plants as buckwheat (*Fagopyrum esculentum*) and sweet alyssum (*Lobularia maritima*), which may also attract and sustain beneficial arthropods, including *Anaphes iole*, which parasitizes *Lygus* eggs.

In some cases, however, cultural controls and biological controls may be at cross purposes. For example, in California almond production, orchard sanitation procedures that remove "mummy nuts" reduce overwintering both by the pest navel orangeworm (*Amyelois transitella* [Walker], Lepidoptera: Pyralidae) (Barnett et al. 1989), and by its parasite *Goniozus legneri* Gordh (Hymenoptera: Bethylidae) (Legner & Warkentin 1988; Legner & Gordh 1992; W. Bentley personal communication1997).

Habitat modification is likely to affect a broad spectrum of resident indigenous or naturalized and insectary-reared natural enemies. This may introduce complications in that some generalist predators may interfere with biological control by key natural enemies, as Rosenheim & Wilhoit (1993) and Rosehneim et al. (1993) showed for control of cotton aphid (*Aphis gossypii* Glover, Homoptera: Aphididae) by common green lacewing (*Chrysoperla carnea* [Stephens], Neuroptera: Chrysopidae).

Vegetational Diversification

A key issue in enhancement is vegetational diversification. The concept of biodiversity does not merely concern the number of species present, but also includes aspects of composition, structure, and function. In turn, each of these aspects includes multiple levels. As discussed by Franklin (1988) and Noss (1990), the three hierarchies of biodiversity can be envisioned as:

- I. Composition
  - A. Landscape types
    - 1. Communities, ecosystems
      - a. Species, populations
        - i. Genes
- II. Structure
  - A. Landscape patterns
    - 1. Physiognomy, habitat structure
      - a. Population structure
        - ii. Genetic structure
- III. Function
  - A. Landscape processes, disturbances; land-use trends
    - 1. Interspecific interactions, ecosystem processes
      - a. Demographic processes, life histories
        - i. Genetic processes

These hierarchies are actually not distinct, but interrelated, and have been represented graphically as interconnected spheres (Noss 1990).

Evidence from native grassland ecosystems shows that increased plant species richness (number of species) leads to enhanced total plant canopy cover, biomass production, and plant survival through droughts, as well as to reduced nitrate leaching (Tilman & Downing 1994; Tilman 1996; and Tilman et al. 1996), and that, in general, community parameters are stabilized by diversity, but that population parameters are not. This suggests that artful management of biodiversified systems may be needed to favor the principal economic "target species," and that multiple economically useful species should be employed in such systems, to ensure overall success. Economically useful species could include those providing multiple benefits. For example, plants that serve as food crops could also promote beneficial insects, improve soil quality, etc.

Farm functions may be influenced by numerous aspects of biodiversity. In particular, ecologists have long held that vegetational diversity can affect densities of arthropods. In some well-documented cases, diversification may lead to reduced incidence of phytophagous arthropods (Costello 1994; Costello & Altieri 1995). Vegetational diversification can affect pests in various ways, with or without the mediation of natural enemies. Diversification may exacerbate pests (notably, *Heliothis* spp. [Lepidoptera: Noctuidae], *Lygus* spp. [Hemiptera: Miridae], stink bugs [Hemiptera: Pentatomidae]) if these build up on one crop and then disperse to another while the latter is vulnerable. Diversification could also provide pests with nectar, overwintering habitat, etc. (Kennedy & Margolies 1985; Andow 1988; Bugg 1991; Zhao et al. 1992). By contrast, diversity may reduce pests if it interferes with pest movement, colonization, and reproduction, or otherwise interrupts pest life cycles. If diversification is used to reduce pest dispersal, colonization, or reproduction on target crops, this is usually termed cultural control. This can involve: (1) maintenance of trap or diversionary crops (Hokkanen 1991; Fleischer & Gaylor 1987), (2) confusing pests visually or olfactorally thus reducing their colonization of target crops (Kareiva 1983), (3) host plant nutritional changes that reduce pest success (Hauptli et al. 1990; Robinson 1996), and (4) microclimatic changes that reduce pest success (Pickett et al. 1990; Solbreck & Sillén-Tullberg, 1990; Volkl et al. 1993; Coll this volume). By contrast, if the aim is to enhance performance of natural enemies, this is considered by strict constructionists to be an aspect of biological control. At times, both cultural and biological controls may operate simultaneously (see reviews by Altieri & Letourneau [1982] and Andow [1988]).