Environmental Issues Associated with Enhancing the Impact of Biological Control Agents

A Student Debate

Fred Gould,
George Kennedy,
and Robert Kopanic
Department of Entomology,
North Carolina State
University, Raleigh, NC

ONE MAJOR GOAL OF GRADUATE EDUCATION IS TO FAMILIARIZE STUDENTS WITH THE CONCEPTS, FACTS, and techniques that are essential to progress in a specific discipline. An additional goal should be to prepare students to use their newly acquired knowledge. One important challenge to scientists working in both basic and applied fields is to use incomplete and often conflicting sets of facts and theories in formulating public policies with broad impacts, or in prioritizing research programs at the level of the individual laboratory or at more general levels.

One common means by which public policies and priorities are determined is through the process of debate in which individuals with different perspectives on an issue present their views in a public forum. We feel that it would be useful for student members of the ESA to gain more experience with the process of debate. To this end, we have organized a series of student debates to be held each year at the national ESA Annual Meeting. The topics debated at the last three meetings were "Risks associated with the use of pesticidal transgenic crop plants" (Indianapolis, IN, 1993), "Environmental issues associated with enhancing the impact of biological control agents" (Dallas, TX, 1994), and "Issues related to the conservation of insect biodiversity" (Las Vegas, NV, 1995). The scheduled topic for debate at the 1996 meeting (Louisville, KY) is "Issues in implementing ecologically sound integrated pest management." The debates are sponsored by the ESA Committee on Student Affairs.

Format for the debates and methods used to prepare for them have evolved through our experience and also are based on input from participants. Currently, four specific statements (or questions) that relate to one broad problem are the focus of the debate. For each statement, one student presents a brief historical background (15 minutes), one student argues that the statement is true (pro position), and one student argues that the statement is false (con position). Each pro and con debater has the opportunity to make her/his argument (10 minutes), and follows up with one rebuttal statement (3 minutes).

In the past, we have solicited the participation of university departments in the debate through personal contacts and by sending invitations and descriptions of the debate to the chairs of all entomology departments (and related departments) in the United States. Preparation for the debate involves seminar and discussion sessions conducted by the participating university teams (at their respective schools) throughout the fall semester. In these sessions, students examine the issues and debate the pro and con positions. The debate organizers randomly assign each team the task of presenting at the ESA Annual Meeting a pro, con, or background presentation for two of the debate issues. Each team selects students to represent their assigned perspective at the national ESA Annual Meeting.

After the debate at the 1994 ESA Annual Meeting, the participants decided it would be useful to publish summaries of their statements. These short summaries, printed below, capture some of the flavor of the debate. We want to emphasize that students were randomly assigned pro or con positions, and so the views presented here are not necessarily the views of the students who made the presentations. We also want to emphasize that in debating, it is essential for the debater to present the strongest case possible in defense of a given position. In building a case for that position, a debater will avoid bringing up details that do not support his or her argument, unless their relevance or veracity is being challenged. It is the job of the opponent to point out these details. We welcome any suggestions for future topics or for approaches to improve the program. Any university departments desiring to participate in these debates are encouraged to contact the Student Affairs Committee of the ESA or the organizers.

Topic

The United States Has Been Negligent in Regulating the Importation, Release, and Use of Generalist Natural Enemies

Background

Katherine Schick
Department of Entomology, University of California, Davis, CA

Recent theorists in biological control have advocated the use of generalist natural enemies because they should survive local extinctions of target pests by utilizing other prey or hosts. When the target pest recolonizes the patch, the generalist biological control agent already may have effective population levels in place for control.

The risks of using generalist natural enemies include pest management risks—diet switching by the generalist may lead to an increase in target and secondary pest numbers—and ecological risks—nontarget species (within and outside the targeted agroecosystem) may be impacted negatively.

The pest management risks of using generalists are illustrated by a study focusing on species in three genera of predatory Hemiptera, *Geocoris, Nabis*, and *Zelus*, which prey on cotton aphids (*Aphis gossypii* Glover) (Rosenheim et al. 1993). In cotton fields, these predators showed a decided preference for lacewing (Neuroptera) larvae, which also prey on aphids. The result was that aphid populations were larger in the presence of both lacewings and predatory bugs than in the presence of lacewings alone.

The implications for biological control are that one cannot assume that the effects of generalist predators are restricted to a single trophic level, and additional predator species may not additively suppress a pest herbivore but may instead feed upon a predator of the target pest, causing an increase in pest numbers.

Ecological risks of using generalist natural enemies include the possible extinction of nontarget arthropod species. Some studies suggest that the introduced sevenspotted lady beetle, *Coccinella septempunctata* L., is causing the decline in populations of native North American coccinellids and could lead to extinctions. Few arthropod extinctions have been demonstrated to be caused by introductions, but given the large proportion of the arthropod fauna that is yet to be described, many extinctions caused by generalist natural enemies could remain unnoticed. Federal regulation of natural enemy importation is authorized by both the Plant Pest Act and the Plant Protection and Quarantine Act (U.S. Code SS 147a-167) and enforced by the Animal and Plant Health Inspection Service (APHIS) of the U.S. Department of Agriculture. Congress gave APHIS regulatory authority to protect the nation's agriculture.

The Lacey Act (16 U.S. Code SS 3371-3378) gives the U.S. Fish and Wildlife Service (USFWS) authority to regulate importation of threatened and endangered biological organisms. However, the USFWS generally defers the permitting of live arthropod importations to APHIS.

The National Environmental Policy Act (42 U.S. Code SS 4321-4370a) requires an initial scoping document publicly announcing planned projects, including the release of an imported biocontrol agent, and an environmental assessment. The assessment may result in a finding of no significant impact, or it may require further review in the form of an environmental impact statement.

A few years ago, there was concern that APHIS' policies might not have followed these environmental regulations. Lockwood (1993a, b) and Carruthers and Onsager (1993) discussed a perceived irregularity in this environmental assessment process as it related to rangeland grasshopper control. This discussion sparked a major controversy among entomologists involved in biological control. The argument centered on releases of an alien *Entomophaga* fungus and parasitic wasp, both possibly generalists, to control native grasshopper species on western rangelands in the United States. Concerns were expressed that these releases might endanger other native rangeland grasshopper species that were not pests.

The risks of using generalist natural enemies include pest managment risks and ecological risks.

References Cited

Carruthers, R. I., and J. A. Onsager. 1993. Perspective on the use of exotic natural enemies for biological control of pest grasshoppers (Orthoptera: Acrididae). Environ. Entomol. 22: 885–903.

Lockwood, J. A. 1993a. Environmental issues in-

volved in biological control of rangeland grasshoppers (Orthoptera: Acrididae) with exotic agents. Environ. Entomol. 22: 503–518.
1993b. Benefits and costs of controlling rangeland grasshoppers (Orthoptera: Acrididae) with exotic organisms: search for a null hypothesis and regulatory compromise. Environ. Entomol. 22: 904–914.
Rosenheim, J. A., L. R. Wilhoit, and C. A. Armer. 1993. Influence of intraguild predation among generalist insect predators on the suppression of an herbivore population. Oecologia 96: 439–449.

Pro Position

Eileen A. Eliason
Department of Entomology, Michigan State University, East Lansing, MI

I will use three levels of argument to demonstrate that the United States has been negligent in its importation and release of generalist natural enemies. I will explain that (1) at the theoretical level, it is difficult to understand the potential negative impacts of generalist natural enemies; (2) at the regulatory level, these negative impacts are impossible to prevent; and (3) at the historical level, use of generalist natural enemies has proven that negative impacts are not only possible but, in fact, frequently occur.

. . . there is increasing evidence that generalists can directly suppress or cause local populations of native nontargets to go extinct . . .

The ideal classical biological control agent possesses high host-specificity, good searching ability, short development time, high fecundity, and the ability to occupy any host niche (DeBach 1974). Recently, however, the ideal of host specificity has been challenged on both theoretical and empirical grounds (Miller and Aplet 1993). This results in generalists being considered seriously for use in classical biological control programs (Miller and Aplet 1993).

Biological control often has been practiced as a modern technology without a strong theoretical foundation. The failures of biological control importations outnumber the successes due to a lack of predictive theory and modeling. Even if adequate theory existed to predict potential for establishment of the biocontrol agent and control of target pests, it would be difficult to predict the larger community and ecosystem level effects of the exotic introductions. Lack of host specificity in the introduced organism magnifies these problems.

Numerous regulations exist that are intended to prevent generalist natural enemies from becoming pests or from having negative impacts. These regulations have been described in the *Background* section. None of these acts specifically addresses the practice of biological control, but each of them is intended to protect our environment. The current federal review process considers potential harm to economically important species but disregards threats or damage done to noneconomic species and to ecosystem integrity (Miller and Aplet 1993).

This lack of an appropriate scientific basis and adequate regulation has resulted in economic, social, and environmental harm. In terms of economic harm, time and money have been spent to achieve pest control, but generalists have not been cost-effective (Beirne 1985). In terms of social harm, some natural enemies have themselves become nuisances. An example of this is the multicolored *Harmonia axyridis* (Pallas), which enters people's homes *en masse* in late fall to overwinter (Lyon 1994). But, most importantly, there is increasing evidence that generalists can directly suppress or cause local populations of native nontargets to go extinct, leading to cascading ecological impacts (Howarth 1983, 1991; Wheeler and Hoebeke 1996). The first example, *Cactoblastis cactorum* (Berg), is a generalist natural enemy of prickly pear. This moth migrated into Florida from the Caribbean and recently has been found attacking *Opuntia spinosissima* (Martyn), a native endangered cactus species (Kass 1990). Another example of a generalist attacking nontargets is *Compsilura concinnata* (Meigen), a tachinid parasite of the gypsy moth, *Lymantria dispar* L., that now attacks more than 200 species (Hauptman 1991). Many other examples exist that support the assertion that the United States has been negligent in its importation and use of generalist natural enemies.

References Cited

Beirne, B. P. 1985. Avoidable obstacles to colonization in classical biological control of insects. Can. J. Zool. 63: 743–747.
DeBach, P. 1974. Biological control by natural enemies. Cambridge University Press, London.
Hauptman, C. 1991. Gypsy moths and generalists. Sanctuary 5: 17–20.
Howarth, F. G. 1983. Classical biocontrol: panacea or Pandora's box. Proc. Hawaiian Entomol. Soc. 24: 239–244.
1991. Environmental impacts of classical biological control. Annu. Rev. Entomol. 36: 485–509.
Kass, H. 1990. Once a savior, moth is now a

scourge. Plant Conservation 5: 3.

Lyon, W. F. 1994. Multicolored Asian lady beetle. Ohio State Extension Fact Sheet HYG-2158-94.

Miller, M., and G. Aplet. 1993. Biological control: a little knowledge is a dangerous thing. Rutgers Law Rev. 45: 285–334.

Wheeler, A. G., and E. R. Hoebeke. 1996. *Coccinella novemnotata* in northeastern North America: historical occurrence and current status. Proc. Entomol. Soc. Wash. (in press).

Con Position

Paul Whitaker, Amy Chenot, Michael Riehle, and Kevin Voss
Department of Entomology, University of Wisconsin, Madison, WI

Over 100 years ago, C. V. Riley imported the vedalia beetle, *Rodolia cardinalis* (Mulsant), from Australia and rescued the California citrus industry from the ravages of the cottony cushion scale, *Icerya purchasi* Maskell. Introduction of this natural enemy took place with no host range studies, no permits, no quarantines, and no regulations. The stunning success with this beetle initiated a long series of natural enemy introductions that continues today. Although a separate regulatory and statutory framework has not been developed to specifically address biological control, this activity has been regulated increasingly over the past century through provisions in a number of acts, statutes, and protocols (see Schick, this article). Regulation has increased concurrently with our awareness of the potential negative consequences that these nonindigenous animals could have in their new environments. Before arguing that the United States has not been negligent in regulating the importation, release, and use of generalist natural enemies, we will first define the terms *negligence* and *generalist*. In legal terms, negligence is the "failure to exercise that degree of care rendered appropriate by the particular circumstances, and which a man of ordinary prudence in the same situation and with equal experience would not have omitted" (Black 1891). For the purpose of this argument, we will consider all natural enemies to be generalists except those few species that are strictly monophagous. We use this strict definition for three reasons: (1) there is little consensus on how to assess the host range of natural enemies, (2) most data available on natural enemy introductions do not distinguish between generalists and specialists, and (3) other definitions of a *generalist natural enemy* are remarkably uncommon in the literature.

Several recent papers have questioned the safety of classical biological control, and specifically, the use of generalist natural enemies (e.g., Howarth 1991, Lockwood 1993). These authors cite many examples of introductions that allegedly resulted in severe nontarget impacts, extinctions, losses of biodiversity, and disruptions of native communities. However, these examples have little relevance to the main thrust of classical biological control in the continental United States. Often, these examples involve vertebrate or mollusk natural enemies, which comprise a small proportion of natural enemy introductions. Most of these examples occurred in tropical and/or island ecosystems, which differ greatly from the temperate, continental ecosystems of the contiguous 48 states (Williamson 1981). Finally, several of these examples are based on anecdotal or circumstantial information (i.e., that the newly introduced natural enemies caused these negative effects is inferred but not proven).

Much of our knowledge of the negative consequences of exotic natural enemies derives from cases cited in the papers mentioned above. Yet, there is remarkably little evidence that these consequences have occurred in the contiguous United States. Nearly 400 species of beneficial arthropods have been introduced into the United States during the last 100 years, and the only documented negative impact has been the accidental introduction of two hyperparasite species that were introduced prior to 1910, before quarantine procedures were instituted (Coulson and Soper 1989). Although it is possible that exotic generalist natural enemies in the United States could be imposing important nontarget effects, it would seem that 100 years, and 400 introductions would be sufficient to reveal their negative impacts.

Despite the scarcity of documented negative consequences arising from the introduction of generalist natural enemies in the United States, there has been increasing scrutiny of this activity over the years under a patchwork of regulations. Although most of these regulations were designed for other purposes, they seem to have been effective in ensuring the safety of classical biological control. Despite this, the National Biological Control Institute of USDA–APHIS has been developing regulations and implementing procedures that address concerns about the use of biological control in the United States (E. S. Delfosse,

This continual tightening of regulations, before negative consequences have been documented, reflects a prudent, cautious approach to biological control.

personal communication). This continual tightening of regulations, before negative consequences have been documented, reflects a prudent, cautious approach to biological control. We can only conclude that the United States has not been negligent in regulating the importation, release, and use of generalist natural enemies.

. . . current methods of pest control are reasonably effective and economical, but not ideal.

References Cited

Black, H. C. 1891. A dictionary of law. Lawbook Exchange, New York.

Coulson, J. R., and R. S. Soper. 1989. Protocols for the introduction of biological control agents in the United States, pp. 135. *In* R. P. Kahn [ed.], Plant protection and quarantine, vol. 3. CRC, Boca Raton, FL.

Howarth, F. G. 1991. Environmental impacts of classical biological control. Annu. Rev. Entomol. 36: 485–509.

Lockwood, J. A. 1993. Environmental issues involved in biological control of rangeland grasshoppers (Orthoptera: Acrididae) with exotic agents. Environ. Entomol. 22: 503–518.

Williamson, M. H. 1981. Island populations. Oxford University Press, Oxford, UK.

Topic

The United States Should Attempt To Enhance the Efficacy of Biological Control by Regulating Pesticide Use

Background

K. F. Wallin, R. W. Hofstetter, S. Steffan, and T. L. Rabey
Department of Entomology, University of Wisconsin, Madison, WI

The biological and economic interactions between chemical and biological controls are complex and difficult to evaluate. On the other hand, the use of chemicals as the primary pest management technique is known to influence some components of biological control; for example, environmental imbalances caused by pesticide application often are detrimental to the efficacy of arthropod natural enemies (van den Bosch and Telford 1964). However, it could be argued that pesticide use occurs because it effectively and economically fills a need left by the inability of natural enemies to restrict the densities of many pests below damaging levels. Despite the inadequacy of data with which to fully characterize the interactions among pesticides, natural enemies, crop protection, and economics, there appears to be consensus on one point: current methods of pest control are reasonably effective and economical, but not ideal. The many attributes of pesticides and biological control must be examined carefully before regulations on pesticide use are enacted to enhance the use and efficacy of biological control.

In the aftermath of World War II, the 1950s and 1960s experienced an enormous unrestricted rise in chemical pest control (Hinkle 1993). Although current regulations require studies on the potential impacts of pesticides on humans and environmental health, they do not require studies examining potential impacts on the efficacy of biological control. Even though successful biological control has been documented for more than 100 years, negative effects on biological control agents are not considered of primary importance when regulating pesticide use. Some scientists and environmental groups have concluded that increased regulation of pesticides, supplemented with biological control research, may be necessary to enhance biological control efficacy.

Widespread use of pesticides is largely the result of convenience, simplicity, effectiveness, flexibility, and economics. Despite the advantages of pesticides, pesticide use may lead to problems such as insect pest resistance, outbreaks of secondary pests, adverse effects on nontarget organisms, and other externalities (Metcalf and Luckman 1975). There have been numerous cases in which overuse of broad-spectrum insecticides has resulted in insecticide resistance and the development of secondary pests, as in the cotton-growing area of the Lower Rio Grande Valley, Texas. However, when pesticide use is approached based on sound ecological principles, chemical pesticides serve as dependable and valuable tools for the pest manager.

Several effective integrated control programs have been developed in which biological control and chemical agents are compatible. The elements of these programs include knowledge of the insect system, monitoring of species composition, use of management models, and a liaison group enabling implementation. Consideration of these elements can provide guidance for the optimum use of pesticides in pest management programs. For example, judicious selection and timing of chemical application can preclude direct mortality to natural enemies in a phytophagous-predatory mite system (Metcalf and Luckman 1975).

In considering regulation of pesticide use to enhance the efficacy of biological control, it will be necessary to fully consider the cost and benefits to agriculture and society in general.

Acknowledgments

We thank K. Raffa and D. Mahr (University of Wisconsin) for their organization and encouragement in a departmental seminar and beyond. We also thank the College of Agricultural and Life Sciences, University of Wisconsin–Madison, for providing travel support.

References Cited

Hinkle, M. K. 1993. Environmental issues of biological control regulation, pp. 13–21. *In* R. C. McDonald, J. D. Harper, and W. A. Dickerson [eds.], Biological control: developing strategies for the 90s. Plant Industry Division, N.C. Department of Agriculture, Raleigh.

Metcalf, R. L., and W. H. Luckman. 1975. Introduction to insect pest management. Wiley & Sons, New York.

van den Bosch, R., and A. D. Telford. 1964. Environmental modification and biological control. *In* P. DeBach [ed.], Biological control of insect pests and weeds. Chapman & Hall, London.

Pro Position

Lisa Carloye
Department of Entomology,
320 Morrill Hall, University of Illinois at Urbana–Champaign, Urbana, IL

Historically, government regulation has been used to stimulate a shift toward ecologically-friendly consumer practices. Regulation-induced shifts in the auto industry have reduced air pollution and could be used to enhance the use of biological control. Several existing government regulations discourage the use of biocontrol and should be changed. For example, government grading standards are used, in part, to convey information about produce quality but do not include information about pesticide residues. By changing grading standards to include pesticide information, perfect produce that is obtained through pesticide use would have a lower grade, and the cost of the pesticide would not be regained through higher profits. Furthermore, government grading standards for fruits and vegetables are often so high that pesticides are applied solely to meet these standards. Biocontrol agents may not control pests below government standards, but they often can control pests at levels below economic injury levels. Thus, if grading standards were relaxed, biocontrol could become a viable alternative (National Research Council 1989).

Because biocontrol products have narrower host ranges and/or are often geographically restricted (although there are exceptions), their markets tend to be narrower than those for chemical pesticides, which are typically less geographically restricted and can have a broad spectrum of activity (Cook 1992). Although desirable from an environmental viewpoint, such specialization results in smaller markets, which in turn results in lower profits. This narrower profit margin makes biocontrol unattractive to industry. The discrepancy between profit associated with biocontrol and chemical pesticides is widened further because many costs associated with pesticide use are not included in the prices paid. Hidden costs include decontaminating soil and ground and surface water, monitoring pesticide residues, and some registration costs. Furthermore, there are health costs for agricultural workers and communities whose aquifers and wells become contaminated. By implementing regulations that require market prices of pesticides to reflect more closely the average cost of their use (including both short- and long-term costs), biocontrol will be able to compete better with pesticides.

> The discrepancy between profit associated with biocontrol and chemical pesticides is widened further because many costs associated with pesticide use are not included in the prices paid.

The registration process itself makes development of biocontrol agents prohibitive. Creatively reducing costs associated with registration requirements would achieve the goal of risk management while minimizing the unintended consequence of deterring biocontrol development. Microbial control agents that cannot grow at animal body temperatures should not be required to undergo toxicology tests (Cook 1992), and closely related organisms that have been shown experimentally to be specific to a host and environment should not need to undergo rigorous, repetitive trials for each species or subspecies. For example, in cases where a pathogen is host-specific, geographically restricted, and poses no human health risks, closely related species known to have similar life histories and restrictions could be registered under the same umbrella label as a pilot species that has undergone extensive registration testing. Relaxing registration requirements to eliminate unnecessary tests would also reduce registration obstacles and costs. Templeton (1992) argues

> . . . why worry about toxicology when conventional wisdom teaches that plant pathogens do not infect animals; and why worry about environmental impact when host-specificity and stability assures no risk to anything but the weedhost?

In calling for relaxation of registration requirements, we must be careful to not imply a relaxation of risk assessment. Careful guidelines must be developed to ensure that regulations minimize risk for both high- and low-risk biocontrol products.

In conclusion, I would emphasize the necessity of using pesticide regulation as a tool to enhance biocontrol. If we want to enhance the availability, quality, and therefore use of biocontrol, we must require that pesticides incorporate the long-term costs of their use into their market price and improve government regulations that encourage development of biocontrol products, while modifying those regulations that encourage pesticide use.

References Cited

Cook, R. J. 1992. Reflections of a regulation biological control researcher, pp. 9–24. *In* R. Charudattan and H. W. Browning [eds.], Regulations and guidelines: critical issues in biological control. Proceedings, USDA/CSRS National Workshop, 10–12 June 1991, Vienna, VA. Institute Food & Agricultural Science, University of Florida, Gainesville.

National Research Council. 1989. Alternative agriculture, pp. 10–20. National Academy Press, Washington, DC.

Templeton, G. E. 1992. Regulatory encouragement of biological weed control with plant pathogens, pp. 61–63. *In* R. Charudattan and H. W. Browning [eds.], Regulations and guidelines: critical issues in biological control. Proceedings, USDA/CSRS National Workshop, 10–12 June 1991, Vienna, VA. Institute Food & Agricultural Science, University of Florida, Gainesville.

While regulating pesticides may reduce pesticide use, biological control intervention will not necessarily occur concomitantly.

Con Position

Christopher Sansone
Department of Entomology,
Texas A&M University,
College Station, TX

The use of pesticides in cropping systems and the urban environment is a two-edged sword. The impacts of pesticides, both negative and positive, are well documented. The impact of regulations on pesticide use patterns is not as well documented, but if a product is regulated, probably less of that product will be used. While regulating pesticides may reduce pesticide use, biological control intervention will not necessarily occur concomitantly.

Regulations can take many shapes and forms. Regulations imply establishing a set of rules to perpetuate uniformity or order and mandatory participation. Shumway and Chesser (1994) concluded that when additional regulations are imposed on pesticide use, farmers usually change to alternative crops rather than increase their use of alternative pest control tactics, such as biocontrol.

Many regulation discussions focus on a percentage reduction of pesticides. The question here becomes, would the reduction in kilograms of pesticide used be biologically relevant? Despite an almost 100-fold reduction in the amount of active ingredient from the organophosphates to the pyrethroids, the same biological problems, such as pest resurgence and resistance, exist with little movement to biological control.

Another problem associated with the regulatory approach is the difficulty of developing regulations that do not impede the development and implementation of alternative tactics for pest management. The registration history of pheromones illustrates how regulations can do more harm than good. In September 1980, Environmental Protection Agency's Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) Scientific Advisory Panel presented draft guidelines for biorational pesticides that were nearly indistinguishable from those for broad-spectrum pesticides. From 1973 to 1980, an average of three pheromone products were registered annually. From 1981 to 1987, no pheromone products were registered. It was only after EPA dropped several requirements in 1993 that new pheromone products again were registered.

The strongest case for regulation of pesticides is conservation of natural enemies. When broad spectrum pesticides are removed from the environment, natural enemies are allowed to play a greater role in pest management. Well-designed integrated pest management (IPM) systems can, and often do, achieve that same reduction in pesticide use without additional regulations on pesticides (Frisbie and Smith 1989). In Texas alone, vegetable IPM programs have reduced pesticide use by 66% on carrots processed for baby food, soups, and frozen foods. Other states can report similar successes involving the implementation of properly designed IPM systems without additional regulations.

Even when commitments to pesticide reduction are put into place, they do not necessarily translate to increased or enhanced biological control. In 1987, the Government of Ontario made a commitment to reduce the use of agricultural pesticides by 50% by the year 2002 (Murphy and Broadbent 1993). An 80% reduction was achieved in chrysanthemums with IPM technology without an increase in the use of biological control.

If regulation of pesticides is not the answer, then what alternatives exist? Much of the development of the insecticide industry after World War II was enhanced by subsidies provided by the Defense Department for developing nerve poisons. Biological control could benefit from the same sort of subsidization through crop insurance for failed biological control attempts, low interest loans to suppliers of natural enemies to enhance the development of this cottage industry, or increased funding for biological control research.

Stronger ties between research, extension, and grower groups are essential. Growers of specific commodities have the greatest vested interest in a biological solution to their pest problems and stand to gain the greatest return from the economic investment. Grower groups could provide commodity check-off funds for applied research and for extension in order to promote biological control. Grower groups also could produce the natural enemies for their constituents in situations where the return on investment is too low to maintain the interest of private insectaries.

Many other changes, such as ecologically sound amendments to future U.S. farm bills and a decrease in the stringency of cosmetic standards on produce, could be implemented to enhance biological control. A public mandate exists to use pesticides more responsibly. Although regulation of pesticides may achieve the goal of pesticide reduction, regulations will not necessarily increase the use of biological control or help producers maintain sustainability and profitability. By creating incentives and designing biologically extensive IPM programs, biological control can be enhanced and producers can maintain their profitability.

References Cited

Frisbie, R. E., and J. W. Smith, Jr. 1989. Biologically intensive integrated pest management: the future, pp. 151–164. *In* J. J. Menn and A. L. Steinhauer [eds.], Progress and perspectives for the twenty-first century. Entomological Society of America, Lanham, MD.

Murphy, G. D., and A. B. Broadbent. 1993. Development and implementation of IPM in greenhouse floriculture in Ontario, Canada. *In* J. C. van Lenteren [ed.], Working Group on Integrated Control in Glasshouses, Bulletin 16. International Organization for Biological Control.

Shumway, C. R., and R. R. Chesser. 1994. Pesticide tax, cropping patterns, and water quality in south central Texas. J. Agric. Appl. Econ. 26: 224–240.

Topic

We Should Develop and Release Pesticide-Resistant Natural Enemies

Background

Brian Bishop
Department of Entomology, Michigan State University, East Lansing, MI

Until recently, there has been little research on pesticide effects on natural enemies (Croft 1990). Before 1958, six papers were published on direct toxicity assessments on natural enemies; between 1958 and 1966, 17 papers were published; and between 1967 and 1973, 42 papers were published (Croft and Brown 1975). As a result, more is known about the effects of pesticides on pests than on predators and parasitoids. Croft and Brown (1975) cited five reasons for this: (1) preferential attention given to control of direct competitors, (2) assumption that natural enemies and pests respond similarly to pesticides, (3) more monetary resources for studying pests, (4) difficulty in rearing natural enemies, and (5) lack of standardized toxicology test methods for natural enemies.

> . . . more is known about the effects of pesticides on pests than on predators and parasitoids.

Of 504 cases of recorded arthropod resistance in 1989, 481 (95.5%) involved pest species, whereas 23 (4.5%) involved beneficials. Two hypotheses, the preadaptation hypothesis and the food limitation hypothesis, have been proposed to explain this discrepancy (assuming that the discrepancy is not primarily due to bias in research effort).

The use of resistant natural enemies is essentially analogous to the well-established strategy of using selective pesticides . . .

The preadaptation hypothesis proposes that phytophagous arthropods already contain enzymes such as multifunction oxidases that allow them to detoxify pesticides, because they must cope with chemical defenses in their food plants. The food limitation hypothesis states that the resistant natural enemies that survive a chemical spraying are left with very few prey/hosts and either starve or emigrate, whereas the few resistant pests have an abundant food supply and can quickly build up populations. Two implications of the food limitation hypothesis are that (1) natural enemies have the potential to evolve resistance rapidly if an abundant food supply is present and, (2) under intensive pesticide use, resistance in natural enemies will not appear until after resistance in the pest has appeared. Data also indicate that differences may exist between natural enemies. In comparison with predators, parasitoids are thought to be both less resistant to pesticides initially and limited in their ability to develop resistance. The need for standardized tests to measure pesticide side-effects on natural enemies is being addressed by the International Organization for Biological Control Working Group, "Pesticides and Beneficial Organisms" (Hassan 1985).

Several research scientists feel that to be effective in IPM programs, natural enemies should have high resistance and should replace susceptible biotypes in the field (e.g., Croft and Brown 1975). Genetic improvement of natural enemies can be accomplished through artificial selection (field or laboratory), hybridization, and recombinant DNA techniques. Results of many laboratory breeding programs indicate that only low levels of resistance are achieved and resistance declines when selection is removed (Croft and Brown 1975). Computer simulation models and field tests indicate that low dosage or reduced chemical applications in the field can lead to the development of resistance in natural enemies while retarding it in pests. However, natural enemies selected for resistance in the laboratory would need pesticides applied often and uniformly to maintain their resistance and remove susceptible biotypes. Hence, maximizing efficacy of laboratory- and field-selected natural enemies may require different management strategies in the field.

Headly and Hoy (1987) conducted a study in the almond industry to determine if the benefit received from resistant natural enemies would be worth the cost of developing and implementing them. They concluded that the almond industry could see a cost reduction of $50–82.50 per hectare, and individual growers could save $60–110 per hectare, if integrated mite management, using resistant predator mites, was adopted.

References Cited

Croft B. A. 1990. Arthropod biological control agents and pesticides. Wiley, New York.

Croft, B. A., and W. A. Brown. 1975 Responses of arthropod natural enemies to insecticides. Annu. Rev. Entomol. 20: 285–335.

Hassan, S. A. 1985. Standard methods to test the side-effects of pesticides on natural enemies of insects and mites developed by the International Organization for Biological Control working group 'Pesticides and beneficial organisms.' Bull. Organ. Eur. Pestic. Policy 15: 214–55.

Headley, J. C., and M. A Hoy. 1987. Benefit/cost analysis of an integrated mite management program for almonds. J. Econ. Entomol. 80: 555–559.

Pro Position

Michael Stout
Department of Entomology,
University of California, Davis, CA

In the future, agriculture will rely increasingly on pest control strategies other than pesticides, and most management programs will probably incorporate multiple control strategies, including biological control. However, because effective biological or alternative control strategies do not exist for many key pests, pesticides will remain a part of pest management programs for the foreseeable future. This presents something of a dilemma because pesticides kill natural enemies as well as pests and, therefore, often are responsible for the failure of biological control. Pesticide-resistant natural enemies, because they allow the application of necessary pesticides while minimizing natural enemy mortality, allow the integration of pesticides and biological control. Once pesticides are made compatible with biological control, it becomes possible to design pest management programs that rely on a combination of the two strategies (as well as other compatible strategies) rather than on pesticides alone, thereby reducing the amount of pesticide use.

Resistant natural enemies and pesticides have been successfully integrated in orchard crops (Brunner 1994). In apple orchards, for example, organophosphates are needed to control direct pests, such as the codling moth, for which the economic threshold is very low. Mites are secondary pests of apple that have evolved resistance to organophosphates; in the absence of predators resistant to organophosphates, pest mite outbreaks are induced by organophosphate applications. This in turn necessitates the use of miticides. However, if resistant predatory mites are present, pest mites are brought under biological control and the need for miticides is eliminated or reduced. Endemic organophosphate resistance in natural enemies has been used in apple management programs for over 25 years. In addition, releases of laboratory- and field-selected predatory mites have been made in areas containing susceptible predators, and the resistant mites have established and persisted (Croft 1976). It is important to note that establishment and persistence of resistant predatory mites in orchard crops has not required increased use—in terms of rate or frequency of application—of the selecting insecticide, and the introduction of resistant predators has curtailed, in some cases dramatically, the need for miticides.

Although resistant natural enemies have, to this point, been used only for control of secondary pests induced by necessary pesticides, they have potential uses in other agricultural situations. There are undoubtedly many situations in which pesticides, natural enemies, and other compatible strategies (e.g., pheromone disruption) could be used in concert against a key pest. Natural enemies and other strategies are not always effective at keeping key pests below their economic thresholds, and pesticides will sometimes be necessary. Because resistant natural enemy populations are not decimated by pesticides, pest mortality provided by resistant natural enemies and pesticides should be additive, not exclusive. Thus, in pest-management programs that require pesticides, resistant natural enemies should provide more consistent biological control, decreasing the total amount of pesticide needed. Similarly, other management strategies, if they are compatible with pesticides and resistant natural enemies, could provide additional sources of mortality and further reduce reliance on chemical control.

The use of resistant natural enemies is essentially analogous to the well-established strategy of using selective pesticides or using broad-spectrum pesticides in such a manner as to achieve selectivity. As such, the use of resistant natural enemies is a potentially valuable method for integrating chemical, biological, and other forms of control. The use of multiple control strategies has, of course, the primary benefit of reducing pesticide use. Reduced pesticide use has the added benefit of retarding pest resistance to pesticides, extending the number of years a pesticide remains useful. As methods for producing resistant natural enemies improve (e.g., through genetic engineering [Presnail and Hoy 1994]), development and introduction of resistant natural enemies may become affordable and feasible for many crops.

References Cited

Brunner, J. F. 1994. Integrated pest management in tree fruit crops. Food Rev. Intl. 10: 135–157.

Croft, B. A. 1976. Establishing insecticide-resistant phytoseiid mite predators in deciduous tree fruit orchards. Entomophaga 21: 383–399.

Presnail, J. K., and M. A. Hoy. 1994. Transmission of injected DNA sequences to multiple eggs of *Metaseiulus occidentalis* and *Amblyseius finlandicus* (Acari: Phytoseiidae) following maternal microinjection. Exp. Appl. Acarol. 18: 319–330.

. . . the release of pesticide-resistant natural enemies might encourage the use of pesticides.

Con Position

Daniel R. Suiter
Department of Entomology, University of Florida, Gainesville, FL

Following are several reasons why the development and release of pesticide-resistant natural enemies should not be pursued. First, the release of pesticide-resistant natural enemies might encourage the use of pesticides. Boller (1987) maintained that the use of pesticide-resistant natural enemies would encourage the use of pesticides. IPM practices typically promote conservation of natural enemies through selective use of pesticides. However, with the use of pesticide-resistant natural enemies, conservation may not be an issue because resistant natural enemies cannot be killed. As a result, the frequency of spraying might increase.

Secondly, the introduction via a transposable element or virus vector of a gene for resistance into a natural enemy might lead to horizontal transfer of genetic material to a pest insect. Recently, the use of transgenic plants has received a great deal of attention. Genes for a variety of desirable traits, such as resistance to viruses and herbicides, have been inserted into crops. Crop plants are capable of transferring genes over relatively long distances to related plants that differ in their life histories. Doebley (1990) demonstrated gene flow between maize and its nearest wild relatives, the teosintes, in Central America and Mexico. The underlying concern is that the escape of genes through pollen and hybridization could enhance the vigor of existing weeds. The concern over the use of transgenic, pesticide-resistant natural enemies is that if horizontal transfer were to occur between the natural enemy and a crop pest, this might confer resistance in the pest.

Another argument against the release of pesticide-resistant natural enemies is economically based. Consider the following scenario: In a certain agroecosystem, there exists an exotic pest among the pest complex. After years of costly foreign exploration, classical biological control specialists discover one of its primary natural enemies, which is then quarantined where host specificity and natural history data are gathered. After mass release, the parasitoid begins having a significant regulatory impact on the pest. In the meantime, the grower's only option is to spray on an interval basis to control the pest. The manufacturer of the product currently being used by the grower then initiates a research program to establish a strain of the parasitoid resistant only to its active ingredient. This scenario would leave growers without a choice of pesticide tools. It is not unreasonable to expect that a program of resistant natural enemies combined with as-needed, reduced pesticide applications would be more effective than either alone. However, if there were only one source of resistant natural enemy, its owner might then have a monopoly on its price.

In this short discussion, I have identified just a few of the drawbacks that should be considered before embarking on the widescale use of resistant natural enemies in IPM programs. Indeed, the permanency of genetically altered arthropod releases leaves no room for error. The ecological costs of such a mistake might be catastrophic.

References Cited

Boller, E. 1987. A closer look at the question of pesticide resistance antagonists. International Organization for Biological Control, Western Palearctic Regional Section. Profile no. 6. International Organization of Biological Control.

Doebley, J. 1990. Molecular evidence for gene flow among *Zea* species. BioScience 40: 443–448.

The process of risk assessment for classical biological control agents is well defined compared to that for genetically engineered control agents.

Topic

Genetically Engineered Natural Enemies Should be Regulated in a Different Manner Than Other Nonindigenous Natural Enemies

Background

Mark A. Pomerinke
Department of Entomology & Nematology, University of Florida, Gainesville, FL

Classical biological control is one of the oldest forms of pest control known today. Biological control involves using a natural enemy, an organism that feeds on another organism, to reduce the number of pests to a noneconomic level. Natural enemies have been utilized as biological control agents since 1200 A.D.

Genetic manipulation is older than most people realize. Ancient agriculturalists picked plants with traits that provided for greater harvest or insect resistance. It has been suggested that interspecific hybridization might provide useful genes for genetic improvement of beneficial arthropods. Genetic improvement of arthropod natural enemies has been achieved through artificial selection (e.g., pesticide resistance in phytoseiids). Today recombinant DNA techniques are being used to improve arthropod natural enemies (Hoy 1992).

Several different laws currently are used to regulate the release of nonindigenous arthropods. Four of most important laws of concern to entomologists are: (1) The Lacey Act (1900), (2) the Plant Quarantine Act (1912), (3) the Federal Plant Pest Act (1957), and (4) Executive Order 11987 (1977). These acts and orders provide authority to the USFWS and USDA–APHIS to regulate movement and release of any nonindigenous arthropod. Because these laws and decrees do not include any information on the release of genetically engineered arthropods, several regulations have been drafted concerning these arthropods. Guidelines drafted in 1972–1975 at the Asilomar conferences in California became the Recombinant DNA Advisory Committee guidelines in 1976. These guidelines help to ensure that researchers will not genetically engineer organisms that might become hazardous to plants or animals if they escape from the laboratory. To help regulate genetically engineered arthropods, the USDA–APHIS developed the following guidelines: Federal Registers 7 CFR parts 330 and 340, and 7 CFR part 340 final rule. These guidelines regulate the introduction of genetically engineered organisms that are plant pests or could potentially become plant pests. However, the above guidelines do not allow for permanent release of any genetically engineered arthropods; only limited or test releases of transgenic arthropods are allowed and no such releases have been made to date. When permission to perform a test or limited release finally is granted, two methods that may be used to ensure that establishment does not occur are climatic condition and a lethal gene. Both methods involve the inability of an arthropod to survive climatic conditions to which it is not accustomed.

All of the above laws are designed to reduce the risk that a mistake will occur. Risk can be defined as the probability of occurrence multiplied by the potential consequences of such occurrence (Ginzburg 1991, ABRAC 1992). Risk assessment is the process of determining if or how much harm could be caused to a nontarget organism should a control agent start to utilize it. The process of risk assessment for classical biological control agents is well defined compared to that for genetically engineered control agents. Weed biological control agents require a determination of whether the control agent can complete its development on any plant in the same or related plant family as the target plant. This information can be obtained by performing choice/no-choice tests. Using information obtained from these tests, a more informed decision can be made on releasing the control agent. No such guidelines exist for genetically engineered natural enemies.

Even with all the laws and regulations in place and the risks analyzed, mistakes in biological control could occur. For example, one author has expressed concerns about extinction of native arthropods being caused by introduced control agents (Howarth 1983). However, there appears to be no conclusive evidence to support his findings. Still, his point is valid, because there are risks and those risks need to be analyzed.

What are the risks and how does one define them for genetically engineered arthropods? As genetic engineering of arthropods becomes more common, concerns about the additional risks from genetically engineered arthropod natural enemies are being discussed more frequently. A recent conference in Gainesville, FL, addressed concerns about releasing genetically engineered arthropods (Risks of Releasing Transgenic Arthropod Natural Enemies, organized by Marjorie A. Hoy and Ernest S. Delfosse, 13–16 November 1993). The conference found four areas that should be addressed by researchers who plan to release genetically engineered arthropods for short term evaluation: (1) attributes of the unmodified organism, (2) attributes of the genetic alteration, (3) phenotype of modified organism compared to unmodified organism, and (4) attributes of the accessible environment.

References Cited

[ABRAC]. **Aricultural Biotechnology Research Advisory Committee. 1992.** Guidelines for research involving planned introduction into the environment of genetically modified organisms. Guidelines recommended to USDA by the Agricultural Biotechnology Research Advisory Committee, 3–4 December 1991. USDA Office of Agricultural Biotechnology Document No. 91–104.

Ginzburg, L. R. [ed.]. 1991. Assessing ecological risks of biotechnology. Butterworth-Heinemann, Boston.

Howarth, F. G. 1983. Classical biocontrol: panacea or Pandora's box. Proc. Hawaiian Entomol. Soc. 24: 239–244.

Hoy, M. A. 1992. Commentary, Biological control of arthropods: enetic engineering and environmental risks. Biol. Control 2: 166–170.

. . . the question is whether or not the biology of a transgenic organism is unique enough to warrant separate regulatory guidelines.

Pro Position

Catherine S. Katsar
Department of Entomology, Texas A&M University, College Station, TX

No indication exists that naturally occurring genotypes identified and selected via molecular techniques are inherently different from genotypes selected by more conventional means. Rather than concentrate on differences in methodology, it is perhaps more relevant to address the potential changes in biology that may result when a natural enemy is genetically modified. The question at hand is not whether a genetically engineered natural enemy is potentially more hazardous than a naturally occurring one; rather, the question is whether or not the biology of a transgenic organism is unique enough to warrant separate regulatory guidelines.

What are the differences in biology associated with a transgenic organism that require an alternative regulatory approach? The concept of one gene coding for one polypeptide is fundamental to our understanding of genotypic expression. At the organismal level, however, phenotype is determined by a complex network of interactions among gene products. Interactions may occur among genes at different loci, among alleles at the same locus, or among genes and the environment. Often, a single gene may affect several traits (Barton 1990, Gavrilets and de Jong 1993). Rarely is the relationship between genotype and phenotype one-to-one.

Because changes in genome structure may result in phenotypic changes in adjacent gene products, care should be taken to determine any secondary effects gene transfer may have on other genetic interactions. By focusing only on the primary gene product, important secondary phenotypic effects may be overlooked. Epistasis and pleiotropy often play a major role in determining phenotype (Falconer 1989).

Before we can understand organismal behavior and gene function as a consequence of varying genetic backgrounds, we must study phenotype in the context of the whole organism. Nonindigenous natural enemies may have characteristics that are expressed only in certain environments or conditions. Similarly, once an indigenous natural enemy has been altered genetically, its response to its previous environment can no longer be predicted adequately. Still, the inner workings of a nonindigenous natural enemy have resulted as a consequence of natural selection. In contrast, the inner workings of a transgenic organism have never before operated together and have only been subjected to limited selection pressure in a laboratory environment.

An exotic agent and GEO are only different in the same way two exotic species are different, with regards to their new habitat.

The ability to manipulate and transfer genes into an array of genetic environments is only the first step in understanding the complexities of living organisms. Whereas individual genes may have predictable results, genetic interactions between nonallelic loci make phenotypic effects unpredictable. Simply put, when dealing with genetic interactions, the old adage, "the whole is the sum of its parts" is not entirely true. Genotype does not specify phenotype unambiguously. Rather, it determines only a range in which phenotypic expression may occur.

It is not whether or not any one of these organisms is inherently more dangerous than the other, but whether or not the characteristics and potential risks associated with nonindigenous and genetically engineered natural enemies make them different enough to warrant separate regulatory guidelines. The objective of the scientific community should be to develop regulatory guidelines that maximize biological and environmental stability while at the same time minimizing counterproductive red tape.

References Cited

Barton, N. H. 1990. Pleiotropic models of quantitative variation. Genetics 124: 773–782.

Falconer, D. S. 1989. Introduction to quantitative genetics. John Wiley & Sons, New York.

Gavrilets, S., and G. De Jong. 1993. Pleiotropic models of polygenic variation, stabilizing selection and epistasis. Genetics 134: 609–625.

Con Position

Stephen Gaimari
Department of Entomology, University of Illinois at Urbana–Champaign, Urbana, IL

Genetically engineered organisms (GEOs) for biocontrol should not be regulated differently than exotics because they raise similar questions and concerns regarding risks.

Two important questions for either type of organism are (1) Will the organism control the target pest? and (2) Will the introduced agent become a pest itself? Possible negative effects include pest enhancement, effects on human health, and attacks on nontargets. Any introduced organism can potentially feed on all available suitable hosts and affect associated species in some way (Howarth 1991). This is precisely what needs consideration for any potential agent, whether GEOs or exotics.

Any organism with combinations of traits novel to an environment is likely to play novel ecological roles. As with an exotic, a GEO may prosper in a new habitat type, geographical area, or season, making it effectively an introduced exotic, likely to enter new biotic and abiotic interactions. Therefore, the "phenotype of a transgenic organism, not the process used to produce it, is the appropriate focus of regulatory oversight" (Tiedje et al. 1989).

The U.S. Congress, Office of Technology Assessment (1993), treats GEOs as nonindigenous by definition, with the central issues for exotics and GEOs being the same.

> Both involve the release of a living organism potentially capable of reproduction, establishment, and ecological effects beyond the initial release site. The specific characteristics of the organism and the receiving environment will determine the consequences of either type of introduction.

Miller and Aplet (1993) pointed out that most public concern with biotechnology revolves around unknown effects of novel organisms on ecosystems into which they are released.

The proper considerations for either type of agent are the organism released, the organisms targeted, the surrounding fauna and flora, and other environmental attributes. The important scientific considerations include the potential survival and reproductive capacity of the introduced agent, its interactions with other organisms, and the effects on community structure and ecosystem function. After release, a GEO is subject to the same natural selection pressures as any other organism (Tiedje et al. 1989), and the one or two altered traits will not preclude the entire genome from overcoming selective pressure.

Host specificity testing stresses the fundamental similarities in answering host-related questions. Host specificity in the field is only known with certainty after release, but prerelease estimates are possible through laboratory studies. Each group of agents must be evaluated by scientists who are familiar with the unique characteristics of these groups (Maddox 1994). The questions are the same among all potential agents for release. Does it colonize or prey on nontargets? Does it kill nontargets? What effects do the agents have on the community? To answer these questions, different approaches must be taken, and the experimental design must fit the agent (i.e., testing must emphasize hosts that are potentially susceptible, based on phylogenetic and habitat considerations). Regulatory requirements should be broad enough to ensure that experiments can be tailored to fit individual cases (Maddox 1992).

The fundamental issues concerned with releases of exotic natural enemies and GEOs are the same: Should we be asking the same questions regarding host specificity and potential interactions with the surrounding environment? Should we be worrying about the same potential risks and effects associated with any introduction? Therefore, prerelease studies on potential effects of either type of organism should be overseen by a single regulating body. An exotic agent and GEO are only different in the same way two exotic species are different, with regards to their new habitat.

References Cited

Howarth, F. G. 1991. Environmental impacts of classical biological control. Annu. Rev. Entomol. 36: 485–509.

Maddox, J. V. 1992. The effects of regulations on the use of insect pathogens as biological control agents, pp. 73–81. *In* R. Charudattan and H. W. Browning [eds.], Regulations and guidelines: critical issues in biological control. Proceedings, National Workshop, 10–12 June 1991, Vienna, VA. University of Florida Press, Gainesville.

1994. An evaluation of opposing viewpoints of classical biological control, pp. 43–51. *In* S.L.C. Fosbroke and K. W. Gottschalk [eds.], Proceedings, USDA Interagency Gypsy Moth Research Forum, 18–21 January 1994, Annapolis, MD. USDA Forest Service, Radnor, PA.

Miller, M., and G. Aplet. 1993. Biological control: a little knowledge is a dangerous thing. Rutgers Law Rev. 45: 285–334.

Tiedje, J. M., R. K. Colwell, Y. L. Grossman, R. E. Hodson, R. E. Lenski, R. N. Mack, and P. J. Regal. 1989. The planned introduction of genetically engineered organisms: ecological considerations and recommendations. Ecology 70: 298–315.

U.S. Congress, Office of Technology Assessment. 1993. Harmful non-indigenous species in the United States. OTA-F-565. U.S. Government Printing Office, Washington, DC.

Acknowledgments

We thank Connie Satterwhite for her help with many drafts of this manuscript. We thank ESA for its support of this venture.

◆

Fred Gould and George Kennedy are professors of entomology at North Carolina State University. Fred Gould teaches insect ecology and conducts research on ecological genetics of insects. George Kennedy teaches IPM and studies plant/insect interactions. Robert Kopanic is a graduate student at North Carolina State University. He is studying ecology and management of cockroaches.