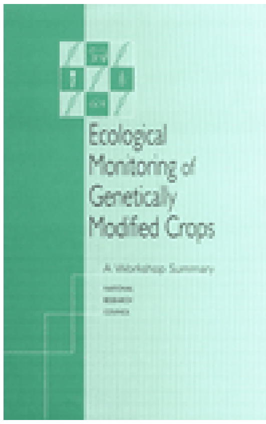

Ecological Monitoring of Genetically Modified Crops: A Workshop Summary

Robert Pool, Ph.D., and Joan Esnayra, Ph.D.Board on Agriculture and Natural ResourcesBoard on BiologyNational Research Council

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by
Robert Pool, Ph.D., and Joan Esnayra, Ph.D.

Board on Biology
Board on Agriculture and Natural Resources
National Research Council

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Preface

Proponents of agricultural biotechnology believe that genetically modified (GM) crops have the potential to provide great ecological benefits, such as reduced pesticide and land use, as well as agricultural benefits. However, given the rapid emergence of commercial GM crops and the likely increase in their use, many groups have raised concerns about the potential unintended, adverse ecological effects of these crops. Some ecological concerns are enhanced development of pest resistance, cross-pollination with wild relatives, and reductions in beneficial insects or birds. Given those concerns and growing public scrutiny, the US Department of Agriculture asked the National Research Council to convene a workshop to consider the latest in monitoring methods and technologies and to ask—What are the challenges associated with monitoring for ecological effects of GM crops? Is ongoing ecological monitoring of GM crops a useful and informative activity? If so, how should scientifically rigorous monitoring be carried out in the variety of ecological settings in which GM crops are grown?

A workshop planning group was appointed whose membership was taken mostly from the Research Council's Standing Committee on Agricultural Biotechnology, Health and the Environment. The role of the planning group was limited to identifying topics, appropriate speakers, and other participants for the workshop. Persons with diverse perspectives and expertise were invited to give presentations and to serve on discussion panels. Presenters were drawn from industry, academia, government, the sustainable agriculture and other farming communities (see appendices). This document is a summary of the workshop and represents a factual recounting of what occurred at the event. The authors of this summary are Robert Pool and Joan Esnayra, neither of whom was a member of the planning group.

This workshop summary has been reviewed for accuracy in draft form by persons who attended the workshop and others chosen for their diverse perspectives and technical expertise in accordance with procedures approved by the Research Council's Report Review Committee. The purposes of this independent review are to assist the Research Council in making the published document as sound as possible and to ensure that it meets institutional standards. We wish to thank the following, who are neither officials nor employees of the Research Council, for participating in the review:

Frederick Ausubel
Bonnie Bowen
Galen Dively
Rebecca Goldburg

Although those listed above have provided many constructive comments and suggestions, it must be emphasized that responsibility for the final content of this document rests entirely with the authors and the National Research Council.

Joan Esnayra
Study Director

Contents

Introduction: Keeping Watch on Genetically Modified Crops

In May 1999, researchers at Cornell University made headlines with a report about genetically modified corn plants and monarch butterflies. The corn was of a type that had been modified to produce an insecticide known as *Bt* toxin to protect it from the depredations of the European corn borer. By virtue of this modification, *Bt* toxin is also produced in the pollen of the corn plants. Cornell scientists found that when monarch caterpillars were raised on leaves dusted with *Bt*-containing pollen, many of them died. Milkweed plants, the only food source for monarch caterpillars, often grow along the edges of cornfields, and the researchers speculated that genetically engineered corn might pose a danger to the beloved butterflies.

As this is written, there is still no proof that the caterpillars are or are not at risk. A number of ameliorating factors could intervene, such as removal of much of the pollen from leaves by wind and rain or the caterpillars' avoidance of the most heavily dusted leaves. Whatever its resolution, the episode has underscored two important points about genetically engineered plants. First, the introduction of transgenic crops or, indeed, of any new crop into an area can have unforeseen consequences for the surrounding ecosystem. Second, the public is particularly sensitive to damage or potential damage caused by genetically modified plants, as opposed to damage caused by plants created by traditional breeding methods.

It was more than 13 years ago that a National Academy of Sciences white paper examined the emerging field of genetic engineering and offered a set of principles to serve as a starting point for the analysis of transgenic organisms and their possible effects on the environment. First, the paper concluded, the act of creating transgenic organisms itself carries no special threat. Second, the risks associated with placing transgenic organisms into an environment are of the same type as the risks associated with releasing any new organism—one brought in from another location, for example, or one that has been created by conventional breeding—into an environment. Third, to assess the risks posed by introducing a transgenic organism into an environment, one need consider only the characteristics of the organism and of the environment, not how the organism was produced. However, at the time these principles were drafted, there were no commercial releases of genetically modified organisms.

In the years since that white paper appeared, genetic engineering of plants has gone from a new and largely untested technique to common agricultural practice. Although genetically modified plants did not become commercially available in the United States until 1995, they now account for a major portion of the crops that American farmers plant each year. In 2000, some 70 million acres of transgenic crops were grown in the United States, including 25% of all corn, 54% of soybeans, and 61% of cotton (Reference: USDA's National Agricultural Statistics Service). Of those acres, 30 million were devoted to plants that have been genetically engineered to produce the *Bt* toxin, and much of the remaining area was planted with crops that have been engineered to resist wide-spectrum herbicides, such as Round-Up (manufactured by Monsanto). A field of such herbicide-resistant plants can be sprayed with the herbicide in question to kill all weeds and leave only the crop plants alive. Other, less-widespread transgenic crops were also grown, such as plants that have been given resistance to particular viruses by having a gene from the virus inserted into their DNA. Although the current disfavor with genetically engineered plants in the European Union might slow their spread among American farmers, many of whom sell to Europe, it seems likely that transgenic crops will remain an important component of American agriculture.

As transgenic crops have become more widespread, so have concerns about their possible risks to human health or to the environment. Some people believe that the risks are no greater than those posed by traditional crops and expect the benefits of transgenic crops to outweigh any disadvantages. Others worry that the risks have not been properly assessed and that the crops will pose dangers that will not become clear until it is too late.

One of the natural responses to the controversy is to gather more information about genetically engineered plants and their effects. In April 2000, when a committee of the National Research Council released a report on transgenic plants and regulation, *Genetically Modified Pest-Protected Plants: Science and Regulation* (National Academy Press, Washington, DC), many of the recommendations were for research to determine more precisely the potential of such crops to harm either human health or the environment. Although the report was careful to say that there is no strict dichotomy between the health and environmental risks that might be posed by transgenic and conventional pest-protected plants, the committee acknowledged that much is still not known about transgenic crops.[1]

Against that backdrop, on July 13-14, 2000, the National Research Council held a workshop on Ecological Monitoring of Genetically Modified Crops. As the title suggests, the workshop specifically excluded monitoring aimed at detecting effects on human health. Its focus was on monitoring for effects that genetically modified crops might have on the surrounding ecosystems, including plants, animals, and microorganisms. The purpose was to lay out the issues surrounding such monitoring, to describe what was known, and to identify what needed further attention.

After 2 days of presentations and discussion, numerous workshop participants expressed the opinion that ecological monitoring of genetically engineered crops is warranted, and they discussed in detail many of the scientific and policy issues that will influence the success or failure of such monitoring. The following is a summary and synthesis of the presentations and discussions in that workshop.

[1]The specific focus of the report was crops, such as *Bt* corn, that have been modified to resist pests, but it noted that many of its conclusions and recommendations applied to other types of genetically modified crops.

The Rationale for Ecological Monitoring

The monitoring of crops is not new. In 1845, when the potato blight that would eventually decimate Irish agriculture first appeared in fields on the Isle of Wight, its arrival was promptly noted in the *Gardener's Chronicle of London*. "Mycologists raced to see who could first identify the fungus that was on the potato leaves," Paul Waggoner, of the Connecticut Agricultural Experiment Station, told the workshop audience, "and within a year one had published a drawing and a Latin inscription in the very first volume of the new *Journal of the Horticultural Society*." In the 20th century, Waggoner said, monitors have spotted such pests and pestilences as Dutch elm disease, the gypsy moth, the corn borer, the boll weevil, Medfly, the Japanese beetle, and the Southern corn leaf blight. Those are examples of a type of ad hoc monitoring. Its purpose is to watch for specific things that can go wrong so that people can respond appropriately. Often such monitoring is no more sophisticated than when farmers observe their crops and report anything unusual.

A second type of monitoring is more systematic and directed. Referred to as "accountant" or "scientific" monitoring by various speakers, its purpose is to gather data to build a detailed understanding of what is going on in a field or in the surrounding area. "Accountants require consistent and comparable records," Waggoner said; that is why, for example, the US Department of Agriculture (USDA) has collected data on farming for more than a century. "Reports of crop yields and area began in the time of Lincoln," Waggoner said; "reports of fertilizer and pesticide use began in the time of Kennedy. Without these data series, one cannot separate anecdote and rumor from genuine trends." The second, scientific sort of monitoring was the major focus of the workshop. "We are talking about more than just waiting for things to appear; we are talking about a proactive monitoring regimen," said Barbara Schaal, of Washington University.

Is this sort of monitoring of genetically engineered crops necessary? After all, it is more difficult to carry out, requires a more sustained effort, and demands a higher level of scientific sophistication than simply acting as a sentinel. If it is necessary, why? What should it be looking for? The workshop participants were asked first to address these basic issues. They found the third question perhaps the easiest to answer because there is already widespread agreement in the field as to what sorts of effects might be expected to accompany the cultivation of transgenic crops.

For *Bt* corn and other crops that have been genetically modified to produce a pesticide, one of the biggest concerns is that widespread use of the crop could lead to the evolution of pests that are resistant to the pesticide. That is of particular concern for organic farmers, said Mark Lipson, of the Organic Farming Research Foundation, because they use the *Bacillus thuringiensis* (*Bt*) bacterium as a natural pesticide. For reasons that are not understood, the bacteria produce a variety of substances that are toxic to caterpillars and many other insects, so dusting with *Bt* allows organic farmers to protect their fields without using chemical pesticides.

A second concern is that crop plants that have been genetically modified to resist herbicides could turn into hard-to-control weeds in succeeding years when their fields are devoted to other crops. "Some of these volunteers can be quite serious," said Peter Day, of Rutgers University, using the term—volunteer—that agricultural scientists use to refer to crop plants that establish themselves without human intervention. "Volunteer potatoes are sometimes a nuisance in succeeding cereal crops, for example, and might have to be dealt with by herbicide treatment."

Both risks are expected to affect mainly farmers. Being resistant to a pesticide is not likely to make a difference in an insect's survival away from a farm, where pesticides are not used. Similarly, crop plants that have been genetically engineered to be resistant to herbicides would be no more likely than nonresistant plants to invade the areas surrounding the farm. But transgenic crops might affect ecosystems away from the farm in various ways, and these must be watched for as well.

One example is the possibility that *Bt* toxin in the drifting pollen of transgenic corn is killing monarch caterpillars. That is a case of what researchers refer to as "effects on nontarget organisms." Of course, chemical pesticides might also kill nontarget organisms and can drift from farmers' fields, but the development of plants that produce toxic pollen is a new phenomenon in agriculture.

Another concern about transgenic plants centers on horizontal gene transfer, that is, the movement of genes from the genetically modified plants to organisms in the surrounding environment. That can happen, for instance, when a virus infects a plant that has been given a viral gene to protect it from a particular virus. Through the process of recombination, the invading virus can add that viral gene to its own complement of DNA and turn it into a new—and possibly more threatening virus. "When the first reports of recombination between a virus and a viral transgene came out, it was thought to be quite anomalous," said Alison Power, of Cornell University. "Now if you talk to molecular virologists, most of them will argue that, sure, it is going to happen. Recombination is going to occur between these viral transgenes and wild-type invading viruses."

Horizontal gene transfer can also occur between crop plants and closely related weeds. "Essentially every crop that we have in our array of domesticates is associated somewhere on the planet with a companion weed," said Hugh Wilson, of Texas A&M University. Those companion weeds are so closely related to the crop that they can hybridize and share genes. Queen Anne's lace is a companion weed to the carrot, for instance, and Johnson grass is a companion weed to sorghum. Generally, the companion weed is descended from the same undomesticated plant that served as the starting point for breeding the domesticated crop, and often the crop and the companion weed have passed genes back and forth over time, so neither can be considered the progenitor of the other. If a transgenic crop is planted in an area with its companion weed, chances are that the transgene will eventually be passed on to the companion weed.

Thus, if the domestic squash is genetically engineered to be resistant to a particular type of virus, sooner or later its companion weed, the Texas gourd, will pick up that same viral resistance. And the viral resistance offers a large enough competitive advantage, Wilson noted, that one line of Texas gourd could displace others, and this would lead to a loss of genetic diversity in the gourd. That is worrisome, he said, because when a problem appears in the domesticated crop—a major blight, for instance—plant breeders must be able to fall back on the broader gene pool of the undomesticated relatives for help in breeding plants that are resistant to the problem. "If we don't have that variation as a bank to go get things that we may need in the future, then we have a problem."

Genes also flow freely among different varieties of the same crop plant, so a farmer growing nontransgenic corn, for example, might find that because his neighbor had planted transgenic stock, his own fields contained some transgenic plants. Or two transgenic varieties could swap transgenes. "There are five herbicide-tolerant canolas on the market in Canada," said Rob MacDonald, of Aventis, and sometimes different varieties are grown in neighboring fields. "One of the risks is the potential development of multiresistant populations of canola due to gene flow between nearby or adjacent fields." A line of canola plants that was resistant to several major herbicides could be a particularly troublesome weed in fields that were planted with another crop. The planting of strategic areas in which nontransgenic crops act as "buffer" zones may be critical to the management of gene flow or pollen migration. Thus, the potential consequences of planting transgenic crops are in four major categories: the development of pesticide resistance in crop pests, the transformation of crops into invasive weeds, harm to nontarget organisms, and gene flow from crops into related plants, viruses, or other organisms. If monitoring is to be done, those are the major things to look for.

Without monitoring, it may be hard to know just how much of a threat each of those possible consequences poses. To some degree, the threat can be assessed by field tests before a genetically engineered variety is released for commercial use, and that is regularly done. But, Schaal noted, such testing cannot catch everything. "On an overall time scale, the prerelease testing is relatively short. It also involves small numbers of plants. But once the organisms are released into the environment, we are dealing with large numbers of individuals, and we are dealing with a long time span, so different scientific aspects come into play. Things that have low probabilities become much more likely when you have large numbers. Also, small effects that can accumulate over time will become apparent over a long period. So we are dealing with a different set of issues when we do ecological monitoring. We don't know whether such effects occur, but we need to have the kind of monitoring that will detect if such small effects begin to accumulate or such improbable events begin to appear."

Besides such issues of scale, the complexity of ecosystems is another argument for monitoring, Schaal said, because laboratory or field tests will never fully replicate all the interactions among organisms in an ecosystem. "The only way to see what happens in an ecosystem is to place the genetically modified crop into an ecosystem. We cannot predict what the outcome will be, so we need to have some sort of monitoring to be assured that we can detect any kind of untoward effects."

In particular, a technique called risk assessment is used to estimate the likelihood that a transgenic problem might damage the environment in some way, and risk assessment, said Bob Frederick, of the Environmental Protection Agency (EPA), demands the sort of data that only detailed monitoring can provide. "Monitoring is a critical component of risk assessment." Calculating the risk of any particular event demands knowledge of two factors, Frederick noted: the probability of the event, and the hazard that event poses. If, for example, one wished to estimate the risk posed by cultivating a variety of squash that had been genetically engineered for resistance to a particular virus, one would begin by deter-

BOX 1: Traditional Agriculture and the Environment

With all the attention paid to possible effects of transgenic crops, it is easy to forget that traditional agriculture's effects on the environment have been nothing short of overwhelming. And, given the proven ecological consequences of traditional agriculture, some researchers at the workshop wondered why transgenic crops should be subject to so much more scrutiny than traditional crops.

"Tens of thousands of years ago, humans were hunter-gatherers," noted Peter Day, of Rutgers University, "and as they learned to save seeds and plant stocks for their first attempts at cultivation, they laid the foundation for plant domestication, plant improvement, and what we today call plant breeding. The ecological impacts of agriculture that resulted from this transition were profound. As the human population grew, it altered the face of the earth."

As Europeans colonized the New World, some 20,000 cultivated plants were introduced into North America and South America, noted Anne Vidaver, of the University of Nebraska, Lincoln. This has reshaped the ecology of the Americas, Vidaver said, from the plants themselves to the insects that depend on them for food, and down to the microorganisms that live on and in the plants.

The effects continue today. On farms, the cultivation of traditional crops can have many of the same ecological consequences that have triggered concern about transgenic crops. As Norm Ellstrand, of the University of California, Riverside, pointed out, traditional farming practices have at times led to the creation of troublesome weeds. "There was an introduction of a forage grass called Michel's grass to the northwestern United States in the 1930s," he said. "This hybridized with cultivated rye, and it gave rise to a new weed that altered the economics of the region such that farmers were unable to grow either rye or wheat in that region." There have been cases where cultivated crops were introduced into a region and wiped out a wild relative, thus diminishing genetic diversity. "The spread of rice cultivation in Taiwan led to the extinction of a wild subspecies of *Oryza sativa*," Ellstrand noted. Furthermore, the use of chemical herbicides can cause weeds to

mining the probability of resistance transfer from modified squash to companion weed. Next, one would determine the hazard that such acquired resistance would present. Might it cause a loss of genetic diversity in the companion weed? If so, would that matter, and how much? Could the weed become a greater pest in agricultural fields, and how difficult would it be to deal with? Answering any of those questions, from the probability of an event to the degree of hazard that it represents, requires data on the plants and other organisms and how they interact with one another. And those data, Frederick said, can be obtained only through monitoring.

Furthermore, in practice, the risk posed by a particular crop can depend critically on how the crop is managed, said Fred Gould, of North evolve resistance to them, and the chemical pesticides can kill desirable insects in much the same way that *Bt* corn pollen is thought to dispatch monarch caterpillars.

Given that traditional agriculture is not without its own risks, one audience member asked whether there is anything inherent in the development of transgenic crops that warrants monitoring them more closely than traditional crops are monitored. "Many of us take the view that the answer to your question is no, there isn't anything special," Day replied. "Transgenic crops are different. Can one say that they are 100% safe? No. One cannot say that of traditional crops, either. So it comes down to one's assessment of the appropriate risk. One needs data to satisfy people's concerns."

In the workshop's wrapup session, MacDonald, of Aventis, echoed that sentiment. "One of my conclusions from the workshop," he said, "is a clear consensus that our agricultural systems do have substantial impact on ecological systems regardless of the technologies that are used—conventional, no tillage, conservation tillage, genetically modified, or organic for that matter." Thus, he said, monitoring decisions should be based on the product itself and not on the process by which it was derived. Another view expressed by panel member and farmer David Winkles, of the South Carolina Farm Bureau, was that the benefits of genetically modified crops outweigh any theoretical ecological hazards and that monitoring is generally unnecessary.

Thomas Nickson, of Monsanto, summed up his point of view by asking a question: "Is it appropriate or even possible to defocus on our fixation with genetically modified crops and step back into the larger system of food production, so that we are dealing with the more important problems? I'm talking specifically to the science community rather than the public at large, because I think the public has a legitimate and genuine concern over genetically modified foods for numerous reasons. But for scientists, is it appropriate—and is it possible—to have this defocusing?"

Carolina State University. In the case of a crop genetically engineered to produce its own pesticide, such as the *Bt* toxin, it is possible to prevent insects from evolving resistance to that pesticide by maintaining refugia—in this case areas planted with crops that do not produce the pesticide—so some percentage of the insects in the fields do not feel any selective pressure to develop such resistance. But if this sort of risk management is to be successful, Gould said, it is necessary to monitor the insects for signs of emerging resistance and to maintain the refugia accordingly. "Monitoring is a very important component here."

In addition to those scientific rationales, there are good social reasons for monitoring. The ecological monitoring of genetically modified crops is more than a scientific issue, noted William Hallman, of Rutgers University. Policies about transgenic crops are influenced by a number of factors, including public attitudes toward the crops, and, Hallman said, public attitudes depend on factors other than scientific ones.

"From a social-psychological perspective, why monitor?" he asked. "One of the answers is that the public wants us to. Even if there is nothing there, monitoring sends the signal that we take this seriously enough to make sure that nothing bad will happen—that we don't expect something bad to happen, but we want to make sure. We take this seriously."

Thus, according to Hallman, even if genetically modified crops pose no greater threat to the environment than conventional crops, there remains a reason to treat the transgenic crops differently. The public sees them as something different—and potentially more dangerous—and rigorous monitoring can help to reassure members of the public that scientists are being careful to safeguard them.

Scientific Issues in Ecological Monitoring

In her introductory remarks, Schaal laid out the scientific issues that the workshop participants had been asked to address: What do we monitor? How do we do ecological monitoring? How frequently do we monitor? Those are, she said, "rather difficult questions."

They are difficult because ecological monitoring is still a relatively new field, and although researchers have examined some issues in great detail, others remain mostly unexplored. During the workshop, speakers looked at what needs to be done in various areas for ecological monitoring to become an effective safeguard.

"The first question is what to monitor," said Power. "What are the organisms? What are the traits of organisms that we want to monitor? How do we choose those organisms?" In some cases, she said, the choice will be straightforward. If, for example, the transgenic crop in question is *Bt* corn and the concern is that the crop's major pest, the European corn borer, will develop resistance to the *Bt* toxin, it is necessary to monitor the corn borers for the appearance of genes that confer resistance. "But for many of the other kinds of ecological risks," she said, "it may be less obvious than that." When one is concerned about effects on nontarget organisms, for example, there are likely to be many different organisms in both the crop fields and the ecosystems adjacent to the fields. "How do we select among those?"

A number of factors should play a role in such a decision. For instance, Power said, researchers should consider the tolerance, or resistance, of various nontarget organisms to the pesticide or other technology when deciding which ones to watch, but tolerance shapes the choice in various ways. "We might logically assume that we are interested in the organisms that we think are going to be most susceptible to the particular technology that we are planning to use. In some cases, however, people doing environmental-impact studies have deliberately chosen tolerant nontarget organisms because they can be sure that they can find them when they go out for monitoring."

Researchers should also consider the abundance of various organisms when deciding which to monitor, but the same sort of conundrum exists. "Do you choose common species that are logistically much easier to deal with in a monitoring scheme," Power asked, "or do you choose rare species that you predict are going to be more subject to risk?"

The distribution of the nontarget organisms is another important factor: "Do you choose cosmopolitan species so that you can make some general rules that hold across the United States or across the world, or do you choose organisms that are highly localized in their distribution and yet again may be the ones that are most sensitive to the environmental perturbation that you are putting out there?"

Finally, Power said, population stability can make a major difference in the success of monitoring a particular nontarget species: "Choosing organisms that have relatively stable populations seems to give you the opportunity to detect impacts more easily because if you see wild fluctuations you may be able to correlate them in some way with the impact you are interested in. But it may be the organisms with unstable populations, which fluctuate wildly under normal conditions, that are most sensitive to the risk you are interested in. "I am not really giving any answers here; I am giving you a sense of the dilemma surrounding how we choose what to monitor."

In addition to deciding which species to monitor, one must decide how long and how thoroughly to monitor. The difficulty here, Power explained, is that a single ecosystem can vary greatly in space and time. If ecosystems were uniform, it would be possible to take one or a few measurements and spot any effects caused by a transgenic crop. But the natural variation of ecosystems makes it necessary to take data from a number of sampling sites over several years to have a reasonable chance of telling the difference between a real effect and chance variations.

Power described a study performed by a British researcher, Mick Crawley, that looked at the potential for transgenic herbicide-resistant canola to be invasive in the UK. "They set up a huge experiment. They planted in 12 sites, and they followed it over the course of 3 years and measured invasiveness in an appropriate way." The final answer was that transgenic canola was not likely to prove invasive in the UK. Then, Power said, after the study was published, a second scientist reanalyzed its data to answer a different question: What if only some of the 12 sites had been sampled, or what if the data had been taken over a period shorter than 3 years? Would the answer have been the same? The reanalysis found that the final answer would have been little changed by taking data at fewer sites but would have been quite different if the study had gone on for just 1 or 2 years instead of 3. Such volatility suggests, Power said, that the year-to-year variation in weather or other factors may make monitoring sensitive to the period over which it takes place. In contrast, the site-to-site variability was apparently not so great in Crawley's study that it would have made much difference to look at fewer than the 12 original sites. "Of course," Power said, "that really depends on the variability of the sites that were chosen for this particular study, and I am not convinced that would be true for all available laboratory sites."

If there were no constraints on time and resources, it clearly would make sense to maximize both the length of the monitoring and the number of sites, but such constraints always exist. "Obviously there is a conflict here between the desire to monitor until we are absolutely sure that there isn't going to be an impact and the desire to get the technology out to users," Power said. "That is a real conflict, and it incorporates both scientific-ecological decision-making and socioeconomic decision-making. I cannot answer the question, but what I can say is that it is important to think carefully about what should be required for field experiments, about what is a realistic but effective design for making sure that year-to-year variability has been accounted for."

A related issue is that if ecological monitoring is to discover changes in ecosystems caused by the cultivation of transgenic crops, it will be vital to know what those ecosystems were like before the introduction of the transgenic plants. "If you monitor something," Schaal commented, "you need to collect a series of different data points to tell whether anything is changing. The collection of these data is critical because you cannot tell whether something has changed if you don't have a baseline."

And because of the natural variability in ecosystems, such a baseline must be more than just a snapshot—that is, more than just data on the ecosystem at one moment. Unless a researcher understands, for example, how much the population of a particular insect normally varies from year to year, it would be impossible to know how to interpret a 30% drop in the insect's numbers the year after a crop of *Bt* corn was planted. "One of the main difficulties and challenges in impact assessment," Power said, "is going to be in separating these impacts from natural spatial and temporal variability." And the problem will only get worse, she predicted, as the global warming trend continues to alter weather and temperature patterns, making year-to-year variability in ecosystems even greater.

Besides providing a basis of comparison for what happens when transgenic crops are introduced, baseline monitoring helps researchers to understand the systems into which genetically modified plants can be injected. For example, Power said, "it has been suggested for years that viruses are not likely to have any effect on natural plant populations, because most natural plants have evolved resistance to viruses. But there had been little quantitative information to address that question, and studies over the last couple of years have come up with more and more examples of naturally occurring viruses that have had substantial effects on naturally occurring plant populations. So we can no longer assume that there isn't going to be any effect of releasing these virus-resistant plants." Without a baseline—that is, without knowing in some detail what is going on or what can go on in nature—it is difficult to make an informed judgment about the effects of genetically modified crops.

Getting the detailed baseline data that researchers need, Power said, will require extensive monitoring programs to watch for disease outbreaks or pest infestations in agricultural systems. "But we don't have such a program for natural ecological systems," she said. "We have some long-term ecological research sites that are meant to begin this process, but these sites are only a decade or two old in most cases. So it is difficult to argue that the baseline monitoring data we have right now are sufficient for many of the kinds of ecological risks that we are interested in."

One way to correct for having so few baseline data is to use control sites—areas where nontransgenic crops continue to be planted—and compare outcomes there with outcomes at sites where genetically modified crops are introduced. If that is done, the selection of appropriate control sites will be critical, noted Anne Kapuscinski, of the University of Minnesota. The control sites must be carefully matched to the release sites on the basis of key ecological variables, and they must be chosen so that inadvertent contamination from genetically modified crops is unlikely. "It is also going to be important to choose carefully which release sites to monitor," she said, "because it will not be feasible to monitor each commercial application of a genetically modified organism."

Ultimately, the purpose of monitoring is to help one to understand the risks and benefits associated with transgenic crops and to be able to respond to or manage the risks effectively. So the monitoring should take into consideration the needs at two interconnected stages of risk decision-making, risk assessment and risk management.

Risk assessment has been defined in a variety of ways over the years, said Bob Frederick of the Environmental Protection Agency, but in essence it is an analytical tool that helps one organize and analyze large amounts of data to estimate the potential risk posed by a process or event of interest. Risk assessors attempt to calculate a numerical value for risk, a value that can then be used in making decisions about whether to go ahead with a particular action.

The basic formula for risk has two entries, Frederick explained: the probability that a particular undesirable event will occur, and the hazard or damages that would accompany that event. Risk is calculated by multiplying the probability of an event by its peril. Thus, to estimate the risk posed by transgenic crops, one must have values for both numbers—probability and hazard.

Power said, "in much of the work done so far in risk assessment of genetically modified crops, we have focused on the probability of the event, trying to get a handle on the number. But the extent of the hazard—what kind of hazards these traits actually confer—is probably more important. An example is the gene-flow literature, in which we now have pretty good estimates of the probability of gene flow for a lot of different crops into their wild relatives, but we still don't have many studies on the extent of the hazard: What does it mean if the gene flow occurs? Does it actually present a hazard?"

Because of that uncertainty, Power said, researchers should focus more on understanding the potential hazards posed by genetically modified crops—the "So what?" question. "Laboratory experiments have shown a variety of examples of hazards from viral recombination that do occur in the laboratory, such as increased virulence, increased host range so that the virus can infect hosts that it would not normally have infected, and changes in transmission, such as viruses that can now be transmitted by an aphid although formerly they were not transmissible by an aphid. Those have been shown under laboratory conditions. The challenge is to figure out how to monitor for them under field conditions."

As an example, Power described studying the effects of putting viral genes into oats to make the oats resistant to a virus. Research showed that the viral genes did indeed make their way into a companion weed, wild oats, and that the genes made the wild oats resistant to the virus as well. "The question is, Once it becomes resistant, is it likely to become more of a weed? Wild oats are a weed both in agroecosystems and in natural habitats in the sense that they outcompete a lot of native perennial grasses in many parts of the West. The existence of risk depends on such factors as the co-occurrence of domesticated and wild oats, gene flow between them, and the occurrence of viable hybrids of oats and wild oats; and all these have been shown quite extensively. We have been working on whether viral-resistance gives wild oats a selective advantage, and the answer is yes. We can see substantial effects on growth, reproduction, and all those things that you would associate with fitness traits. The next step is to ask about it in the field, and that is essentially where we are now."

BOX 2: Solving the Monarch Mystery

Little is simple in ecological monitoring. It might seem easy, for example, to answer the question, "Is *Bt* corn killing monarch caterpillars, or isn't it?" But as John Pleasants, of Iowa State University, demonstrated, even such seemingly easy questions can demand tremendous time, resources, and patience to answer.

Monarch caterpillars feed only on the leaves of the milkweed plant, which often grows close to corn, either in or along the edges of fields. If the corn has been genetically modified to produce the *Bt* toxin, the toxic pollen from the corn can make its way to the leaves of milkweed plants and be eaten inadvertently by the caterpillars.

The ideal way to determine whether the *Bt* corn actually harms the caterpillars, Pleasants noted, would be to perform a field study: watch a group of caterpillars in a natural setting, determine which are exposed to *Bt* toxin and which are not, and see whether the exposed caterpillars are more likely to die than the unexposed. Unfortunately, he decided, such a field study would be impractical.

"To do this on a sufficiently large scale," Pleasants explained, "you need a lot of replication, and this requires lots of resources. We can't just go out and find lots of *Bt* fields and lots of non-*Bt* fields and look at naturally occurring larvae on naturally occurring milkweed plants—we can't get the milkweed where we want it, and the number of larvae is too small.

"So you end up having to contrive some sort of experimental field situation. You bring potted plants out there, and put larvae on plants, and so on. But that requires a lot of effort. You need plenty of potted plants, and you need a colony of monarchs so that larvae are available. Some recent studies have done this, but almost always on a very limited scale—maybe one or two replicates."

To get enough replication—that is, to do the experiment a number of times, varying the conditions from time to time—Pleasants and colleague Richard Hellmich decided on a combination field-laboratory study in which they would perform some measurements in the laboratory and others in the field and then combine them to reach a conclusion. They would go to corn fields to measure the pollen density in and near the fields. Then in the laboratory, they would feed milkweed leaves to monarch caterpillars with different pollen densities—some with the pollen density found right at the edge of the field, some with the density found 1 meter from the field, some 2 meters, some 4 meters, and so on. By seeing how many of the caterpillars survived at each of these levels, they could arrive at a measure of how dangerous the *Bt* corn was to caterpillars at various distances from the field.

"One of the advantages of having the laboratory component," Pleasants explained, "is that you are not so time-constrained. When you do it in the field, you have a window of opportunity when corn plants are pollinating." They still had to take his pollen-density measurements when the corn was pollinating, but that was much simpler than preparing enough milkweed plants with monarch caterpillars on them at just the right time to do the experiment.

"We took seven different fields. At each sample point, we put a little microscope slide coated with glycerine to capture the ambient pollen flow at that point." The team constructed assemblages of milkweed stems, called "bouttonnieres," that mimicked how the milkweed leaves would pick up pollen from the air. From that, Pleasants created tables showing how much pollen would probably be found on milkweed leaves growing at various distances from a cornfield. It was only an approximate measure; many things can happen in the field to cause variations in the pollen levels. He found, for instance, that rain will wash about 90% of the pollen off the milkweed leaves. But it was a reasonable approximation.

The next step was to create experimental setups where they raised monarch larvae on milkweed leaves that had been sprayed with carefully calibrated amounts of pollen. They recorded the effects of eating the leaves, including deaths and effects on the caterpillars' weight gain. Finally, they calculated what the effects would be in a natural setting at various distances from a cornfield. Their analysis also looked at several types of *Bt* corn, including one, Event 176, that expressed the *Bt* toxin in the pollen and others that expressed the toxin only in green leaves.

The research team found that only Event 176 had an appreciable effect on the caterpillars. For the other varieties of corn, it took such high doses of the pollen to have an effect that only a few caterpillars—those living right at the edge of a cornfield and unlucky enough to live on leaves with a particularly dense dusting of pollen—would be harmed by a weight loss, and mortality would be negligible. For Event 176, however, a significant number of the caterpillars living at the edge of a cornfield died, and it was only at distances greater than 4 meters that effects disappeared completely.

The experiment, as carefully as it was done, can only approximate what happens in the field, Pleasants noted, and a number of variables might make the reality very different from the calculated version. "It's possible, for example, that in a benign laboratory environment it takes a high dose to have an effect, but in a field environment where larvae are stressed out by a lot of things, a much lower dose might push them over the edge.

"But it is possible that you might overestimate the toxicity in the laboratory, because there is so much variability in a field situation. In the laboratory, we force them to eat leaves with a particular pollen density. In the field, they could have choices. There might be variability in pollen densities on a leaf itself or on different leaves of one plant."

Many other factors must be considered to make the laboratory results completely relevant to the field, Pleasants added. For instance, the timing of the monarch life cycle should be compared with the growth cycle of the corn to see exactly what the pollen densities are when the monarch larvae are feeding. Someone should also determine, he said, just how important milkweed in or near cornfields is to monarch production. "In other words, if you imagine a landscape with different kinds of habitat—corn, beans, some *Bt* corn, natural areas, roadsides—and imagine the distribution of milkweed across that landscape, the question is where the monarch production is coming from."

Despite its shortcomings, Schaal noted, the sort of real data that this experiment generated is invaluable to those debating the ecological consequences of transgenic crops. "It's interesting to see what the levels of pollen deposition are," she said. "That allows you to begin to evaluate various risks."

BOX 3: Type I Versus Type II Errors

On the surface it might seem to be nothing more than an esoteric disagreement about proper statistical technique. In reality, however, the growing debate about type I versus type II errors has the potential to shape policy on genetically engineered organisms in profound ways, so it pays to delve deeply enough into the issue to understand where the disagreement arises and what the stakes are.

Because ecosystems naturally have a great deal of random variation, both in space and in time, monitoring will seldom offer unequivocal evidence to support one conclusion or another. To test whether *Bt* corn plants growing near cornfields are killing monarch caterpillars, for instance, one might monitor monarch deaths in two spots, one of them next to or in a field with genetically engineered corn and the other next to or in a field with conventional corn. But if more die in the field next to the *Bt* corn, that does not necessarily mean that the *Bt* toxin is to blame; the result could simply be a chance difference between the fields. That is what statistics is designed to measure: How likely is it that the effect one sees is nothing more than chance variation? Or, conversely, how likely is it that the effect can be accepted as real? In theory, one could set the standard of proof for such a statistical test at any desired level, demanding that the effect be somewhat likely, moderately likely, or very likely before stating that the data offered evidence to support one's conclusion.

In practice, however, researchers generally demand the same standard of proof from every statistical test. "As scientists, we are pretty much indoctrinated with the notion that we should be looking for significance levels at the 0.05 level," noted Power. In other words, scientists generally do not accept an effect as proved unless the statistical evidence is so strong that there is less than a 5% probability that the effect—in this case, the death of monarch caterpillars near *Bt* corn—was the result of chance. In statistical terms, this is known as minimizing type I errors—errors in which one says that there was an effect when there actually was not—in other words, a false positive. "If you think about it," Power said, "this is clearly a bias in favor of the technology. It is a bias in favor of releasing the technology because we are saying that you have to be sure at the 95% confidence level that there really is an impact or else we are going to assume that there is no impact."

That is not necessarily the best approach, Power said. "What ecologists have

In short, one of the most important tasks for ecological monitoring will be to help researchers to establish what hazards can be posed in the environment, such as making wild oats a more successful weed, by putting transgenic crops into the field.

On a related note, Frederick said, monitoring programs can be designed to provide various details that risk assessors have identified as important but that are unknown or poorly known. Before a complete risk assessment is done, for example, risk assessors can decide which areas are more or less likely to involve risk and then assign monitoring intensity on that basis to make it more relevant and useful.

increasingly been arguing is that we ought to be thinking more and more about type II errors," that is, the error of saying that there is no effect when such an effect is actually there—in other words, a false negative. Minimizing type II errors would turn the traditional approach on its head and demand that a preponderance of evidence show that there was no effect before concluding that nothing was happening. In the case of the monarchs, for instance, even if they were unaffected by living next to *Bt* corn, it would take much monitoring at many sites before a researcher would declare *Bt* corn safe. Until then, the results would be worded to say that the data failed to rule out the possibility that *Bt* corn was harming the caterpillars.

An emphasis on avoiding type II errors is a much more conservative course than the current practice of minimizing type I errors. It would raise the bar much higher for tests of genetically modified crops, in essence minimizing the chance of concluding they do not increase harm to the environment when, in fact, they do increase harm to the environment. And that might be what society wants, said Kapuscinski. The types of harm that matter most to society—that people want most to avoid—are precisely the sort that arise from type II errors, such as assuming that a transgenic crop is safe and planting it, only to find later that it causes some ecological damage. People seem less worried about type I errors, whose practical effect would be to keep a safe transgenic crop off the market.

In practice, though, researchers need not necessarily choose between avoiding type I or avoiding type II error in performing their analyses, Kapuscinski said. "To some extent there is a tradeoff between the two," she said, but researchers can create monitoring experiments that take into account both kinds of error. "In designing monitoring plans, one key criterion should be to try ahead of time to figure out what level of type II versus type I error you can accept and how you will design your experiments to achieve that."

Power concurred: "The intermediate strategy is to at least consider both kinds of error rather than simply considering type I error, which is what we have been doing pretty much across the board in our risk assessments."

Once the decision has been made to release a transgenic crop, its effects on the surrounding ecosystem can depend heavily on how the crop is managed, and that too has implications for monitoring. "If we want to have adaptive management strategies in which we alter the management of a particular crop, we need to have data on which to base the alterations of management," Schaal said.

Gould offered an example of how monitoring might be used in preventing pests in a field of *Bt* corn from evolving resistance to the *Bt* toxin. The trick to preventing the resistance from developing is to maintain refugia—areas of corn where the pest is not exposed to the *Bt* toxin or the selective pressures that promote resistance development. This cannot be done blindly, however. Gould showed how one can create models of how resistance might develop in a population of insects, monitor the pests to detect signs of such incipient resistance, and use the model and the monitoring to plan refugia accordingly. Without such careful management, the fields could end up inhabited by insects that are not susceptible to *Bt* toxin.

Ideally, monitoring should be designed so that it can detect both unexpected and unpredicted events and events that are expected. To illustrate her point, Kapuscinski described how attempts to rebuild self-reproducing salmon populations in the Pacific Northwest backfired when carefully planned spawning interventions resulted in a decrease rather than an increase, in salmon abundance. She summed up this way: "If I were to state in one sentence the primary implications of all these carefully examined cases of failures in living-resources management, I would say that the responsible institutions and users were blind-sided by surprising feedback from the system or, to use the terminology of Sengue, 'fixes that backfire.' So, if you remember nothing else from what I spoke about today, it should be that we should be prepared for ecological surprise. We should expect ecological surprise." Another reference to unexpected results came from Guenther Stotsky, of New York University, who reported that *Bt* corn decomposes more slowly than non-*Bt* corn (probably because it has higher lignin content). His research showed that *Bt* toxins can remain active in the soil for several months—not an expected result. Despite our lack of knowledge about the ecological implications of these findings, they underscore the importance of being prepared for the unexpected.

Policy Issues in Modeling

Putting ecological monitoring of transgenic crops into practice successfully will demand more than an understanding of the scientific underpinnings. Workshop participants found that the designers of such monitoring programs will need to take a number of other issues into account, including existing programs, the availability of resources, and public attitudes.

When developing programs to monitor genetically modified crops, researchers should first recognize that the establishment of such programs will not be written on a blank page. "Many environmental monitoring programs are already under way or have been completed," said Steve Bartell, of the Cadmus Group, a consulting firm that works on environmental issues. The focus of the existing programs include environmental resources such as agricultural lands, forests, wetlands, estuaries, rivers, streams, lakes, as well as particular groups of organisms for example, birds. "In developing monitoring for genetically modified crops," Bartell said, "we ought to at least go back and see what those programs are doing—how they are set up, how they identified what to measure in relation to their objectives—and look at some of the statistical design, some of their mechanics of monitoring."

Beyond that, it is possible that ecological monitoring of transgenic crops might be able to piggyback on—or at least borrow data from—the existing programs. "It's very important to evaluate existing monitoring programs to see which might contribute baseline information, if nothing else," Bartell said. "Those programs might also be suitable for modification to use for looking at issues of genetically modified crops."

Two speakers at the workshop described long-running monitoring programs that are carried out by the US government. Each has something to offer those who would design ecological monitoring programs for genetically modified crops.

Warren Lee, of USDA, described the natural-resources inventory, begun after passage of the Rural Development Act of 1972, which required USDA to assess the conditions and trends of soil, water, and related resources and report to Congress at intervals not to exceed 5 years. The inventory uses both remote sensing and onsite data collection to gather information about major land-resources areas and watershed levels. Because it is not feasible to track information on every bit of land in the United States, the inventory uses a sampling method that is statistically designed to give representative information about land use from data on a small percentage of the total land.

"We have 300,000 primary sample units across the United States," Lee said, and most of the units contain three sample points at which data is drawn. The data describe the land not just at the point but within a specific distance from the point, and each point is classified into one of 69 categories depending on the use of the land and its cover: water, grass, forest, and so on. In addition, the inventory gathers a huge amount of other information, such as who owns the land, habitat composition, conservation practices, and soil characteristics and erosion.

The most important lesson from the natural-resources inventory, Lee said, is the necessity of knowing what you are trying to do before you get started. "We really need to understand what we are trying to understand. We need well-defined needs and well-defined requirements: Where are we going to collect the information? What are we going to collect? How is it going to be collected? How will it be used and analyzed?" Beyond that, he said, paying attention to the specific details of data collection is essential. "We want valid, compatible, and consistent data, and that demands training, technical support, data-collection quality-assurance instructions, checks and evaluations, accurate interpretation and classification, and quality, quality, quality."

USDA also collects data on farms across the United States with its Agricultural Research Management Studies. The surveys have three main objectives, said Jorge Fernandez-Cornejo, an economist at USDA's Economic Research Service: "first, to gather information about agricultural production, resource use, input use, and farm practices; second, to determine the cost of production; and third, to determine farmers' net income and financial situation."

The surveys gather data about farms in nine categories, including field characteristics, seed, fertilizer applications, pesticide applications, pest-management practices, use of machinery, and irrigation. Recently, the surveys have begun to collect data on the use of genetically modified crops. "We like to answer three types of questions," Fernandez-Cornejo said. "First, what factors led the farmer to adopt genetically modified crops? Second, what is the impact of adoption on pesticide use, on yields, and on farm profits? And finally, what is the suspected diffusion pattern of the adoption?"

Besides government monitoring programs, companies that sell genetically modified seed often carry out their own monitoring programs, which might also be useful in setting up monitoring for ecological effects of transgenic crops. Aventis sees such monitoring as part of its stewardship of its products, MacDonald said. "Stewardship is viewed as a business responsibility that extends beyond regulatory requirements," he said, "and that is why we often voluntarily conduct monitoring after commercialization. It is in the company's interest to ensure the sustainability of this technology."

"Product stewardship also involves the development of good agricultural practices for using the technology," MacDonald explained. "We have a benefit-risk assessment during the safety evaluation of the product, which leads to a recommendation for managing the benefits and the risks. And that is where monitoring comes in. Monitoring is an effective way to assess the efficacy of your management program. We can take the information from monitoring and update our guidance so that the outcome is best agricultural practices, or we can use the information to update our monitoring efforts to refine and focus the activities that we are looking at."

Any ecological monitoring scheme should start with an understanding of what has already been done, from government surveys to industry stewardship programs, and work from there. A second factor to take into account will be the availability of resources. If time and money were no object, it might be possible to design near-perfect monitoring programs, but time and money are always limited, so the design of the program will always demand tradeoffs.

"For a successful monitoring effort," Lee said, "you need to have a clear purpose, well-defined needs, well-defined requirements, and—I cannot emphasize this enough—adequate resources. Everyone I talk to says, 'Gee, I would sure like to have those statistically reliable data at my county level.' Well, I say, 'Give me the money, and we can do it.' But although most people in Congress like to have the information, they don't necessarily like to pay for it. The conflict that everyone in this room will face is getting adequate resources to get quality data. So I cannot emphasize enough: You must define the needs well so that you can target resources to get the job done."

BOX 4:
Understanding Public Attitudes Toward Transgenic Crops

To be effective, any ecological monitoring of genetically modified crops will have to take public attitudes and opinions into account. To do that, one must know what those attitudes are and how they are developed. Hallman studies just those issues.

The first thing one must understand about how people think about genetically modified crops, Hallman told the workshop, is that people actually don't think or know much about them. "The latest data suggest that 50% of Americans have read little or nothing about biotechnology. Only about 10% report that they have heard or read a great deal about biotechnology." Surprisingly, the level of public awareness has not grown a great deal over the last decade, even as biotechnology has made its way from the laboratory to the farm. "One of the first good studies done on awareness of biotechnology in the United States was done by the Office of Technology Assessment and released in 1987. It found at that time that 63% had heard relatively little or almost nothing about biotechnology and 6% had read or heard a lot."

This relative unfamiliarity with biotechnology offers both an opportunity and a danger, Hallman said. "Relatively uninformed opinions are what we call uncrystallized; that is, they are not well thought through. They are not necessarily strongly held. They are subject to change." In short, he said, biotechnology is not something that Americans have made up their minds about. "If you look at the opinion polls that ask people to rank the hot political issues, genetically modified crops are not high on the list. It's not something about which people have been forced to make personal decisions, by and large.

"I want to emphasize that: It's not something that people have had to make personal decisions about. That is important because once people make decisions, their opinions become more crystallized. When that happens, they adjust their attitudes and opinions to support their decisions. They pay much more attention to confirming information. They discount inconsistent information. And, more maddeningly, they reinterpret disconfirming information to support their decisions."

Thus, Americans are open to being convinced that genetically modified foods are a good thing; but they could also decide that genetically modified foods are something to be avoided. "Given the current state of uncrystallized opinion, at least in the United States and in other parts of the world, when do you begin communicating about this? Clearly, the answer is now, while people's opinions are still uncrystallized, while people are still relatively open to new information, and before people are forced to make a decision about genetically modified crops."

Hallman listed several factors that could make people turn against biotechnology in agriculture. So far, people haven't thought much about transgenic products, Hallman suggested, because they seem to represent incremental advances over familiar products. A truly novel product, however, would make people pay attention, and the wrong product could crystallize their opinions against genetically modified organisms. "Once we start creating things like glow-in-the-dark grass or other kinds of products that are seen as trivial by the public, that will force some people to make some decisions," Hallman said, and those decisions might not be approving.

Any sort of accident or adverse event, particularly one that threatened what are perceived as vulnerable populations, could also set people against genetically modified foods. "If there is 'genetic contamination' of baby food, for example, it would cause people to re-evaluate their positions. In general, anything that happens to babies, to kittens, to bunnies, to butterflies, or to old people will get people's attention and cause them to make decisions."

Various social factors could also play a role. "Perceived injustice, perceived unfairness, or perceived lack of control can make people come down on one side or another," Hallman said. "There are some social conformity pressures as well: people who are perceived leaders or respected persons come down on one side or another, and it then becomes socially acceptable to be for or against."

Perhaps the most important thing for biotechnology scientists to understand, he said, is that if people are to be convinced to favor transgenic foods, it will have to be on their terms, not on the scientists' terms. "People see a fundamental difference between genetically modified crops and traditional crops. One of the implications of this concerns the argument, We don't monitor traditional crops, so why should we monitor genetically modified crops, when they are functionally equivalent? But that argument doesn't resonate with people. People think that the two are fundamentally different."

Scientists and others who would communicate with members of the public about genetically modified crops should first understand the framework that people have for understanding such things and then work within that framework. "It is important to find out the right starting points for folks," Hallman said. "We need monitoring data about public opinions, just as we need environmental monitoring data. In the United States, we lack good data on this."

Whatever people think and however poorly informed they are, scientists should not make the mistake of concluding that the public is irrational, Hallman said. "There are several real dangers in believing that the public is irrational. One is concluding that because the public is irrational, efforts to provide information and education are a waste of time and money. They can't make good decisions, so why educate them? Another is concluding that because the public is irrational, they can't make good decisions about biotechnology. It would follow that those of us who are rational, the experts, and those who agree with us should make the decisions that are 'good' for the public.

The first assumption ensures that the public will not have the tools needed to make informed decisions, and the second ensures that the public will become angry that decisions about the acceptability of a perceived risk are being made for them.

"I beg you not to treat the public as irrational. Treat them with respect, and give them the information that they need to participate in this process."

Resource limitations will force researchers to make choices about which sorts of monitoring they will do. For example, Schaal noted, "if we are going to begin looking at ecosystems, then things become very complicated. It seems to me that the farther away we get from the farmer's field, the more complex the monitoring is, the more expensive it is, and the less likely there are to be funds to do it."

"It will be important," Bartell added, "to select ecological effects that are compatibly scaled with the monitoring resources. It doesn't make sense to choose a measurement that requires 50 years of monitoring to demonstrate an impact if the necessary resources to perform such longer term monitoring cannot be reliably committed."

A third issue that will affect monitoring programs is the question of who will carry out the monitoring. The answer is not obvious, said Neal Stewart of the University of North Carolina at Greensboro. "Should it be the primary industry? Should it be someone like Cadmus? And how much can we involve farmers in monitoring, inasmuch as they seem to be the closest to the situation?"

In many ways, the individual farmer is a natural choice to do much of the monitoring, noted Jeremy Sweet, of the National Institute of Agricultural Botany in the UK. "Who is going to see the unexpected first? It's most likely to be the person growing the crop. So the main thing is to engage the farmer in this program as much as possible and to have the farmer, if you like, as a partner in this, being involved in the development and the stewardship of the crops, and see that the farmer is contributing."

Other speakers, however, questioned whether farmers could be trusted with the monitoring, given that their self-interest might be in conflict with the interest of accurate monitoring. "There is a disjunction between assumptions made by the scientific community and the reality of what is going on with farms and farmers," said Lipson. "Compliance with refuge-area requirements, for example, deserves a great deal more independent scrutiny than it has been given. Frankly, it is not what it is purported to be according to my experience in the farm community. Likewise, the reliance on farmers to report anomalies in the performance of crops is questionable. I heard several times that this is what the scientific community is relying on in order to determine what questions it should be asking or where it should be making investigations. I think that is highly problematic." With regard to monitoring for the spread of herbicide-resistant weeds, Steven Duke, a USDA researcher, said this is already being done by farmers, extension agents, and weed scientists. "There has been a lot of monitoring already. There are herbicide-resistance action committees that are organized to glean all the data they can from all over the world on herbicide resistance and report it as quickly as possible," said Duke.

The question remains: Who should do the monitoring? And if it is the farmers, how can researchers be assured that their monitoring reports are accurate and unbiased?

Several speakers made the point that no monitoring system that is designed without keeping the public in mind can expect to be successful, at least in a public-policy sense. "One of the dilemmas facing the European Union right now," MacDonald said, "is a lack of confidence in the regulatory system, and in the government in general, as to its ability to safeguard the food supply. This has been driven by a number of tragic food crises that the EU has faced, which have shaken public confidence. We have to identify strategies that can improve public confidence, and monitoring can go a long way to achieving that goal."

"Trust is emerging as a very important issue," said Lynne Frewer, of the UK's Institute of Food Research, in Norwich. "Increasing trust means increasing the transparency of the whole risk-management process, which means laying bare the uncertainties that are inherent in that process."

Hallman added, "giving people a sense of control is key to this. It is not enough to have scientists saying, 'Trust me, trust me, trust me.' People don't respond to that well. Instead, it is important to have a process that is open and to do things like monitoring, even when you don't have to, so that people don't have to trust the opinion of an expert."

Those who design ecological monitoring programs for genetically modified crops could learn something, Bartell suggested, from the US national laboratories run by the Department of Energy, which have had to regain public trust as they clean up a variety of sites that have been contaminated by nuclear wastes and other hazardous materials. "One of the ways that they have effectively addressed those problems," Bartell noted, "is to allow the development of local stakeholder committees so that the public can introduce what it thinks are the important issues in relation to the cleanup and associated risk-assessment and risk-management issues." Finding ways for the public to have input into the design and oversight of monitoring operations would make it much more likely that the public would trust the results of monitoring.

Appendix A
Agenda

BOARD ON BIOLOGY
WORKSHOP ON ECOLOGICAL MONITORING OF GENETICALLY MODIFIED CROPS

July 13-14, 2000

I. Putting Monitoring In Context

Thursday, July 13th

8:30 Welcome and Introduction
Barbara Schaal, Washington University

8:45 A History of Real-Life Monitoring
Paul Waggoner, Connecticut Agricultural Experiment Station

9:15 Traditional *vs*. Transgenic Agriculture: What is the baseline for comparing ecological benefits and risks?
Peter Day, Rutgers University

10:00 Risk Assessment versus Monitoring: Appropriateness and Timing
Bob Frederick, Environmental Protection Agency

10:35 BREAK

10:50 Monitoring: The Challenges of Ecological Complexity
Alison Power, Cornell University

11:20 Adaptive Management as a Framework for Ecological Monitoring of GMOs
Anne Kapuscinski, University of Minnesota

11:55 The Logistics of Monitoring
Warren Lee, United States Department of Agriculture

12:35 LUNCH

1:35 Panel: International Perspectives on Monitoring of Transgenic Crops
Jeremy Sweet, National Inst. of Agricultural Botany, UK
Phil Dale, John Innes Center, UK
Rob MacDonald, Aventis, Canada
Lynn Frewer (moderator), Institute of Food Research, UK

II. Examples of Ecological Monitoring, (part one)

2:35 Monitoring for the effects of Gene Flow
Rob MacDonald, Aventis

3:25 BREAK

3:40 Gene Flow: A Case Study of Invasive Weeds
Hugh Wilson, Texas A&M University

4:25 Gene flow: from canola to weeds and monitoring
Neal Stewart, University of North Carolina-Greensboro

5:10 ADJOURN FOR THE DAY

Friday, July 14th

II. Examples of Ecological Monitoring, (part two)

8:30 Using Ecological Models in Risk-Based Environmental Monitoring
Steve Bartell, Cadmus Group

9:05 Monitoring for Resistance in Target Pests: *Bt* Corn
Fred Gould, North Carolina State University

9:45 Monitoring for the Evolution of Pathogen Resistance
Anne Vidaver, University of Nebraska

10:15 BREAK

10:30 Monitoring for Herbicide Tolerance in Weeds
Stephen Duke, United States Department of Agriculture

11:05 Monitoring for Direct Effects on Non-Target Species:
John Pleasants, Iowa State University

11:40 Monitoring for Indirect Effects on Non-Target Species: Soil Microbes, Earthworms, and Nematodes
Guenther Stotzky, New York University

12:15 LUNCH

1:15 Panel: Monitoring for Ecological Community Effects
Arthur Allen, United States Geological Survey
Tim Seastedt, University of Colorado
Guenther Stotzky, New York University
Henry Gholz (moderator), National Science Foundation/University of Florida

2:00 Panel: Monitoring for Changing Farm Practices
Jorge Fernandez-Cornejo, United States Department of Agriculture
Mark Lipson, Farmer
Thomas Nickson, Monsanto
David Winkles, Farmer
Allison Snow (moderator), Ohio State University

2:45 BREAK

III. Wrap-Up Session

3:00 Public Risk Perception and Environmental Impact of GM Crops—Implications for the Development of an Effective Risk Communication Strategy.
William Hallman, Rutgers University

3:30 Panel Discussion: Establishing Criteria and Priorities for a Monitoring Program
Steve Bartell, Cadmus Group
Max Carter, Farmer
Stephen Duke, United States Department of Agriculture
Fred Gould, North Carolina State University
David Andow (moderator), University of Minnesota

4:30 Concluding Remarks
Barbara Schaal, Washington University

5:00 END OF PROGRAM

Appendix B:
Biographies of Invited Speakers

Arthur Allen is a wildlife biologist in the Social, Economic, and Institutional Analysis Section of the US Geological Survey's Midcontinent Ecological Science Center in Fort Collins, Colorado. Mr. Allen has been a wildlife biologist with federal resource agencies for 26 years, holding positions with the US Forest Service, Fish and Wildlife Service, and National Biological Survey. Since 1993, his primary responsibility has been monitoring of habitat quality associated with the over 30 million-acre Conservation Reserve Program (CRP) of the US Department of Agriculture (USDA). His current work focuses on assisting USDA in definition of CRP grassland-management options that maintain long-term quality of habitats in Great Plains and midwestern agricultural ecosystems.

***David A. Andow** is professor of entomology at the University of Minnesota and has expertise in insect ecology and biotechnology. His research interests include the ecology of insects in agricultural systems, resistance management for transgenic plants, conservation of the Karner blue butterfly, and biotechnology science policy. He served on the Agricultural Biotechnology Research Advisory Committee (ABRAC) in the Office of the Secretary of the US Department of Agriculture and chaired the ABRAC Risk Assessment Subcommittee. He has also served on the Environmental Protection Agency Science Advisory Board's Biotechnology Subcommittee

*Indicates Planning Committee Members

and chaired the Department of the Interior's Karner Blue Butterfly Recovery Planning Team. Dr. Andow obtained his PhD in ecology from Cornell University in 1982.

Steven Bartell is a principal of the Cadmus Group, Inc., and manages its Oak Ridge, Tennessee, office. Dr. Bartell's primary research and technical interests include ecosystem science, ecological modeling, and ecological risk assessment. He has conducted ecological risk assessments for a variety of physical, chemical, and biologic stressors in aquatic and terrestrial ecosystems for public-sector and private-sector clients. Dr. Bartell has served two terms as a member of the Environmental Protection Agency Science Advisory Board (SAB) Ecological Processes and Effects Committee and is a member of the SAB executive subcommittee on the use of ecological models in supporting environmental regulations. He currently serves on the editorial boards of *Risk Analysis*, *Human and Ecological Risk Assessment*, and *Chemosphere*. He has written more than 100 technical publications concerning ecology, environmental sciences, and risk assessment, including the books *Ecological Risk Estimation* (Lewis Publishers, 1992) and the *Risk Assessment and Management Handbook*. Dr. Bartell also holds an adjunct faculty position in the Department of Ecology and Evolutionary Biology, University of Tennessee, Knoxville. Before joining the Cadmus Group, he was vice president and director of SENES Oak Ridge, Inc. From 1980 to 1992, he was a senior staff scientist in the Environmental Sciences Division, Oak Ridge National Laboratory.

Max Carter is a farmer in Coffee County, in Georgia's coastal plain region. In 1976, he changed from conventional to no-till farming of corn, soybeans, peanuts, and cotton. National Resources Conservation Service and extension agents began taking visitors to his farm to demonstrate the advantages of no-till agriculture. He serves as treasurer and board member of Georgia Conservation Tillage Alliance, an organization that was founded to promote conservation in farming. He has been president and is now chairman of the board for the Coffee County Conservation Tillage Alliance.

Phil Dale is head of the Genetic Modification and Biosafety Research Group at the John Innes Centre, Norwich, UK. Dr. Dale worked in agriculture for several years before graduating in agricultural botany and obtaining a doctorate in plant genetics. After a period of plant-breeding and genetics research at the Welsh Plant Breeding Station (1972-1985), he became research group leader at the Plant Breeding Institute, Cambridge (1985-1990). Here he was involved in the first field experiments with genetically modified (GM) crops in the UK (1987 onward) and led several

UK and EU research programs on the biosafety assessment of GM crops. In 1990, Dr. Dale moved to the John Innes Centre in Norwich, where he is currently directing research on GM crops, primarily with respect to behavior and stability and their environmental and food safety. From 1993 to 1999, he was a member of the UK Advisory Committee on Releases to the Environment. In 1998, he became a member of the UK Advisory Committee on Novel Foods and Processes, and in 2000 he joined the newly formed Agriculture and Environment Biotechnology Commission, advising the UK cabinet.

Peter Day is the founding director of the Biotechnology Center for Agriculture and the Environment, established in 1987 at Cook College, Rutgers, The State University of New Jersey. He began his career in plant science at the John Innes Institute, where he completed a University of London PhD in plant pathology and genetics in 1954. From 1979 to 1987, he was director of the Plant Breeding Institute in Cambridge, England; and from 1964 to 1979, chief of the Genetics Department at the Connecticut Agricultural Experiment Station in New Haven. Dr. Day is interested in the genetics and molecular biology of host-parasite interaction and the application of molecular biology to crop-plant improvement. He has written more than 100 papers and a number of books, the most recent of which (with coauthor Hermann Prell) is *Plant-Fungal Pathogen Interaction: A Classical and Molecular View*. He participated in the National Academy of Sciences 1972 report on genetic vulnerability in major crops and chaired the Committee on Managing Global Genetic Resources, which published two reports in 1991 and two more in 1993. He was also a member of the National Institutes of Health Recombinant DNA Advisory Committee from 1976 to 1979; it developed the first national guidelines for rDNA research. From 1986 to 1992, he served on the Board of Trustees of the International Center for Maize and Wheat Improvement in Mexico.

Steven Duke is research leader of the US Department of Agriculture (USDA) research group at the National Center for Natural Products Research, Oxford, Mississippi. He is involved in discovery and development of natural products for pest management and for other uses, such as nutraceuticals and botanical supplements. Earlier, he was director of USDA's Southern Weed Science Laboratory. He has published extensively in plant physiology and biochemistry and has edited and written several books, including *Herbicide-Resistant Crops*, published in 1996. Over the last decade, he has written numerous reviews on herbicide-resistant crops and has published several research papers on herbicide-resistant weeds. He was recently elected president of the International

Weed Science Society. Dr. Duke earned his PhD in botany at Duke University in 1975.

Jorge Fernandez-Cornejo has been an economist at the Economic Research Service (ERS) of the US Department of Agriculture (USDA) since 1990. While at ERS, he has worked in pest management, technology adoption, and agricultural biotechnology. He has written more than 70 publications, including 12 USDA publications and close to 30 articles in refereed journals, including the *American Journal of Agricultural Economics*, the *European Review of Agricultural Economics*, *Applied Economics*, *Oxford Agrarian Studies*, the *Journal of Economic Studies*, and the *Journal of Sustainable Agriculture*.

Robert Frederick is acting deputy director of the Washington Division of the National Center for Environmental Assessment (NCEA) in the Environmental Protection Agency (EPA) Office of Research and Development. He has served as assistant center director for research planning and program manager for the Ecological Risk Assessment Research Program in NCEA. From 1993 to 1996, Dr. Frederick was executive secretary of the Biotechnology Advisory Commission at the Stockholm Environment Institute in Stockholm, Sweden. Dr. Frederick has had many roles within EPA, including research program manager in EPA's Office of Environmental Processes and Effects Research; section chief in the Office of Toxic Substances, Exposure Evaluation Division, Environmental Fate Section; and representative to the National Institutes of Health Recombinant DNA Advisory Committee. He has also served on the US-European Commission Task Force on Biotechnology Research, as coordinator of the Office of Science and Technology Policy committee on biotechnology research, and on the International Steering Committee for the 4th International Symposium on the Biosafety Results of Field Tests of Genetically Modified Plants and Microorganisms. He has lectured on biosafety issues in many countries, including China, Cameroon, Syria, Namibia, Kenya, Zimbabwe, Hungary, Argentina, Sweden, Denmark, Germany, and India. His publications include more than 15 on biotechnology regulation.

***Lynn Frewer** is head of the Consumer Science Division at the Institute of Food Research in Norwich, UK. Her research involves consumer risk perception and communication, including the underpinnings of public resistance to genetically modified foods. She is developing and applying psychologic methods to the understanding of consumer attitudes toward emerging food technologies with the long-term goals of effectively involving the public in the decision-making process and increasing public confidence in government regulators. Dr. Frewer was a member of the joint

Food and Agriculture Organization/World Health Organization expert committee on risk communication and collaborates internationally with scientists in the European Union, Australia, and New Zealand. She obtained her PhD in applied psychology from the University of Leeds, UK.

***Henry Gholz** is professor of ecology in the School of Forest Resources and Conservation at the University of Florida. He has conducted research in temperate and tropical forest ecology, nutrient balances, and trace-gas fluxes from forest canopies. Dr. Gholz has conducted research in Costa Rica, Brazil, Bolivia, and Mexico and was a visiting senior scientist in the UK. He has served as program manager for the ecosystems program at the US Department of Agriculture and as an international forestry adviser to the US Agency for International Development. Dr. Gholz received his PhD in 1979 from Oregon State University. He served as a member of the National Research Council committee that produced *Forested Landscapes in Perspective* (1997).

Fred Gould is William Neal Reynolds Professor of Entomology at North Carolina State University, where he studies the ecology and genetics of plant-insect interactions. Over the last 14 years, he has focused much of his research on interactions between genetically engineered *Bt* crops and their pests. Dr. Gould received his BS in biology from Queens College of City University of New York and his PhD in ecology and evolutionary biology from the State University of New York, Stony Brook. He has served on three National Academies committees that generated reports that dealt with transgenic pest-protected crops.

William Hallman is an associate professor in the Department of Human Ecology at Rutgers University, where he teaches courses on risk perception, risk communication, and the politics of environmental issues. He received his MA and PhD in psychology from the University of South Carolina and was honored with the Dissertation of the Year award from the Division of Community Psychology of the American Psychological Association. He has an active research program in public perception of agricultural biotechnology. His latest paper on the subject will be published in an upcoming issue of *HortScience*. Dr. Hallman has written more than 25 papers and book chapters concerning public perception of risk, risk communication, and how individuals and communities cope with perceived environmental threats. He is a member of the American Psychological Association, the American Evaluation Association, and the Society for Risk Analysis and has served as a consultant to state and federal agencies, utilities, industry associations, private corporations, and nonprofit groups.

Anne Kapuscinski is professor of fisheries and conservation biology at the University of Minnesota and an extension specialist in aquaculture and biotechnology for the Minnesota Sea Grant College Program. Dr. Kapuscinski's laboratory examines the influence of genetic modification and natural genetic makeup on long-term sustainability and evolutionary potential of managed fish and shellfish populations. She is active in analysis and formulation of policies affecting the sustainability of aquatic biodiversity. Dr. Kapuscinski was a member of the Scientists' Working Group on Biosafety, and is a coauthor of *A Manual for Assessing Ecological and Human Health Effects of Genetically Engineered Organisms*. She was recently appointed to the US secretary of agriculture's Advisory Committee on Agricultural Biotechnology. In 1997, the secretary of agriculture awarded her the US Department of Agriculture's highest individual award for her accomplishments in promoting sound public policies related to applying biotechnology to aquaculture and conserving genetic diversity in fish. She is the founding director of the Institute for Social, Economic, and Ecological Sustainability (ISEES) and serves as an associate director of the MacArthur Program on Global Change, Sustainability and Justice. Dr. Kapuscinski earned her PhD in fisheries genetics in 1984 at Oregon State University.

Warren Lee has served as director of the Resources Inventory Division (RID), Natural Resources Conservation Service, since March 1999. In that capacity, he manages and directs the National Resources Inventory. In April 1999, he was appointed by Agriculture Secretary Glickman to represent the US Department of Agriculture (USDA) on the Interagency Contact Group of the National Drought Policy Commission. He joined the Senior Executive Service in January 1993. Since then, he has served as director of the Conservation Operations Division, leader of the National Wetlands Team, and director of the Watershed and Wetlands Division before becoming director of RID. His career has taken him from Montana to Washington state to Colorado to Hawaii and to Washington, DC, where he served in a variety of technical and management capacities. His last field position was as state conservationist in Hawaii. Mr. Lee received a BS in agricultural engineering from Montana State University in 1969 and did graduate work in public administration at Eastern Washington University. He is a registered professional engineer. He has received many honors for his work over the years, including two USDA Honor Awards.

Mark Lipson is the policy program director for the Organic Farming Research Foundation in Santa Cruz, CA. His work there since 1995 has been focused on federal agricultural research policy and cultivating institutional support for organic farming research and education. He wrote

Searching for the "O-Word" (1997), which documented and analyzed the lack of federal support for organic agricultural research. Since 1983, he has been a partner in a multifamily organic farming enterprise near Davenport, CA. He was chairman of the California Organic Foods Advisory Board from 1991 to 1998. He is a member of the US Department of Agriculture Advisory Committee on Agricultural Biotechnology. He serves on the Governing Council of the Consortium for Sustainable Agriculture Research and Education (CSARE). In 1992, he received the Steward of Sustainable Agriculture award from the Ecological Farming Conference. He graduated with honors from the University of California, Santa Cruz in 1981 with an undergraduate degree in environmental planning and public policy.

Robert MacDonald is global product safety manager in the Regulatory Affairs Group of Aventis Crop Science, Inc. in Regina, Saskatchewan, Canada, where he is responsible for designing and coordinating the safety-data packages for genetically modified (GM) rapeseed-oil products. After completing postgraduate training in the Department of Environmental Biology at the University of Guelph, he was employed by Hoechst Ag in 1991 and conducted some of the first environmental and food-safety research trials on GM rapeseed in Canada. He has since conducted diverse inhouse safety-assessment studies and has worked with regulatory authorities at the local and international levels. He is now coordinating several postcommercialization GM monitoring trials as a component of an overall product-stewardship initiative for individual GM crops.

*__Donald Mattison__ was named medical director of the March of Dimes in January 1999. He oversees the medical, public-health, and scientific basis of the foundation's programs. Previously, he was dean of the Graduate School of Public Health at the University of Pittsburgh, where he also was professor of environmental and occupational health. In addition, he was professor of obstetrics, gynecology, and reproductive services in the university's School of Medicine. Dr. Mattison has held numerous academic, clinical, and research appointments, including professor of interdisciplinary toxicology in the Department of Pharmacology and professor of obstetrics and gynecology at the University of Arkansas for Medical Sciences and chief of the Section on Reproductive Toxicology, Pregnancy Research Branch, at the National Institute of Child Health and Human Development. He was a member of the US Public Health Service, where he attained the rank of commander and later served in the reserves. He now serves on various national committees related to environmental health, public health, and disease prevention, including the Children's Environmental Health Advisory Committee of the US Environmental Protection Agency as chair of the Board on Health Promotion and Disease Prevention of the Institute of Medicine; and as vice-chair of the Board on Environmental Studies and Toxicology of the National Research Council. He also serves on the Science Advisory Board of the National Toxicology Program, National Institute of Environmental Health Sciences, and the Science Advisory Board of the National Center for Environmental Health of the Centers for Disease Control and Prevention. In 1997, he was elected a fellow of the American Association for the Advancement of Science, and in 1999, a fellow of the New York Academy of Medicine. He is the author of numerous scientific journal articles, and he coedited the seminal contribution on *Male Mediated Developmental Toxicology*. Dr. Mattison earned a BA at Augsburg College in Minnesota, an MS at the Massachusetts Institute of Technology, and an MD at the College of Physicians and Surgeons, Columbia University. He is a diplomate of the American Board of Toxicology and a fellow of the Academy of Toxicological Sciences.

Thomas Nickson began his career at Monsanto in August 1981 as a chemist; for the next 10 years, he was involved there in process chemistry, in addition to organofluorine, organophosphorus, and natural-products research. Dr. Nickson is now with the Ecological Technology Center and is responsible for developing risk-assessment and risk-management approaches that will be used to ensure the ecological and environmental safety of Monsanto's agricultural products. Dr. Nickson received his BS in chemistry from University of Notre Dame and his PhD in 1982 from the State University of New York at Buffalo.

John Pleasants is a temporary assistant professor in the Zoology and Genetics Department at Iowa State University, where he teaches evolution and Web-based courses in introductory biology and environmental biology. His current research involves monitoring monarch butterfly use of milkweed in agricultural and nonagricultural habitats and assessing the potential levels of *Bt* corn pollen deposition on milkweed plants in and near *Bt* cornfields. He is also interested in pollination ecology, foraging ecology, population biology and genetics of endangered plant species, and assessing the timing of pollution events by using tree rings.

Alison G. Power is professor in the Section of Ecology and Systematics at Cornell University. Her research focuses on agroecology, interactions between agricultural and natural ecosystems, biodiversity in managed ecosystems, the ecology and evolution of plant pathogens, and tropical ecology. She has worked on the ecology and epidemiology of three primary disease systems: leafhopper-transmitted pathogens of maize in Central America, rice tungro virus in Thailand, and the barley yellow dwarf virus in grain crops and wild grass hosts in the United States. Her current research addresses the ecological risks posed by genetically engineered crops expressing transgenic virus resistance. Dr. Power is a fellow of the Aldo Leopold Leadership Program of the Ecological Society of America, a member of the Oversight Committee of the McKnight Foundation Crop Collaborative Research Program, and a member of the Technical Committee of the Sustainable Agriculture and Natural Resources Management Collaborative Research Support Program of the US Agency for International Development. She received her PhD in zoology from the University of Washington in 1985.

***Barbara Schaal** is professor of biology and genetics in the Department of Biology of Washington University in St. Louis. In 1999, Dr. Schaal was elected to the National Academy of Sciences for her investigations of the genetic heterogeneity of plant populations. Her work on the application of DNA analysis to plant evolution at the population level showed unexpectedly high diversity and led to the development of DNA "fingerprinting" in plants. Her research includes the use of gene genealogies and coalescence theory to detect geographic patterns of gene migration between populations of North American native plants. She conducts studies on species relationships in plants native to South America, Africa, and Asia and on theoretical issues related to the conservation of rare plants. Her work examines the population-genetics effects of habitat destruction and fragmentation and seeks to provide guidance for conservation and restoration work. Dr. Schaal has served as chair of Washington University's Department of Biology, chair of the Review of Genetic Resources Unit for the Center for International Tropical Agriculture, chair of the Scientific Advisory Council for the Center for Plant Conservation, executive vice president of the Society for the Study of Evolution, associate editor of *Molecular Biology and Evolution*, and president of the Botanical Society of America. She received her PhD in population biology from Yale University in 1974.

Tim R. Seastedt is professor in the Environmental, Population, and Organismic Biology Department and a fellow of the Institute of Arctic and Alpine Research at the University of Colorado. He received a BA in zoology from the University of Montana, an MS in biological sciences from the University of Alaska, and a PhD in ecology from the University of Georgia. His research has focused on plant-soil, plant-animal, and animal-soil interactions in terrestrial ecosystems. For the last 20 years, Dr. Seastedt has been involved in the long term ecology research programs in grasslands and alpine tundra and has developed monitoring and research programs to measure biotic responses to management and global-change impacts. A past president of the Association of Ecosystem Research Centers, Dr. Seastedt is interested in the application of ecosystem science to management and policy issues and is studying the consequences of invasive species in grasslands.

***Allison Snow** is associate professor of evolution, ecology, and organismal biology at Ohio State University. Dr. Snow has conducted research on gene flow and hybridization in several crop-weed systems. Her laboratory uses molecular techniques to investigate transgene escape to weedy relatives of crops. Dr. Snow's current research focuses on the effects of transgenic-insect resistance on herbivory and fitness in wild sunflowers. She has published extensively on the ecological implications of genetically modified crops and has been an associate editor of *Ecology* and *Evolution*. She recently served on the steering committee for the US Department of Agriculture workshop on the ecological effects of pest-resistance genes in managed ecosystems and on the Board on Agriculture and Natural Resources Committee on Genetically Modified Pest-Protected Plants. Dr. Snow received her PhD in botany from the University of Massachusetts in 1982.

Neal Stewart is associate professor of biology at the University of North Carolina-Greensboro. He teaches courses in plant physiology and biotechnology and a Web-based distance course on the risks and benefits of agricultural biotechnology targeted for a general audience. His research addresses transgenic-plant ecology, gene expression, and gene flow and plant-insect interactions. His laboratory produces transgenic plants for crop improvement and as delivery agents for oral vaccines. Other projects use transgenic plants as biosensors to detect and report the presence of pathogens, toxins, and land mines. He received an MS in ecology in 1990 and a PhD in plant physiology from Virginia Tech. He performed post-doctoral research at the University of Georgia from 1993 to 1995.

Guenther Stotzky is professor of biology at New York University. His major subjects of research include various aspects of microbial ecology and environmental microbiology and virology, with emphasis on the role of surface-active particles (such as clays and humic substances) in the activity, ecology, and population dynamics of microorganisms, especially in soil. His current research focuses on the fate, gene transfer, and effects of genetically engineered microorganisms in natural habitats and the persistence and biologic activity of the toxins from *Bacillus thuringiensis* (*Bt*) in soil, especially when released from transgenic *Bt* plants and bound on surface-active particles. He has studied the effects of air pollution and heavy metals on microorganisms. He is the author or coauthor of 185 research papers and 78 review articles and book chapters and the editor or coeditor of five books on soil biology and biochemistry. He is a fellow of four scientific societies and the recipient of numerous honors, awards, and grants.

Jeremy Sweet is head of the Chemistry and Plant Pathology Department at the National Institute of Agricultural Botany (NIAB) in Cambridge, UK. He has been leading the research program on genetically modified (GM) crops at NIAB for several years and has been monitoring the cultivation of the first GM crops in England. His team is conducting research for the Department of the Environment, Ministry of Agriculture, Fisheries, and Food, and for biotechnology companies on the environmental and agronomic impact of GM crops. He is coordinator of the Botanical and Rotational Implications of Genetically Modified Herbicide Tolerance project, looking at various herbicide-tolerant crops grown in rotation at several centers, and is coordinator of a European Science Foundation program on the impact of GM plants.

Anne K. Vidaver is professor and head of the Department of Plant Pathology and director of the Center for Biotechnology at the University of Nebraska-Lincoln. She has just been given the limited appointment of chief scientist for the US Department of Agriculture (USDA) National Research Initiative Competitive Grants Program. Dr. Vidaver, a native of Vienna, Austria, graduated from Russell Sage College with a BA in biology which was followed by an MA and a PhD in bacteriology with a minor in plant physiology at Indiana University-Bloomington. She has served as president of the American Phytopathological Society, the Intersociety Consortium for Plant Protection, and the board of the Henry A. Wallace Institute for Alternative Agriculture. She chairs the National Plant Pathology Board of the American Phytopathological Society and the Food and Agriculture Committee of the American Society for Microbiology's Public and Scientific Affairs Board. She is a former member of USDA's National Agricultural, Research, Extension, Education, and Economics Advisory Board and serves on the Board of Directors of USDA's Alternative Agricultural Research and Commercialization Corporation. Dr. Vidaver's research has focused principally on plant-associated bacteria. This work has included systematics, epidemiology, and control; plasmid, bacteriophage, and bacteriocin characterization; and genetics. Her work has led to her being an adviser or consultant for several companies and several federal agencies, including membership on the National Institutes of Health Recombinant DNA Advisory Committee and USDA's Agricultural Biotechnology Research Advisory Committee. She is the author or coauthor of over 180 scientific articles and a book. In collaboration with colleagues, she also holds two patents.

Paul E. Waggoner is Distinguished Scientist at the Connecticut Agricultural Experiment Station, New Haven. His research investigates the forces of consumption and agricultural productivity changing land use, especially the extent of farming and forests. He was educated in meteorology and plant pathology, receiving his PhD from Iowa State University. Recently, he and colleague Donald Aylor wrote a history of plant epidemiology in the 20th century. Dr. Waggoner composed the first mathematical simulator of a plant pest and demonstrated the role of leaf stomata in the hydrologic cycle. He was the director of The Station in 1972-1987 and is a member of the National Academy of Sciences.

Hugh D. Wilson is professor and curator of the herbarium in the Department of Biology, Texas A&M University. Dr. Wilson's research includes biosystematics and floristics. Biosystematic studies use comparative analysis of multiple data sets to define patterns of variation, resolve biotic units, and order those units according to evolutionary and structural relationships. He has focused much of his effort on crop-plant evolution, with emphasis on crop-weed genetic structure among populations of domesticated and allied free-living elements of the genera *Chenopodium* (quinoa) and *Cucurbita* (squash). Research with this group has involved basic isozyme genetics, assessment of weed-crop gene flow, analyses of morphogenetic variation, and crop-weed pollen competition. Dr. Wilson received his BA and MA from Kent State University and his PhD in botany from Indiana University (Bloomington) in 1976. His postdoctoral research was completed at the University of Wyoming.

David Winkles is the president of the South Carolina Farm Bureau. He was a founding director of the United Soybean Board, appointed by Secretary of Agriculture Ed Madigan (1991-1999), and served as chairman of the board in 1996-1997. The board has worked to build markets for soybeans domestically and internationally. Mr. Winkles is now serving on the US Department of Agriculture Advisory Committee on Agricultural Biotechnology, appointed by Agriculture Secretary Dan Glickman. The committee advises the secretary of agriculture on policy related to the creation, application, marketability, trade, and use of agricultural biotechnology. Mr. Winkles has also been active with the soybean industry at the state level. He is a member of the Board of Directors of the American Farm Bureau Federation. He graduated from Clemson University with a BA in economics and has done graduate work in agricultural economics. He served on the Commission on the Future of Clemson

University, Extension Committee, in 1997-1998 and is now on the Clemson University Public Service and Agriculture Advisory Board. He also is president of D. M. Winkles, Inc., a 1200-acre farming operation that produces corn, wheat, soybeans, and timber.