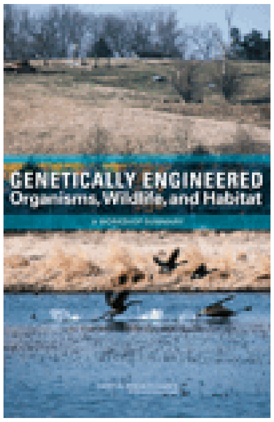

Genetically Engineered Organisms, Wildlife, and Habitat: A Workshop Summary

Paula Tarnapol Whitacre, Rapporteur, Planning Committee for the Workshop on Research to Improve the Evaluation of the Impacts of Genetically Engineered Organisms on Terrestrial and Aquatic Wildlife and Habitats, National Research Council

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GENETICALLY ENGINEERED Organisms, Wildlife, and Habitat

A WORKSHOP SUMMARY

Paula Tarnapol Whitacre, *Rapporteur*

Planning Committee for the Workshop on Research to Improve the Evaluation of the Impacts of Genetically Engineered Organisms on Terrestrial and Aquatic Wildlife and Habitats

Board on Agriculture and Natural Resources

Division on Earth and Life Studies

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Preface

Great advances have been made in the development and application of genetically engineered organisms (GEOs) since the first commercial introduction of transgenic corn plants in 1995. These technologies have provided enormous benefits to agricultural crop production and have the potential to transform fields such as aquaculture, biofuel production, bioremediation, biocontrol, and even the production of pharmaceuticals. However, biotechnology is not without risk and continues to be an extremely controversial topic. Chief among the concerns is the potential ecological effects of GEOs that interact with wildlife and habitats.

The U.S. Geological Survey (USGS) is charged with providing scientific advice to inform federal agencies that manage natural habitats and wildlife. USGS has identified biotechnology and bioengineering as one of their major challenges for future research. Seeing an opportunity to get ahead of the problem, Kay Briggs and Robert Szaro of the Biological Resources Discipline of USGS approached the Board on Agriculture and Natural Resources of the National Research Council (NRC) to organize a two-day workshop to identify research activities with the greatest potential to provide the information needed to assess the ecological effects of GEOs on wildlife and habitats. It was particularly exciting that the workshop was designed to approach the research questions from a habitat, rather than transgenic organism, perspective.

An eight-member steering committee met once in person and several times by telephone to organize the workshop. The committee worked very hard over a short period of time to develop an ambitious agenda and recruit an extraordinary list of presenters and participants. It was a true pleasure to work with this group of experts; the members came with diverse perspectives and backgrounds and their thoughtful contributions to the planning process resulted in a very successful workshop. The committee acknowledges the work of Paula Tarnapol Whitacre for attending and faithfully summarizing the events of the workshop in this summary. The committee is also grateful for the support of the NRC staff: Robin Schoen, Susan Park, Nancy Caputo, and Karen Imhof.

Anne Kapuscinski, *Chair*
Planning Committee for the Workshop on
Research to Improve the Evaluation of the
Impacts of Genetically Engineered Organisms
on Terrestrial and Aquatic Wildlife and Habitats

Acknowledgments

This report is a summary of a workshop convened by the National Research Council (NRC) to identify research that could improve the understanding of environmental effects of genetically engineered organisms on natural habitats and the wildlife within those habitats. The workshop would not have become a reality without the support of the Biological Resource Discipline (BRD) of the U.S. Geological Survey (USGS). Kay Briggs, Coordinator for BRD's work in Conservation Biology and Genetics, was the initial catalyst for the workshop. Bob Szaro, Chief Scientist for Biology, and Sue Haseltine, Associate Director for Biology at USGS, identified funding within the agency to support the meeting.

We thank our colleagues who served on the planning committee, each of whom brought deep and varied expertise to the process of planning the workshop. Their knowledge and perspectives on a diversity of genetically engineered organisms and ecosystems were critical to the success of the meeting. Although the planning committee designed the workshop, they did not participate in writing this report. That was ably accomplished by Paula T. Whitacre, who attended the workshop and prepared this summary using presentation materials, tapes of the plenary sessions, and the copious notes she took throughout the meeting. We are grateful to the individuals who made presentations at the workshop that set the stage for the group discussions, and we are appreciative to all of the individuals who attended and participated in the working groups.

A few of them were also asked to serve as reviewers of the report. They were chosen, along with one individual who was not in attendance, for their diverse perspectives and technical expertise in accordance with procedures approved by the NRC's Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making sure the published report is as sound as possible, and to ensure that the report meets institutional standards of objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We thank the following for their review of this report:

Meredith Bartron, U.S. Fish and Wildlife Service
David Harry, Oregon State University
Richard Hellmich, Iowa State University
Allison Snow, Ohio State University
L. LaReesa Wolfenbarger, University of Nebraska, Omaha

Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the workshop summary nor did they see the final draft before its release. The review of this report was overseen by Michael T. Clegg, University of California, Irvine. Appointed by the NRC, he was responsible for making certain that an independent examination of the report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the author and the institution.

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Setting the Stage

Less than two decades ago, genetically engineered organisms (GEOs) were the subject of much scientific study, but not part of everyday life. By 2006—eleven years after the first commercial introduction of corn plants engineered to produce their own insecticide (the delta endotoxin gene of the bacterium *Bacillus thuringiensis*, or *Bt*)—more than 123 million acres of land in the United States were planted with genetically engineered crops. Today, 89 percent of all soybeans, 83 percent of cotton, and 61 percent of corn grown in the United States are the products of genetic engineering (Fernandez-Cornejo and Caswell, 2006). Other GE plants, trees, microbes, insects, and fish are on the horizon.

A key question related to GE crops has been their potential and actual effects on the environment, and numerous studies have been conducted to assess the risks and examine the outcomes of transgenic crops. Those studies have generally informed and strengthened the regulatory oversight of GEOs, but questions still linger in the scientific community about whether GE crops have been evaluated in a broad, long-term ecological context that might expose more subtle effects over time. Those questions also apply to the next generation of GEOs that are in development or poised for field study. Given the diversity of taxa involved and novel traits contemplated, ecologists wonder how the environmental effects of the new GEOs might be manifested, if at all, and how such effects can be detected.

With those concerns in mind, research leaders at the U.S. Geological Survey's (USGS) Biological Resources Division (BRD) asked the National

Research Council (NRC) to organize a workshop of developers of GEOs, ecologists, land managers, and others to discuss GEOs in the context of ecological research. Rather than assessing the potential environmental risk of any particular transgenic organism, the USGS was interested in identifying different research approaches that could be useful in anticipating, understanding, and detecting effects of GEOs on wildlife and natural habitats. This report is a summary of the discussions that emerged from that workshop, held in Irvine, California, on November 6 and 7, 2007.

POTENTIAL TRAITS AND EFFECTS

Almost all currently produced GE (also known as genetically modified, or GM) crops contain genes for herbicide tolerance, *Bt* production, or both. But beyond these crops, research and testing are under way in a large variety of plants (including trees), microorganisms, and animals (including insects and aquatic species) to introduce a much broader range of traits with potential benefits for farmers, consumers, and other users of GE products (see Box 1-1). These traits include resistance to disease, drought tolerance, greater nutritional content, production of pharmaceutical products, and altered starch structure for industrial uses such as in biofuels. Transgenic plants and animals engineered to produce vaccines and human proteins already have been created and some are being field-tested. The potential to genetically engineer insect and aquatic species for the purpose of developing effective biocontrol agents is another subject under active investigation—for example, a GEO that can help control a non-native aquatic species—yet at much earlier stages of development.

One of the primary reasons that most GEOs have not been commercialized or even extensively field-tested is the continued uncertainty about their risks to the environment, both managed and wild. In a number of reports published by the National Research Council (NRC 2000, 2001, 2002a, 2002b, 2004), potential environmental impacts identified included the following:

- Direct and indirect effects on plant and animal species coexisting with transgenic plants and animals.
- Interbreeding or hybridization with and horizontal gene transfer to species related to the GEO, creating novel organisms in the ecosystem that are potential pests, competitors, or that depress the fitness of wild relatives.
- Spread of biologically active agents, such as viruses, to non-transgenic species, and the emergence of recombinant viruses.
- Spread of novel proteins produced by the GEO to the air, water, or soil in which plants and animals live.

BOX 1-1
Genetically Engineered Traits in Experimental Development

Crops
- Drought and salt tolerance
- Nitrogen and water use efficiency
- Nutritional amendments—oils and proteins/amino acids
- Herbicide tolerance mechanisms (novel)
- Disease and pest resistance (plant insecticides, lectins)
- Biofuels (cellulosic digestion; carbohydrate storage)
- Senescence/ripening/phenology
- Industrial uses—starches/oils/fibers

Microorganisms
- Fungi and bacteria with enhanced virulence characteristics for insect control
- Fermentation of substrates, antimicrobial producers, probiotics for "active" foods, attenuated vaccines (bacterial and viral)
- Phage for plant disease control
- Biofuels related (cellulose, lignin degradation)
- Nitrogen fixation in non-traditional plants
- Insect symbionts for paratransgenic control

Animals
- Growth promotion—(growth hormone) cattle, fish, shellfish
- Medically valuable proteins in milk
- Disease resistance (antimicrobial peptides, viral resistance, BSE) in cattle, swine, poultry, fish, bivalves
- Insects—disease resistance and pharmaceutical production
  - Vector disruption—(Malaria, Dengue)
  - Product quality—(silk, high value proteins)
  - Viral resistance in honey bees

Source: Chris Wozniak (workshop presentation)

- Indirect effects on wildlife and habitat ecosystems because of changes in the management of agriculture, forestry, and fisheries related to GEOs.

The ability to understand the potential for these effects to occur on a large scale over a long time period—particularly in the cases of trees, aquatic species, and microbes—is confounded by regulatory requirements for the confinement of an experimental GEO during testing. That poses a difficult challenge for GEO developers and evaluators. There is little known about the likelihood or magnitude of impact of GEOs, so they cannot be released into the environment for research purposes. Yet, a better understanding of the potential and actual effects of GEOs relative to other influences on the environment (for example climate change, invasive species, or land use changes) requires approaches that take into account both the specific characteristics of GEOs and the character and resilience of the environment, as well as the extent of the interaction between the GEO and the environment. That understanding could be best achieved by observation in an actual environmental setting.

How will this impasse be overcome? In her welcoming presentation, Anne Kapuscinski described the role of ecological research in informing the decision-making process of risk assessment. That role includes gathering information, identifying the appropriate parameters for consideration, and analysis of complex systems. Because interest in the development and implementation of GEOs with a variety of traits is likely to increase in the future, concerns about potential environmental hazards need to be translated into specific research questions that produce data to inform those who evaluate and manage the risks of GEOs. That does not mean that ecological research is necessarily narrow; it may be focused on how natural systems operate more generally to elucidate more general principles. But that information is also relevant to work of risk assessors in the federal agencies with regulatory authority and the agencies tasked with overseeing the integrity of publicly owned land.

FEDERAL RESPONSIBILITIES

In 1986, the Coordinated Framework for the Regulation of Biotechnology defined roles for federal agencies in regulating the products of biotechnology. The framework focused on products being developed at the time, mainly transgenic microbes and plants, and did not focus on taxa of other GEOs or on the effects of GEOs on wildlife and their habitats.

In order to address uncertainties about these issues and other emerging products of biotechnology, in May 2000, the White House Office of Science and Technology Policy and the Council for Environmental Quality undertook a review of the relevant agencies and statutes for regulating biotechnology products. This review, completed in January 2001, along with a number of federal and state laws, covers oversight of GEOs today (CEQ/OSTP 2001).

Under this policy, the U.S. Department of Agriculture (USDA) (and particularly its Animal and Plant Health Inspection Service [APHIS]), the U.S. Environmental Protection Agency (EPA), and Food and Drug Administration (FDA) share responsibility for regulating GEOs. USDA has the authority to provide permits for testing of GE plants and some animals, for regulating their production, including an assessment of environmental risks. EPA has authority over plants and microorganisms that produce pesticides (such as the *Bt* crops). FDA must approve the marketing of GEOs as food, and under the National Environmental Protection Act, FDA may also consider the environmental effects of production of transgenic animals.

Among many federally funded research programs on GEOs, the USDA Biotechnology Risk Assessment Grants (BRAG) Program was established in 1992 by an act of Congress. Through the Farm Security and Rural Investment Act of 2002, the BRAG Program funds "research designed to identify and develop appropriate management practices to minimize physical and biological risks associated with genetically engineered animals, plants and microorganisms." According to Chris Wozniak, who presented information about BRAG, approximately 140 projects have been funded (maximum award of $400,000) since 1992, with an emphasis on studies that "will provide information useful to regulators for making science-based decisions in their assessments of genetically modified organisms" (USDA, 2008).

Other agencies also become involved as GEOs interact—or have the potential to interact—with the environment. For example, the Department of Interior's Fish and Wildlife Service and Bureau of Land Management (BLM) and the Department of Commerce's National Marine Fisheries Service may assert the authority of the Endangered Species Act, the National Invasive Species Act of 1996, and other federal legislation. In addition, most oversight authority for wildlife and fisheries resources rests with the states, six of which, as of this publication, have issued regulations prohibiting releases of aquatic or marine GEOs.

WORKSHOP PURPOSE AND ORGANIZATION

The Department of Interior's USGS does not have regulatory or oversight authority over GEOs, but its mission to provide reliable scientific information to other agencies and to the public gives it an important role in strengthening the information base about the effect of GEOs on the environment. The USGS BRD, one of the agency's four broad topical disciplines, "works with others to provide the scientific understanding and technologies needed to support sound management and conservation of our Nation's biological resources" (USGS, 2008).

Bob Szaro (USGS) explained that the USGS is a scientific advisor to several federal agencies with stewardship responsibility for public lands, including the BLM, the National Park Service, and other agencies. In that capacity, the BRD requested that the NRC organize a workshop to further approaches to understanding the effects of GEOs on terrestrial and aquatic ecosystems. The workshop's expected outcome was to identify fundamental information needs and prioritize research directions. It also was designed to identify existing research and monitoring that could provide a platform for GEO-related research on the ecological effects of GEOs and lead to new partnerships, projects and resources for these complex and critical areas of inquiry. BRD asked the workshop planning committee and workshop participants to focus on approved GEOs already in the environment and those that may reasonably be expected to be developed within the next five to ten years (see Box 1-2).

In early 2007, a committee of nine scientists was appointed to plan the workshop. An in-person meeting and numerous conference calls culminated in the two-day Workshop on Genetically Engineered Organisms, Wildlife, and Habitat at the Arnold and Mabel Beckman Center in Irvine, California, November 6 and 7, 2007.

The workshop involved federal, university, and other scientists who conduct research on GE plants, trees, microbes, insects, and fish, as well as those who focus on the ecosystems that these GEOs might affect. Representatives of federal agencies involved in regulatory oversight also participated. The workshop began with some basic information on GEOs, including an overview of what GEOs exist and what new GEOs are planned for development in the next five to ten years, and an overview of the USGS and specifically, the BRD. The information from the introductory session has been summarized in this chapter.

The workshop continued with presentations on the status of current research—and, as importantly, on current research gaps—on the effects of GEOs on terrestrial and aquatic wildlife and habitats. These presenta-

BOX 1-2
Statement of Task

An NRC committee will organize a public workshop of experts, resource managers, and others to identify research activities with the greatest potential to provide scientific information and data that would improve the ability to assess the ecological risks and impacts of genetically engineered organisms (GEOs) on terrestrial and aquatic wildlife and their habitats in the United States. The workshop will be organized around key concerns related to the interaction of GEOs with natural environments and consider the specific types of data needed to evaluate the risk and impact of GEOs on wildlife and their habitat. In addition to identifying various scientific approaches to obtaining the necessary data, the workshop will consider whether and how research needs and approaches for evaluating the risk and impact of GEOs might complement or build on existing research, surveillance, and monitoring activities in natural areas. A rapporteur will produce an individually-authored summary of the workshop.

tions describing current GEO research were organized by taxa, and were followed by presentations of potential models which could be used to study GEOs in the environment. Models presented included invasion ecology, gene flow, and landscape analysis. These presentations helped inform the breakout discussions and are summarized in Chapter 2 of this publication.

The plenary presentations and group discussions did not evaluate the potential risks of GEOs to the environment or the methodologies for risk assessment. Instead, discussions within the workshop explored how GEOs could be studied in the context of natural habitats, what some of the interactions of GEOs with the environment could be, and what research questions related to environmental interactions would be important to consider.

In keeping with the statement of task, the heart of the workshop, as reported in Chapter 3, focused on breakout sessions to identify research that could be pursued to better understand GEO-ecosystem interactions. For the breakouts, participants were divided by ecosystem type: two groups focused on the agriculture/wildland interface, and one each on the silviculture/wild forest and on the aquaculture/aquatic habitat interface. These groups identified several broad research priorities for "their" interface, and then reported back in a plenary session for clarification and discussion. In a second round of breakouts, participants began to develop research proposals to address the research topics identified. Although time constraints made detailed proposals impossible, they serve as a starting point for funding and regulatory agencies, particularly as they seek to fill information gaps in assessments of the risks of GEOs to wildlife and habitat. As additional input to USGS and others, the final thoughts on the workshop by committee members and participants are contained in Chapter 4.

The agenda for the workshop can be found in Appendix A. Short biographies of the committee members and workshop participants are contained in Appendix B. The role of the workshop planning committee was to develop the agenda for the meeting, invite speakers, and recruit participants. This report, which is meant to present a factual summary of what occurred at the workshop, was prepared by a rapporteur, independent of the committee, and was reviewed for accuracy by several participants who were in attendance.

2

Current Research: What Is Known and What Are the Gaps?

Participants were invited to the workshop, by design, for their wide array of expertise. They included people with primarily research, regulatory, or land management responsibilities; those who are involved in research and development of genetically engineered organisms (GEOs) in different taxa (plants, trees, microbes, insects, fish) and those who focus more on the biology and ecology of wildlife and habitats; and those who work in government, academia, and nonprofits. For this reason, the planning committee began the workshop with presentations that would allow participants to get a sense of the "state of the science" in different research areas.

As summarized in this chapter, the first set of presenters provided an overview of GEO research by taxa. In the following session, researchers shared lessons from other disciplines that may have applications to GEO research. Each set of presentations was followed by a short, but lively discussion period.

STATUS OF RESEARCH ON EFFECTS OF GEOS ON WILDLIFE AND TERRESTRIAL AND AQUATIC HABITATS

The current state of research and development and commercialization of GE plants, microorganisms, insects, and other animals is variable, ranging from widespread production of some GE crops to very circumscribed research, mostly through modeling and in labs and other contained settings, of the other taxa. Confinement so that transgenic organisms are not released into the environment is of high concern, both from biological and legal/regulatory standpoints.

Research on Effects of GE Crops – La Reesa Wolfenbarger

L. LaReesa Wolfenbarger (University of Nebraska, Omaha) framed consideration of the environmental effects of GE crops by looking at research in three, interrelated categories: the impacts of GE crops on wildlife food (insects eaten by birds and other animals) in farm fields and adjacent land; impacts on wildlife in farm fields; and impacts on wildlife in land adjacent to farm fields, such as grassland, forests, riparian areas, wetlands, or streams.

Wildlife Food in Farm Fields and Adjacent Habitat

According to Wolfenbarger, most relevant studies have focused on the abundance of wildlife food, particularly non-target and beneficial arthropods, in the presence or absence of a GE crop. Although the basic research question is whether and how GE crops impact the abundance of wildlife food, she noted that an important factor to emerge was the background effects of different agricultural practices. For example, a meta-analysis by Marvier at al. (2007) showed decreases in the abundance of non-target insects of the orders Coleoptera, Hemipteran, Hymenopterans and particularly Lepidoptera in fields planted with transgenic cotton expressing *Bacillus thuringiensis* (*Bt*) proteins relative to non-transgenic cotton. However, the abundance of all insects were much lower in fields planted with cotton crops (transgenic or not) sprayed with insecticide. A key finding of the study was that one's view of what is ecologically beneficial depends on the points of comparison. About 80 percent of cotton acreage in the United States is sprayed with insecticides, said Wolfenbarger.

Similarly, results of a comparison of the effects of *Bt*-corn on wildlife food depended on whether it was compared with insecticide-sprayed or nonsprayed corn and the types of insecticide (Wolfenbarger et al., 2008); currently, she said, about 25 percent of the U.S. corn crop (75 percent of sweet corn) is treated with insecticide. Finally, Cattaneo et al. (2006) looked at the impact of *Bt*-cotton and other agronomic practices on the diversity of wildlife food in farm fields relative to the diversity in adjacent habitat, using the adjacent, uncultivated area as the baseline. They found that relative to uncultivated areas, cotton cultivation had a negative impact on ant density and a positive impact on beetle density, but those findings were irrespective of whether the crops grown were or were not transgenic.

The conclusion Wolfenbarger drew from these studies was that GE crops do affect wildlife food, but that variations in agricultural practices, including cultivation itself, and the use of insecticides, can have larger effects.

Turning to wildlife food in adjacent habitats, Wolfenbarger presented results of a study by Rosi-Marshall et al. (2007) that looked at growth and survival of Trichopterans (an insect order that includes the caddis fly and whose larvae are aquatic) that feed on corn by-products in streams. In lab tests, the Trichopterans that fed on *Bt* corn by-products showed decreased growth compared to those that fed on non-*Bt* corn by-products. Because these small flies are a basal component of the aquatic food web, their decreased growth may be of significance. Effects on survival were only detected in the lab at exposure rates two to three times the maximum measured in field sites.

Wolfenbarger was the first of several presenters at the workshop to refer to the United Kingdom Farm Scale Evaluations (FSE) as a valuable source of information on the effects of GE herbicide-tolerant crops on wildlife and habitat (see Box 2-1). Overall, the FSE showed mixed impacts of herbicide-tolerant crops, with wildlife food populations (seeds and arthropods) increasing, decreasing, or not affected depending on the crop and type of wildlife food (Andow, 2003). One finding of the FSE was that the herbicide Atrazine was more effective in controlling weeds than glyphosate, the latter which is used in conjunction with herbicide-tolerant crops. It is known that weed diversity and abundance affect wildlife food such as arthropods, so the effectiveness of the herbicide has implications for that food supply, noted Wolfenbarger.

BOX 2-1
UK Farm Scale Evaluation: GE Crops at a Landscape Level

From 1999 to 2004, a large study of the environmental impact of herbicide-tolerant GE crops was conducted in the United Kingdom, known as the Farm Scale Evaluation (FSE). Sponsored by the Department for Environment Food and Rural Affairs, farmers planted transgenic and unmodified maize, rapeseed (two types), and sugar beets on 60 sites around the country to measure the effects of these crops. Biodiversity, as exhibited by weeds, seeds, and invertebrates, was measured within the fields and at their margins.

The FSE not only produced valuable data for a range of different studies, but also has proven to be a good model in how to set up large-scale comparative field studies.

SOURCE: U.K. Department for Environment, Food, and Rural Affairs, 2008.

Wildlife in Farm Fields

Wolfenbarger turned to two studies that explored the effects of GE crops on wildlife. First, when a subset of the FSE fields in the United Kingdom were surveyed to look at bird diversity and local abundance, the differences in abundance paralleled results in the food supply—more weed seeds meant more seed-eating birds. Yet, overall, models based on the FSE data predicted a change in conservation status of only 1 of the 39 species studied (Butler et al., 2007). Second, researchers at the University of Tennessee did not find differences in Brazilian free-tailed bat activity in *Bt* and non-*Bt* cotton fields smaller than 200 acres, but a laboratory feeding trial with a small number of the bats showed active *Bt* toxin in their fecal samples. Follow-up studies with field-collected fecal samples are in progress (Federico et al., 2008).

Wildlife in Adjacent Habitats

Wolfenbarger briefly explained her own research on wildlife in habitats adjacent to farm fields; results were still preliminary at the time of the workshop. Her strategy is to look at high conservation priority wildlife (grassland birds and butterflies) in farmland-adjacent habitats compared to natural habitats. Farming activity is one of many variables affecting them, and the use of GE crops is one variable among many different farming practices.

Research Gaps

GE crops have been shown to affect the local abundance of wildlife and of wildlife food, but these can only be appreciated in the context of overall agricultural practices associated with the GE crop compared to the conventional alternative, which may have greater influence on the direction and the magnitude of the change. Context, Wolfenbarger underlined, becomes key to the interpretation of the results.

She added that an important knowledge gap remains in knowing how changes in wildlife food within and adjacent to farm fields will affect populations, species, and special or sensitive communities. This, she suggested, may be an area where field studies and modeling will help scientists, regulators, and the public better understand the effects of GE crops on wildlife and habitats.

Research on Effects of GE Trees—Chung-Jai Tsai

The 20th anniversary of GE trees occurred in 2007: The first was an herbicide-tolerant poplar with the aroA gene, developed in 1987. The first insect-resistant (*Bt* and chloramphenicol aminotransferase) transgenic spruce was developed in 1993. Field trials took place in 1989 and 1993. In her presentation, Chung-Jai Tsai (Michigan Technological University) said despite this early activity, there is far more limited field experience with transgenic trees as compared to agricultural crops. The 363 notifications[1] of field trials for transgenic trees have accounted for only 3 percent of total notifications to the Animal and Plant Health Inspection Service (APHIS) of the U.S. Department of Agriculture (USDA) since 1989. According to Tsai, in the United States, only one company (down from seven) and five universities (down from nine) are now engaged in active trials, mostly with pine, followed by poplar, eucalyptus, and sweet gum. Growth modification is the primary trait studied in active trials, followed by flowering and lignin production.

Tsai reported briefly on three cases involving GE trees, all outside the United States, that provided some findings with ecological implications. The first case involved fields studies in the United Kingdom and France of birch and poplar trees engineered for lignin modification (Pilate et al., 2002). In the second case, the effects of an insect-resistant, commercially-produced poplar in China on insects were examined (Ewald et al., 2006). The third study looked at gene flow from transgenic poplars in one of these Chinese plantations (Ewald et al., 2006). The three studies did not find that transgenic trees cause significantly different effects than their non-transgenic counterparts, but Dr. Tsai stressed that all three studies raised unanswered questions and that more research is needed, particularly in the long term and across multiple sites, before any definitive conclusions can be drawn.

The UK-France study, which was cut short halfway through its eight-year original plan because of vandalism at the UK site, looked at the target trait (lower lignin content) but also at comparisons of the ecological effects on the herbivory (as insects, microbes, and animals fed on the trees), soil mesocosms, and decomposition between GE and non-GE trees. A similar profile of insects was observed visiting the transgenic and non-transgenic trees, and the soil microbial diversity under the trees was also similar. A slightly higher rate of root decomposition was found in the transgenic trees, a finding that is consistent with the modified lignin trait, which would make the roots more susceptible to microbial degradation. (Pilate et al., 2002).

In introducing the second case—*Bt* poplar—Tsai noted China has been particularly aggressive in the development of GE trees to overcome its dependence on imported wood. Two GE poplars (*Bt* poplar and a

[1]A notification is an administratively streamlined alternative to a permit, if the organism meets certain eligibility criteria and pre-defined performance standards.

Bt/API[2] hybrid) are now in commercial release, the first such commercial use in the world, and planted on more than 237 hectares on seven sites. She said researchers studying non-target insect communities on these sites have found the effects to be dependent on the characteristics of the site and on the scale of the plantation, but that more research is needed to reach definitive conclusions (Ewald et al., 2006).

Gene flow was studied at one of these sites, since a large concern with GE trees in the field is the spread of their pollen to non-GE trees, said Tsai. The study at one plantation showed the spread of male *Bt* pollen was very rare at distances of 500 meters or greater, and that seed germination under field conditions was also much lower than for seeds stored at room or refrigerated temperatures. Because the site was very arid, weather conditions might have influenced gene flow and germination, so no general conclusions about gene flow could be drawn (Ewald et al., 2006).

Tsai explained that pollen dispersal is only one aspect of gene flow that makes the logistics of field study immense. Models have attempted to address this and other aspects. One model (known as Simulation of Transgene Effects in a Variable Environment, or the "STEVE" model) uses spatial and landscape data, combined with field measurements, to make predictions about gene flow. However, she warned, the model, while valuable, still needs experimental data to validate and improve it, and is not a silver bullet to make reliable predictions.

Tsai recapped some of the challenges related to risk assessment of GE trees. She believes the foremost challenge is the inability to perform large-scale field experiments; few studies have been permitted outside of China. In addition, Tsai said the nature of risk-benefit assessments makes measuring commercial impacts easier as compared to ecological impacts, which must be hypothetical or extrapolated. Setting the context, as the case studies showed, is an important consideration. Tsai noted that abundant outcrossing already exists in nature, and setting a baseline when studying the effects of GE trees is significant—especially whether they would be planted in natural sites or, more likely, in plantations, on idle agricultural land, or even on waste sites as phytoremediation. Finally, she noted wildlife and natural habitats are in a constant state of flux, caused by climate change, human activities, and natural disasters. These changes make it more complex to predict changes that might be caused by the introduction of GE trees.

Tsai reported on the beginnings of a consensus within the forest sci-

[2] *Bt*/API hybrid is a complex cross of multiple poplars that result in a tree with limited seed generation and a very poor ability to germinate in natural conditions.

ence community, developed at two recent conferences,[3] about studying the impact of GE trees on the environment:

- Greenhouse and small-scale plantings will continue, but they are insufficient to address ecological risks.
- Ecological risks cannot be modeled using annual systems like corn or soybeans.
- The efficacy of biological confinement has not been evaluated in the field over the long term.
- Modeling is essential, in conjunction with field data collection.
- Not all traits and species are equal, so prioritization must take place.
- Absolute versus relative risk must be taken into account.
- Proxy learning can come from intensively managed systems or natural hybrids.
- Learning by doing is required.

Research Gaps

What is known and especially what is not known about the effects of GE trees on the environment led Tsai to underscore what she feels is the greatest research need: the establishment of long-term research field trials, to include monitoring beyond reproductive age. She suggested the Long-Term Ecological Research (LTER) Program of the National Science Foundation and the Free Air CO_2 Enrichment (FACE) facilities of the Department of Energy (see Box 2-2) as potential models for long-term ecological studies. Setting up field trials at even pre-commercial scale is beyond the resources of what an individual academic or federal laboratory can undertake, so Tsai urged partnerships with the private sector.

Tsai believes traits, species, and sites should be prioritized so that resources are allocated for the traits and species with greatest economic or ecological relevance and so that sites represent various ecological systems. She suggested that a co-facility that brings together researchers, such as FACE, may be a way to solve funding and security challenges. In terms of regulatory limitations, she shared her belief that if conditional release beyond flowering or to the point of harvest remains unallowable, research cannot move forward.

[3]Institute for Forest Biotechnology Symposium on Genetically Engineered Forest Trees: A Workshop to Identify Priorities for Ecological Risk Assessment, May 3-4, 2007, Raleigh, NC; Institute for Forest Biotechnology Meeting on Growing Trees and Stemming Risks: Ecological Impacts Associated with the Products and Practice of Forest Biotechnology, March 19-21, 2006, Vancouver, Canada (Tree Genetics and Genomics Special Issue, April 2007).

BOX 2-2
About FACE

Free Air CO_2 Enrichment (or FACE) facilities are operated by the U.S. Department of Energy (DOE) Office of Biological & Environmental Research. There are four sites in the United States: a sweet gum plantation at the DOE Oak Ridge National Laboratory, a Mojave Desert location on the DOE Nevada Test Site; a loblolly pine plantation in the Duke Forest in North Carolina, and a hardwood facility, including aspen, at the USDA Forest Service Harsaw Experimental Forest in Wisconsin. A poplar site (EUROFACE) is located in central Italy.

The sites facilitate research that logistically would be difficult, if not impossible, for an individual researcher or group to undertake independently. For example, more than 100 scientists from 22 institutions and 9 countries are taking advantage of the FACE facility in Wisconsin, studying the effects of increasing tropospheric ozone and carbon dioxide levels on the structure and function of northern forest ecosystems.

SOURCE: Aspen FACE, 2008.

Research on Effects of GE Fish—Robert Devlin

Since the 1980s, Robert Devlin (Fisheries and Oceans Canada) reported, more than 30 species of fish have been genetically engineered by transferring a wide range of genes related to metabolism, disease resistance, reproduction, and other purposes, with growth enhancement as the principal trait studied.

The consequences of different transgenes on the phenotypes of the fish are expected to differ widely, according to Devlin. For example, overexpression of growth hormone (GH) in Atlantic salmon, carp, tilapia, and other fish species produced significantly faster growth, but other characteristics, such as altered endocrine profiles, reduced disease resistance, and swimming ability, have also resulted.

The interplay of a wide range of fish habitats, genotypes, phenotypes, and other variables could mean a myriad of consequences of GE fish. Animal behavior—in the GH case, the fact that the transgenic fish become, as Devlin called them, "feeding machines"—complicates predictions of the ecological effects.

Ideally, fisheries scientists would like to have data from nature, but it is not currently allowable or desirable to release fertile GE fish into aquatic ecosystems. Devlin explained that a planned introduction of transgenic fish has been proposed to assist with elimination of feral carp in Australia, but this is still in very early stages of consideration. He noted that, to his knowledge, no GE fish have even been inadvertently released into nature from aquaculture production facilities, although theoretically this could occur through storms, shipping accidents, or human error. Containment is critical because recovery of fish from most aquatic environments is essentially impossible.

If GE fish and aquatic organisms escaped or were released, Devlin said there may be direct effects on non-transgenic conspecifics (fish of the same species) and other organisms in the ecosystem as a result of resource competition, altered pathogen susceptibility or transfer, and indirect genetic effects, among others. If the transgenics survived, there could be sustained effects, if they breed with each other or with conspecific, non-transgenic fish.

The framework laid out by Kapuscinski et al. (2007) can help assess the risks to the environment of GE fish. At a high level, this would involve looking at relevant components and processes in an ecosystem (using information on biotic and abiotic functions of aquatic ecosystems); the phenotype of the transgenic fish (including those traits the transgene intentionally altered, and those traits that emerged as "side effects" of the transgene on fish physiology or behavior) and the full range of the types of interactions likely to occur between the fish and different components of the ecosystem. When this information is gathered, the next step in the framework is to identify the likelihood of interactions, the hypothetical consequences of those interactions, and the degree of uncertainty in predicting those outcomes.

Instead of studies in nature, other research approaches might be used to try to understand both the fitness of a transgenic in any number of ecosystems and the consequences of survival to that ecosystem. Therefore, models to simulate these dynamics are important tools. In addition, the individual genetic, physiological, and behavioral characteristics of transgenics can be examined in controlled lab conditions and semi-natural environments that approximate nature. Finally, Devlin noted that non-transgenic surrogates (for example, salmon with a non-transgenic growth hormone) can be released into nature to try to observe effects.

From a risk assessment point of view, the question is whether these methods can generate reliable data. According to Devlin, these approaches certainly provide valuable data, but the fact that they do not fully mirror fitness in nature, especially for larger species, is problematic in terms of providing full answers to questions about the effects of GE fish on wildlife and habitats.

Thus it is necessary to conduct studies under as many different experimental conditions as possible. Environmental conditions (for example, different levels of food availability) and rearing conditions can strongly affect phenotypes, and although these cannot be accurately replicated outside of nature, one valuable contribution of lab experiments is their ability to reveal phenotypic differences that may be more subtly manifested in nature.

Devlin noted that many complex phenomena that will affect consequences in nature need to be untangled. For example, differences in the genetic background between strains of the same fish species (for example a wild type versus domesticated strain) will also greatly influence the resulting phenotype resulting from a transgenic transformation.

Antagonistic pleiotropy, in which some traits can simultaneously produce beneficial and detrimental effects on fitness, is another phenomenon in need of study. He illustrated with data showing how transgenic fish in a contained experimental system outcompeted non-transgenics for food (thus growing much faster) but experienced higher mortality than the non-transgenic when a predator was introduced into the system.

To contain GE fish, researchers continue to develop physical and biological containment systems, yet more needs to be done. For example, sterilization techniques have been shown to be 99.8 percent successful—yet even a 0.2 percent failure rate would mean the escape of large numbers of transgenic fish into the environment so releasing fish using these techniques is not permitted. Some combination of these methods, he suggested, may ultimately create more complete containment.

Research Needs

Devlin identified six research needs to study the effects of GE fish on the environment:

- The development of large, variable-environment facilities to rear and assess transgenic fish in conditions that are as close to nature as possible.
- Assessment of whether complicating gene-by-environment (G × E)[4] interactions and antagonistic pleiotropic effects are pervasive for critical fitness traits. If these effects cannot be well defined, then laboratory experiments will be able to identify some of the forces at work in predicting fitness, but not accurately estimate magnitudes.
- Integration of ecosystem models with demographic and genetic models, attempting model validation with surrogate (non-GEO) models in nature.

[4] G × E signifies genotype by environment interactions, in which the growth, performance, or behavior of specific genotypes (e.g., transgene, transgenic events, or other genetic entity) is affected by specific environments.

- Development of methods for uncertainty analysis to facilitate predictions and regulatory decisions.
- Assessment of background genetic effects on transgene phenotype.
- Improvement on biological containment methods to minimize exposure of transgenic fish to ecosystems, through a combination of layers of containment.

Research on Effects of Microbes—Michael Allen

Microbes add complexity to the discussion of the effects of GEOs on wildlife and their habitats, asserted Michael Allen (University of California, Riverside). Although fewer than a dozen microbial traits have been approved for release, the diversity of GE microbes in development is vast and includes those developed for plant protection, improved nutrition, metal absorption, and other functions. Rather than list all the properties described in the hundreds of papers written about them, Allen suggested that he focus his presentation on the challenges and approaches to the study of microbes.

First, the dispersal of microbes cannot be contained, even with the kinds of facilities described earlier in the workshop for fish. Referring to the movement of microbes, Allen observed, "if it can happen, it will." Microorganisms can travel long distances through events such as fire, hurricanes, and human or animal movement. However, even small distances can matter, especially at the interface of developed and wildland habitat. Ecologists have long observed that problems are often associated with the introduction of any exotic species into the natural environment, transgenic or not. For example, he said the presence of exotic grasses is believed to contribute to a more frequent fire cycle in California.

According to Allen, issues to think about when studying GE microorganisms include: horizontal gene transfer between microorganisms; the persistence of a GE microbe or its gene product in the environment; direct impacts on microbial populations through the creation of genetic bottlenecks; other direct effects, such as toxicity; and indirect impacts on an ecosystem through altered food webs, community structure, and nutrient cycling.

Despite a large amount of literature about gene transfer between microbes, Allen said that not much is known about the outcomes of horizontal transfer or about indirect effects of the introduction of a new microbe, such as host-species shifts. Another need is to understand the effect of acute versus chronic toxicity, especially in a field environment where microbes might persist at low levels. Moreover, Allen noted it is

BOX 2-3
NEON: New Technologies to Understand Ecological Consequences

The National Ecological Observatory Network has been proposed as a continental-scale research program by the National Science Foundation to understand the impacts of climate change, land-use change, and invasive species on ecology. Planning for NEON is currently under way.

Twenty proposed sites, one in each eco-climatic domain in the United States, are intended to operate as a national observatory, linked by advanced cyberinfrastructure to record and archive ecological data for at least 30 years. The long-term NEON data collected at these sites are expected to support improved ecological forecasting to optimize natural resource management and provide early warning of biological natural hazards.

SOURCE: National Ecological Observatory Network, 2008.

difficult to design experiments that look beyond direct toxicity effects to effects that move through the entire food web.

A number of studies argue for the need to study ecosystem processes, but Allen believes that the technology to look at these processes is outmoded. One good opportunity, he suggested, is to link to some of the new technologies contemplated in the National Ecological Observation Network (NEON; see Box 2-3). For example, integrating isotopes with sensing technology, perhaps the next big development in the field of ecology, can be used to detect very subtle differences in ecosystem functions.

Research Needs

Allen summarized by pointing out that society has more than one alternative when it comes to making decisions about managing, for example, agricultural pests: It can give up agriculture in affected areas, it can use or not using chemical spray pesticides, it can use or not use GEOs to enhance productivity and/or reduce pest damage, it can use or not use agents that decompose toxins, to name a few. Thus, Allen believes that studies comparing the effects of GE microbes with chemical pesticides would be helpful in informing these decisions.

To understand the appropriate role of microbes as it relates to these alternatives, Allen suggested a few places to focus research efforts to improve understanding of the effects of GE microbes:

- Use new ecological monitoring technologies.
- Engage in long-term studies, like those in NEON, not only for natural systems but also for agricultural and urban development.
- Study effects based on a single versus multiple introductions over time.
- Study the movement, persistence, and recombination under different event scenarios, given that "the unusual is the usual in long-term ecological dynamics."
- Study the effects of small perturbations on threatened populations under stress.
- Study indirect consequences and a complex systems approach of GE microbes, looking at food webs, nutrient cycling, and community composition.

Research on Effects of GE Insects—Thomas Miller

Thomas Miller (University of California, Riverside) focused on GE insects to conclude the round of presentations on GEO research by taxa. He noted that a new pest or disease enters California every 60 days—and that no insect pest species has ever been eradicated by humans. Nonetheless, the "toolbox" to combat insect pests includes the development of disease-resistant plants, biological control, cultural control, chemical control, and now, although in the earliest stages, biotechnology. From Miller's perspective, when a new pest or disease is identified, resources are allocated to develop the tools that can solve the problem, but not to study the side effects.

Miller presented two examples of the development of GE insects to solve pest problems related to agricultural production. His first example was pink bollworm (*Pectinophora gossypiella*), which came to the United States with cottonseed. Miller and his USDA colleagues have developed a transgenic, sterile bollworm that is currently in field trials in Arizona. The transgenic bollworm would be released as a biocontrol agent. Miller noted that the effect of the bollworm (transgenic or otherwise) as either a source of wildlife food or as a predator on wildlife is not known, but as Wolfenbarger had suggested earlier, the impact of cotton cultivation itself might be more disruptive to the environment than the presence or absence of a transgenic insect. The regulatory concerns associated with the potential release of the transgenic bollworm are related to where in the bollworm genome the transgene is inserted, if the insertion is stable, the fitness effects from the insertion, and the possibility of horizontal gene movement. Because it was a partner in this research, the USDA-APHIS is paying for the field studies for environmental assessment.

Miller's second example was an approach to controlling Pierce's disease of grapes, which is caused by a bacterial pathogen (*Xylella fastidiosa*) that is vectored by an insect, the glassy-winged sharpshooter. Miller developed a transgenic version of another bacteria (*Alcaligenes*) found in the insects guts that he believes would displace the Pierce's disease pathogen in the insect, leading to reduced transmission of the disease between grapevines. Regulatory approval to bring this approach into field trials has moved very slowly, in part because of the novelty of the approach. A probability model has been developed to predict effects of the introduction of the transgenic bacteria, but the model needs data that can only be derived from field trials. For field trials, regulators required that any grapevines (onto which the bacteria would be introduced) must be destroyed. Miller said that was a nonstarter for getting the cooperation of grape growers with the research.

Research Needs

Miller stressed the need for field trials to get data to fill in the knowledge gaps and added that the study of ecological impacts requires interdisciplinary approaches. In the case of Pierce's disease, for example, looking at the effects of the problem and potential solutions involves understanding bacteria, pathogens, insects, grapevines, immunology, wildlife, and ecology.

Miller believes partnerships with industry and government can facilitate the process. In the case of pink bollworm, USDA identified the problem and a potential solution, and provided much-needed funding. Regulatory approval by APHIS, while still complex, has also been more smoothly coordinated. He suggested perhaps USGS and FWS could play a similar pivotal role in other GEO research.

Discussion on Taxa-Specific GEO Research Needs

During the question-and-answer session with the five presenters, many of the comments related to the balance between field study and regulatory requirements, as well as how to choose the most relevant topics to investigate.

Field Study

A common goal across taxa is to conduct ecologically relevant studies in field settings. A few participants suggested that one potential approach for some species might be to partner with USGS and others to identify appropriate field sites where conditions and confinement are adequate. FACE, NEON, and the LTER Network seemed to possible starting points.

For some species, such as fish, that can't be field tested, an important step would be to develop indicators of the processes, in terms of life history, that can be most accurately mimicked in a contained facility.

When the point was raised that releases can occur despite precautions and U.S. bans, for example the use of transgenic insects in other countries, Allen suggested at least using these escapes as a learning opportunity. Along those same lines, another participant suggested making better use of currently grown GE crops to study ecological effects. "We have grown a billion acres of GE crops and have barely begun to assess the ecological effects," he said, "so I challenge us to more effectively determine and summarize what has already happened with the global experiment that has being going on for more than a decade."

There is a need to work with regulators to resolve the impasse, as one participant termed it, between the need for high-quality ecological information and regulatory requirements to minimize environmental risk. Is it possible, he asked rhetorically, to get to the point where we do not need complete containment so that fieldwork can take place? Another participant suggested that uncertainty is part of the risk assessment process and research on uncertainty should be embraced, rather than avoided. In fact, he said, it is the rare events that may be most important.

Secondary Effects and Baselines

Teasing out indirect effects is tough, but essential, Allen said. It is often said that tillage, soil types, climate, and other factors override the effects of GEOs, but that does not negate the possibility that a secondary effect can be critical in the long term. Allen believes more sensitive measurement methods will help scientists look at these more subtle effects.

A participant questioned whether a comparison at the farm-field level is the appropriate baseline, since effects may go beyond the field. In those cases, he asked what should the baseline be? Wolfenbarger replied that current GE row crops do not move into habitat on the margin, but that may be an important consideration with newer technologies. She said one approach may be a gradient that encompasses a cultivated area and the natural areas around it. Another audience member wondered who decides what impacts to look for, and whether these were always anticipated to be negative, as opposed to positive impacts? Wolfenbarger suggested that this workshop, by virtue of its sponsorship by a federal agency, was an attempt to integrate societal values about what is important into how the agency will target its resources.

Selecting Research Subjects

A final point relates to choosing which processes or interactions to study. How do we pick research subjects that give us meaningful data? Sometimes the less threatening systems (the release of an organism with a "neutral" trait) are the easiest to agree on for release, but they are also less interesting in terms of what they can show. Tsai agreed the driving force to study ecological risk should be dealing with ecologically relevant traits, looking at the long term and in multiple sites.

FUNDAMENTAL AND CROSSCUTTING RESEARCH FOR ASSESSING ECOLOGICAL EFFECTS OF GEOS

As committee member Steven Strauss said in introducing the next plenary session on crosscutting issues, case-by-case study when looking at GEO organisms is necessary because of the diversity of traits, organisms, and environments. But, at the same time, this diversity can be so overwhelming that generalities to make predictions and pool resources are also needed to move forward. Presentations in this session covered three ongoing areas of research that can complement the study of GEO effects: invasion ecology, gene flow, and detection and monitoring.

Research Approaches from Invasion Ecology—Diane Larson

Diane Larson (U.S. Geological Survey) discussed the concept of invasiveness, the attributes of invading species and their recipient environments, and approaches ecologists take to study the effects of invasions. This research suggests some parallels for research into GEOs.

She first reviewed two general hypotheses of invasion ecology. The enemy-escape hypothesis states that when a non-native organism finds its way into a new environment, it is subject to reduced attack (from predation, parasitism, and competition) relative to its native environment. As a result, the non-native organism can increase growth and reproduction. This hypothesis, said Larson, serves as the rationale for using biological control to reduce the growth and reproduction of invaders. A related genetic-based hypothesis—the evolution of increased competitive ability—states that escape from enemies allows an organism to shift from making defensive compounds to putting all of its effort into growth and reproduction. Both these hypotheses imply that researchers need to look at all guilds of enemies, including microorganisms, that keep an organism in check—"the whole system," as Larson said, "not just one individual plant against one individual enemy." Potential application of these hypotheses to GEO research includes anticipating whether genetic tradeoffs will make GEOs more or less competitive in an unmanaged habitat; for example, if a fitness cost associated with the *Bt* gene would reduce its competitive ability in an unmanaged setting.

Larson said that one of the most significant factors affecting the likelihood of the invasiveness of a species, shown time and time again, is propagule pressure: the more an organism is introduced, the more likely it is to become established and subsequently invasive. She noted that this principle is also useful in determining the optimal release size of biocontrol organisms, and may help reveal the likelihood of a GEO encountering a compatible relative in the surrounding habitat, which might allow for gene introgression. Other species attributes studied by invasion ecologists that may be relevant to GEO effects include the species' use of "novel weapons" that increase its competitiveness, the species' life history, the existence of mutualisms that support the survival of the organism, and its tolerance of environmental amplitude (see Table 2-1).

Turning from the characteristics of an invasive species to the environment in which it is introduced, the evidence suggests that the most significant attribute to consider is disturbance. Disturbance facilitates invasion, because resources like nutrients and space are freed up and the stable interactions of native species are disrupted.

Larson added that the primary phase of an invasion, when the invader is gaining momentum, may present the best time to control it (Dietz and Edwards, 2006). In a GEO context, this could suggest studying the conditions in which a GEO will colonize beyond the disturbed area and, thus, which areas should be monitored.

A second attribute of the recipient environment is biotic resistance; in other words, interactions with the native species can prevent the spread of a newcomer, and this might be related to the degree of biodiversity present in the environment. Support for this hypothesis varies, said Larson, and seems to be scale-dependent. A comparison of colonization in areas with varying native diversity, which might suggest way to create buffers or barriers, is one way that study of biotic resistance could apply to research in GEOs.

Effects of Invasive Species

Larson explained the effects of invasive species include hybridization, which can threaten native genotypes and endangered populations and can result in either in increased or decreased vigor of the new genetic combinations. According to Larson, other effects with potential application to GEO research include changes to native community structures, interactions with mutualists, relationships with other invasive species, changes in the availability and cycling of nutrients, ecosystem engineers, and predator-predator aggression (Table 2-2).

TABLE 2-1 Research On Factors That Contribute to Invasiveness, and Their Potential Application to the Study of GEOs

Attribute	Correlates with Invasiveness	Research Approaches	Potential Application to Research on GEO Impacts
Propagule pressure	Frequent introductions, large introductions	Monitoring of introductions; landscape analysis	Predicting likelihood of a GEO encountering a compatible relative in surrounding habitat
Novel weapons that improve competitiveness	Allelopathy (production of toxic or defensive compounds), new predatory behaviors	Chemical ecology, ethology, use of realistic habitats	Examining effects of novel root exudates Development of novel behaviors
Life history	Early sexual maturity, short generation time, rapid growth, high reproductive capacity	Matrix models of life/death events to estimate survival	Potential effect of habitat (managed and unmanaged) on GEO's demographics
Mutualism	Assisted by pollinators and seed dispersing organisms (e.g. birds), mycorrhizae	Observations; manipulative field and greenhouse experiments	Likelihood of dispersal of pollen or of plant to other areas; survival in unmanaged areas
Environmental amplitude	Thermal tolerance, drought tolerance	Climate envelope/ modeling	Potential spread of organisms modified for increased environmental tolerance

SOURCE: D. Larson.

Larson closed with what she termed "nagging odds and ends" from invasion ecology that might apply to GEOs:

- The lag times sometimes seen between the first introduction of a non-native species and their invasive effects can be long, even hundreds of years.
- Invasions can be cryptic.

TABLE 2-2 Research of Effects of Invasions and Potential Parallels to GEOs

Effect	Impacts	Research Approaches	Potential Application to GEO Research
Hybridization	New genetic combinations that increase or decrease fitness of a native population	Modeling, experimental crosses in controlled settings	Spread of gene via hybridization, leading to persistence or loss of gene
Changes to native community structure	Competition, apparent competition, predation	Controlled field and pot/mesocosm experiments, food or interaction web analysis	Changes in trophic interactions, such as rapid growth, replacement of predators, or herbivore resistance
Interactions with mutualists	Pollen quality or quantity effects on native plants, parasitism of fungi	Manipulative or observational field studies, comparison of mycorrhizal colonization	Effect of GE pollen, pollen dispersal to native relatives, potential effects of root exudates on soil mutualists, horizontal gene transfer
Relationships with other invasive species	Invasion cascades or meltdowns	Observational field and lab/greenhouse studies	Potential interactions that would facilitate invasion by the other species
Change in availability/cycling of nutrients	Changes in litter quality or quantity; changes in detritivore community	Nutrient manipulation; observational	Effects of GEOs on litter; changes in environmental nutrient availability or cycling
Ecosystem engineering	Creation, modification, maintenance, or destruction of habitat	Observational studies, modeling	Potential effects, but also potential utility in restoration
Predator-predator aggression	One invader against another	Observational; realistic habitat variation	Potential for a rapidly growing GEO to influence native species

SOURCE: D. Larson

- Baseline information about the environment pre-invasion is important to know.
- Monitoring should include defining an objective threshold for action: at what point will the changes revealed through monitoring mean some action is taken?

Working from the Gene and Organism and Moving Upward—Paul Gepts

As Paul Gepts (University of California, Davis) said when he introduced the title of his presentation, it is the "upward" part of the topic, beyond the organism, as the process of gene flow takes place, which is especially challenging. Variables in an organism, gene or trait, and the environment all affect the process of gene flow (see Figure 2-1).

Looking at a myriad of individual cases, Gepts asserted that gene flow will take place, but that flow varies greatly by organism: a corn plant, for example, has millions of pollen grains per plant but they are wind dispersed, as compared to a soybean plant, which has only a few thousand grains but which are insect-pollinated. Local events are most frequent, he said, but long-distance gene flow, harder to measure, also occurs. Gepts

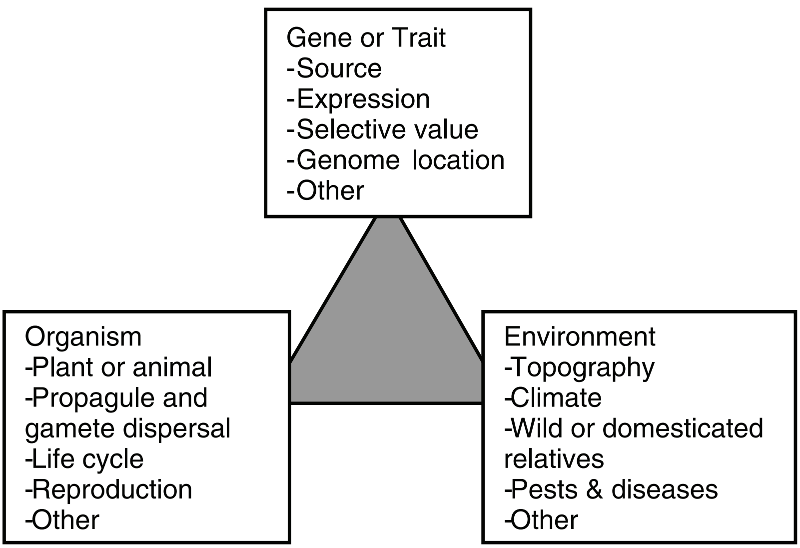

FIGURE 2-1 Variables that may affect gene flow and persistence in the environment.

described several current studies that are combining modeling with pollen capture in the atmosphere to document long-distance gene flow.

Gepts explained that variables at the gene or trait level depend on the source of the gene. In the case of a GEO, that might include another species from which the gene was taken. Gene expression, selective value, and location in the genome also affect the likelihood of the gene to move into a population and to be expressed, keeping in mind that expression is dependent on G × E interactions.

Finally, said Gepts, environmental factors affect gene flow. Throughout the world, areas that were once centers of crop domestication have wild and domesticated relatives in proximity to each other; even in the United States and Europe, where few agricultural crops originated, crops with close wild relatives can be found. Gepts explained that a number of factors will determine gene flow and whether a gene (including a transgene) escapes from a domesticated to a wild plant via pollen. Whether the escape results in ultimate establishment in a different genetic background, however, is in the realm of population genetics: the level of migration between the bred and wild variety will depend on the size and diversity of the populations, inheritance characteristics, and migration.

Research Needs to Study GEO Gene Flow

Gepts concluded by identifying issues related to organisms, genes or traits, and the environment that would yield important information for GEOs:

- Organism: The dispersal ability of gametes and propagules.
- Gene or trait: The influence of genome location on expression. (The ability to target the location of a gene insertion in a genome would be of tremendous benefit in this regard.)
- Environment: The fate of transgenes and their products through a variety of methods.

At present, the many factors that affect gene flow can be listed and described separately, Gepts said. But what is needed is a way to look at them in combination through development of a multifactorial, quantitative, integrative risk factor.

Strategies for Effective Detection and Monitoring—Michelle Marvier

As the third in the series of presentations on crosscutting research, Michelle Marvier (Santa Clara University, California) addressed the question of which approaches will be most useful to distinguish the ecological impacts of GEOs against the backdrop of many other potential sources of environmental change. She explained that many confounding factors can affect wildlife and habitat, and it is difficult to tease out a specific cause why changes occur. The strategic selection of indicators, combined with spatial and temporal comparisons, can help provide answers.

The key to effective monitoring, she stated, is selecting indicators that are sensitive to specific environmental changes. Meta-analysis, modeling, and literature reviews to discover other variables of ecological effects can help to identify sensitive indicators.

Marvier presented a meta-analysis of more than 150 publications and unpublished reports that looked at nontarget effects of *Bt* crops (Marvier et al., 2007), noting meta-analyses could be useful for other topics unrelated to transgenic effects, such as the effects of pesticides or other agricultural practices. She suggested that the searchable database created for the *Bt* meta-analysis[5] could also be used to look at other aspects of the effect of GEOs on wildlife and habitats.

A second way to select good indicators is through modeling. Marvier explained that models can identify life history traits and species that are better indicators than others; different stressors that may slow population growth, including GEOs, can then be run through the model. Simulations show a predator species is generally a more revealing indicator to monitor than a prey species. Similarly, a fast-growing species is a better indicator since differences will show up more rapidly. Thus, practical guidance from modeling suggests selecting indicator species with a higher trophic position, high rate of population growth, and low environmental sensitivity.

A third approach is to look at the literature to consider other variables that integrate many ecological effects but do not rely on precise abundance estimates. Marvier provided one example measuring the mean trophic level of fish caught in a marine ecosystem as a proxy for measuring fishing pressure, given that a precise count of all the fish in an ecosystem is impossible.

In addition to indicator species selection, monitoring requires good contrasts as focal points of study; a location where GEOs have been released contrasted with a location where they do not exist, or an environment before and after the releases. She said this information is difficult to find, especially at a county level, in part because GEO releases are often kept confidential. Some researchers have developed relationships with farmers and can obtain planting information, but this is on a case-by-case basis. Marvier said maps are critical to providing spatial contrasts for GEO presence and abundance, as well as a historical perspective for

[5]Available at: http://delphi.nceas.ucsb.edu/*Bt*crops/main/search

temporal comparisons. Local initiatives, such as the bans on GE crops in Mendocino County, California, and in the state of Vermont, can be seen as opportunities, as these areas can serve as a basis of spatial comparison. She suggested the USGS' mapping capabilities could be used to contribute to understanding the ecosystem effects of GEOs, with precautions taken in recognition of the privacy issues associated with the data.

Discussion on Crosscutting and Fundamental Research Needs

During this question-and-answer session, much of the discussion centered on the feasibility of mapping because of the availability (or lack thereof) of information. Several participants pointed out that the location of large-scale releases can be determined and, thus, mapped, because of the need for an Experimental-Use Permit (EUP) for areas 10 acres and more. Marvier said smaller field trials, such as those looking at pharmaceuticals, are harder to find out and may involve traits of particular concern. Even if the information can only be made available after the trial has taken place, she urged disseminating it for monitoring purposes. Another participant suggested it is the larger releases that will yield the most important information about scale and, in the long term, the most data. A lot of information about those releases is available, but requires digging state by state.

Challenges to Mapping

The principal challenge to reliable mapping of GEO releases is the issue of privacy, suggested several participants. County-level data are often not available because they could be tracked to private landowners. It was suggested that a group like this workshop could stimulate the USGS or another agency to put together publicly available databases; however, privacy issues, which are of concern in Congress, make collection of data on private property a sensitive issue for USGS and other agencies, with no simple solution. Another participant warned about the pitfalls of relying on a map without benefit of knowing the full context, such as the confounding factors behind the decisions about whether or not to use GEOs and more detailed information about farming practices in the area.

Negative Connotations

Another participant felt the discussion had a pejorative tone. Land use changes over time: A farmscape may have been a forest 200 years ago and may be planted with a totally different crop in the future. Do we engage in studies to look for the negative impacts of those developments? He took issue with the language used in the session; for example, looking for indicators as warnings for negative impacts of GEOs, when, in fact, the effect may be neutral or positive.

Endpoints

It is hard to monitor without thinking about endpoints, suggested a participant. When designing a study to look at either pre-release risk assessment or post-release monitoring of transgenic fish, for example, it is hard to come up with indicators of impacts as the focus moves from the initial entry of an organism to its spread further into the environment. Different situations require direct measurements or indicators.

The speakers responded about some endpoints to look at from their research perspectives. Gepts suggested monitoring the wild relatives of crops, such as through GIS surveys, to see how they fare in the presence of transgenic crops. Larson said a matrix model may help predict potential invasive effects before a release is made, particularly in the area outside of a crop field. Marvier suggested looking at non-target effects, moving beyond the local release environment and the plant that has been manipulated.

Potential Bias

One participant expressed concern about potential biases in a meta-analysis if it relies on the available published literature. Marvier said she went beyond the published literature by using the Freedom of Information Act to get studies submitted by industry to the government for regulatory approvals.

Predictive Power

Larson was questioned about the ability to predict the invasiveness of a species that has not been previously introduced even if there is pre-invasion information about the species and the environment (but not the interaction); in fish, it is believed to be only about 70 percent. Larson said she did not think the percentage was any higher in plants. Thus, she said, invasive species studies do not provide the power of prediction that some regulators of GEOs might like, if it can be assumed that GEOs are likely to behave in the same way—an assumption that is subject to debate.

3

Research Questions, Approaches, Projects, and Needs

To fulfill the main charge of the workshop, participants divided into groups to identify key research topics at the interface of managed and natural ecosystems where genetically engineered organisms (GEOs) would be likely to interact with wildlife and their habitats. These interfaces, which included agriculture/wildland; silviculture/wild forest; and aquaculture/aquatic habitat provided the context for discussing the potential interactions that might occur, and possible approaches to observe or study them. Approximately ten participants were assigned to each group, based on their area of expertise. (Because of the participant numbers, two separate agriculture/wildland groups met for a total of four breakout groups).

Each group met twice. During the first breakout session, the groups were asked to identify research questions or topics related to the potential impacts of GEOs on wildlife and habitats at the given interface and to consider the range of research approaches available that could address these topics and themes, including fundamental or theoretical research, modeling, laboratory, and field approaches.

During a second breakout session, the groups were assigned with building on the research topics they identified by drafting more specific proposals for research at their respective ecosystem interface. As workshop committee chair Kapuscinski said in explaining the charge to the group, "Imagine that next week, cross-organizational teams were asked to submit proposals. What would you propose to study?" Recognizing that these proposals were produced in just a few hours, they nonetheless are

BOX 3-1
Summary of Research Proposals Identified by Breakout Groups

Agriculture/Wildland Interface
- Large-scale experimental comparisons of agricultural practices
- Documenting landscape and regional scale changes
- Global pollinator initiative
- Wildlife surrogates in lab-based GEO tests
- Long-term studies of insects and microbes

Silviculture/Wild Forest Interface
- Creation of a national infrastructure for collaborative research
- Development of a model to assess gene flow

Aquaculture/Aquatic Habitat Interface
- Direct effects of transgenic native fish species
- Ecological effects of non-native GE fish

useful bases on which to elaborate research that will answer some of the questions about the effects of GEOs on the different ecosystems.

The report-outs of the two breakout sessions are summarized below, organized by habitat interface; Box 3-1 contains a list of the research proposals generated by the four groups.

AGRICULTURE/WILDLAND INTERFACE

Two separate groups met to discuss research topics examining the potential impacts of GEOs at the interface of agricultural lands and wildlands. Each group developed its ideas for questions that would be important to pursue, and they also described different approaches or tools to address those questions. Richard Hellmich (U.S. Department of Agriculture Agricultural Research Service [USDA-ARS]) and Deborah LeTourneau (University of California, Santa Cruz) summarized the discussions of their respective breakout groups in the plenary session.

Research Questions

Research questions identified by the groups include the following:

What Are the Effects of Gene Flow?

In the context of agricultural crops, gene flow means that a gene has moved from a GEO crop and has been sexually incorporated into a wild population of plants in the field or near the field, or perhaps into microbes of the rhizosphere. The fact that this movement has occurred might be considered an "effect" on its own, but a fundamental question is whether there will be consequences of gene flow on wildlife and their habitats. The answer to that question might depend on the nature of the gene involved, whether it persists in the natural environment because it confers fitness to organisms into which it has moved, how those organisms relate to the rest of their environment and whether the transgene has altered that relationship, and how widespread the gene flow is.

What Are the Direct and Secondary Effects of GE Crops?

Direct effects include toxicity or some other negative effect on an organism. But there might also be secondary effects, for example if the GE crop resulted in the "removal" of food eaten by wildlife (such as insects or weeds). How far into the food web, it was asked, might those secondary effects be observed, for example that might result in changes in population sizes?

What Are the Effects of GE-Related Agriculture Practices Relative to Other Practices?

Not only do GE crops have potential direct and secondary effects, but because certain agricultural practices are associated with the use of GE crops, they might have effects as well. For example, no-till planting of GE crops causes less soil disturbance than traditional plowing, and crop residue is also left on the surface of the soil. Pesticide use will be different for *Bt*-crops than conventional crops. Picking up on the studies described by Wolfenbarger, the group felt that an examination of the effects of agricultural practices should include comparators that place into perspective the significance of any changes relative to the alternative.

How Would GE-Bioremediation Applications be Evaluated?

One suggestion for a research topic was whether it would be possible to use the tools of genetic engineering to develop plants or microbes or other organisms that would be released in order to improve compromised or degraded ecosystems (e.g. transgenic microbes to metabolize soil contaminants or transgenic ash trees to protect against emerald ash borers). The group felt such applications—for the purpose of environmental bioremediation—probably would not arise out of a commercial motivation (as GE crops have) but might be developed with public funding. The use of GEOs to improve ecosystems was thought to be something that the U.S. Geological Survey (USGS) might champion to improve the environment. The same questions about gene flow and direct and indirect effects would also apply, but with a twist, because the goal is to have a purposeful impact on the environment. Some felt that this would be an opportunity to demonstrate to the public the positive impacts of biotechnology while generating research information on the interactions of GEOs with wildlife and natural habitats.

Research Approaches

In addition to suggesting important research questions, the two groups identified possible methods and approaches to studying the questions listed above.

Identification and Use of Indicator Species

It might be possible to identify species that would be useful indicators of direct effects of GE crops on wildlife, both for direct toxicity testing or other negative effects, and for examining effects at higher trophic levels. Perhaps standard protocols could be developed using indicators to evaluate the risk of GE crops to wildlife.

Hellmich noted that he participates in the International Organization for Biological Control, which is working to harmonize protocols for laboratory testing of surrogate species, particularly for so-called Tier 1 tests on safety. He thought USGS could contribute by identifying species of interest to add to the list. It was pointed out that sometimes a compromise about the selection of indicators is needed—the species (often insects) must be widely available and easily reared in a lab, even if a more informative indicator may exist. Another point made was that indicators should reflect effects on wildlife at different life stages (for example, pupae, juveniles, adults).

Historical Data Analysis

A compilation of relevant historical, geographic, and socioeconomic data on land use and environmental quality can help evaluate different scenarios or hypothesis about the negative or positive effects of GEO use. As an example, LeTourneau cited a theory that the use of GE crops would lead to more intensive farming on smaller parcels of land (leaving more land in an unmanaged or wild state). Another theory is that GE crops reduce pesticide runoff and reduce soil erosion. These potential benefits could be examined through the lens of historical land use and environmental data.

Planned Experimental Comparisons

The breakout group thought that a U.S. version of the U.K. Farm Scale Evaluation (FSE; see Box 2-1) could be useful in examining the effects of different agricultural practices, including the use of GE crops, on habitats and organisms, both on farms and in surrounding landscapes. Such a study would require partnerships among government agencies, such as between USGS and USDA, as well as incentives to growers to use specified alternative practices. The group noted the FSE provides valuable lessons for a U.S. version, but that there are a wider range of agricultural practices employed in the United States. The group also proposed that such a study would need to anticipate future changes in cropping practices, such as an eventual second generation of GE crops that would replace current *Bt*-crops or the next generation of herbicide-resistant crops as resistance to the herbicide glyphosate develops in field weeds. The study would examine the effects of refuges, buffers, riparian zones, and other wildlands, perhaps more than the FSE.

Spatial Modeling

Existing data might help to predict the spatial distribution of GEO impacts on wildlife. For example, existing Canadian data on GE rapeseed (canola) could be used to form a hypothesis about the evolution and spread of glyphosate resistance to weeds in the United States. In addition, if glyphosate were to become ineffective against weeds, herbicide use might change and that, in turn could have effects on wildlife. Other areas to look at are habitat replacement by drought- and salt-tolerant crop expansion, as well as expansion of crops modified for production of biofuels and industrial materials.

Targeted Data Collection and Integration

In addition to analyzing and integrating historical data, an effort could be made to collect data in farmlands that would permit detection of landscape-level and long-term effects of transgenic organisms. Key data to augment existing databases could include increased monitoring of agricultural habitat, a comprehensive database on commercial releases and field tests of transgenic events by county, determination of the incidence of high exposure of organisms in order to see spatial overlap with releases, coordination with the Forest Inventory Assessment database, and use of GIS mapping to detect robust impacts or early warning signs.

Use of Existing USGS Monitoring Systems

The emphasis on mapping, spatial modeling, and combining new and existing databases to put GE questions into context was in part to build on USGS' strengths. The question was asked whether existing USGS efforts could be used to track effects of GE crops on wildlife and habitats. Looking for effects on pollinators, it was suggested, might be a good fit, given the recent high level of interest in monitoring their status. Would USGS water quality monitoring programs identify effects of GE crops if there were any?

This discussion prompted USGS participants to describe some of their agency's efforts and capabilities for data collection. Bob Szaro noted that the USGS is looking at landscape change, including agricultural practices, particularly now that the Department of Interior has a broader perspective on the landscape that it manages. Adding GEOs to these efforts would be location-dependent, since information is more available in some places than others. The USGS is working toward a coordinated national effort; participants suggested such an effort on the agriculture/wildland interface would be of huge value for many sectors of society. Many questions that are controversial could be more definitively answered and, depending on the answers, laid to rest or addressed. Kay Briggs added that USGS currently has a better handle on public lands in the West and on the wildland-urban interface, principally because Department of Interior lands are located there and because of firefighting concerns. But more information will be available in the future: USGS is talking about moving toward a national Light Detecting and Ranging (LIDAR) database and making satellite imagery available to the public at no charge via the Internet.

Research Proposals

The agriculture participants regrouped in the second breakout session to see if they could develop more research proposals based on the research topics summarized above. Subgroups of three or so participants developed the research questions below, and began to flesh out strategies for how each question could be answered.

Study of the Effects of Agricultural Practices on Wildlife and Habitats

Using the U.K. Farm Scale Evaluation as a model, this research question, summarized by Emma Rosi-Marshall (Loyola University, Chicago), could be addressed through a large-scale working farm experiment, situating study sites in areas where wildlife and habitats of concern overlap with agriculture, looking at current agricultural practices, as well as those anticipated in the next decade.

The group proposed two regions to study soy and corn farming: The Platte River Valley because it is already designated as a USGS Priority Ecosystem Science Study Area and is a hotspot for migratory birds, and, as a contrast, upstate New York because of its different scale of agricultural land use, as well as different pests, wildlife, and habitats. The group also suggested Arizona and Georgia to compare organic, conventional, and transgenic cotton production, again because of the two states' different wildlife, habitats, and agricultural practices.

Data collection, the group suggested, could take place within fields, on the margins, and in adjacent wildlands, and could measure biodiversity, species of concern and their habitats (such as migrating wildlife and endangered species), and water quality.

The group's envisioned outcome is data to help determine the effects of agricultural practices, including GE crops, on wildlife and habitats. It was suggested that support for the activity might be sought from the USDA Biotechnology Risk Assessment Grants (BRAG) program (see Chapter 1), which supports research beyond predicting worst-case scenarios. Although a specific study size was not discussed, Rosi-Marshall said the group envisioned a study on a larger scale than that in the United Kingdom, which had 60 sites.

Study of Consequences of GE Practices at the Landscape and Regional Scales

Speaking for his breakout group, Norman Ellstrand (University of California, Riverside) described the objectives of the study as trying to elucidate putative risks and benefits of GE crops to guide future policy decisions. The project would integrate spatial data about cropping practices with data from previous monitoring studies on species distribution and abundance, environmental quality, and socioeconomic and demographic patterns. The project would record and measure changes in the distribution of transgenics (and transgenes) over time, and be used to predict future distribution of transgenes and their effects.

The proposed approach would be to add a new information layer to current maps. The new layer would plot transgenic events and alternative practices at the county scale or finer, using GIS analysis for past distribution effects. Spatial modeling would be used to predict future distribution.

Study of the Effects of Agricultural Practices (Including GE Corps) on Pollinator Abundance and Function, Including the Role of Pollinators in Gene Flow from Crops

Diane Larson (USGS) summarized her group's proposal to estimate the number and diversity of bees and other pollinators on different habitat types in the agricultural landscape, to measure the seed set of selected native outcrossing species of plants, and to characterize landscape loads of pollen, including GE pollen. Because the study would focus on agricultural practices, which is broader than the use of GE crops, the study would be able to document the impact of GE pollen relative to other practices.

The group suggested the many different types of stakeholders would first need to be engaged on a study steering committee. Stakeholders would include farmers, beekeepers, members of the Xerces Society, scientists, and others. A pilot study could develop methods and mapping resources, later scaling up to a long-term study that would include restoration if problems were identified.

It was suggested that recent concern about the abundance and distribution of pollinators might mean that there is public interest in providing resources to study them. Other groups may have interest in combining resources, perhaps through establishment of a pollinator database similar to that which exists for birds.

Exploration of Surrogate Species for Lab-Testing of Possible Effects of GEOs on Non-Target Wildlife

The objectives of this proposal would be to develop lab-based (tier) tests for select wildlife species associated with GEOs, including lab-rearing methodology, and to determine how well Tier 1 tests predict outcomes of higher-tier tests. Hellmich, speaking on behalf of the subgroup, recommended consultations with experts in USGS, the Fish and Wildlife Service, and other agencies to identify candidate species that would potentially be exposed to GE crops and trees, and consultations with regulatory scientists to develop tests that ideally could be harmonized for international use. He noted that regulatory approval of some testing materials might be necessary.

The group could not identify specific surrogate species, although it was suggested that insects would probably be the initial surrogates studied. He reiterated the opportunity for USGS to become involved with the

International Organization for Biological Control. There was also some discussion about the iterative progressive methods used in a tiered testing scheme (e.g., Tiers 1-4 used by EPA) and whether GEOs adhere to the paradigm of when and how to test at each level.

Baseline Studies of Insects and Microbes

Guy Knudsen (University of Idaho) reported on the discussion of his group, which felt that a 5- to 10-year time frame was too short to develop a specific research agenda about the effects of GE insects and microbes on wildlife and habitat. While there are GE insects and microbial applications in the pipeline, few, if any will likely be in use in the next five to ten years except in small-scale trials.

Over a slightly longer time frame, however, there will be many different kinds of GEOs released, including engineered sterile insects, paratransgenic insects (insects containing GE microbes), and engineered biocontrol fungi and bacteria. Potential ecological effects include possible gene flow into native populations, nontarget activity of antibiosis (growth inhibition) or pathogenicity, the alteration of rhizosphere communities, and the alteration of species composition in wild plant communities. Rather than specific proposals to look at effects, this subgroup emphasized understanding insect and microbial ecology, and the need to look beyond food chains and food webs to symbioses and biogeochemical relations.

Therefore, the shorter-term research agenda might be to collect baseline information and to survey and characterize the associations of plants and animals with insects and microbes (such as mutualists, commensals, and parasites) in the context of a wildland biotic community. That information could lead to the development of models that could be used to examine a range of "what if" scenarios involving the release or escapes of GE microbes or insects.

Because the issue of containment (or lack thereof) will be an issue with introduced organisms, the group felt it might be worthwhile to develop and refine technology for rapid detection and tracking of specific arthropods and microbial genotypes in the environment. Because arthropods and microbes are so fundamental to ecosystem processes, a change in the microbial flora may have the surprising potential to affect wildlife more than other, better-researched species. Participants urged the USGS and other research agencies to keep this in mind, even if the diversity of organisms, in addition to the time frame, made it difficult to develop research proposals at this workshop.

SILVICULTURE/WILD FOREST INTERFACE

A third breakout group examined the interface between managed forest plantations where GE trees may be grown and surrounding wild forest habitats. The results of the group's two breakout sessions to first identify topics and then research proposals, are reported here.

Research Topics

As reported by David Harry (Oregon State University), the group's thoughts crystallized around three priority research areas: 1) gene flow; 2) general experimental approaches using exemplars; and 3) development of new technologies for genetic manipulation.

Gene Flow

Because current environmental concerns and regulations prevent gene flow from being studied in the field, the group felt that simulations and alternatives using GEO proxies, such as natural mutants, are needed. The effect of factors, such as flowering, phenology, and pollen viability on gene flow rate and distance, need to be better understood. Eventually, if GE trees are to be released, there is likely to be some gene flow, because containment is never complete. Therefore, the group would like to see agreement on an acceptable threshold of gene flow, which might be established by research with proxies, at least in terms of risk quantification.

One participant observed that there are different opinions about whether it is possible to draw generalizations about the risk of categories or types of genes. He suggested that some research on gene-by-environment-by-organism (G x E x O) effects shows that hybrids that result from a cross of a transgenic and non-transgenic species have improved fitness characteristics, suggesting that containment must be maintained. However, he added, much can be learned by setting up pre-flowering systems, perhaps with some additional redundant systems built in.

Another participant noted that when the question was posed to a scientific advisory panel a few years ago about an acceptable level of gene flow, the response was that even a tiny level of gene flow just shifts the time frame of the effects: thus, the acceptable level, according to this panel, was zero. The Catch-22, summarized Harry, is that because we do not know what the fitness effects are, there can be no release—but without field study, the fitness effects will not be known. An acceptable level of gene flow perhaps could be on the order of a mutation rate, proposed a participant, because that kind of gene flow would be the same as a mutation occurring within the population.

Start with Simple Approaches

The group noted that case-by-case research is important, but if that cannot always be achieved, then moving forward will require using exemplar species and traits. Despite limitations created by containment requirements, some kinds of field experiments can take place, particularly with trees before they reach the flowering stage (recognizing that with trees, as opposed to smaller plants, this stage could last many years). The effects of modified lignin or other commercially important phytochemicals, Harry suggested, are researchable even today. A matrix to design or plan field studies could help lay out questions and risks.

Gene flow is the major concern related to field trials of GE trees because that represents a biological (and self-replicating) escape. Studies to determine the fitness benefits and nontarget effects of transgenes could be conducted in creative ways in contained, semi-wild environments if the will and vision were present, keeping in mind regulations governing this type of research on public lands.

Some participants suggested that gene flow might not be the only way a transgenic tree could affect the environment, and asked what kinds of studies could help us to understand the ecological interactions between GE trees and wildlife moving through the area. Members of the working group admitted that trees in field trials might have an impact on the broader community of herbivores, microbes, animals, and other organisms moving through the area, but posited that this is less of a concern than gene flow. They noted that GE trees would most likely be used in plantations, not in wildlands (with a few exceptions, such as the reforestation of native American chestnut trees), which assume different types of forest management. The appropriate baseline for studying the impact of a stand of transgenic trees on transient wildlife would be a comparison of GE versus non-GE plantation-managed trees, rather than comparison with a natural forest. That kind of study could rely on existing data about effects of conventional plantation forestry on wildlife and ecosystem services.

Biotechnology

The effects of genetic background in forest trees on GE expression and the resulting phenotype is much less understood than in agricultural crops. The group saw a need for better technology for inserting genes precisely and for alternative breeding approaches for moving genetic constructs into different genetic backgrounds.

Research Proposals

The forestry group identified two research proposals to study the priority areas they identified, as reported by Richard Lindroth (University of Wisconsin).

Creation of a National Infrastructure for Collaborative Research to Address Key GE issues, Using Exemplar Species and Traits

The forestry subgroup identified an overriding need for "big science" to study the effects of GE trees on a large and long-term scale. The important questions to answer, the group felt, are beyond the realm of individual investigators. Rather, they need to be addressed through multiscale, multilevel, long-term studies that will require significant scientific, social, regulatory and political commitments. National Ecological Observatory Network NEON (see Box 2-3) is as an example of the large-scale effort needed to study the effect of GE trees on wildlife and habitats.

Taking off from NEON, this group proposed a "GEON" (GE Observatory Network) to conduct studies on three focal areas: the production and yield characteristics of GE trees, their impacts on biodiversity, and their impacts on ecosystem function. The overall goal of the proposal is to develop baseline information on the consequences (both positive and negative) of GE forestry for wildlife, forest ecosystems, and commerce.

The first exemplar traits to examine would be *Bt* insertion and lignin modification, and possibly others such as phytoremediation. The experimental design proposed by the group would encompass single tree plots to understand growth, fitness, and competition, as well as growth/yield block plots to understand community and ecosystem effects. The plots should include nontransgenics and transgenics both with and without the trait of interest.

Some caveats to a GEON are that some issues cannot be addressed adequately at this scale and that appropriate controls would be complex and variable. A GEON would also require significant funding, although no specific amount was estimated in this exercise.

Development of a Model to Assess Gene Flow

The group's second proposal would lead to better understanding of the effects of gene flow from GE trees on wildlife and habitat. The group proposed development of spatially explicit landscape models linked to the results of exemplar studies. Perhaps with the assistance of USGS mapping expertise, the research could answer questions about where genes will move and what impacts may occur.

A model could be refined using new genotyping platforms for parameter estimation (such as non-GE trees), and "innocuous" GE markers for tracking. The model, once developed, could also be used to determine appropriate levels of containment for specific genes and environments, as well as the importance of rare long distance movements, such as severe storms or animal transport.

The question was raised about this group's suggestion to compare GE trees both with and without the trait of interest (null transformant). Although this has been done in crops, these comparisons have not been done with GE poplar and pine. Another important comparison would be the difference in GE effects on managed versus unmanaged areas. Understanding the impacts of the spread of transgenes into a wild area on the fitness of transgenic offspring is important for addressing the issue of ecosystem services.

AQUACULTURE/AQUATIC HABITAT INTERFACE

A significant challenge in studying the ecological effects of GE fish, in addition to the containment issue referred to earlier, is their diversity, said Tim King (USGS), as he introduced the priority research areas of the aquatic subgroup. Most fish are fusiform-shaped, he quipped, but that is about where the similarities end.

Research Topics

The group identified two "top-tier" research topics and two "top-tier" research approaches needed to help understand the effects of GE fish on the environment:

What Are the Gene X Environment Interactions of GE Fish?

Documenting the physiological characteristics of transgenic fish under many different aquatic environmental conditions would generate data on the range of possible outcomes that might occur if transgenics were released into the wild. Observing the variability of transgenes on fish behavior, growth, and survival, including the variability of antagonistic pleiotropic (opposing) effects, is essential for predicting critical fitness traits and ecological consequence traits, the group felt. This is more complex than it sounds because these interactions are very species- and situation-specific, and may even be strain-specific in some cases.

There was question as to whether a framework could be established to figure out which genetic traits and environments are the most important to assess. But King noted that the field is at the earliest stage of developing systematic protocols and methodologies, given the many species with highly variable genetic backgrounds and environments. The mere process of developing these systems would serve as a starting point to eventually determining what kinds of studies to do and also help regulators frame their questions in the future. It was suggested that a group with the right expertise get together to brainstorm a key set of traits on which to focus. This consensus could help identify what needs to be asked.

How Does Genetic Background Affect Trait Expression?

Related to the first research topic, the group felt that it is essential to understand better how subtle differences in the genome into which transgenes would be introduced would affect critical fitness and ecological consequence traits for fish and aquaculture targets. As Devlin's (Canada Department of Fish and Oceans) earlier presentation revealed, the effects of transgenes are very different when introduced into a wild-type fish versus a cultivated fish of the same species.

Research Approaches

Development of Models of Critical Fitness and Ecological Consequences

One approach to understanding and predicting fish-environment interactions is to develop models with real world conditions in mind. Thus, the breakout group felt that models need to be integrated with data collected on real ecosystems, fish demography, and information about the fish genetics as it relates to critical fitness traits and ecological consequence traits. This is something the group felt that USGS should contribute to and even excel at, given its Status & Trends of Biological Resources program and strong mapping capability.

Collecting Baseline Ecological Data

In addition to collecting data for models, the group felt that the synthesis of existing baseline ecological data on aquatic systems was an important activity for documenting the current conditions of a wide variety of existing aquatic environments. Gap analysis could be used to determine where the collection of new data is essential.

Important, but lower priorities for research efforts and approaches proposed by this group include the following:

- Trial applications of uncertainty (sensitivity) analysis methods.
- Research and development to improve and assess the effectiveness of bioconfinement methods.

- Use of transgenics to control invasive species.

Research Proposals

In its second breakout session, the group developed two broad research proposals that might be conducted using species that are of highest importance in the U.S. aquaculture industry: catfish, rainbow trout, tilapia, followed by Atlantic salmon and shrimp. Other species of concern include ornamental fish and transgenic biocontrol species.

Before describing its proposals the group first explained that in order to conduct the research, there would need to be large, confined mesocosm facilities that mimic the wild or natural environment. The development of those facilities is a tall order in itself, given the many variables that define the real environment. Indeed, one workshop participant asked how one would know if the mesocosm would adequately reflect a real environment. Another asked if there were a serious scientific threat to releasing experimental fish at very small scale semi-natural or natural environments. The fisheries group responded that if permission were even granted to use a part of an estuary to study salmon, for example, it would be so cordoned off that researchers would learn less than with good artificial facilities.

A third participant drew comparisons with trees that can be studied before flowering or with insects that can be sterilized, and asked whether fish could be made sterile and then studied for that one generation. Members of the fisheries group said that transgenic sterility is under development. Other sterilization techniques, such as triploidy (a sterile fish with three copies of chromosomes) exist, but there are effects of sterilization on growth and other characteristics that are essential to understand.

The fisheries group, said Jim Winton (USGS), is convinced of the need for large contained facilities, and has spent a lot of time discussing how to improve mesocosm facilities. It became clear, he said, that an important first step is to take an inventory of existing facilities, perhaps modify some of them, and set up a network so that scientists can work on a larger scale. Another important point of discussion was how to develop principles so that experiments help the risk assessment process, even if the experimental subject is not the exact species or environment that a regulatory agency has to deal with.

The two research proposals of the fisheries group are as follows:

Exploring the Environmental Impacts of GE Native Fish Species

The group proposed research to look at the effects of genes that influence growth enhancement, disease resistance, and sterility/reproductive reduction in native fish, such as catfish and rainbow trout. The research would explore four subjects:

- G × E interactions: The study would compare the impact of varying temperature, food, and pathogens on GE fish as compared to wild/native species.
- Genetic background effects: The study would compare various commercial-use stocks to understand the effect of different genetic backgrounds of recipient populations.
- Competition with natives: Using mesocosms developed to reflect the extremes of the G × E interactions, the study would examine how GE fish compete relative to natives.
- Gene flow to natives: Behavioral studies of reproduction would be conducted in the different mesocosms at the time of spawning.

Study of the Ecological Effects of Non-Native GE Fish

The second research proposal generated in this breakout session would be to determine how transgenic properties (growth, disease resistance, sex control, and others) influence the effects of non-native GE fish on the broader ecosystem. In particular, the studies would examine four variables:

- Competition with native species: The study would ask if the GE traits make a non-native fish more or less competitive with a community of native fish.
- Food web interactions: The research would look how a non-native GE fish would impact the naturally existing food web.
- Habitat use and environmental boundaries: The research would examine the range of a GE fish and its use of physical and biotic resources in the aquatic environment.
- Reproductive fitness: The research would explore whether the transgenic traits influence the ability of the non-native GE fish to become established.

Field studies that look at the same ecological effects of unmodified non-native fish and that parallel these four studies would inform future risk assessments and mesocosm studies.

This research might be conducted with the goal of understanding the implications of using transgenic technologies to develop biocontrol agents. The control of invasive species would involve the delivery of disruptive genes carried by the released transgenic biocontrol fish to the invasive species through breeding. It was noted that an international symposium on this topic currently is being organized.

4

Concluding Thoughts

Workshop organizing committee members Norman Ellstrand (University of California, Riverside), Bruce Tabashnik (University of Arizona), and Anne Kapuscinski (University of Minnesota) made closing remarks. Ellstrand reminded the group that many things have changed since Paul Berg organized the Asilomar Conference in 1975 to discuss the safety of the then still-nascent field of biotechnology. After the introduction of the first genetically engineered crop in 1994 (the "Flavr Savr" tomato), he said, polarization increased between, at the extremes, those who said biotechnology research should not be pursued and those who felt it should be pursued whole-heartedly. Ellstrand emphasized that genetically engineered crops are now here to stay, with many other products on the horizon; at the same time, scientific-based concerns about transgenes, and particularly their impacts, are recognized as important to examine.

Tabashnik showed snapshots he had taken during the course of the workshop and encouraged participants to foster their new acquaintances into friendships and research collaborations, a theme echoed by Kapuscinski. She emphasized the long-term benefits of the collegial and collaborative atmosphere of the workshop, as scientists from different fields worked together in the breakout groups to develop research proposals.

In the final discussion session, participants were asked to identify take-away messages in addition to the priority research areas and proposals to study the effects of GE crops, trees, microbes, insects, and fish on ecosystems. Thoughts from the final session, and other issues related to considerations for ecological research on GEOs raised earlier in the meeting, are summarized below. These do not represent the consensus of the group, but reflect the diversity of issues that arose during the workshop.

Scale Scale is an issue in looking at the environmental effects of GEOs, and for that reason, experiments and experimental protocols at a larger scale, from mesocosms up to landscapes, are likely to be needed, depending on the taxa and containment constraints. Many participants identified large-scale, organized collaborative projects that support different research objectives, including those on GEOs, as perhaps the only way to design and fund the scale of analysis needed. Studies on a large ecological scale can take advantage of emerging remote sensing technologies that improve traditional methods of observation.

Context The context in which GEOs are used or introduced has important implications for evaluating the relative impact of GEOs on the environment. The size and magnitude of the effects of GEOs may be determined by the system in which they are used, and that system (for example, row-crop agriculture) may itself have much larger impacts on the environment than the isolated effects of GEOs.

Comparisons, Contrasts, Baselines In evaluating the effects of GEOs on natural habitats and wildflife, selecting the appropriate comparator is critically important to the study design. It will be easier to detect subtle ecological effects if the contrast between comparative systems is sharp. The establishment of baseline states (e.g. before introduction of GEOs) can help to create the contrast needed to make appropriate evaluations of effects.

Sensitive Indicators Identifying indicator species or processes that are sensitive to specific environmental changes could assist in the detection of the effects of GEOs, especially secondary, indirect effects.

Models Models are a useful tool for studying processes that cannot be directly observed and the development of models is a research objective in and of itself. Models have limitations, of course, and need to be modified as experimental data becomes available. Nevertheless, models can identify where the most critical data needs exist, where effects are most likely to be observed, and the appropriate end points for studies looking for meaningful effects. Models can be used to envision scenarios such as the effects of multiple introductions on the ability of a species to establish, the circumstances that most enable gene flow, or the effects of small perturbations on sensitive populations and food webs.

Proxy Learning Given regulatory restrictions on field trials of GEOs, there may be little choice but to find non-transgenic surrogates to study ecological effects of GEOs. However, giving significant thought about which traits, species, and ecological sites to study will make a difference in utility and relevance of the research for evaluating GEOs. Organisms with neutral traits may be easier to release but whether the research will be applicable to a GEO may not be clear. Another way of learning by proxy is to use escapes and degregulated (approved) introductions of GEOs as a focal point for research. That research would be enabled by better mapping of the locations of releases of GEOs and the collection of baseline data before planned introductions. The latter two issues could be facilitated by federal agencies involved in regulating GEOs.

Large Facilities and Containment For some research, such as studies of aquatic organisms, the use of large, contained facilities that simulate natural habitats and ecosystems may be the best way to answer critical questions about the range of possible effects of GEOs. For all organisms, improving methods of biological containment is an area of research that could eventually enable field releases if there were sufficient confidence that containment (no reproduction or gene flow) is complete.

Genetic Background Because gene flow and ecological effects of GEOs are a function of the interactions of genes, organisms, and environment, there are significant research opportunities at each of these interfaces. A rich area for study across all taxa is the effect of different genetic backgrounds (for example, a wildtype or cultivated species) on the expression of phenotypes (traits) resulting from a transgene. Understanding the biological basis of differences in phenotypic expression is fundamental information that could reduce uncertainty about the likely behavior of GEOs in the environment.

Several workshop participants observed that the U.S. Geological Survey and other agencies can take advantage of the momentum of ongoing efforts, including those on an international level. Similarly, synergy can come from ongoing efforts in non-GEO research, such as in the areas of monitoring and mapping. For the experiments proposed that will require regulatory oversight and permits, it was suggested by one participant that researchers should work with regulatory agencies in the planning stages. On the other hand, other experiments based on GEOs that have already been approved and are in the environment, can begin outside of the regulatory arena.

Although the need for research on the effects of GEO organisms is long term with many issues still to be worked out, many participants agreed that the need for such research is urgent. As Ellstrand reminded the group, GEOs are here to stay. As occurred so successfully in this workshop, scientists with biotechnology expertise working with those who study wildlife and habitats can have a profound impact on answering questions about GEO effects that are critical to ecosystems in the United States and around the world.

Anne Kapuscinksi closed the meeting by saying that in the next five years, she hoped that new projects—be they field studies, mapping, or stronger networks of existing facilities—will have already begun, through allocation of new resources, better leveraging of existing resources, and cooperation on institutional and investigator levels. Ten or twenty years from now, many of the analyses suggested in the workshop may have been completed, so that society has a fuller understanding of the risks of genetically engineered organisms (GEOs). With that knowledge, she hopes actions can be pursued to mitigate against the real risks, steer away from traits that may cause problems, and pursue the use of GEOs in areas in which risk issues have been laid to rest.

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Appendix

Appendix A

Agenda

WORKSHOP ON GENETICALLY ENGINEERED ORGANISMS, WILDLIFE, AND HABITATS

Arnold and Mabel Beckman Center of the National Academies
Irvine, CA
November 5-6, 2007

Monday, November 5, 2007

Session I:	Introduction and Setting the Stage
8:00 a.m.	Welcome and Workshop Overview Anne Kapuscinski, Chair, Planning Committee
8:15	Biological Sciences at the U.S. Geological Survey Robert Szaro, USGS
8:30	GEOs and the USDA Biotechnology Risk Assessment Research Grants Program: What's Here, What's Coming? Chris Wozniak, USDA
8:45	Panel Discussion With Session I Speakers
Session II:	Current Research on Effects of GEOs on Terrestrial and Aquatic Wildlife and Habitats
9:10	Research on Effects of GE Crops on Terrestrial Wildlife and Their Natural Habitats LaReesa Wolfenbarger, University of Nebraska

9:30	Research on Effects of GE Trees on Wildlife and Their Natural Habitats, Chung-Jui Tsai, Michigan Tech University
9:50	Break
10:10	Research on Effects of GE Fish on Aquatic Wildlife and Their Natural Habitats Robert Devlin, Fisheries and Oceans Canada
10:30	Research on Effects of GE Microbes on Wildlife and Their Natural Habitats Michael Allen, University of California at Riverside
10:50	Research on Effects of GE Insects on Wildlife and Their Natural Habitats Thomas Miller, University of California at Riverside
11:10	Panel Discussion with Session II Speakers
11:30	Working Lunch
Session III:	Fundamental and Cross-cutting Research Issues for Assessing Ecological Effects of GEOs
12:30 p.m.	Research Approaches from Invasion Ecology Diane Larson, USGS
12:50	Working from the Gene and Organism Upward, Paul Gepts, University of California at Davis
1:10	Strategies for Detecting Ecological Effects of GEOs in Nature Michelle Marvier, Santa Clara University
1:30	Panel Discussion with Session III Speakers
2:00	Break
Session IV:	Breakout Session by Ecosystem Type
2:15	Review Charge to Participants: Identify Priority Areas for Research on Ecological Effects of GEOs

2:30	4 Breakout Groups (Refer to Breakout Instructions for Group Assignments) • Agriculture/Wildland (Terrestrial and Aquatic) Interface (2 Groups) • Silviculture/Wild Forest Interface • Aquaculture/Aquatic Habitat Interface
5:00	Adjourn for the Day

Tuesday, November 6, 2007

Session V:	Summary and Synthesis of Session IV from Breakout Groups
8:00 a.m.	Presentations from Each Session IV Breakout Group • 10 Minute Presentation and 5 Minute Discussion Per Group • As a Group, Identify a Combined List of 4 Priorities. These 4 Priorities Will Define the Breakout Groups for Session VI
9:30	Break
Session VI:	Breakout Session by Priority Area
10:00	Review Charge to Participants: • Identify Fundamental Information Needs and Prioritize Specific Research Directions and Questions • Identify Existing Research, Surveillance, and Monitoring Activities that Might Serve as Platform for Research on GEOs
10:15	Breakout Groups by Priority Area
12:30 p.m.	Working Lunch
Session VII:	Summary and Synthesis of Session VI from Breakout Groups
1:30	Presentations From Each Session VI Breakout Group • 10 Minute Presentation and 5 Minute Discussion Per Group

Session VIII: Plenary Discussion

2:30 Group Discussion

- What Were Common Themes Among the Various Breakout Groups?
- How Can USGS and Other Groups Build on Current Activities to Advance Our Knowledge of These Effects on Terrestrial and Aquatic Wildlife and Their Habitats?

3:30 Concluding Remarks
Norm Ellstrand, Bruce Tabashnik, and
Anne Kapuscinski

4:00 Adjourn

Appendix B

Participant Biosketches

Michael Allen is Chairman and Professor, Department of Plant Pathology at the University of California, Riverside. His research focuses on the biology and ecology of microbial-plant-soil interactions. Dr. Allen documents how natural succession occurs following disturbances of soil and studies ways to use spatial structure of plants to enhance recovery of soil organisms. He received an MS and PhD in botany from the University of Wyoming.

Meredith Bartron is the regional geneticist for U.S. Fish and Wildlife Service, at the Northeast Fishery Center Conservation Genetics Lab in Lamar, Pennsylvania. She received her PhD from Michigan State University and BSc from the University of Montana. The Conservation Genetics Lab is focused on the application of genetic principles and techniques to conservation and management issues. Focus areas of work include broodstock management, interaction between genetic population structure and habitat, and use of genetics for management of threatened or endangered species.

Kay Marano Briggs is the Coordinator for the USGS Biological Resources Discipline's Conservation Biology and Genetics work. Her background is in microbiology with an emphasis in sulfur oxidizers. She is responsible for ensuring that USGS conservation biology and genetics work is known to the public and available for their reference.

Steven M. Chambers is currently Senior Scientist in the Division of Ecological in Albuquerque, New Mexico. He holds BA and MA degrees in biology from the University of California, Riverside, and a PhD in Zoology from the University of Florida. His published research has been primarily in the area of the genetics of natural populations, including conservation genetics, and the use of genetic data in taxonomy.

Robert Devlin is a Research Scientist in the Aquaculture Division of the Canada Department of Fish and Oceans. He holds a PhD in zoology from the University of British Columbia. Dr. Devlin studies salmonid biology using molecular tools. He has developed transgenic salmonids with enhanced production traits, and his research explores the benefits and the risks associated with this technology.

Norman C. Ellstrand (Committee Member) is a Professor of Genetics in the Department of Botany and Plant Sciences at the University of California, Riverside, and Adjunct Professor at Keck Graduate Institute of Applied Life Sciences. He received his Ph.D. in Biology from the University of Texas, Austin, in 1978. His research now focuses on applied plant population genetics, with a current research emphasis on the nature and consequences of gene flow, including the escape of engineered genes. He has published a book on that topic, *Dangerous Liaisons? When Cultivated Plants Mate with Their Wild Relatives*.

Brian A. Federici is Distinguished Professor, Entomology, Genetics, and Microbiology in the Department of Entomology & Interdepartmental Graduate Programs in Genetics and Microbiology. His research focuses on the basic biology and development of insect pathogens that show promise for use as control agents in ecologically sound IPM programs aimed at managing major insect crop pests and vectors of human and animal diseases. Current research emphasizes studies of two types of insect pathogens, (1) *Bacillus thuringiensis* (*Bt*), a bacterium that kills insects via one or more insecticidal proteins, and (2) insect baculoviruses and ascoviruses, large double-stranded DNA viruses that attack many economically important insects. He holds BS and MS degrees in Biology and Medical Entomology from Rutgers University and a PhD in Insect Pathology from the University of Florida.

Ian Fleming is a Professor and Director of the Ocean Sciences Centre of Memorial University of Newfoundland. His research integrates perspectives from ecology and evolution with fishery and conservation biology, and his areas of expertise include fish behavioral and evolutionary ecology, reproduction, life history, and population biology. He has worked extensively on the management and conservation of wild fish populations, particularly salmon, and the ecological interactions with marine finfish aquaculture, including transgenic Atlantic salmon. He received his PhD in 1991.

Bob Frederick is a Senior Scientist in the Environmental Protection Agency's Office of Research and Development at the National Center for Environmental Assessment (NCEA). With the Agency since 1984, his responsibilities have included coordination of the Biotechnology Risk Assessment Research Program and the risk assessment of genetically modified products. He has served as an EPA representative to the National Institutes of Health Recombinant DNA Advisory Committee; a Federal Coordinating Biotechnology Research Subcommittee; the United States-European Community Task Force on Biotechnology Research; and as EPA coordinator of Office of Science and Technology Policy's crosscut on biotechnology research. He is currently a member of the Evaluation and Advisory Board for the USAID sponsored Program on Biosafety Systems administered through the International Food Policy Research Institute. From October 1993 to September 1996, he was Executive Secretary of the Biotechnology Advisory Commission (BAC) at the Stockholm Environment Institute, Stockholm, Sweden. While with BAC, he organized and taught in six international workshops on biosafety and biodiversity in Nigeria, Argentina, Zimbabwe, Kenya, and Sweden and has lectured and instructed on biosafety issues in more than twenty countries.

Paul Gepts received a PhD in plant breeding and plant genetics at the University of Wisconsin with Fred Bliss, pursued a postdoc with Michael Clegg at UC Riverside, and became a faculty member at UC Davis. His research has led to Phaseolus genetic and genomic tools, including a core molecular linkage map in common bean, a set of phylogenetically arrayed BAC libraries, a QTL mapping of domestication traits, and a detailed analysis of the phaseolin seed protein locus. His recent research has been devoted to describing the importance of gene flow in the common bean. Although the species is predominantly self-pollinated, molecular data provide evidence that existing levels of gene flow affect the distribution of genetic diversity between wild and domesticated populations as well as within the genome between domestication-linked and -unlinked regions. His findings have obvious implications for genetic containment or lack thereof.

Doug Gurian-Sherman is a senior scientist at the Union of Concerned Scientists. He was a senior scientist at the Center for Food Safety in Washington, DC, from 2004-2006, and before that, was founding co-director and science director for the biotechnology project at Center for Science in the Public Interest. He went to CSPI from the U.S. Environmental Protection Agency, where he was responsible for assessing human health and environmental risks from transgenic plants and microorganisms, and developing biotechnology policy. He obtained his BS degree from the University of Michigan School of Natural Resources and masters and doctorate degrees in Plant Pathology from the University of California at Berkeley before doing post-doctoral research on rice and wheat molecular biology with the U.S. Department of Agriculture. He served on FDA's advisory Food Biotechnology Subcommittee from its inception in 2002-2005.

David Harry has a background in applied breeding, evolutionary biology, and biotechnologyin plants and animals. Dr. Harry has worked in academia, public research labs, and in the private sector as a corporate scientist as well as a private consultant. He is currently at Oregon State University as Associate Director of the Outreach in Biotechnology program.

Richard Hellmich has been a Research Entomologist with the USDA–ARS, Corn Insects and Crop Genetics Research Laboratory in Ames, Iowa for 14 years. The mission of this lab is to develop sustainable ways to manage insect pests of corn. Dr. Hellmich's research focuses on European corn borer ecology and genetics, insect resistance management, and evaluation of non-target effects of transgenic maize.

Randy Johnson, National Program Leader, Genetics Research, USDA Forest Service R&D. Forest Service genetics research is conducted in eight research teams across the country. From 1994 until March 2007, Johnson was a research geneticist with the PNW Research Station in Corvallis, Oregon. Research included: breeding Douglas-fir for resistance to Swiss needle cast, genetics of wood quality, incorporating genetic gain into growth models, developing seed movement guidelines for restoration species (genecology), and computer modeling to increase breeding efficiency. Past jobs have included shrub breeding at the U.S. National Arboretum, director of the New Zealand Radiata Pine Breeding Cooperative, and doing epidemiology with NIDA and NIA.

Anne R. Kapuscinski (Committee Chair) is a Professor of Fisheries, Wildlife, and Conservation Biology; Founding Fellow of the Institute on the Environment, director of the Institute for Social, Economic, and Ecological Sustainability (ISEES); and a Sea Grant Extension Specialist in Aquaculture and Biotechnology at the University of Minnesota in St. Paul. She obtained her PhD in fisheries from Oregon State University in 1984. Dr. Kapuscinski's expertise is in aquaculture, fisheries genetics, and methodologies for assessing risks of introduced organisms; her current research focuses on the environmental risk assessment of transgenic fish. Dr. Kapuscinski was the 2001 Pew Fellow in Marine Conservation, and she received the U.S. Department of Agriculture Honor Award in 1997. She has served on three previous NRC committees: the Committee on Biological Confinement of Genetically Engineered Organisms; the Committee on Atlantic Salmon in Maine; and the Committee on Protection and Management of Pacific Northwest Anadromous Salmonids.

Peter Kareiva is Chief Scientist for The Nature Conservancy, where his research focuses on the modeling and mapping of ecosystem services, and exploration of future global trends that could impact conservation. He has conducted research regarding genetically engineered organisms for over 20 years, with studies that range from mathematical models of GMO spread, to field studies of gene flow, to field studies of invasiveness, and most recently meta-analyses of experiments concerning the impact of *Bt* crops on non-target organisms. Prior to his current job, Peter taught at several universities (University of Washington, Brown University, UCSB, Santa Clara University, University of Virginia, Swedish Agricultural University), and served as Director of the Conservation Biology Division at NOAA's Northwest Fisheries Science Center in Seattle.

Tim King is a fish biologist with the Biological Resources Division of the U.S. Geological Survey in Kearneysville, West Virginia. Dr. King studies the population genetics and diversity of numerous aquatic species, including Atlantic salmon, Sturgeon, Brook trout, Spotted salamander, and Horseshoe crab.

Guy R. Knudsen (Committee Member) is a Professor of Microbial Ecology & Plant Pathology in the Department of Plant, Soil, and Entomological Sciences at the University of Idaho in Moscow. He received his PhD in plant pathology from Cornell University in 1984. Dr. Knudsen's research focuses on microbial ecology and soil microbiology, including biological control of soilborne plant pathogens, microbial source tracking in wilderness and forest watersheds, quantitative modeling of disease processes in plant and insect populations, and bacterial gene transfer in soil and the rhizosphere. He has been a member of several previous national committees on biotechnology risk assessment, including the USDA-ARS Biotechnology Risk Assessment Review Panel and the U.S. EPA-OTS Biotechnology Risk Assessment Working Group.

Diane Larson is a Research Biologist with the Biological Resources Discipline of the US Geological Survey, located at the Northern Prairie Wildlife

Research Center, Minnesota Field Station. She has been studying invasive plants in mixed-grass prairies of the northern Great Plains since 1996. Her research focuses on ecological effects of invasive plants and evaluation of control methods, including the role of restoration in prevention of infestation. Her current work involves the role of plant-soil feedback in restoration of invaded prairies.

Deborah Letourneau is Professor of Environmental Studies at UC Santa Cruz. Her laboratory is interested in insect-plant interactions and the potential for insect-resistant traits to increase the invasiveness of *Bt* crops. Dr. Letourneau received an MS in biology from the University of Michigan and a PhD in entomology from the University of California, Berkeley.

Richard L. Lindroth is a professor of ecology in the Department of Entomology at the University of Wisconsin-Madison. He received his PhD in ecology from the University of Illinois-Urbana. His research group investigates the chemical mediation of ecological interactions, ranging from plant biochemistry to community dynamics to ecosystem function. A major focus of their work is how genetics, environment, and G x E interactions shape the chemical composition of plants and implications thereof for ecological processes. Related research addresses the impacts of global environmental change (elevated CO_2, ozone) on ecological interactions.

Michelle A. Marvier (Committee Member) is an Associate Professor in the Department of Biology and the Executive Director of the Environmental Studies Institute at Santa Clara University in California. She obtained her PhD in biology from the University of California, Santa Cruz, in 1996. Dr. Marvier's research is focused on ecological risk assessment applied to genetically engineered crops and the conservation of biological diversity. Her research has spanned a broad range of ecological topics, including salmon conservation and biological invasions. She is currently an Associate Editor for *Frontiers in Ecology and the Environment*.

Thomas Miller holds a BS in physics and a PhD in entomology, both from UC Riverside. He joined the faculty of UC Riverside in 1968 where he pioneered the application of neurophysiology to insecticide mode of action studies. He subsequently contributed to the discovery of the modes of action of cyclodiene and pyrethroid insecticides, and went on to improve the measurement of resistance in cotton pest insects in the field. After improving the detection of diapause in pink bollworm, he developed a transgenic pink bollworm to improve the sterile insect technique for this pest and for this was awarded the Gregor Mendel Gold Medal award for Research in the Biological Sciences from the Czech Academy of Sciences in 2003. Dr. Miller began applying the strategy of paratransgenesis (the transformation of symbiotic microbes in insects) to control Pierce's disease of grape in 1999 and conducted field studies on the behavior of symbiotic control endophytes in commercial vineyards in California in 2003-2005. He is currently leading an effort to develop biotechnology tools for control of desert locust in cooperation with the Ministry of Agriculture in Morocco. He has been a Plenary Lecturer on these transgenic insect topics at International Congresses and Society meetings around the world. .

Sara Oyler-McCance is the co-director of the Rocky Mountain Center for Conservation Genetics and Systematics which is a collaborative lab among USGS, the University of Denver, the Denver Botanic Gardens, the Denver Zoo, and the Denver Museum of Nature and Science. Her research focuses on the molecular genetic analyses of individuals, populations, and species, addressing questions of taxonomy, demography, mating systems, gene flow, genetic diversity, and molecular evolution. Sara uses expertise in molecular biology and ecology to assist federal and state management agencies with specific conservation or management issues. She received her PhD in Fish, Wildlife, and Conservation Biology from Colorado State University and has worked for USGS for nine years.

Susan Park is a program officer with the Ocean Studies Board of The National Academies. She earned her PhD in oceanography from the University of Delaware and her BA and MA in biology from the University of Pennsylvania. Prior to joining the Ocean Studies Board, Susan spent time working on aquatic invasive species management with the Massachusetts Office of Coastal Zone Management and the Northeast Aquatic Nuisance Species Panel. In addition to her work with the Ocean Studies Board, she is currently assisting the Board on Agriculture and Natural Resources.

Les Pearson is Director of Regulatory Affairs for the tree genetics company Arborgen. Headquartered in Summerville, South Carolina, Arborgen is a global leader in the research, development and commercialization of applications and solutions in tree genetics, including varietal forestry, that improve wood growth and quality for the forest products industry.

Alison G. Power (Committee Member) is a Professor of Ecology and Evolutionary Biology at Cornell University in Ithaca, New York. She also has a joint appointment in the Department of Science and Technology Studies, and is currently the Dean of the Graduate School. Her research focuses on biodiversity conservation in managed ecosystems, interactions between agricultural and natural ecosystems, agroecology, the ecology and evolution of plant pathogens, invasive species, and tropical ecology.

She obtained her PhD in Zoology from the University of Washington in 1985. Dr. Power serves as President-Elect of the Ecological Society of America for 2007. She has served on three previous NRC committees: the Committee on California Agricultural Research Priorities: Pierce's Disease; the U.S. National Committee on Scientific Committee on Problems of the Environment (SCOPE); and the Committee on Agricultural Sustainability and the Environment in the Humid Tropics.

Emma Rosi-Marshall earned a PhD in Ecology from the Institute of Ecology, University of Georgia in 2002 and is currently an assistant professor at Loyola University, Chicago. She is a stream ecosystem ecologist and her research focuses on carbon cycling and food webs. Her work spans a number of issues and ecosystems, but primarily deals with the effects of human activity on stream ecosystem function. She has conducted research on evaluating stream restoration, measuring input rates of crop byproducts to agricultural streams, and works on the effects of the Glen Canyon dam on the endangered humpback chub in Arizona.

Robin Schoen is the Director of the Board on Agriculture and Natural Resources (BANR) of the National Academies. Prior to joining BANR, she was Senior Program Officer for the Academies' Board on Life Sciences (BLS), where she directed studies on topics such as stem cells, plant genomics, and invasive plants. Before joining BLS in 1999, she worked in various capacities in the Academies' Office of International Affairs, the National Research Council Executive Office, and the former Commission on Life Sciences. Her work during that time focused on involving U.S. scientists in efforts to strengthen biology internationally. She holds an MS in science policy from George Washington University.

Eric Silberhorn is a biologist and member of the Environmental Safety Team in the Office of New Animal Drug Evaluation. He prepares guidance for industry and reviews environmental impact documentation needed for the approval of new animal drugs, including biotechnology products. Prior to joining the FDA, Dr. Silberhorn was a consultant for over 15 years to pharmaceutical, pesticide, and specialty chemical companies on aquatic toxicology and ecological risk assessment issues. Dr. Silberhorn earned his doctoral degree in toxicology from the University of Kentucky, and a BS and MPH from the University of Michigan.

Greg Simmons works as a supervisory entomologist for the United States Department of Agriculture, Animal Plant Health Inspection Service, Plant Protection and Quarantine, Center for Plant Health Science and Technology Laboratory (USDA-APHIS-PPQ-CPHST) in Phoenix, Arizona. He is a lead entomologist on a team of scientists working on the development of biological methods of pest control using beneficial insects, sterile insect release, and genetic control technology with genetically engineered insects. He currently works on pink bollworm to support the eradication and suppression programs but has also worked on biological control and sterile insect release technique for other program pests such as glassy-winged sharpshooter, screwworm, and silverleaf whitefly. Greg Simmons has a BSc from the University of Washington in botany, an MS in ecology and evolutionary biology, and a PhD in entomology from the University of Arizona.

Rebecca Stankiewicz Gabel is a Sr. Biotechnologist with Biotechnology Regulatory Services (BRS) of the United States Department of Agriculture's Animal and Plant Health Inspection Service. She is working with the Animals Branch in BRS to examine the need for regulating genetically engineered animals. She also provides guidance and support for NEPA issues within BRS. Rebecca holds a PhD in Genetics from the University of Connecticut.

Wendylee Stott is currently a research investigator under contract with the University of Michigan and the Great Lakes Science Center, USGS. She did undergraduate and graduate work in molecular biology at the University of Guelph and finished her graduate work with a PhD from McMaster University where she studied genetic variation among lake trout from the Great Lakes. Before coming to the Great Lakes Science Center in 2000, she worked for the Ontario Ministry of Natural Resources where she held several positions, including research technician, assessment biologist, and information specialist. Her current research program involves the use of genetic technology to develop economical, efficient, reliable procedures to evaluate species and stock identity. The information is used to manage wild populations and hatchery supplementation programs, devise informative indicators for exploited fisheries, and determine stock identity of fish involved in harvest disputes.

Steven H. Strauss (Committee Member) is a professor in the Forest Science, Molecular and Cellular Biology, and Genetics Programs at Oregon State University. He directs a university-industry research cooperative that aims to advance knowledge of plant molecular physiology, adaptation, and genomics with the goal of providing new options for tree biotechnology. He is also director of the University program Outreach in Resource Biotechnology, which seeks to promote public and professional understanding of the potential benefits and risks associated with natural resource biotechnologies. He holds a PhD in genetics from the University of California at Berkeley, an MFS in Forest Science from Yale University, and a BS in biology from Cornell University. Dr. Strauss's research interests are genomics, biotechnology, and biosafety issues related to the use of genetically engineered forest trees, and his current research focuses on modifying the architecture, chemistry, and flowering of poplars for wood, bioproduct, and energy uses. He is a Stanford Institute for the Environment Leopold Fellow (2005). Dr. Strauss has served on two additional NRC Committees. He has edited two books and published more than 150 scientific and professional publications.

Robert C. Szaro is currently Chief Scientist for Biology for the US Geological Survey in Reston, Virginia. In this capacity he provides oversight for USGS's Biological Research and Monitoring (BRM) efforts of more than $140 million and 17 science centers which focus on issues such as adaptive management, biodiversity, global change, fire ecology, threatened and endangered species, monitoring, wildlife, fisheries, environmental contaminants, genetics, ecological systems, wildlife diseases, and invasive species. From July 2000 to July 2004 he served as Deputy Station Director for the USDA Forest Service's Pacific Northwest Research Station in Portland, Oregon. Previously, he served as Coordinator for the Special Programme for Developing Countries of the International Union of Forestry Research Organizations (IUFRO-SPDC) and the Agricultural Attaché (Forestry) for the U.S. Embassy in Vienna, Austria (August 1996 to June 2000). From 1989 to 1996, he served in several capacities in the Forest Service's National Headquarters in Washington, D.C. He was Research Ecologist with the USDA Forest Service in Tempe, Arizona (1978-1988) and Research Wildlife Biologist with the U.S. Department of the Interior Fish and Wildlife Service in Laurel, Maryland (1976-1978). He has authored more than 120 papers and edited three books on the conservation of biodiversity, sustainable resource management and the implementation of ecosystem management.

Bruce E. Tabashnik (Committee Member) is a Professor and Department Head of Entomology at the University of Arizona in Tucson. He received his PhD in Biological Sciences from Stanford University in 1981. Dr. Tabashnik studies the evolution and management of insect resistance to insecticides and transgenic plants. His current work focuses on the evolution of resistance to insecticidal proteins from the bacterium *Bacillus thuringiensis* (*Bt)*. As a faculty member at the University of Hawaii, he discovered field-evolved resistance to *Bt* in Diamondback moth. He is currently studying pink bollworm resistance to *Bt* cotton. His more than 200 scientific publications have been cited more than 5,000 times. He has received many awards for his professional service, most recently the Industry Appreciation Award from the Arizona Cotton Growers Association.

Paula Tarnapol Whitacre, the workshop rapporteur, has written and edited meeting reports for the National Institutes of Health, Resources for the Future, and the National Academies, among other organizations. She writes for Resources magazine and for several environmental education publications, and has edited National Research Council books and reports for almost 10 years. She is a former communications director for the Society of American Foresters and for GreenCOM, an environmental education and communication project funded by the U.S. Agency for International Development. Ms. Whitacre has BA and MA degrees in international relations from Johns Hopkins University.

Chung-Jui Tsai is a Professor of forest genomics and biotechnology at the School of Forest Resources and Environmental Science, Michigan Technological University. She was Director of the Biotechnology Research Center at Michigan Tech from 2002 to 2007. Her research areas include wood formation, lignin biosynthesis, secondary metabolism and metabolic engineering. She has been involved in genetic engineering and risk assessment research of lignin-modified poplar trees.

John Wenburg has been the Director of the Conservation Genetics Laboratory, U.S. Fish & Wildlife Service (FWS), Alaska Region since 2001. He holds a PhD from the University of Washington in Seattle, and an undergraduate degree in Biology and Philosophy from Lewis and Clark College in Portland, Oregon. Dr. Wenburg is currently a member of the FWS National Science Committee and has been working in fisheries conservation genetics since the early 1990s.

Jim Winton is Chief of the Fish Health Section at the Western Fisheries Research Center in Seattle where he heads a team of scientists, technicians, post-doctoral researchers, graduate students, and visiting scientists working to improve methods for the detection of fish pathogens, determine factors affecting the epidemiology of fish diseases, and develop novel control strategies for reducing losses among both hatchery-reared and wild fish. Jim is also an Affiliate Professor in the School of Aquatic and Fishery Sciences at the University of Washington where he serves on departmental or graduate student committees and teaches the occasional lecture. He has served as: President of the Fish Health Section of the American Fisheries Society, member of the Editorial Boards of the *Journal of Aquatic Animal Health, Diseases of Aquatic Organisms*, *Journal of Fish Diseases*, and *Journal of Applied Ichthyology*, and member of the International Committee on Taxonomy of Viruses, the

American Type Culture Collection, the USDA Aquaculture Technical and Scientific Committee, and the Fish Disease Commission of the World Organization for Animal Health. Significant awards include the Department of Interior Meritorious Service Award (1999), American Fisheries Society Fish Health Section S. F. Snieszko Distinguished Service Award (2000) and the Department of Interior Distinguished Service Award (2006). He is an author of more than 150 scientific publications.

L. LaReesa Wolfenbarger (**Committee Member)** is an Associate Professor in the Department of Biology at the University of Nebraska at Omaha. Dr. Wolfenbarger received her PhD from Cornell University in 1996. Her current research focus is on the ecological effects of transgenic crops and agricultural practices, and on land management for grassland bird conservation. She also has significant experience with the science policy and outreach aspects of transgenic crops. Prior to her appointment at the University of Nebraska, Dr. Wolfenbarger worked with the U.S. Environmental Protection Agency on synthesizing science related to agricultural biotechnology for regulators and policymakers.

Chris Wozniak is a Biotechnology Special Assistant at the U.S. Environmental Protection Agency (EPA). Previously, he was a National Program Leader in the USDA Cooperative State Research, Education, and Extension Service, and before that, a biologist with the EPA, specializing in the regulation and registration of microbial biopesticides, such as fungal pathogens of insects, and plant-incorporated protectants (PIPs), such as maize and cotton engineered for insect resistance. Before joining the EPA in 1997 he worked for the USDA's Agricultural Research Service, conducting research on plant transformation techniques and biological control mechanisms for insects in sugarbeet. After receiving Bachelor's and Master's degrees in biology from Drake University, Wozniak completed his PhD at the University of Nebraska-Lincoln, focusing his research on cell differentiation and protein synthesis in plants.