Report on Workshop on Possible Ecological and Evolutionary Impacts of Bioengineered Organisms Released into the Environment
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growth and yield result. In the case of oilseed rape, the yield "penalty" for using the herbicide-resistant genotype is ≈10–20%. Does this penalty mean that the resistant genotype is less valuable agronomically than its susceptible parental genotype? This question poses a decidedly ecological problem.

Oilseed rape normally is sown so that ≈150 seedlings/m^2 become established. If, for example, an equal number of wild oat (*Avena fatua*) plants establish simultaneously, then yields of herbicide-susceptible rape cultivars are reduced by ≈50%. This yield reduction is far greater than the 10–20% penalty suffered by the farmer who planted herbicide-resistant oilseed rape and also used the appropriate herbicide. However, the important question is, at what intermediate level of weed infestation does the economic reduction caused by weed interference to a susceptible crop match the combined costs of herbicide application and yield penalty of the resistant crop? Only plant competition experiments, the kinds habitually conducted by plant population ecologists, can answer this question satisfactorily. Until such experiments are performed, large amounts of money and chemicals may be wasted. As more and more crop species are engineered for herbicide resistance, the more important an understanding of the clearly ecological herbicide/weed/crop relationship becomes.

Although the examples of research projects described in the preceding paragraphs reflect my own narrow research interests, biases, and limitations, I hope these examples will give some indication of the intent, scope, and possibilities of ecological biotechnology. I also hope that I have helped to make readers of this *Bulletin* aware that the potential accomplishments of ecologists in biotechnology are too many, too great, and too necessary to be calculable. Of course, we cannot and should not abandon our more traditional ecological research. It is the patterns and processes found in such research, both in the past and in the future, that provide much of the theoretical framework from which we make ecological decisions. Yet I believe that we are now obliged to take a leading role in a new activity, and thereby, govern its direction in the future. Accordingly, a good deal of our time and energy must be spent in development of new skills and in consideration of new and exciting problems. Lastly, in an era of apparent pessimism, I wish to impart to my ecological colleagues how refreshing it is to see a new branch of science that is intellectually creative, highly applicable, and through which we can look forward to the future with gusto.

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REPORT ON WORKSHOP ON POSSIBLE ECOLOGICAL AND EVOLUTIONARY IMPACTS OF BIOENGINEERED ORGANISMS RELEASED INTO THE ENVIRONMENT

On 28–31 August 1984, seven ecologists and evolutionary biologists from academic institutions participated in an important workshop on the possible risks associated with release of biologically engineered organisms into the environment. The workshop was sponsored by the United States Environmental Protection Agency (EPA) and the Council for Research Planning. Other participants included academic geneticists, scientists from the biotechnology industry, and representatives of Federal regulatory and granting agencies (EPA, OTA, FDA, USDA, USDHHS, NIH, and NSF). The following position paper, adopted unanimously by the ecologists and evolutionary biologists attending the workshop, expresses their concern about possible ecological and evolutionary hazards associated with deliberate or accidental release of genetically engineered organisms and recommends initial steps be taken to assess and minimize these risks.

Of particular interest to ESA members is the fact that the EPA is currently developing procedures for assessing risk and regulating release of genetically engineered organisms. The EPA proposal, which is expected to be completed soon, should appear in the Federal Register and be mailed to many ecologists. Concerned members should watch for this document and make whatever responses they feel appropriate.

The text of the position paper is as follows:

Recent advances in biotechnology offer the potential for producing new varieties of organisms that can have enormous benefits for health, agriculture, and environmental management. On the other hand, there are serious concerns about the possible effects of deliberate or accidental release of genetically engineered organisms into the environment. Such release poses potential adverse consequences for natural and human-modified (*e.g.*, agricultural and urban) ecosystems for the following reasons:

(1) Genetic engineering techniques raise the possibility of creating new varieties of microbes, plants, and animals that may be qualitatively or quantitatively different from the vast majority of variants that are found in nature or that can be produced by conventional biotechnology (*e.g.*, artificial selection).

(2) The results of introductions of exotic species and historical changes in the roles of native species show that natural communities are not saturated, and there are many ways in which new genotypes can become incorporated into the trophic web. The continual evolution of species in communities has not led to perfection or saturation.

(3) Products of biotechnology pose problems different from those of nonliving substances that are released into the environment because genetic material has the capacity to replicate and organisms can increase in numbers and spread into new areas.

(4) It is possible that traits of genetically engineered organisms that have been developed to produce beneficial effects may be transmitted infectiously by plasmids, viruses, or other means to other organisms in which they may have adverse effects.

(5) Since the goal of many applied genetic engineering programs is to produce organisms of novel structure and function, these organisms can be expected to play different ecological roles than their progenitors and relatives. Commercial and academic research programs presently are attempting to develop new varieties that use new substrates for growth and development, modify microenvironments, extend the limits of tolerance of physical conditions, and confer resistance to predators and pathogens.

(6) Engineered organisms can have potentially deleterious environmental impacts by affecting the outcomes of direct interactions among species (including the natural and managed regulation of pests by predators and pathogens), by altering the indirect relationships among species, by influencing the geochemical processes that support all ecosystems, and by changing the rate and direction of the evolutionary responses of species to each other and to their physical and chemical environments.

Because of these considerations, the introduction of novel genotypes produced by genetic engineering requires careful investigation of possible adverse consequences. Both unintended genetic and unanticipated ecological effects are of concern. Quantitative experimental procedures will be needed to evaluate specific concerns in each case. The possible unintended consequences of most concern will depend on the particular kind of organism in question, and the specific characteristics of its intended release. Although the natural environment is so complex that it will not be possible to predict all the adverse effects of this (or any other) technology, ecologists and evolutionary biologists possess sufficient expertise to design and to execute these assessment procedures. Although these will not assure zero risk, they should substantially reduce the likelihood of unanticipated impacts that would be costly or impossible to mitigate.

In order to deal responsibly with the wide spectrum of possible ecological and evolutionary consequences of anticipated biologically engineered organisms, the following constitute a minimum program. Steps to implement these activities should be initiated immediately and pursued vigorously.

While it is our conviction that risk assessment must be on a case by case basis, the following potential adverse effects should always be considered:

1) Genetic
   i) Rate and nature of horizontal (infectious) genetic transmission.
   ii) Stability of the engineered genetic change(s) (role of movable genetic elements).
2) Evolutionary
   i) Likelihood and nature of host range shifts.
   ii) Likelihood of unregulated propagation.
   iii) Likelihood of changes in virulence (parasites and pathogens).
3) Ecological
   i) Effects on competitors.
   ii) Effects on prey/hosts/symbionts.
   iii) Effects on predators/parasites/pathogens.
   iv) Role of introduced organism as vector of pathogens.
   v) Effects on ecosystem processes (biogeochemical effects).
   vi) Effects on habitat.

In addition to the need for a priori assessments of the risks associated with the release of genetically engineered organisms, there should also be an effort to so modify these organisms that the potential hazards are minimized. This can be accomplished in one of two ways. (a) When possible, to "disarm" the novel organisms ecologically, so that they will not be likely to spread beyond the range where they are intended to be effective. (b) By the incorporation of characters that will facilitate recall (leases), *e.g.,* sensitivity to broad classes of antibiotics and phage for bacteria.

The program of release should be followed by a continuous process of monitoring for changes in the released organisms and the community.

Although risk assessment can be instituted now with present personnel in ecology and molecular biology using available knowledge in these disciplines, there is a need for further basic research and for a larger body of experts in certain areas.

(1) Although there is a sound foundation for assessing the potential adverse consequences of release, there is need for an increased level of basic research into the nature of interactions among coexisting species and the rules by which groups of species are knit together into functioning communities.

(2) Ecologists and evolutionary biologists with expertise on the taxon proposed for release and on the types of target communities must be involved in the study. They also can advise genetic engineers on the design of new genotypes in ways that can facilitate the study, and can help to reduce the probability of adverse effects. Thus, there is a general need for increased graduate training in evolution and ecology.

(3) There is a particular need for enhanced training programs in certain ecological and evolutionary areas, such as microbial and soil ecology, to increase the corps of specialists who can participate in these studies.

(4) More basic research is needed on the transfer of genetic information between species by infective and other nonreproductive means in higher organisms.

(5) More research is also needed on the role of movable genetic elements in evolution and adaptation, and the possible induction of genomic reorganization and evolutionary volatility.

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