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ECOLOGICAL RESEARCH AT EPA: NEW DIRECTIONS

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Because the Environmental Protection Agency is charged with protecting the environment from man-made stresses such as pollutants and habitat loss and modification, it develops, implements, and enforces regulatory programs intended to limit the use, release, and disposal of contaminants in the environment. The effectiveness of these programs depends on basic information about the sources, fate, and effects of environmental pollutants. The critical role research plays in identifying environmental problems, estimating the kinds and degrees of risk posed by those problems, and predicting the consequences of pollution control choices impels EPA to support a vigorous research program to identify and characterize environmental problems. This program is planned and administered by the Office of Research and Development (ORD).

An article has described the activities of ORD's Office of Health Research (*1*). This present article describes the development of strategies for ecological research within ORD. The laboratories of the Office of Modeling, Monitoring Systems, and Quality Assurance and the Office of Environmental Processes and Effects Research (OEPER) conduct most of this research.

The responsibility for environmental research at EPA was purposely delegated to an office that is independent of regulatory mandates, to ensure scientific objectivity and an integrated perspective on the nature and sources of environmental stress. ORD's autonomy enables it to take the integrative approach to environmental research as defined in President Nixon's speech to Congress on Reorganization Plan No. 4, July 9, 1970: "The EPA would have the capacity to do research on important pollutants irrespective of the media in which they appear, and on the impact of these pollutants on the total environment." In recent years, ORD's environmental research has focused on cross-media pollutant effects, diffuse sources of pollution (e.g., nonpoint sources, acid deposition), and issues of global concern (e.g., stratospheric ozone depletion, climate change). Now, in response to the growing need to set realistic priorities for environmental risk reduction efforts, EPA is redesigning its ecological research strategy to address fundamental questions relevant to directing environmental policy, such as:

- What is the current extent and status of ecological resources in the United States (i.e., estuaries, wetlands, forests, arid ecosystems, surface waters, agricultural ecosystems)?
- What resources are degrading or improving, where, and at what rate?
- To what levels of stress or pollution are resources exposed, and where is the exposure greatest?
- What are the probable causes for degrading or improving conditions?
- Are affected resources responding to control and regulatory programs?

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The need for change

Traditionally, EPA's focus has been site specific—the individual point source, a single landfill, a geographically defined stream section. Research has focused on the effects of certain chemicals on a few or even a single species tested under laboratory conditions, usually assuming that the effects of one chemical are independent of effects of others. Research priorities have been determined largely by regulatory mandate and public perception of environmental problems rather than by a scientific understanding of the relative risks to environmental and human health. This approach has improved the regulation and reduction of specific environmental pollutants, particularly those from large, centralized sources (*2*). Individual pollutants and species, however, are not isolated in the environment, nor are adverse effects necessarily confined to the immediate location of discharge. Recognizing the limitations of the regulation-driven approach to ecological risk assessment, EPA, in conjunction with its Science Advisory Board (SAB), has developed a new research strategy that will help the Agency determine priorities for research and regulation objectively, on the basis of a better understanding of the magnitude and extent of environmental problems.

The SAB's recommendations

In a report entitled *Future Risk: Research Strategies for the 1990s*, the SAB made a series of recommendations to reshape EPA's strategy for addressing environmental problems in the next decade and beyond (*3*). Foremost is the recommendation that to support its regulatory role most effectively, EPA must fully develop its functions as a science agency, a technology transfer agency, and an education agency. The SAB also recommended that the Agency emphasize early recognition of emerging environmental problems and pollution prevention, stating that a "strategic shift in emphasis from control and cleanup to anticipation and prevention is absolutely essential to our future physical, environmental, and economic health." In a companion report, *Reducing Risk: Setting Priorities and Strategies for Environmental Protection*, the SAB emphasized that the Agency's long-range strategic planning should be driven by continuing assessments of the relative risks posed by each of the environmental problems that affect the nation and by an analysis of opportunities available for reducing ecological and human health risk (*4*).

RARE RESOURCES, SUCH AS THE REDWOOD FOREST OF THE U.S. WEST COAST, WILL BE INTENSIVELY MONITORED UNDER EMAP.

EPA's research strategy can no longer be determined solely by immediate regulatory needs. It must focus on providing an integrated picture of cumulative risk to the environment that includes estimates of the severity of risk to particular ecological resources to ensure the most appropriate distribution of efforts and finances for environmental protection.

Research strategy for the 1990s

The Ecological Risk Assessment Program. Following the SAB's recommendations, ORD developed an ecological research strategy for the 1990s using the risk assessment framework, known as the Ecological Risk Assessment Program. Risk assessment is the *scientific component* of the process of formulating policy and regulations for controlling pollutant releases and other environmental stressors. The goal of an environmental policy based on risk assessment is to maximize risk reduction where the opportunities are the greatest. Risk assessment predicts and quantifies probabilities and uncertainties of specific events (*4*) such as the decline of biotic diversity in a stream or dieback in a mountain forest. It also estimates the potential for adverse effects from various kinds of stress, based on behavior, fate, and effects research.

EPA's new ecological research strategy focuses on determining the condition of environmental resources at the ecosystem level. The Agency's standard approach to risk assessment relies predominantly on single-species toxicity tests and media-specific exposure models (*5*); however, understanding the impact of cumulative environmental stress on whole biotic communities and populations of different species will be necessary to assess and quantify ecological risk on a regional, ecosystem scale. Assessment endpoints are being expanded to consider sublethal effects, including behavioral, developmental, and reproductive changes that may have long-term effects on ecosystem structure and function.

The intended result of this approach is to provide the scientific foundation for environmental policies that ensure the sustainability of the nation's ecological resources. This foundation will be developed by synthesizing information on which risks are most widespread and serious and which have the best potential for cost-effective reduc-

tion. Traditional environmental impact assessments have resulted in deterministic statements of localized hazard that do not constitute a quantification of the risk to a community and cannot be extrapolated to larger geographic scales (*6, 7*). This new "top-down" approach to environmental research will enable decision makers to evaluate more efficiently the overall benefits and trade-offs associated with alternative regulatory and control strategies. This should enable the formulation and implementation of the most effective environmental management programs that can be focused on the highest priority environmental risks.

ORD's new ecological research program is also a multiagency, cooperative effort. ORD has arranged interagency agreements and memoranda of understanding with several federal resource management agencies, including the National Oceanic and Atmospheric Administration and the U.S. Departments of Agriculture and the Interior, to share data and monitor jointly for the most efficient use of federal resources. Joint monitoring efforts already are under way with these agencies, and interactions are planned with others as well.

EPA's new ecological research strategy (*5*) is organized around six elements:

- environmental monitoring and assessment (hazard identification),
- ecological exposure assessment,
- ecological effects (dose–response relationships),
- ecological risk characterization,
- ecosystem restoration and management, and
- risk communication.

The elements of the Environmental Risk Assessment Program are similar to those of traditional risk assessment (*8, 9*); however, the emphasis is on applying risk assessment to a higher level of biological organization. Currently, the knowledge and technology to evaluate pollutant exposure, transport, transformation, ultimate location, and effects at ecosystem and regional levels are not well developed. The initial goal of the program, therefore, will be to develop methods and predictive models for assessing ecosystem-level ecological responses, for extrapolating to the regional scale, and for developing reliable estimates of uncertainty in such risk characterizations. Much of the basic information required to develop such methods and models will be provided by the first element of the strategy, the Environmental Monitoring and Assessment Program.

The Environmental Monitoring and Assessment Program (EMAP). Currently, most environmental monitoring is compliance monitoring that is limited to local environments; it focuses on identifying polluting activities and pollutant concentrations that can be linked unequivocally to sources. Because such monitoring provides minimal information about the effects of pollution and environmental stress on the *entire* ecosystem, it is impossible to determine the condition of the integrated system or whether regulations and pollution control strategies are broadly effective for sustaining the condition of the ecosystem. The traditional narrow focus on specific pollutants and acute environmental effects has resulted in neglect of growing systemic problems such as stratospheric ozone depletion, accelerated eutrophication, and wetlands loss. EMAP is designed to identify the regions and ecosystems most affected by increasing environmental stress, to determine priorities for environmental regulation and pollution control, and to evaluate the cumulative effectiveness of environmental regulations for sustaining ecological resources.

Objective. As the foundation of the Ecological Risk Assessment Program (*4*), EMAP will develop and implement techniques to monitor the status and trends in the condition of representative ecosystems that are at risk from multiple environmental stressors. EMAP will involve long-term regional and national monitoring of forests, arid ecosystems, agricultural ecosystems, the Great Lakes, surface waters, and near-coastal ecosystems. The data collected for EMAP will illustrate any serious changes occurring in these resource categories and identify associations between such changes and the predominant stressors that affect them.

Process. EMAP scientists will determine the extent of each major ecological resource type (landscape characterization) and identify and evaluate biological, chemical, and physical indicators for each resource category that best illustrate current and changing ecological responses to environmental stress (*10*). Each resource category will be sampled randomly, in proportion to its abundance, to estimate the distributions of the values of the chosen indicators with known confidence. An unbiased, standardized monitoring design will enable statistical comparisons to be made between the indicator values within resource categories and will provide quantitative estimates of confidence in the measured values. These comparisons will identify associations between biological response and exposure to particular stressors and illustrate trends in biological response.

EMAP will develop and use biological response indicators to assess environmental quality (*11, 12*). Biological response indicators must be quantifiable, applicable across a range of habitats and geographic distances, clearly related to ecological condition, and must represent a societal value. In addition to response indicators, EMAP will measure exposure indicators to identify possible reasons for poor condition and to identify relationships between changes in response indicators and changing stresses on the ecosystem over time. Habitat indicators will be measured to account for natural variations in biological response indicators. The definitions of these types of indicators and the relationships among them are summarized in Figure 1.

Scientists working on EMAP will develop conceptual models of the relationships within and between ecosystems and between indicators and ecosystem status. Currently, basic biological and physical processes that affect both pollutant fate and effects in ecosystems are not well understood. Developing models to predict how pollutants and other stresses affect ecological responses at different scales, ultimately ranging from the individual ecosystem to landscape and regional scales, will require major advances in knowledge about how ecosystems respond to integrated effects of interacting physical, chemical, and biological stressors.

Products. Annual summaries of ecological status and trends information will be produced for each region being monitored. In addition, EMAP will produce periodic interpretive reports that synthesize status and trends data to determine whether ecological conditions have improved or deteriorated in particular regions and to identify associations between observed changes in condition and stressors influencing ecological resources in the region. Together, these reports will help

EPA evaluate the cumulative effectiveness of its environmental regulations and pollution control strategies and will highlight issues requiring immediate attention. EMAP reports also will provide additional regional data for existing local monitoring programs.

Another important product of EMAP will be new environmental monitoring technology. Biological indicators developed for EMAP will be useful to state and local resource managers for developing environmental criteria and quality standards. The EMAP sampling design can be adapted for use on smaller spatial scales to address specific problems in greater detail. EMAP will test and perfect monitoring equipment and provide standard protocols for field and laboratory ecological sampling activities.

Initial directions. Initial EMAP research is concerned with developing biological indicators and designing an integrated statistical monitoring protocol for collecting indicator data. EMAP scientists also are evaluating statistical procedures for effective analysis of trends and are developing indices that combine multiple biological indicators.

Small-scale demonstration projects are being used to test the feasibility of the monitoring activities planned in each ecosystem, to provide representative data for use in developing analysis strategies, and to evaluate the usefulness of candidate indicators before full-scale regional or national implementation. EMAP demonstration projects were conducted in the estuaries of the Virginian biogeographic province and in forests of the Northeast during the summer of 1990. Additional demonstration and pilot projects were completed in 1991 in estuarine and wetland ecosystems of the Gulf of Mexico, in lakes in the Northeast, and in other resource categories.

Other elements of risk assessment

Existing risk assessment programs within EPA will contribute to ORD's new ecological research strategy at lower levels of biological complexity. Many existing programs are gradually expanding their scope to consider cumulative impacts of combinations of pollutants and other stressors and to consider nonlethal assessment endpoints. These programs may pursue more detailed research on major ecosystem and community-level problems identified by EMAP. Two examples of existing EPA risk assessment programs, EcoRisk and the biotechnology risk assessment research program, are described below.

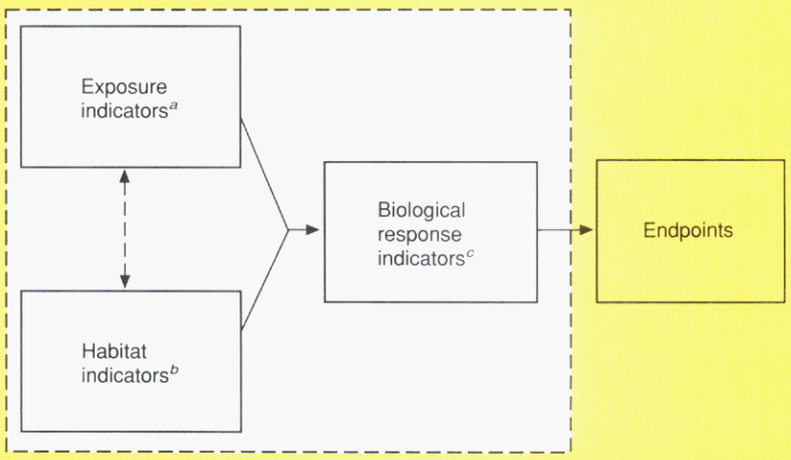
EcoRisk. The Ecological Risk Assessment Research Program (EcoRisk) was begun by OEPER in 1985, primarily to meet the needs of Office of Pesticides and Toxic Substances for predictive models, databases of chemical and biological properties, and software for assessing ecological risks from chemical pollutants. EcoRisk integrates the results of chemical exposure and hazard research to compare the risk associated with different uses of chemicals resulting from various options for regulating pesticides and toxics (*13*). EcoRisk research provides mathematical models that accommodate varying patterns and levels of environmental release of chemicals, makes inferences about types of responses to be expected in natural environments, and estimates the uncertainties in such risk assessments.

Some specific projects developed in EcoRisk include the following: a mathematical model to describe plant uptake and fate of xenobiotic chemicals; databases pertaining to uptake and toxicity of chemicals for plants; new population models for wildlife response to toxicants; methods to predict aquatic species' susceptibility to toxic effects of industrial chemicals and pesticides; techniques and models for relating single and multi-species laboratory tests to the natural environment and for evaluating community and ecosystem responses to toxicants; and improved technology for predicting ecosystem recovery from toxic chemicals. In keeping with the Agency's new strategy for ecological research, EcoRisk is attempting to broaden its assessment endpoints to include reproductive, developmental, and behavioral effects of toxicant exposure. The program also is beginning to address higher levels of biological integration and to expand its scope beyond single chemicals to complex mixtures and to a broader definition of environmental stressors.

Biotechnology risk assessment research. ORD's biotechnology risk assessment research program focuses on four aspects of risk related to genetically modified microorganisms that may have agricultural, industrial, or medical applications: detection and enumeration of such microorganisms introduced to the natural environment; distribution and stability of genetic material in the natural environment; environmental effects of genetically modified microorganisms; and human health effects of genetically modified microorganisms (*14*).

Biotechnology risk research encompasses exposure, effects, and control studies. Research on potential ecological effects of genetically modified microorganisms must first identify probable effects through standard laboratory tests. A broad spectrum of test systems ranging from single species to modeled eco-

FIGURE 1
EMAP indicator strategy



[a] Environmental characteristics that provide evidence of the occurrence or magnitude of exposure to physical, chemical, or biological stress (e.g., sediment contaminants).
[b] Physical attributes that characterize conditions necessary to support an organism, population, or community in the absence of pollutants (e.g., salinity and type of sediment).
[c] Environmental characteristics that provide quantitative evidence of the overall conditions of a resource such as aquatic life or biomass.

systems are being examined because many potential effects cannot be predicted from current scientific knowledge. Research in this area focuses on identifying potential direct effects and developing criteria to distinguish effects from normal environmental variation.

One objective of field research is to corroborate laboratory data through application of genetically modified microorganisms to experimental release sites. Methods have been developed for detecting such microorganisms and assessing their long-term effects during field studies. Distribution and dispersion characteristics are being mapped and compared with mathematical models. As different microorganisms are considered for field release, procedures for inoculation, sampling and equipment design, monitoring, and data interpretation are developed and evaluated. Information being produced by biotechnology risk assessment research may prove vital for early recognition of future ecological problems, as the development and use of genetically modified microorganisms increases in the United States.

Global climate change

In keeping with EPA's new emphasis on pollution prevention and basic ecological research, the Agency is participating in the U.S. Global Change Research Program, a multiagency program developed and administered by the Committee on Earth and Environmental Sciences of the Federal Coordinating Council for Science, Engineering, and Technology. Its goal is to improve understanding of the interacting physical, geological, chemical, biological, and social processes that regulate the global environment in order to establish the scientific basis for formulating national and international environmental policy (*15*).

EPA's role in the program is to quantify the relative contributions of anthropogenic and biological sources of important atmospheric trace gases, and to model the effects of climate change on the interaction of trace gases in the atmosphere. Special emphasis is being given to particularly climate-sensitive regions, such as tundra, high-latitude wetlands, and forests. This research will help provide the process-level understanding and modeling capabilities to predict global change and develop feasible mitigation and adaptation strategies.

The future of ecological research

The SAB recommended that EPA take a leading role in encouraging the education of future generations of environmental scientists and engineers to ensure the continuation of high quality, long-term, ecological research. The utility and progress of ecological research is predicated on the existence of a skilled research community. The development of such a community begins in the nation's academic environmental research institutions.

ORD's Office of Exploratory Research administers two programs designed specifically to expand the Agency's contact with academia and to support the training of new environmental scientists. The Competitive Grants Program provides investigator-initiated research grants for exploratory environmental research in health, biology, engineering, socioeconomics, and chemistry and physics related to air and water. This program has expanded recently; its annual grant budget increased from $8 million in the 1989 budget year to $23 million in the 1991 budget year. The budget for the Academic Research Centers Program, which funds university-based environmental research centers, is projected at about $5 million annually (*5*).

A new direction

Ecological research at EPA, particularly EMAP, represents a new direction in Agency environmental research. A distinct shift in emphasis to higher levels of biological organization (i.e., community, ecosystem, regional, and global levels) rather than species and population levels and to the effects of multiple stressors is occurring throughout ORD's research programs. This "top-down" risk assessment approach will facilitate determination of the relative risks associated with the many impacts on the nation's ecological resources. An ecosystem and regional-level understanding of relative environmental risk will provide the context for determining the most effective distribution of resources for more specific research at lower levels of biological organization and development of cost effective management strategies. ORD's ecological research will focus on providing the information needed to set rational priorities for environmental regulation based on a scientific understanding of the extent and severity of current and emerg-

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ing problems. The results of this approach should help to improve the effectiveness and timeliness of environmental policies and regulations for controlling environmental problems before they reach crisis proportions and for sustaining environmental resources.

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