1990's Global Change Action Plan

Utilizing a Network of Ecological Research Sites

A Proposal from Sites Conducting
Long-Term Ecological Research
Workshop held November 1989, Denver, CO

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Photograph Legends

Front cover, top to bottom: coastal salt marsh with cordgrass at high tide, North Inlet LTER, South Carolina coast; old-growth conifer forest of western red cedar, western hemlock, and Douglas-fir, H.J. Andrews LTER, Oregon; dry steppe/grassland with bunchgrasses, U.S. Department of Energy Arid Lands Research Park, Hanford, Washington; moist grassland with flowering lupine and phlox (blue) and balsamroot (yellow), eastern Washington state. **Back cover:** Arctic tundra, Toolik Lake, North Central Alaska.

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Participating Agencies & Organizations

Centro de Ecología, Cuidad Universitaría, México

Earth Science and Applications Division, National Aeronautics and Space Administration

Environmental Protection Agency

Forest Service, U.S. Department of Agriculture

Long-Term Ecological Research Network (LTER). *Seventeen sites representing the following ecosystems: forest (coniferous, taiga, wet tropical, hardwood, temperate deciduous-coniferous, deciduous), old-field/oak savannah, prairie (shortgrass, tallgrass), desert grassland, agricultural system, coastal marine, north temperate lakes, tundra (Arctic, alpine), shrub-steppe/grassland/desert transition*

National Environmental Research Parks, U.S. Department of Energy. *Four research sites representing the following ecosystems: arid grassland/shrub-steppe, wetland, forest (coniferous, deciduous)*

National Oceanic and Atmospheric Administration, U.S. Department of Commerce

National Park Service, U.S. Department of the Interior

National Science Foundation, Directorate of Biological, Behavioral and Social Sciences

New York Botanical Garden, Institute of Ecosystem Studies, Mary Flagler Cary Arboretum

Smithsonian Institution, Environmental Research Center

U.S. National Committee for Global Change Research

World Wildlife Fund

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Introduction

An existing network of long-term ecological research sites proposes an integrated program of research on Global Change. This proposed program focuses on some of the world's most pressing environmental issues.

What is unique about this research program is the focus on causes as well as effects of Global Change, specifically the *interactions* between terrestrial organisms, ecological processes and Global Change. That is, we recognize here that issues of Global Change cannot be treated fully without giving attention to the major controls and feedbacks which terrestrial ecosystems exert on Global Change, including the Earth's atmosphere.

Terrestrial ecological systems are important in Global Change research because, as is well known, changes in our global atmosphere can profoundly alter climate patterns and, hence, the productivity of ecosystems, the biodiversity of plant and animal species and human life itself. Both biological processes and human activities alter our ecosystems and our atmosphere.

Basic biological processes affect the atmosphere both by producing and consuming "greenhouse" gases. These processes include: **photosynthesis**, the process by which plants convert sunlight into biomass; **evapotranspiration**, the process by which plants release water vapor from the atmosphere; and **decomposition**, the process by which plants, animals, and soils break down organic matter, releasing gases.

Human-influenced changes have well-known effects on the atmosphere as well as on the health of ecosystems. For example, deforestation and other land-use changes can destroy or severely damage whole ecosystems, affecting global climate. The release of pesticides and toxic materials creates atmospheric pollution. Such human-influenced changes are the subject of current policy debates and human concerns.

In recognition of the critical importance of ecological research in understanding, predicting and ameliorating Global Change, an ad hoc group of scientists representing 25 major ecological research sites met in Denver, Colorado, in November 1989 to consider how a network of ecological sites might contribute to research on Global Change. Global Change was defined broadly to include these four components:

- changes in **global climate**
- changes in **biodiversity**
- changes in **land use**
- changes in **pollutants**

The 25 sites included 17 long-term ecological research (LTER) sites funded by the National Science Foundation, four National Environmental Research Parks (Department of Energy), and sites supported by the National Park Service (Sequoia-Kings Canyon National Park), the Smithsonian Institution (Smithsonian Environmental Research Center, Chesapeake Bay), the Institute of Ecosystem Studies (New York Botanic Garden/Cary Arboretum), and NOAA (The Great Lakes Research Lab). Other participants included representatives from the Environmental Protection Agency, NASA, the National Science Foundation, the World Wildlife Fund, and the Centro de Ecología, México.

During the workshop, the participants agreed upon four areas in which Global Change research is essential:

- **Major Experiments**
- **Modeling and Synthesis Projects**
- **Ecological Monitoring**
- **Development of Technologies**

Within these four broad areas, workshop scientists identified 12 high priority Action Items, which are critical to our understanding and the possible amelioration of Global Change. The human component of Global Change was clearly recognized as central to all.

These 12 Action Items are intended to suggest direction for ecological aspects of Global Change research and as focal points around which groups of scientists can organize their efforts. No single organization or group, including those represented at the workshop, has the expertise to carry forward all 12 Action Items.

Leadership from agencies and other institutions on the Action Items will vary reflecting the differing responsibilities and levels of expertise. There are clearly major roles for many agencies, some of which are obviously based upon interests and expertise, although specific roles have not been identified. By developing action-oriented networks, groups of scientists can work with agencies to bring the appropriate expertise together. In subsequent workshops and meetings, additional Action Items may be identified and proposed.

Similarly, while the workshop participants were primarily "ecosystem" scientists, the research plan proposed here requires the expertise of a wide range of scientists--from physical scientists (hydrologists, atmospheric scientists, geographers, modeling experts, GIS and remote sensing specialists, etc.) to biological scientists, including general ecologists, community ecologists, systematists, population biologists, physiological ecologists and ecosystem scientists.

The Action Plan

The proposed action program can be summarized in 12 Action Items along with a major program to train essential technical and scientific personnel (see "Education" section):

1. **Soil Warming Experiment** to determine effects of soil warming on biotic communities and on ecosystem processes, particularly soil carbon levels and trace gas emissions, over a broad range of ecosystems.

2. **Carbon Dioxide Enrichment Experiment** using enclosed ecosystems to determine the effects of heightened CO_2 levels on plant, animal and microbial biota and on ecosystem processes, including productivity and water-use efficiency.

3. **Mega-landscape Experiment** to develop the design for one or more major landscape-level experiments focused on key issues in conservation biology.

4. **Development of General Hydrologic Models** to provide a family of linked models which incorporate soil, surface, and ground waters and which are applicable to a full range of ecosystem types.

5. **Development of Regional Predictions of Weather Patterns with Global Change** to provide localized models of patterns of precipitation and of climate-driven disturbances, such as storms, and to link these regional models to global climate models.

6. **Analyses of Interactions Between Changing Land Use and Global Change** to evaluate probable effects of altered climatic regimes on patterns of land use and feedbacks into the atmosphere.

7. **Analyses of Altered Disturbance Regimes** to analyze effects of altered patterns of major disturbances, such as wildfire and severe windstorm, on the characteristics and distributions of ecosystems.

8. **Accelerate Research on Scaling of Ecological Phenomena** to develop and demonstrate various methodologies for extrapolating information across large ranges in temporal and spatial scales.

9. **Develop Ecological Monitoring at a Network of Research Sites** to provide baseline information on the biotic and abiotic environment and to document changes over time.

10. **Develop Use of Remote Sensing Imagery** for regional interpretations of ecological phenomena, such as changes in boundaries between different ecosystems due to climatic change.

11. **Develop and Deploy Mobile Ecological Laboratories and Rapid-Response Teams** to provide expanded field capabilities for ecological research, especially following catastrophic disturbances.

12. **Develop and Install Forest Canopy Access Systems** to provide extensive and dependable access to high forest canopies for study of ecosystem-atmosphere interactions and canopy biological diversity.

Benefits of the Network-Based Program

The proposed program utilizes a large existing network of sites committed to long-term research and offers unique opportunities and benefits in the implementation of the overall federal program for study of Global Change (Committee on Earth Sciences, 1990). The long-term ecological data generated by sites within this network is of critical importance in POLICY FORMULATION. Many ecological processes operate over long time periods, and short-term trends can be extremely deceptive. Further, because of the high degree of yearly variability in many ecological phenomena, it can be extremely difficult to identify long-term trends. Important long-term data sets exist at sites in this network which can be used to develop policy as well as to identify research needs and set funding priorities.

The proposed program identifies critical SCIENTIFIC ISSUES which have previously received little or no detailed attention in deliberations over Global Change research. For example, ecologists and atmospheric scientists need to collaborate in the development of regional predictions of disturbance and precipitation regimes; alterations in these regimes will have profound effects on terrestrial ecosystems. Major "flagship" experiments are needed to address critical questions, such as understanding the interacting effects of CO_2 enrichment and soil warming on the biota and on ecosystem functions.

The proposed program builds on an ESTABLISHED NETWORK of research sites which represent major long-term data bases and established interdisciplinary teams of scientists, as well as academic training centers and in-place facilities, representing an exemplary series of North American ecosystems. These existing data bases and infrastructure make possible rapid synthesis of current knowledge and implementation of new projects.

The site network approach offers UNIQUE OPPORTUNITIES needed in Global Change research. Development of shared data bases is already underway and is facilitated by existing electronic linkages between computer systems at sites utilizing the national Internet. Comparative studies are essential to compare ecological responses across a wide range of ecosystem types, a major weakness of ecological science up to the present. A site network provides excellent comparative opportunities. The extensive scientific data bases at long-term research sites also provide outstanding opportunities for the development and testing of new technologies. Existing sites have the infrastructure and stability necessary for the establishment and conduct of major, long-term collaborative experiments.

The proposed program will begin creation of the SCIENTIFIC TECHNICAL CADRE that will be needed to carry forward not just the research and monitoring programs, but also to participate in management programs as society begins to respond to Global Change.

Hence, the proposed program allows efficient development of some critical ecological elements of the Global Change program by making use of an existing network of sites committed to long-term research. It will not only contribute to completion of immediate, high-priority scientific tasks but will also create a LEGACY of trained scientists, long-term data bases and experiments that will be critically needed by future generations.

PROPOSED RESEARCH PLAN
and
12 ACTION ITEMS

LARGE "FLAGSHIP" EXPERIMENTS

1: Soil Warming Experiment

Establish a multi-site study to provide critical data on how soil warming affects soil biological processes (particularly greenhouse gas emissions) and interactions among communities of plants and animals.

One prediction of global climate change is an increase in temperature. Many ecological processes and relationships in soils and among plants and animals can be affected directly and indirectly by increased temperature. These effects could be studied in a multi-site experiment using relatively simple manipulations of soil temperature and soil water (irrigation).

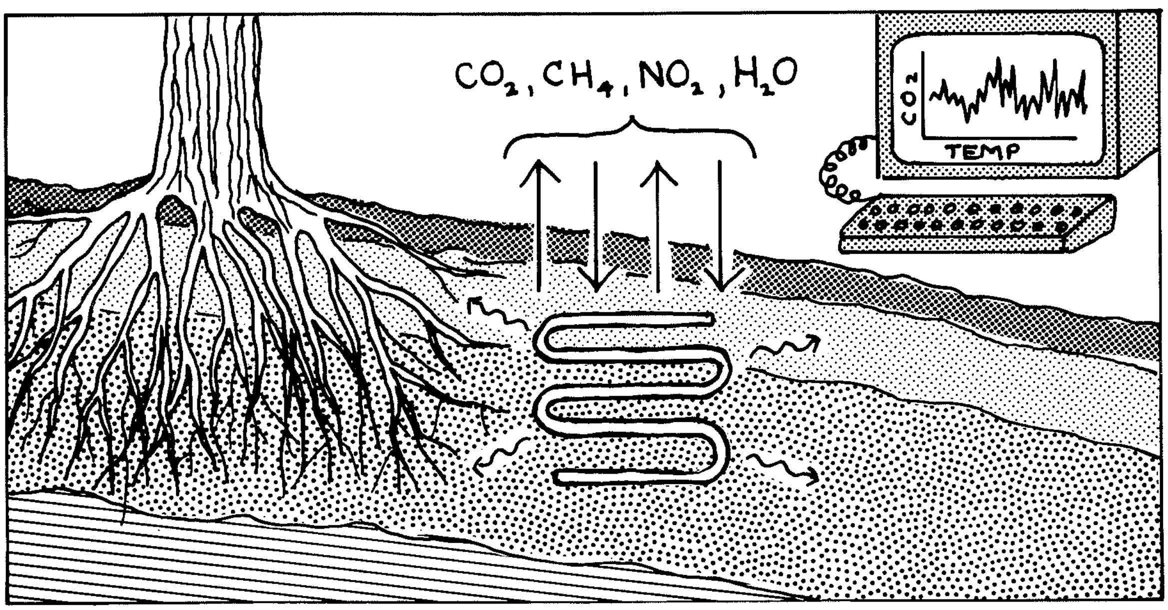
One major objective would be to quantify effects of elevated soil temperatures on storage of carbon and fluxes of greenhouse gases, including carbon dioxide. The relationship between temperature and soil carbon pools is poorly understood, but is particularly important because large carbon pools are associated with soil organic matter and detritus. Altered carbon dynamics may also alter nutrient supplies which, in turn, may have major effects on plant growth.

A second objective would be to determine the ecological effects of increased soil temperatures (and altered moisture) on changes in plant and animal communities, including community shifts of animals and plants. For example, increasing temperatures may affect cold-blooded animals by increasing their activities, perhaps speeding up their life cycles.

In its simplest form, this experiment would extend over a decade and include all major continental and estuarine ecosystem types. A more complex form of this experiment could be developed to study interactions of temperature and moisture along two gradients--a gradient in temperature and a gradient in moisture. The temperature gradient could extend from cold-dominated tundra sites in Alaska to the warm, moist tropical rainforests.

Along another gradient, as one crosses the mid-section of America from northern Minnesota and Wisconsin to the deserts of the Southwest, water stress is important.

These temperature and water treatments will affect many ecosystem processes, as well as community-level effects on organisms themselves. Data would be collected on changes in plant, animal and microbial communities. Net primary production, carbon storage, evapotranspiration and water balance, trace gas fluxes over soils, nutrient input/output balances would be measured. Using models of biological function, hydrology, and soil chemistry, results of these experiments would be synthesized and extrapolated to larger scales. Models will need to be sufficiently simple to be driven within a geographic information system (GIS) context using data bases likely to be available from existing sources or through remote sensing. It would be necessary to coordinate this activity with agencies responsible for current and experimental remote sensing instruments (e.g. NOAA, NASA), and with agencies responsible for basic soils, climatic, and topographic data set construction (e.g. USGS, USDA, and NOAA).



- **Experimentally alter soil temperature and moisture**
- **Multi-site experiment along continental gradients in North America**
- **Measure greenhouse gas fluxes, carbon storage, and soil biological processes**
- **Study interactions and community shifts of plants and animals**

2: Carbon Dioxide Enrichment Experiment

Create enclosed ecosystems with artificially elevated (even doubled) atmospheric carbon dioxide levels, and provide definitive data on responses of organisms and ecological processes to increased carbon dioxide.

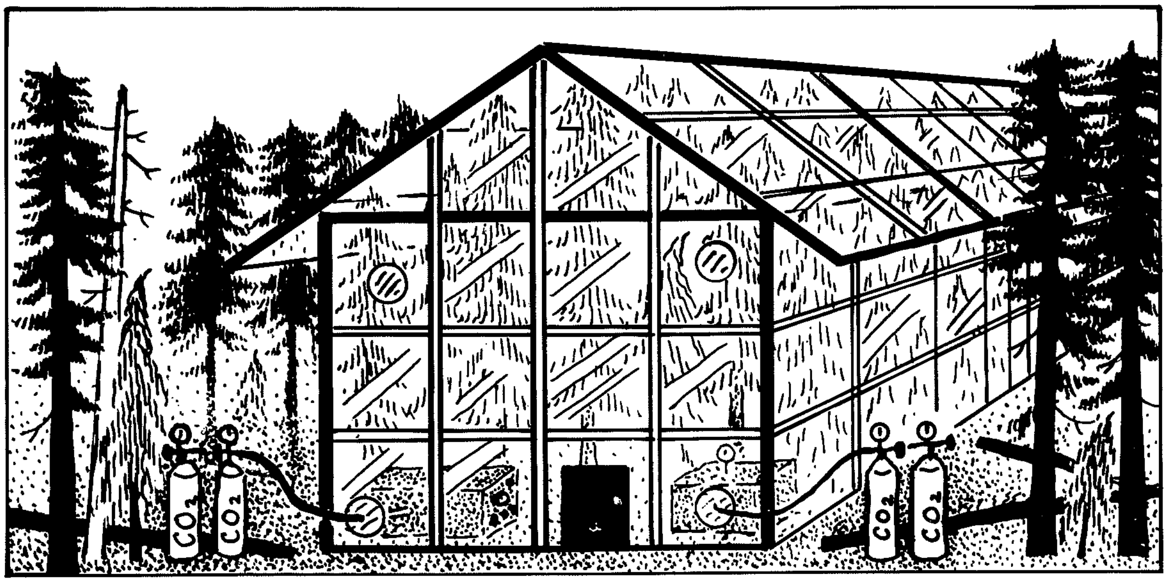
While many aspects of the changing global climate are controversial, everyone agrees that atmospheric carbon dioxide (CO_2) concentrations are increasing--and faster than at any time in the past century. Not only do CO_2 changes affect heating of the earth (the "greenhouse effect"), but they also affect interactions of plants and animals, including humans--all organisms which release CO_2 and consume CO_2 (plant photosynthesis). Despite all of this, there are no large-scale experiments to study the effects of this change on human beings and the Earth's ecosystems.

We propose construction and operation for at least 10 years of a set of large-scale "greenhouses" in several representative ecosystems. Atmospheric levels of CO_2 would be increased above current atmospheric levels in order to study the effects of an enriched CO_2 atmosphere on plants, animals and microbes. These structures would be designed to minimize other environmental effects, such as water balance, especially in large stature (forest) ecosystems. Installations would be limited to a few sites by the expense of establishment and operation. Eight installations are recommended to allow the collection and comparison of data across critical types of ecosystems--grassland, agricultural, desert, wetland, coniferous forest, hardwood forest, boreal forest and tundra. Details of greenhouse design (e.g., open-topped vs. closed greenhouses) and experimental design would be determined in a series of workshops.

Measurements to determine the ecological effects of increased CO_2 on short-term and long-term responses by plants, animals, and microorganisms, would emphasize carbon balance (production, storage and release). At the process level, both primary productivity and water-use efficiency are of concern. Increased carbon availability can alter decomposition rates, nutrient availability, below-ground microbial species composition, production of plant defense compounds, allocation of carbon and nutrients above- and below-ground, trace gas fluxes, primary productivity, and water-use efficiency.

Experiments would also consider community-level responses; multiple stresses resulting from CO_2 enrichment will have different effects on the biota, causing changes in populations and community structure. For example, balances between annual and perennial plants might be altered, changing the biodiversity of ecosystems.

Development of models of CO_2 effects would be the focal point of the research program, since models can help design the experiment, organize the resulting data and predict future effects. A major goal in modeling is to produce the most reliable predictions possible. Aggregation of carbon budgets would require linking models at small scales to models at larger landscape scales and, further, to regional and then global-scale models. Success would depend on integration of both field and remotely-sensed observations, using advanced geographic information systems (GIS).



- **Large, enclosed greenhouses with increased atmospheric CO_2**
- **Major experiment with complex facilities at eight sites**
- **Measure effects on organisms: biodiversity, competition**
- **Measure effects on processes: carbon flux and storage, productivity, and water-use efficiency**

3: Mega-Landscape Experiment

Design large-scale experiments for definitive tests of effects of landscape structure on ecological processes and biodiversity.

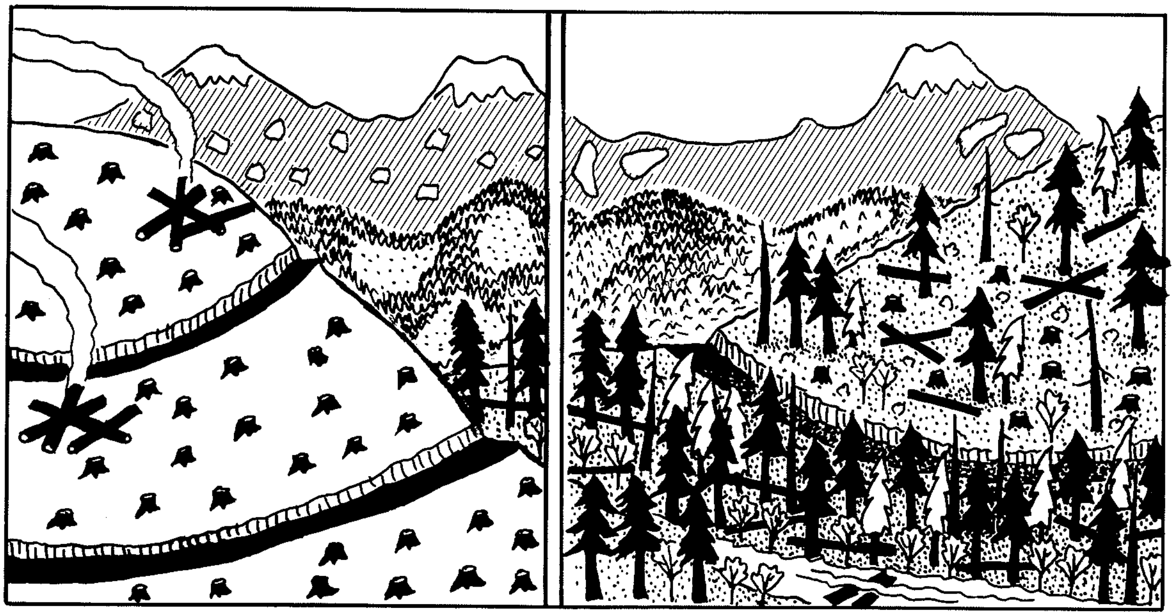
There are many critical questions concerning the effects of Global Change on landscapes and landscape-level processes, including effects on biological diversity (such as persistence and movement of organisms), disturbance regimes (see Action Item 7), and hydrologic regimes (such as minimum and peak flows). Key issues include the following:

- size and arrangement of patches, connectivity and other measures of the ease with which organisms can move through a landscape (e.g., role of corridors);
- cumulative effects of management activities on various processes (e.g., flood flows and sediment yields), and;
- interactions between landscape patterns and the propagation of disturbances, such as wildfire, insect epidemic, and windstorm.

These are extremely difficult issues to study scientifically, particularly on an experimental basis. One of the few examples is the critical-size-of-ecosystems project implemented in the tropical forest of Brazil's Amazon River basin. In this project, isolated forest patches of varying size were created to study effects of patch size on overall biodiversity and population and community dynamics of animals and plants.

An effort to identify the major Global Change-related, landscape-level scientific questions and to develop experimental designs to address these questions is proposed. This would be a multi-disciplinary effort. Ecological scientists would, of necessity, include systematists and population biologists, as well as those with ecosystem and landscape-level orientation. Strong participation by applied scientists associated with management agencies and basic scientists involved in conservation biology would be needed. The study design would include a comparison of the relative importance of corridors and an altered landscape matrix in movement of organisms. The design would also evaluate the respective roles of large and small reserved areas. Large reserved areas are usually separate from managed lands, while smaller reserved areas usually are maintained as a part of the managed land mosaic.

Subsequently, multi-site, multi-agency implementation of the experimental designs is proposed. For example, in the western coniferous forests, a mega-landscape experiment might include the effects of different patch sizes (both for cut-over and reserved areas) and effects of corridors and partial cutting practices on overall biological diversity. In a coastal area, experiments might address issues such as the effects of agriculture and other human uses on a patchwork of reserved areas.



- Large-scale, landscape-level experiments
- Multidisciplinary efforts are essential
- Cooperative project with land management agencies
- Patch size and landscape connectivity are key issues
- Landscape manipulations and biodiversity responses

MODELING and SYNTHESIS PROJECTS

4: Development of General Hydrologic Models

Develop regional hydrologic models which incorporate soil, surface and ground water components and which are suitable for a variety of ecosystems.

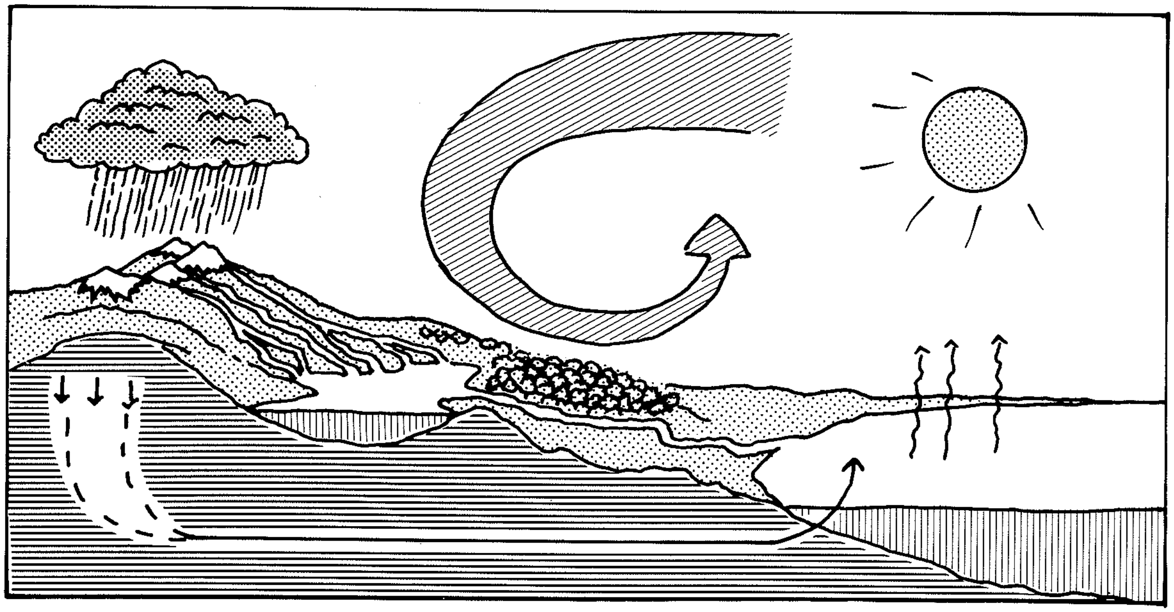
The development, calibration, and testing of general, regional hydrologic models suitable for all biome types is proposed. Moisture regimes are of critical importance in both terrestrial and aquatic ecosystems and are expected to be drastically impacted by Global Change. Exemplary issues involving linkages between hydrologic and ecological processes include:

- effects of changes in soil water on biotic composition of communities, ecosystem processes, and trace gas fluxes;
- quantity and quality of surface waters, including the nature of extreme events (e.g., high and low flows);
- changes in quantity and quality of groundwaters; and
- effects of deforestation on flood flows.

Regional hydrologic models which can be used to address such important questions are generally not available. These models would provide powerful tools for comparing diverse ecosystems, identifying processes and areas particularly sensitive to Global Change, analyzing geographic or landscape patterns of hydrology responses, and predicting effects of alternative Global Change scenarios.

There are three critical elements in the proposed hydrologic models. First, linkage of soil, ground, and surface water components is necessary. Second, it must be possible to make the model spatially explicit using geographic information systems (GIS). And, third, the hydrology model must be linked to the output of the regional atmospheric models.

Creation of these general hydrologic models requires collaboration between physical and ecological scientists. The hydrologic modeling efforts of the U.S. Geological Survey and other federal agencies are logical starting points. The biotic elements, including hydrologic parameters closely tied to ecological responses, require increased attention.



- **Major modeling effort**
- **Soil, surface, and ground water components integrated**
- **Spatially-explicit models linked to GIS**
- **Driven by regional atmospheric models**

5: Regional Predictions of Weather Patterns with Global Change

Develop models which can provide regional predictions of precipitation and other climatological phenomena.

A meteorological modeling project is proposed to develop regional predictions of precipitation and of disturbance regimes (frequency of fires, storms, hurricanes). These regional models will be linked to global climatic models. Currently, global climatic models are not designed to predict changes in climate at the regional level, nor have they been directed to these precipitation/disturbance parameters.

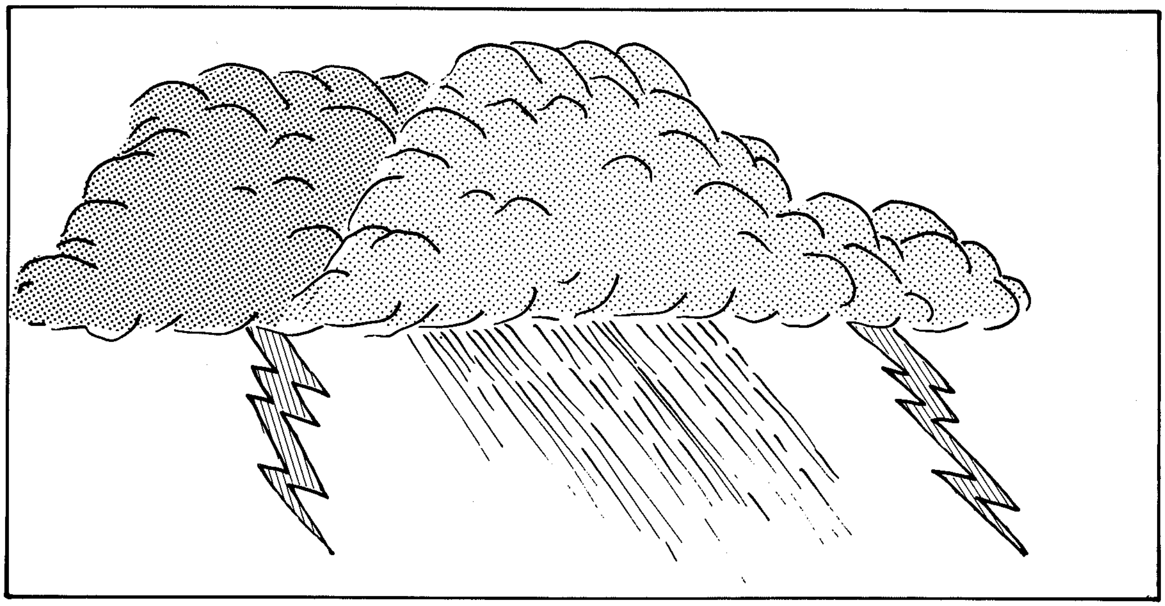
Such predictive capabilities are imperative if we are to assess ecological impacts of Global Change and subsequent feedbacks to the atmosphere because:

- site moisture regimes are critical variables in determining ecological responses; and
- major disturbances, such as hurricanes and drought-induced wildfires, will drive much of the change in ecosystem composition and structure (see Action Item 7).

While scenarios derived from global climatic models currently provide realizations of the general circulation of the atmosphere resulting from perturbations such as doubled carbon dioxide concentrations, these models do not provide estimates of sub-grid scale phenomena, such as synoptic weather system frequency, magnitude and geography.

Mesoscale numerical models at the regional level, which run in tandem during Global Change modeling experiments, are some years away. Interim approaches need to be developed to provide these predictions. Model output statistics (MOS) may be one technique for estimating frequency and magnitude of weather systems from Global Change realizations that is within the scope of current technology. Synoptic weather system event probabilities are required to link global climatic change to landscape disturbances and resulting dynamics in the distribution and composition, structural, and functional features of the ecosystems. These predictions are also critical for prioritizing parameters for existing ecosystem models.

This project will provide a critical link between atmospheric and ecological scientists on an issue which currently receives little attention from either group. Although atmospheric scientists, such as those associated with the National Center for Atmospheric Research, may take the leading role, extensive collaboration with ecological scientists would be necessary to see that the appropriate parameters are addressed at the spatial and temporal scales required for assessing ecological impacts.



- Major modeling effort
- Predict precipitation and disturbance regimes
- Regional predictions linked to Global Change models
- Collaboration between atmospheric scientists and ecologists

6: Analyzing Interactions between Land Use and Global Change

Analyze reciprocal relationships between land-use changes and global change and identify critical issues for further research.

Land-use and climate change will interact strongly over the coming decades. For biota, the effects of land-use change, along with those of altered disturbance regimes (Action Item 7), are likely to be more direct and more immediate than the effects of climate changes. However, in general, land use is planned with little regard for either its effects on Global Change or the effects of Global Change on land use.

Changes in land use have been and will continue to be a dominant factor in Global Change, as broadly defined. A comprehensive analysis of these interactions is proposed with the twin objectives of:

- predicting effects of land-use change on key biota and processes at a variety of spatial scales, and

- planning a comprehensive research program which incorporates modeling, comparative studies, and large-scale experiments.

The proposed analysis will consider a variety of questions. How can Global Change be expected to influence the geographic pattern and efficiency of important land uses, such as agriculture, forestry, and fisheries? How will these altered patterns affect biotic diversity, including availability and balance between habitats and changes in community composition? How will these land-use changes affect carbon and nutrient storage, trace gas fluxes, hydrologic regimes, and radiation balance? How effectively can remote sensing be used to detect changes in land use? Included here are concerns with change in management practices (e.g., type of agriculture) as well as in land-use type (e.g., conversion of forest to agricultural land).

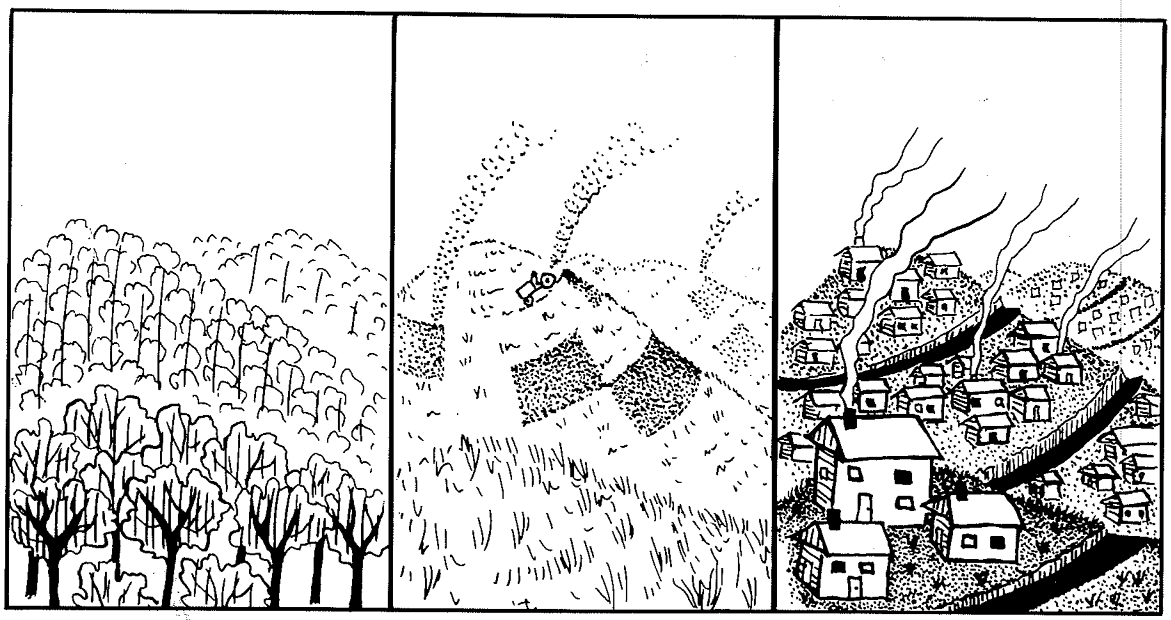
Synthetic approaches, including modeling, will be used to provide predictions and identify critical research needs. Several scientific approaches will be appropriate including:

- spatially-explicit projections of land-use changes under various scenarios and theoretical analyses of their effects on ecosystem processes, disturbance regimes;

- analyses of distribution and movements of biota;

- comparative studies of biotic responses in different regions with altered land use; and

- large-scale field experiments, possibly overlapping with some approaches developed under Action Item 3.



- **Synthesis and modeling effort**
- **Effects of land-use changes on Global Change**
- **Effects of Global Change on land use**
- **Identification of critical research programs**

7: Alterations in Disturbance Regimes Under Global Change

Predict effects of altered disturbance regimes (wildfire, hurricanes, floods) under Global Change on ecosystems and their biota.

Global Change-driven alterations in disturbance regimes, such as wildfire, droughts and windstorms, are likely to create more rapid, widespread, and comprehensive internal changes to many ecosystems than the direct effects of altered climate. Established ecosystems have a substantial ability to tolerate changes in temperature and moisture conditions, an ability that is largely lost when a catastrophic disturbance destroys its integrity. Hence, alterations in the frequency, intensity, distribution, size, and seasonality of major climate-driven disturbances under Global Change are critical variables in any analysis of the effects of Global Change on both the distribution and abundance of biota and on the structure and function of ecosystems, including feedbacks into the atmosphere.

A comprehensive analysis is proposed of the effects of Global Change on disturbance regimes and the ecological consequences of these changes, including effects on biological diversity. The first task is a product of Action Item 5--predictions of Global Change-induced alterations in frequency, intensity, distribution, size, and seasonality of disturbances such as wildfire, tropical storms and hurricanes, frontal storms, snow and ice storms, tornados, floods, and intense droughts. These geographically-explicit disturbance scenarios must be a collaborative effort between atmospheric and ecological scientists.

Predicting ecological impacts is the analytic task of this action item. Issues include:

- effects of altered disturbance regimes on biota, ecosystems, landscapes, and regions, including such aspects as primary productivity and carbon storage, fluxes of trace gases, and community composition;

- interactions of altered disturbance regimes with existing and potential land-use patterns and management practices (also links with Action Item 6); and

- interactions of altered disturbance regimes with chronic stresses created by environmental pollutant loadings and altered climates.

One product of this analysis will be identification of additional research needs. Expanded knowledge of ecosystems recovery processes following catastrophic disturbance is an obvious example. Mobile laboratories and scientific rapid-response ECOSWAT teams (Action Item 11) are proposed to take better advantage of the opportunities provided by natural catastrophic events.

Experimental re-creations of disturbance processes--intensive fire, large-scale windthrow of forest and altered hydrologic regimes, offer substantial potential and are already being conducted at several long-term research sites. For example, at the Harvard Forest LTER, simulated windthrow experiments are being conducted to evaluate hurricane effects on ecosystem processes.

- **Synthesis and modeling effort**
- **Ecological impacts of Global Change-altered disturbance regimes--wildfire, flood, storm**
- **Interaction of disturbances and land-use**
- **Identification of critical research and experiments**

8: Analyses of Phenomena at Different Scales in Time and Space

Accelerate existing efforts to develop and demonstrate approaches to problems of spatial scaling of ecological phenomena.

A program to develop and demonstrate various approaches to the problem of scaling is proposed. Currently most ecological data are collected at small scales--individual plants, small plots. In order to make predictions at landscape and regional scales, the small plot data must be scaled up to larger areas. Furthermore, remotely-sensed data is collected at very large scales, and linkages to ground-based data are difficult to establish. Extrapolation to larger spatial scales presents many problems, particularly when model construction and aggregation are used.

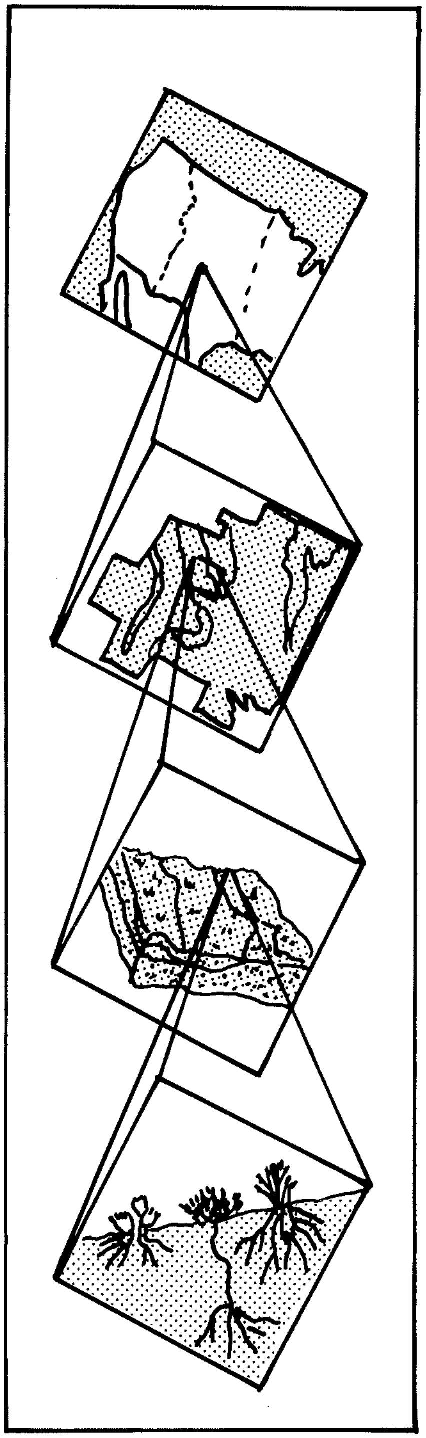
For example, an individual leaf of a plant responds strongly to changes in humidity, ozone, air temperature, and carbon dioxide content. In a plot, the whole plant must be considered. At larger scales, scientists have to consider not only the response of leaves and plants to atmospheric changes, but also variations in the structure, dynamics and spatial distribution of communities of plants, such as a forest. Large-scale studies must treat the atmosphere and the biosphere as strongly interacting components of a global system.

This program would characterize the natural scales of ecological processes and determine how processes operating at different scales are coupled. Results from modeling the climate-induced change of large, heterogeneous ecological systems would be compared to temporal changes documented in the fossil record. Existing experimental approaches to the scaling problem would be expanded, and new approaches developed. These new approaches could, for example, consider whether scaling from species to functional guilds is valid, or, whether plant-animal interaction models can be scaled up in size.

Several promising approaches to scaling issues make use of geographic information systems (GIS) in model development:

- Several models of forest stands
- "Century" soil organic matter model in use at Colorado State University
- Dynamic models expressing connectivity between GIS cells
- Watershed-level GIS models, such as those developed by the Smithsonian's Chesapeake Bay lab and the Arctic Lakes and Tundra LTER group at the Marine Biological Lab, Woods Hole, Massachusetts

The research proposed for this Action Item would allow continued development of these modeling approaches, as well as initiation of other demonstration projects.



- **Develop methods to solve scaling problems--spatial and temporal**
- **Accelerate existing modeling programs**
- **Identify additional approaches**
- **Demonstrate/disseminate successful methodologies**

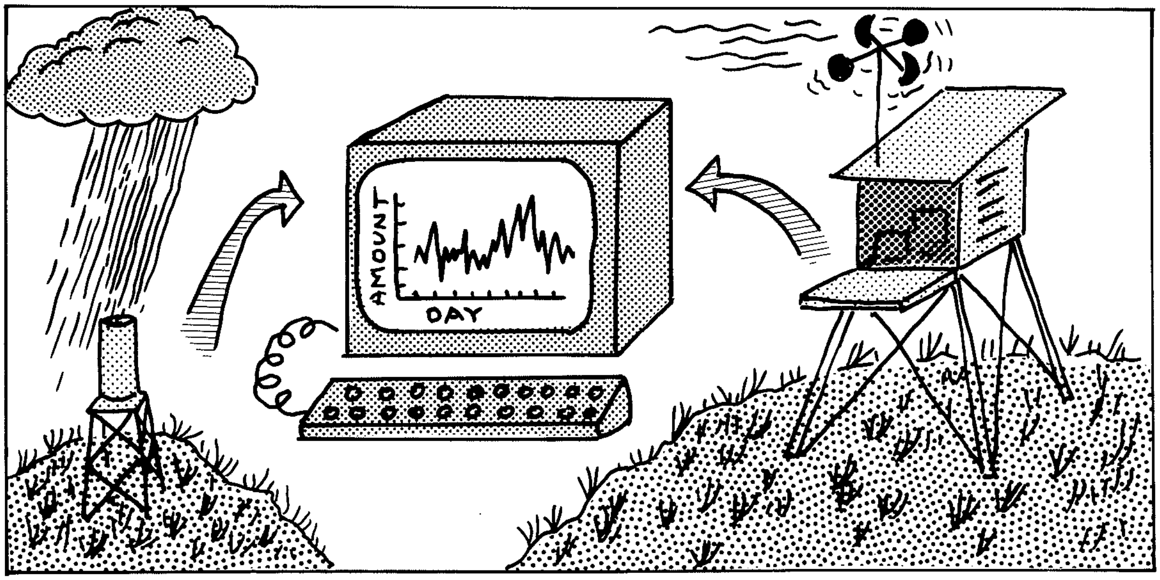
MEASUREMENT OF GLOBAL CHANGE

9: A Network of Ecological Monitoring Sites

Establish an integrated program for environmental monitoring, utilizing existing ecological research sites.

The establishment of integrated long-term measurement programs at major research sites is proposed to provide essential information on and to document changes in the biotic and abiotic environment. At the whole organism level, structural biotic changes include changes in organismal richness, abundance, and distribution. Other structural biotic changes include state variables, such as soil organic matter. Functional biotic changes include changes in processes like primary production, decomposition, nutrient cycling, and trace gas fluxes. Abiotic measurements should include trace gas concentrations, and remotely sensed data, such as vegetative indices (e.g., chlorophyll levels) and surface water temperatures.

Many of these data are critical to the Global Change research programs. All agencies conducting major environmental monitoring programs could utilize this network of ecological research sites, thereby taking advantage of existing programs, databases and infrastructures. Examples of proposed monitoring programs include the Environmental Protection Agency's Environmental Monitoring and Assessment Program (EMAP), the U.S. Fish and Wildlife Department's program to monitor coastal wetlands, and the U.S. Forest Service's Forest Health Monitoring program.



- **Establish long-term measurements at existing sites**
- **Both biotic and abiotic components**
- **Multi-agency collaboration**
- **Comparable methods across network of sites**
- **Comparable data base management systems**
- **Synthesis and modeling of data**

DEVELOPMENT OF TECHNOLOGIES

10: Remote Sensing Imagery

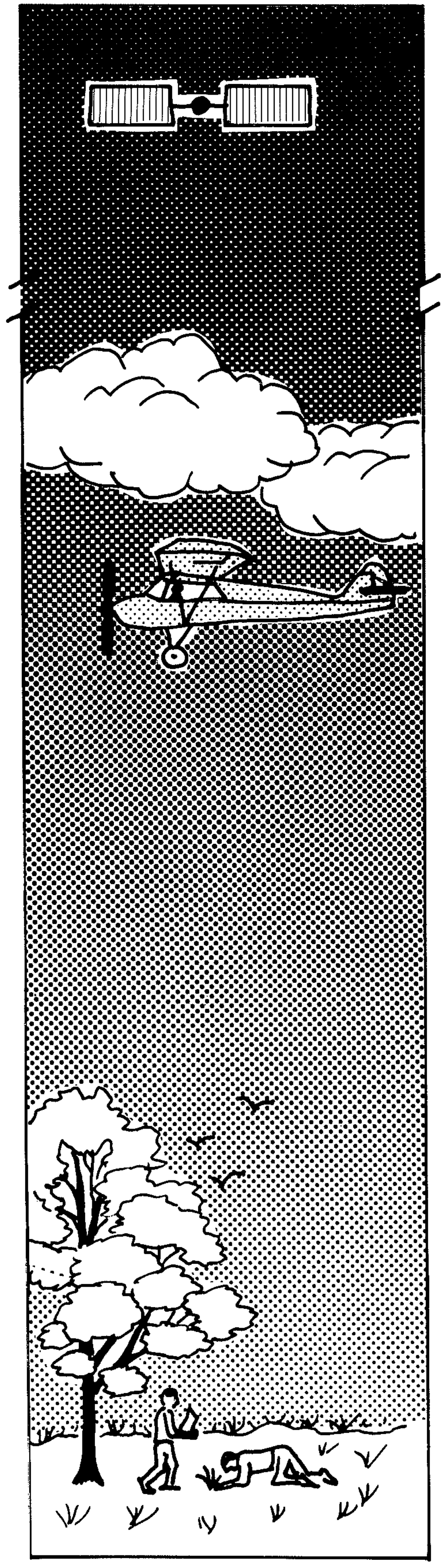
Develop regional interpretations of remotely-sensed biotic and abiotic data using existing ecological research sites for developmental work.

Studies are proposed to allow better regional interpretations of remotely-sensed abiotic and biotic data for use by scientists, land management agencies, and policymakers. The current atmospheric remote observing system was designed for weather prediction, not for a host of ecological purposes. A partnership should be developed between ecologists using remotely-sensed data and agencies, such as NASA, who can provide ecologically significant data. The currently available AVIRIS sensors mounted on aircraft are particularly useful to ecologists. In the future, these studies will rely heavily on the proposed NASA Earth Observing System (EOS) mission with its new ecologically relevant sensors.

It is critical to develop meaningful vegetation indices from remote images as well as improved abilities to detect changes in land use, particularly human-induced changes and management regimes, such as clear-cutting of forests. Plant water content may be inferred from remote imagery and used to evaluate the effects of altered water availability (due to climate change) on plant competition scenarios, with major implications for plant community structure. Remotely-determined chemical composition of plants may change and alter their future susceptibility to insect attack. Extinctions of plant and animal populations may occur as the minimum size of their habitats are reached; these size changes could be evaluated remotely.

For example, it may be possible to detect "movement" of the black spruce forests northward into the tundra. Other examples of ecological phenomena, which remote sensing could detect, include climate monitoring, shifts in boundaries between different ecosystems due to climate change, evaluation of land use change, and determination of the nature and extent of fire and flood.

- Enhance value of remote imagery in Global Change
- Biologic interpretations, including vegetation indices
- Major focus on geographical shifts
- Use existing intensive sites for ground truth



11: Mobile Ecological Laboratories/Ecological Rapid-Response Teams

Create mobile ecological laboratories and associated teams to enhance studies of ecological responses to catastrophes and provide general technical support of Global Change programs.

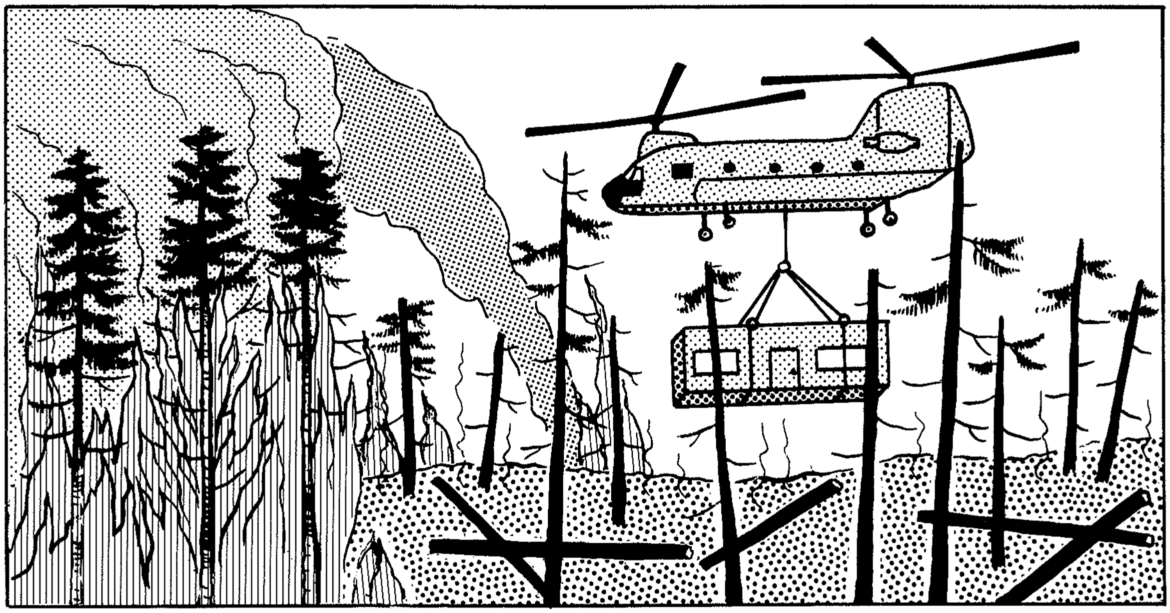
Natural catastrophes offer outstanding opportunities to study the effects of large-scale disturbances on and recovery processes in ecosystems. Such disruptive influences are similar to those expected under Global Change. Yet, lack of organizational and analytic capabilities for responding to such events has resulted in major losses of opportunities associated with events such as the Yellowstone fires and Hurricane Hugo. Indeed, many critical responses occur in the first days and weeks following the disturbance, often before scientists can move into the area, let alone mobilize to study early recovery.

Development of mobile field laboratories and associated rapid-response (ECOSWAT) scientific teams is proposed to provide quick response to such events, as well as to provide for wider availability of critically needed analytical facilities and expertise for Global Change research. Many important parameters and cutting-edge methodologies are not widely available or are too expensive to duplicate. Systematic expertise for many critical groups of organisms is also a serious limitation.

Creation of at least three mobile field laboratories is proposed. Each would utilize several container-sized modules suitable for transportation by fixed-wing aircraft and helicopter. These would be self-contained units with two to three permanent technical staff. Studies of catastrophic or other unusual ecological events would have priority in usage of these facilities. However, these mobile laboratories could be used to service other major Global Change experiments (Action Items 1 and 2) and for inventory and monitoring programs at other times.

An important element in this proposal is the establishment of permanent ecological rapid-response teams for each mobile laboratory. These interdisciplinary teams would develop contingency plans for scientific responses to catastrophic events and make their rapid implementation a professional priority. Teams would include scientists with expertise in systematics, community ecology, and population biology, as well as physical and biological scientists experienced at the ecosystem and landscape levels.

The mobile laboratories and associated teams would support and supplement efforts of the local scientific community at the site of a catastrophic event. The ECOSWAT teams would not attempt to duplicate or replace efforts by local scientists.



- Air-mobile capability
- Field capabilities for sophisticated techniques
- Rapid response to natural catastrophes
- Associated with permanent, organized ECOSWAT teams

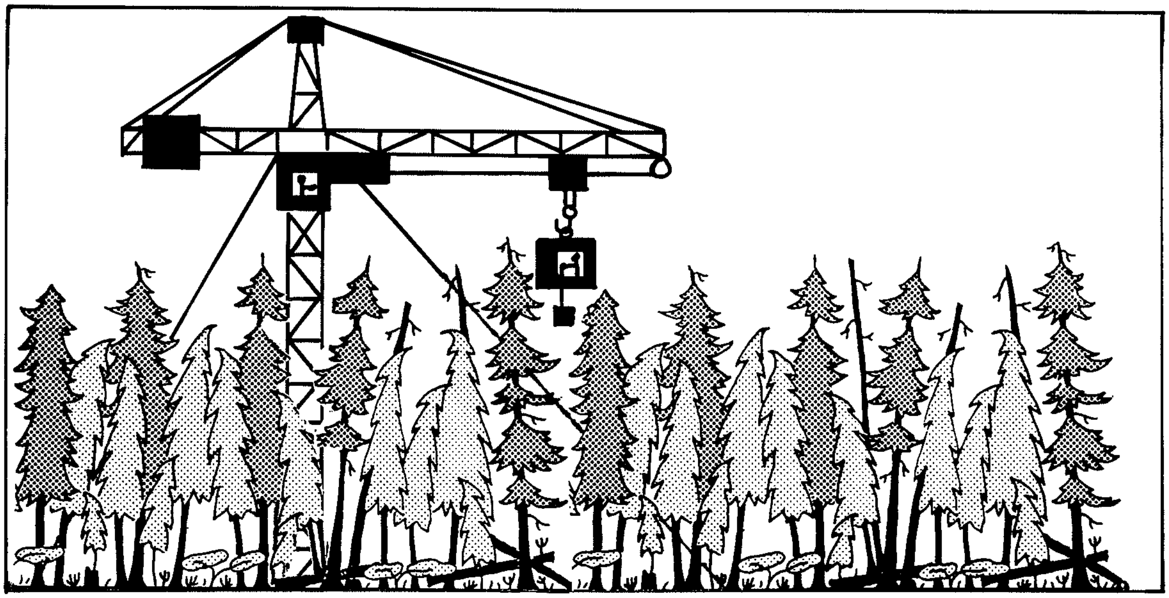
12: Development of Forest Canopy Access Systems (CANACSYS)

Develop and install tree canopy access systems, based primarily on construction crane technology, in major forest types.

The canopy is an extremely important component of a forest both in terms of ecosystem processes and biological diversity. The canopies are structurally diverse with complex architectures and immense foliar and branch surface areas. Canopies are critical habitat for a large diversity of organisms, including very large numbers of invertebrates. As the interface between ecosystem and atmosphere, canopies are sites of many critical processes --photosynthesis, transpiration, interception, condensation, and particulate precipitation-- many of which are critical considerations in Global Change. Unfortunately, the challenge to gain access to forest canopies has seriously hindered their study. Scientific investigations have been few and limited to a small number of adventurous investigators able to meet the physical and mental challenges of existing approaches (such as rock climbing techniques).

It is proposed to develop canopy access systems (CANACSYS) which provide safe and dependable access to large areas of high forest canopies and to install them in a representative series of forest ecosystems. One approach which appears to have great promise is the adaptation of construction crane technology. Such cranes occupy small areas at their base yet can provide access to more than 2 hectares (4.942 acres) of forest in the horizontal dimension and to a vertical profile that extends from the forest floor to heights of 80 meters or more, including points above a canopy. Other useful technologies include inflatable webs lowered to the canopy surface by helicopter, and sets of towers which are linked by cables or catwalks above the canopy.

These access systems should be installed in a representative cross-section of forests including western conifer, eastern deciduous, tropical, and boreal types. This will provide a cross-site capability for comparative analyses of biological, physical and chemical aspects of forest-atmosphere interactions. At some locations access will be required for canopies in both natural and managed ecosystems to facilitate comparisons of the effects of management practices. Installation of CANACSYS is viewed as urgent because of the relevance of so many canopy-related processes to Global Change issues.



- Develop essential access to forest canopies
- Large areas and full vertical profiles
- Safe and dependable
- Analysis of forest/atmosphere interactions
- Atmospheric "scavenging"
- Key processes, including gas exchange
- Analysis of canopy biodiversity
- Utilize construction crane technology

SPECIAL TOPICS

Education

There are major short- and long-term educational needs associated with implementation of the program outlined here. Available scientific personnel are not adequate in number and orientation. Deficiencies exist in many essential disciplines including scientists oriented toward: biological systematics, especially in identification and functional roles of invertebrate, fungal, and microbial organisms; ecological modeling, especially at larger spatial and longer temporal scales; applications of remote sensing; and interfaces between disciplines, such as between meteorology and ecology.

Heroic and immediate efforts are required to insure that the necessary scientific personnel are trained and employed in Global Change research. In some especially critical cases, such as systematics, traditional academic programs must be expanded into specific training programs to create and support the necessary cadre of scientists.

> **Funding for a major project for training and operational support of technical/scientific expertise in critical areas is proposed as part of this Global Change action program.**

Training might include three-year, post-graduate fellowships. Operational support following graduation would be provided to hosting institutions or agencies based on a 50-percent cost share, including both salary and other support costs. Initial efforts should include development of personnel with expertise in both the systematics and ecological functions of invertebrates and other poorly known groups of organisms.

Greatly expanded education of graduate students in the philosophy and methodology of research requiring interdisciplinary teams is critical. Most ecological students are still being trained in traditional approaches involving individual investigators and small scales of experimentation with a single disciplinary perspective. One outstanding value of the existing network of long-term ecological research sites is the existence of inter-disciplinary teams that can provide models for other groups and training grounds for students.

There is also a critical shortage of leadership for program development and for higher-level synthesis. Relatively few scientists can develop and direct the large ecological research programs that are required. Similarly, few personnel are available with the ability to provide either qualitative or quantitative syntheses in these complex, cross-disciplinary programs. Major efforts are needed to encourage and train potential scientific leaders.

A final important institutional need is for traditional academic institutions to recognize and reward inter-disciplinary research and educational activities. Faculty should be encouraged to participate in research projects involving inter-disciplinary teams, rather than discouraged, as is often the case.

International Ecological Networks

Research on Global Change must be an international effort, just as the solutions to global problems must involve international cooperation. Pollution does not stop at political boundaries. Changes in the ozone layer over Antarctica are probably related to changes throughout the globe. Deforestation in any part of the globe may alter atmospheric chemistry over vast areas. These examples simply emphasize the necessity for an integrated, coordinated network of sites studying Global Change.

This Action Plan recommends a number of research Action Items, many of which can be carried out by an existing network of long-term ecological research sites in North America. This North American network could be linked to other emerging international networks, such as the network of Biogeosphere Observatories proposed by the International Geosphere Biosphere Program (IGBP), the network of Biosphere Reserves for Global Change Research proposed by UNESCO's Man and the Biosphere Program (MAB), and the Northern Science Network of sites in Canada, the United States and the U.S.S.R. The member sites of the North American network of ecological sites support the formation of such international networks and offer their assistance.

Implementation of the Action Plan

The proposed action plan can be implemented during the next six years for an estimated cost of $143 million with additional costs of $70 million for training and support of personnel in critical areas (Appendix 1). All of the activities could be nested within the larger U.S. Committee on Earth Sciences (CES) program and the international programs being developed by IGBP, Scientific Committee on Problems of the Environment (SCOPE), World Climate Research Program (WCRP), UNESCO's MAB program and others.

As noted earlier, agency leadership and responsibilities would vary by Action Item. For example, based on their past experience and interests, the National Science Foundation and the U.S. Department of Energy might offer leadership for Action Item 1, "The Carbon Dioxide Enrichment Experiment." Similar examples could be developed for a number of the other Action Items, involving agencies such as the USDA Forest Service, the U.S. Department of Agriculture, the U.S. Geological Survey, the National Oceanic and Atmospheric Administration, the National Aeronautics and Space Administration, the National Park Service, the Environmental Protection Agency, and National Center for Atmospheric Research. Cooperation and collaboration among numerous educational institutions, private industry, and non-profit environmental groups would be expected.

Implementation of the Action Plan, continued

The program could begin in FY 1991 with a number of workshops and other critical planning activities, which would cost about $1 million. Beginning in FY 1992, funding would support development of specific Action Items within the four major categories: Experiments, Modeling and Synthesis, Monitoring, and Technology Development.

The two major experiments (Action Items 1 and 2) would begin with detailed planning and engineering work in FY 1992, with construction and installation phased over several fiscal years. Operation of the experimental facilities would be a continuing cost, following establishment. Total estimated costs of installations for these three Action Items is $27 million, with an additional $20 million in operating costs.

Synthesis and Modeling Action Items (3, 4, 5, 6, 7, 8) would begin with developmental efforts: creation of models or development of detailed research plans. Subsequent support would be continuing application of models and implementation of research programs, including landscape-scale experiments, on issues of land use and disturbance. Total estimated costs are $46 million over a six-year period.

Ecological Monitoring and Development of Technologies are Action Items which include planning and research phases as well as continuing costs. After initial planning, a network of monitoring sites would be implemented with equipment, followed by measurement, monitoring and synthetic research activities. For technological development of remote-sensing, canopy access systems, mobile ecological laboratories and ECOSWAT teams, the phases would include planning, instrument development and evaluation, implementation, research and synthesis. Annual costs would vary. Preliminary estimates suggest costs of about $49 million.

The educational program is the largest single item in the proposed Action Plan and is designed to increase the currently-scarce scientific and technical expertise needed in the ecological aspects of the global change program. Biological systematics should receive special emphasis. This proposed program would provide three-year fellowships at $25,000 per person per year, followed by operational support for each trained individual ($50,000 per year). Institutions and agencies would compete for graduates of this program by offering matching support.

Appendix 1: Proposed Budget

Schedule of costs for the 12 Action Items and the Educational Program over a six-year period

Fiscal year 1991		**$ millions**		
Initial planning activities, all items		1		
12 ACTION ITEMS (Fiscal years 1992-1996)				
1: Soil warming experiment				
Installations (28)	7			
Operation	10	17		
2: CO_2 enrichment experiment				
Installations	20			
Operation	10	30		
3: Mega-landscape experiment				
Planning	2			
Installations	10	12		
4: Hydrologic model		5		
5: Regional climate predictions		5		
6: Land use Interactions				
Planning	1			
Research programs	10	11		
7: Altered disturbance regimes				
Planning	1			
Research programs	8	9		
8: Scaling ecological phenomena		4		
9: Ecological monitoring				
Planning, installation	6			
Monitoring	4	10		
10: Remote imagery				
Research programs	8			
Imagery for sites	6	14		
11: Canopy access systems				
Installations (12)	6			
Operation	5	11		
12: Mobile laboratories & ECOSWAT				
Construction (3)	9			
Operation	5	14		
Subtotal			**143**	
Educational Training/Support Program				
Fellowships		50		
Salary, operational support		20	**70**	
TOTAL COSTS				**$213**

Appendix 2: Denver Workshop Participants

Representatives from Agencies and Organizations:

Centro de Ecología, Cuidad Universitaría, Cuidad de México, México: Victor Jaramillo, Ciudad Universitaría

Environmental Protection Agency: Ron Neilsen, EPA/Oregon State University, Corvallis OR; John Sigmon, Washington, D.C.

Forest Service, U.S. Department of the Agriculture: Jerry F. Franklin, Pacific Northwest Research Station; Frederick J. Swanson, Oregon State University, Corvallis, Oregon

Long-Term Ecological Research Network: Jerry F. Franklin and Stephanie Martin, LTER Network Office, University of Washington, College of Forest Resources, Seattle, Washington

National Park Service: Ray Herrmann, Colorado State University, Fort Collins, Colorado

National Science Foundation: Franklin Harris and Caroline Bledsoe, Biological, Behavioral and Social Sciences Directorate, National Science Foundation, Washington, D.C.

National Aeronautics and Space Administration: Diane Wickland, Earth Science and Applications Division, Washington, D.C.

U.S. National Committee for Global Change Research: Francis Bretherton, University of Wisconsin, Madison, Wisconsin

World Wildlife Fund: Robert Peters, Washington, D.C.

Site Representatives:

Long-Term Ecological Research (LTER) Sites:

1. H.J. Andrews Experimental Forest (AND), coniferous forest, Oregon: Frederick J. Swanson, USDA Forest Service, Corvallis
2. Arctic Tundra (ARC), Alaska: John E. Hobbie, Marine Biological Lab, Woods Hole, Massachusetts
3. Bonanza Creek Experimental Forest (BNZ), taiga forest, Alaska: Josh Schimel, University of Alaska, Fairbanks
4. Cedar Creek Natural History Area (CDR), old field/oak savannah, Minnesota: representative not present
5. Central Plains Experimental Range (CPR), shortgrass prairie, Colorado: William K. Lauenroth and Robert Woodmansee, Colorado State University, Fort Collins
6. Coweeta Hydrologic Laboratory (CWT), deciduous forest, North Carolina: Lindsay Boring, University of Georgia, Athens
7. Hubbard Brook Experimental Forest (HBR), hardwood forest, New Hampshire: Charles T. Driscoll, Syracuse University, Syracuse, New York
8. Harvard Forest (HFR), temperate deciduous-coniferous forest, Massachusetts: John Aber, University of New Hampshire, Durham; Jerry M. Melillo, Ecosystems Center, Woods Hole, Massachusetts

LTER sites, continued

9. Jornada Experimental Range (JRN), desert grassland, New Mexico: representative not present

10. Kellogg Biological Station (KBS), row-crop agriculture, Michigan: representative not present

11. Konza Prairie Research Natural Area (KNZ), tallgrass prairie, Kansas: Timothy R. Seastedt, Kansas State University, Manhattan

12. Luquillo Experimental Forest (LUQ), wet tropical forest, Puerto Rico: Frederick N. Scatena, Institute of Tropical Forestry, Rio Piedras

13. North Inlet Marsh-Estuarine System (NIN), coastal marine, South Carolina: Elizabeth Blood, University of South Carolina, Columbia

14. North Temperate Lakes (NTL), north temperate lakes, Wisconsin: John J. Magnuson, University of Wisconsin, Madison

15. Niwot Ridge/Green Lakes Valley (NWT), alpine tundra, Colorado: Nelson Caine and David Greenland, University of Colorado, Boulder

16. Sevilleta National Wildlife Refuge (SEV), shrub-steppe/grassland/desert transition, New Mexico: James R. Gosz and Paul Risser, University of New Mexico, Albuquerque

17. Virginia Coast Reserve (VCR), coastal marine/barrier island-estuary, Virginia: Bruce P. Hayden, University of Virginia, Charlottesville

Environmental Research Parks (major funding from the Department of Energy)

18. Batelle Memorial Institute (BMI), arid grassland/shrub-steppe, Washington: L.E. Rogers, Batelle Pacific NW Laboratories, Richland

19. Idaho National Engineering Laboratory (INEL), arid grassland/shrub-steppe, Idaho: Dale Bruns, Center for Environmental Monitoring and Assessment, Idaho Falls

20. Oak Ridge National Laboratory (ORNL), deciduous forest, Tennessee: Jerry Elwood, Oak Ridge National Laboratory, Oak Ridge

21. Savannah River Ecology Laboratory (SREL), conifer forest, South Carolina: Rebecca Sharitz, Savannah River Ecology Laboratory, Aiken

Other Ecological Research Sites:

22. Institute for Ecosystem Studies (IES), New York Botanical Garden, Mary Flagler Cary Arboretum, New York: Gary Lovett, Institute for Ecosystem Studies, Millbrook

23. Great Lakes Environmental Research Laboratory (GLERL), Michigan: Stephen Tarapchak, NOAA/US Department of Commerce, Ann Arbor

24. Sequoia-Kings Canyon National Park (SEKI), coastal forest, California: David Parsons and Nathan Stephenson, National Park Service, Three Rivers

25. Smithsonian Environmental Research Center (SERC), Chesapeake Bay estuary, Maryland: David L. Correll, Smithsonian Institution, SERC, Edgewater

Appendix 3: Photographs and Figures

Cover Photographs

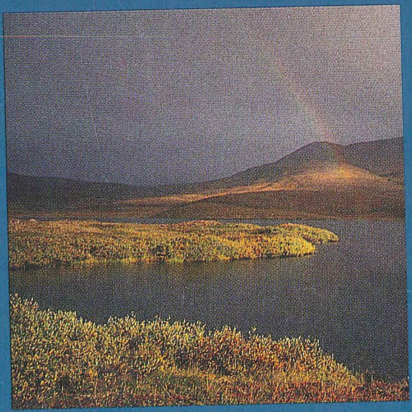
Top to bottom, front page:

Salt marsh, North Inlet LTER, South Carolina Coast
Old-growth conifer forest, H.J. Andrews LTER, Oregon
Dry steppe/grassland, DOE Arid Lands Research Park, Hanford, Washington
Moist grassland, eastern Washington

Back page:

Arctic tundra, Toolik Lake, North Central Alaska

Figures



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