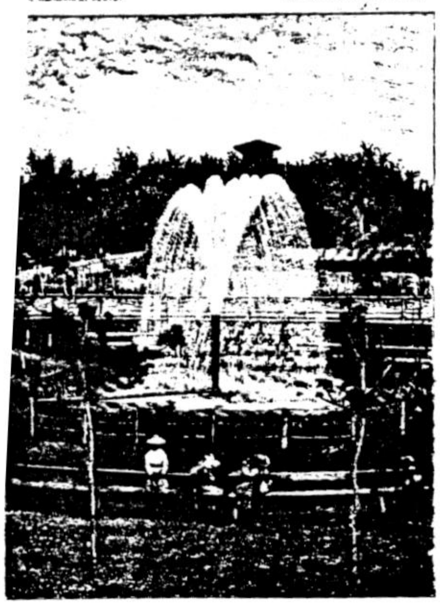

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The Long-Term Ecological Research Program

Frederick J. Swanson and Jerry F. Franklin

Major developments have emerged in the field of ecology as a result of taking a long-term approach to both basic and applied research [*Strayer*, 1986]. In recognition of both the advantages of long-term research programs and the historical difficulty of sustaining such research efforts, the National Science Foundation (NSF) instituted its Long-Term Ecological Research (LTER) Program in 1980 [*Callahan*, 1984]. The LTER Program has a number of important links with the geosciences and is likely to play a significant role in work on terrestrial, freshwater, and estuarine ecosystems within the International Geosphere-Biosphere Program (IBGP); it is thus a good time for us to begin communicating with geoscientists who are helping to shape IGBP.

LTER Sites

The LTER Program began in 1980 with the funding of six sites, a number that has now grown to 15 (Table 1 and Figure 1). An anticipated 1988 grant competition may bring the network to 20 sites. The existing sites span a great array of terrestrial and aquatic ecosystems — desert, prairie, tundra, forest, small stream, big river, lake, and estuary. Common threads among these diverse ecosystem research sites include

- established research sites with long-term records of environmental and biological variables (assurance of continued security and availability of sites for research are critical for their selection; in many cases, LTER sites contain areas of relatively pristine, preserved ecosystems, as well as areas where large-scale manipulative experimentation is possible),
- established interdisciplinary teams of researchers with stable leadership and institutional support,
- programs of research in five core areas (described below), and
- a commitment to work with other sites in the LTER network.

These research and administrative responsibilities are supported in part by modest funds (about $365,000 per site per year) provided through NSF's LTER grants program.

The field sites not only serve the LTER efforts but are intended to attract cooperators and allied research programs. Extensive knowledge of site conditions and histories make the sites ideal locations for large-scale field experimentation dealing with issues of global change. As an example, a lake acidification project involving multiple institutions (U.S. Environmental Protection Agency, Duluth; University of Wisconsin, Madison; University of Wisconsin, Superior; U.S. Geological Survey; University of Minnesota, Minneapolis; University of Minnesota, St. Paul; Wisconsin Department of Natural Resources) has been established at the Northern Lakes LTER site and forms a natural complement to and extension of the LTER research.

Another example of large-scale, multidisciplinary research at an LTER site is FIFE (First ISLSCP Field Experiment, where ISLSCP is the International Satellite Land Surface Climatology Project), sponsored by the National Aeronautics and Space Administration (NASA) and currently underway at the Konza Prairie LTER site. Contemporaneous ground-based field studies of the Konza Prairie LTER program provide ground truth for a tremendous array of remotely sensed data. This NASA–LTER interaction sets the stage for important advances in the use of

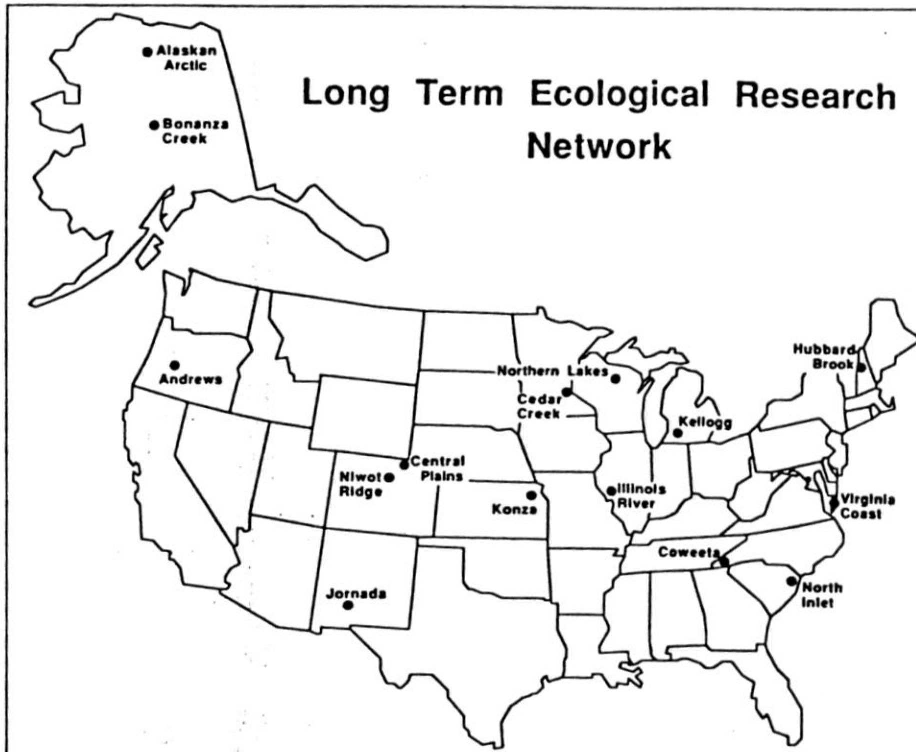

Fig. 1 Location of LTER sites.

ecological modeling and innovative technologies for measuring and integrating large-scale (landscape, regional, global) spatial variation in ecological processes.

LTER Research

The core areas of LTER research are

- pattern and control of primary production,
- spatial and temporal distribution of populations selected to represent trophic structure,
- pattern and control of organic matter accumulation in soil and sediment,
- patterns of biogeochemical cycling through soil, groundwater, and surface water, and
- patterns and frequency of disturbances, both natural and human induced.

Despite common work in these core areas, the research programs at individual sites are quite distinctive, responding to local environments, interests of researchers, and histories of site management and research.

Temporal Scales

The long-term aspect of LTER research takes many forms. Long-term direct experiments involving disturbance by fire, grazing, and manipulation of nutrients, pollutants, and water are the centerpieces of research at most sites. Retrospective studies, based on the techniques of paleolimnology, paleopedology, and dendrochronology, are used at several sites to place the course of ecosystem change and disturbances in a historical context. Chronosequence techniques, which involve the substitution of space for time, are employed at sites with long-lived dominant species (such as the forests of the Pacific Northwest, where conifers may attain ages of over 1000 years). Maintenance of long-term records of physical and biological characteristics of upland and fluvial environments provide an opportunity to measure the effect of natural disturbances. For example, the comparative impact of a severe drought in 1986 on an Appalachian forest and on a coastal estuarine-forest landscape is being assessed by a intersite study. Modeling of ecosystem function, based on process-level studies and constrained by results of retrospective work, are used to predict future ecosystem behavior. Many sites combine these techniques, if appropriate to the ecosystem.

TABLE 1. LTER Sites, Environments, Institutions, and Major Topics of Research

Site	Environment	Institutions	Major Research Themes
Alaska Arctic	tundra	Woods Hole Oceanographic Institute	Biogeochemical cycling, soil, and vegetation patterns in relation to landforms
H. J. Andrews Experimental Forest	forest, stream	Oregon State University, USDA Forest Service	Forest-stream interactions, disturbances, forest dynamics, log decomposition
Bonanza Creek	forest river	University of Alaska, USDA Forest Service	Ecosystem response to fire and fluvial disturbance
Cedar Creek Natural History Area	prairie, forest, lake, bog	University of Minnesota	Effects of nutrients, fire, herbivores, and other disturbance on primary production, succession, and soil processes; dynamics of the prairie-forest ecotone
Central Plains Experimental Range	shortgrass, steppe	Colorado State University, USDA Agricultural Research Service	Effects of erosion, hydrology, landforms, herbivores on soil and vegetation properties; biogeochemical cycling
Coweeta Hydrologic Laboratory	forest, stream	University of Georgia, USDA Forest Service	Land-stream interactions, ecosystem response to disturbance, biogeochemical cycling
Hubbard Brook Experimental Forest	forest, stream	Cornell University, Syracuse University, USDA Forest Service	Biogeochemical cycling, ecosystem response to disturbance
Illinois-Mississippi Rivers	river, forest	Illinois Natural History, Water, and Geological surveys, Western Illinois University	Sediment and biogeochemial cycling, floodplain-river interactions
Jornada Experiment Range	shrub- and grassland	New Mexico State University	Ecosystem response to erosion and manipulation of water and nutrient availability
Kellogg Biological Station	agricultural ecosystems	Michigan State University	Ecological constraints on agronomic productivity; impact of agriculture on the larger landscape; biogeochemical cycling
Konza Prairie Research Natural Area	tallgrass prairie, stream, forest	Kansas State University	Roles of fire, grazing, precipitation in ecosystem
Niwot Ridge–Green Lakes Valley	tundra, forest, lakes, stream	University of Colorado	Effects of climate, water, soil on sediment movement and biogeochemical cycling; paleoecology
North Inlet (Hobcaw Barony)	forest, stream, salt marsh, estuary	University of South Carolina	Biogeochemical and sediment cycling
Northern Lakes (Trout Lake Biological Station)	lakes, forest	University of Wisconsin–Madison	Precipitation, groundwater, geochemical, landform influences on lake ecosystems
Virginia Coast Reserve	estuary, barrier island, nearshore marine	University of Virginia	Island-marsh-estuarine interactions, landform response to sea level rise, primary and secondary succession, island ecology and biology

Spatial Scales

Although the initial emphasis of LTER was the time dimension, issues of global change and a growing interest among ecologists in landscape-scale phenomena have pushed the research to larger spatial dimensions as well. Much traditional research in terrestrial, estuarine, and freshwater ecology has been carried out at the scales of plots (square meter to hectare), stream reaches, and individual lakes. However, several LTER projects have designed their research programs within the context of hierarchy of spatial scales, including the soil particle, landscape, and globe [*French*, 1986; *Woodmansee and Adamsen*, 1983].

A crucial scale of research is the landscape, encompassing many hectares and multiple patches of vegetation, stream reaches, or lakes. Several LTER projects are examining biological properties of ecosystems in relation to landforms and position within the landscape [*Swanson et al.*, 1988]. Examples include patterns of soil and vegetation along topographic sequences from ridge top to valley floor or playa, interactions between rivers and adjacent forests as controlled by landforms, the biogeochemistry of lakes in relation to location within their drainage basins, and the effect of sea level rise on terrestrial nutrient flux.

To move to the regional scale, several LTER groups are using networks of satellite field sites, modeling efforts, and remote sensing to examine regional patterns of primary productivity and other biological processes in relation to climate [*Dyer and Crossley*, 1986; *Sala et al.*, 1988].

These are all important steps in understanding the links among plot, landscape, regional, continental, and global scales of ecosystem function.

LTER Network

Although LTER sites are selected on the basis of peer evaluation of the quality of research proposed at the individual sites, the collection of LTER sites is developing into an integrated network. The substantial effort that goes into intersite activities is lead by a coordinating committee consisting of principal investigators from all sites, a chairman,

WaterWatch *(cont. on p. 36)*

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and an NSF representative. Workshops are held to further collaborative research and to share ideas and techniques. Common standards for meteorological monitoring [*Greenland,* 1986] and data management [*Michener,* 1986] have been established. Joint research and exchange of scientists among sites are used for comparative studies and to test hypotheses in a variety of environments.

LTER and IGBP

The LTER Program will contribute substantially to the terrestrial, freshwater, and estuarine biology phases of IGBP in view of characteristics of the field sites, research programs, and LTER network as a whole. LTER sites are obvious "biosphere observatories" [*National Research Council,* 1986] because of their long direct and surrogate records of environmental variables, structure, and composition of biological communities, and biogeochemical processes. These long-term records are a distinctive contribution of terrestrial biosphere observatories to assessing global change; they stand in contrast to satellite and oceanographic observation platforms that typically record snapshots in time. Furthermore, the research infrastructures and high-quality physical environments at biosphere observatory sites suit them ideally for further cooperative large-scale research efforts.

LTER sites are well-suited for examining questions about how ecosystems respond to stress. Many of the LTER sites have long-term field experiments underway that deal with system stability and productivity. Effects of changes in climate or pollution load may be detected within and predicted from these field experiments.

Modeling of biological interactions with atmospheric variables at landscape and regional scales can yield predictions of the response of ecosystems, such as the response of agro-ecosystems and rangelands of the Great Plains to climate change. Moreover, such models could also encompass effects of the biota on the physical environment, including the atmosphere.

Maintenance of biological diversity at local, regional, and broader scales is an important issue within the scope of IGBP [*National Research Council,* 1986]. Portions of most LTER sites are reserved natural ecosystems and thus serve as refuges for species and genotypes threatened by land uses such as forestry, grazing, agriculture, and suburbanization. Collections of organisms and species lists document diversity at these sites, providing the potential to record change in diversity in response to global and local changes in the environment. Several sites have long-term experiments designed to determine how various environmental factors control local diversity.

The LTER network of research programs is a prototype in several respects of the type of cooperative research that would be required within a large-scale, interdisciplinary enterprise such as IGBP. LTER's most important contribution to IGBP probably will be the existence of a large, cooperating group of ecosystem scientists with broad perspectives on how the terrestrial biosphere interacts with the atmosphere and oceans. These broad perspectives are an outgrowth of the diversity of disciplines and environments from which these scientists come.

For more information about the LTER program, contact Judy Brenneman, Forestry Sciences Laboratory, 3200 Jefferson Way, Corvallis, OR 97331 (telephone: 503-757-4340). The LTER Program also publishes the "LTER Newsletter," which contains information on research activities.

References

Callahan, J. T., Long-term ecological research, *BioScience, 34,* 363, 1984.

Dyer, M. I., and D. A. Crossley, Jr. (Eds.), Coupling of ecological studies with remote sensing, *U.S. Dept. State Publ. 9504,* Washington, D.C., 1986.

Greenland, D., Standardized meteorological measurements for long-term ecological research sites, *Bull. Ecol. Soc. Am., 67,* 275, 1986.

Michener, W. K. (Ed.), *Data Mangement in the Ecological Sciences, Belle W. Baruch Library Mar. Sci. Sci.,* vol. 16, University of South Carolina Press, Columbia, S.C., 1986.

National Research Council, *Global Change in the Geosphere-Biosphere: Initial Priorities for an IGBP,* National Academy Press, Washington, D.C., 1986.

Sala, O. E., W. J. Parton, L. A. Joyce, and W. K. Lauenroth, Primary production of the central grassland region of the United States: spatial pattern and major controls, *Ecology,* in press, 1988.

Strayer, D., An essay on long-term ecological studies, *Bull. Ecol. Soc. Am., 64,* 271, 1986.

Swanson, F. J., T. K. Kratz, N. Caine, and R. G. Woodmansee, Landform effects on ecosystems, *BioScience,* in press, 1988.

Woodmansee, R. G. and F. J. Adamsen, Biogeochemical cycles and ecological hierarchies, in Nutrient Cycling in Agricultural Ecosystems, *College Agric. Exp. Stn. Spec. Publ. 23,* Univ. of Georgia, Athens, 1983.

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