Long-Term Research at the USDA Forest Service's Experimental Forests and Ranges

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The network of experimental forests and ranges administered by the US Department of Agriculture Forest Service consists of 77 properties that are representative of most forest cover types and many ecological regions in the nation. Established as early as 1908, these sites maintain exceptional, long-term databases on environmental dynamics and biotic responses. Early research at these sites focused on silviculture, ecosystem restoration, and watershed management. Over time, many of the properties have evolved into a functional network of ecological observatories through common large-scale, long-term experiments and other approaches. Collaboration with other institutions and research programs fosters intersite research and common procedures for managing and sharing data. Much current research in this network focuses on global change and interdisciplinary ecosystem studies at local to global scales. With this experience in developing networks and compiling records of environmental history, the experimental forests and ranges network can contribute greatly to formation of new networks of environmental observatories.

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Properties dedicated to the study of the environment, ecosystems, and natural resources have long been an integral part of the national and global infrastructure for science, education, and information. These properties have guided the management of natural resource systems, such as watersheds, forests, and rangelands. Key discoveries with wide-ranging impact on environmental policy and natural resource management have emerged from long-term studies at field research facilities. Sustained ecosystem research at Hubbard Brook Experimental Forest in New Hampshire, for example, revealed the existence of acid rain in North America and the ramifications of this form of pollution—as well as other human alterations of the atmosphere—for forests and watersheds (Likens 2004). Fundamental characterization of old-growth forests, and of the dynamics of forests of the Pacific Northwest, based on studies at the H. J. Andrews Experimental Forest in Oregon influenced a major shift in forest management policy in that region and beyond (USDA FS/USDI BLM 1994, Franklin et al. 2002). Research in the Luquillo Experimental Forest in Puerto Rico documented the effects of hurricanes on Caribbean forests, setting the stage for understanding how disturbances influence tropical forests (Walker et al. 1996). These examples demonstrate how sustained, interdisciplinary studies at research sites can lead to discoveries based on designed studies or on simple serendipity. The experimental forests and ranges and the research groups working there in long-term collaborations are seedbeds for discovery.

Evolving social issues and science questions calling for increasingly broadscale and interdisciplinary ecological research have contributed to two developments in the field. First, research programs at individual sites have evolved over time to blend sustained long-term, interdisciplinary studies with new short-term studies to sharpen the focus on contemporary issues. Second, there has been a trend toward collections of research sites functioning increasingly as research

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networks that span regions and continents. These steps have been critical in making the results of ecological sciences relevant to societal problems across a range of scales.

In light of continuing changes in these vital national systems of research properties, and of the prospects for developing major new ecological and environmental observatory networks (e.g., the National Ecological Observatory Network, or NEON; *www.neoninc.org*) and hydrological observatories (the Consortium of Universities for the Advancement of Hydrologic Science, Inc., or CUAHSI; *www.cuahsi.org*), it is timely to reflect on existing capabilities and lessons learned as a basis for planning future research networks and their accompanying research agendas. The US Department of Agriculture (USDA) Forest Service's experimental forests and ranges provide valuable historical records of environmental change, experience in operating networks of research properties, and coverage of important types of ecosystems and natural resource systems.

In this article we describe the network of experimental forests and ranges of the USDA Forest Service, highlight a handful of this network's scientific contributions to date, and comment on its potential for contributing to the national research agenda. We pay particular attention to the network's representation of the nation's ecosystems and its relevance to research addressing environmental change and natural resource management issues in the United States. We illustrate the evolution of research activity in this network, from individual studies focused on isolated sites and local research needs to research that increasingly takes advantage of networks of sites considered across broad temporal and geographic environmental gradients. We argue that the complexity of the environmental challenges facing humanity in the new millennium (Millennium Ecosystem Assessment 2005) requires a research focus that addresses environmental complexity at the scales of time and space where the problems are rooted. To do so, site-specific research must be reinforced with networks of sites arrayed along environmental gradients that collectively represent the broad scale of ecological space that is of interest to resource conservation.

Ecological research networks

The establishment of research networks has long been a matter of interest to ecologists (Heal and Grime 1991). While efforts to understand and protect global ecosystems benefit from research conducted both in networks and at isolated biological field stations (Whitesell et al. 2002), networking has the advantage of allowing for the establishment of comparative ecological studies, the installation of experiments along abiotic and biotic gradients, and the quick assessment of the variability in processes and structures of ecosystems (Cole et al. 1991).

A wide variety of ecological research networks exists, ranging from loose confederations of sites allied mainly for administrative purposes to thematically focused, tightly coordinated, and geographically distributed research programs. These types of networks differ greatly in a number of respects, including the types of opportunities they provide for manipulative research, and the extent of the near-pristine conditions they offer for use as controls. The long-standing UNESCO (United Nations Educational, Scientific and Cultural Organization) Man and the Biosphere, or MAB, system of biosphere reserves (*www.unesco.org/mab/*), for example, is a global network of sites with a design encompassing control areas, areas with opportunity for manipulative research, and demonstration areas. However, there is no coordinated, sustained source of funds to support research across this network. Most of the 47 biosphere reserves in the United States are within the US Department of the Interior's National Park System or the USDA's National Forest System, and 12 are in the experimental forests and ranges network. The system of national parks offers many research opportunities (Parsons 2004), but opportunities for manipulative research are limited by its preservation mandate.

One of the best-known systems of ecological research sites is the Long Term Ecological Research (LTER) Network, initiated by the National Science Foundation (NSF) in 1980 (Hobbie et al. 2003). This network of nearly 30 sites in the United States and Antarctica, ranging from urban centers to wild alpine and forest systems to deserts (Hobbie et al. 2003), is funded to conduct long-term ecological research with a significant degree of intersite coordination. However, the limited number of LTER sites results in very limited sampling of individual types of ecosystems, such as forests or grasslands (Turner et al. 2003). Also, with very few exceptions, LTER initially emphasized pristine ecosystems, where human impact is minimal.

Many other types of broadscale observation programs track specific aspects of environmental change, including MODIS (Moderate Resolution Imaging Spectroradiometer) and other remote sensing programs supported by NASA (National Aeronautics and Space Administration); the National Atmospheric Deposition Program; AmeriFlux; and the US Geological Survey's stream-gauging network. In a recent review of ecological research networks from around the globe, Melinda Smith (Department of Ecology and Evolutionary Biology, Yale University, New Haven, CT, personal communication, 21 August 2005) argued that integrative, multidisciplinary, broadscale ecological networks were needed to understand ecological systems and how they respond to human activities. However, Smith could not identify a single network, among the 49 reviewed, that satisfied the requirements she thought were needed to address the challenges facing ecologists and society in the 21st century. Attributes considered critical for future ecological networks include (a) a science design that balances contributions of individual scientists and institutional controls, (b) combined observational and experimental approaches, (c) strong intersite coordination, (d) interdisciplinary approaches, (e) coverage of broad geographic regions, (f) multiple grains or scales of sampling, and (g) long-term design and operation. As we will show, the USDA Forest Service's network of experimental forests and ranges has all of the attributes Smith identified, although not all attributes are present at all sites. Moreover, whereas most existing networks support observational (rather than experimental) research of short duration and of a single spatial grain, the experimental forests and ranges network has a tradition of large-scale and long-term experimental research.

One common characteristic of many temperate, boreal, and tropical ecological research sites, whether in networks or collections of individual sites, is their focus on environments that have undergone little recent human influence. Increasing human demands for ecosystem products and services drive the alteration of most ecosystems of the world, either directly through on-site land use or indirectly through altered climate, altered atmospheric chemistry, facilitation of invasion by exotic species, or other means. Increasingly, scientists are recognizing the extent and impact of human influences in ecosystems previously considered pristine (Thompson et al. 2002). Ecological research networks are critical for advancing this line of research.

The experimental forests and ranges network

A major contemporary challenge facing ecologists is to understand environments influenced by human activity (Bawa et al. 2004, Palmer et al. 2004). Fortunately, this has been the subject of much of the research at the USDA Forest Service's network of experimental forests and ranges for nearly a century.

The establishment and evolution of experimental forests and ranges. Shortly after the USDA Forest Service was established in 1905, early leaders of Forest Service research began to establish experimental forests and ranges (in some cases termed "experimental stations"), with the general objective of addressing large-scale problems of forest, range, and watershed management. The period of establishment extended from 1908 until the early 1970s (Adams et al. 2004). Most of the experimental forests and ranges were established on national forest lands, but some were located on state or privately owned lands. Meteorological observations and baseline characterization of vegetation, soil, and watershed conditions commenced. The early work of experimental forests and ranges established the scientific basis for management of forest (box 1) and range (box 2) vegetation and watersheds in many regions. At the outset, many investigations in places such as the Escambia Experimental Forest in Alabama, the Great Basin Experimental Range in Utah, and the Starkey Experimental Forest and Range in Oregon also involved the restoration of deforested, overgrazed, and degraded forests and rangelands.

Early concerns about the state of water supplies and water quality led to the establishment of experimental watershed studies at more than two dozen experimental forests and ranges (figure 1). Early watershed research at Coweeta Hydrologic Laboratory in North Carolina, the San Dimas Experimental Forest in California, and other sites examined basic components of the hydrologic system and the effects of vegetation management on streamflow, particularly peak flows and water yield. Studies at Coweeta established the foundation for the development of basic concepts in forest hydrological sciences (Swank and Crossley 1988).

In the 1980s, experimental forests and ranges numbered 110 (Adams et al. 2004), but today the network contains 77 formally designated sites covering 196,300 hectares (ha) (figure 1). Individual sites range in size from 47 to 22,500 ha, and many encompass entire watersheds. Scientists working at

Box 1. Development of forest management systems.

Experimental forests and ranges have been important for developing successful forest management practices in their respective regions.

The Escambia Experimental Forest, established in 1947 in Alabama in second-growth longleaf pine (*Pinus palustris*), is representative of millions of hectares in the southern United States. Through long-term studies, USDA Forest Service scientists examined the ecology of this endangered ecosystem, including fire ecology and management issues related to natural regeneration, growth and yield, uneven-aged and even-aged structures, economics, and other topics (Boyer and White 1990, Boyer 1993, Farrar 1996). A shelterwood method for regenerating longleaf pine, now commonly used throughout the southern United States, was developed at this experimental forest (Croker 1987, Boyer 1993).

The Wind River Experimental Forest in Washington is the birthplace of today's silvicultural techniques for management of the Pacific Northwest's extensive Douglas fir (*Pseudotsuga menziesii*) forests (Miller et al. 2004). Studies beginning as early as 1912 examined the autecology and regeneration of Douglas fir; the effects of fertilization, thinning, pruning, and spacing on production; and the nursery production of seedlings to help reforestation of extensively logged and burned lands. Silvicultural systems developed at Wind River have found wide application in the region where Douglas fir grows.

The Cutfoot Experimental Forest in Minnesota was established in 1932, but research there dates back to 1923. The forest has been home to over 100 studies on thinning, release and improvement cutting, growth studies, and reforestation in pine forests and has been influential in shaping today's red pine (*Pinus resinosa*) management practices in the Lake States. Some of the old studies are being used to address today's issues. For example, in a study of growing stock levels of red pine, research has established that the culmination of mean annual increment for red pine can extend well beyond the traditional rotation age of 50 to 70 years. In fact, mean annual volume increment curves show no strong indication of culmination at 140 years of age, at least in part because of periodic growth increases after seven thinnings, which did not begin until the trees were 85 years old.

Box 2. Development of range management systems.

Basic and applied studies at several of the experimental ranges have been pivotal in the development of range science and management.

For example, at the Great Basin Experimental Range in Utah, long-term records of climate, streamflow, and vegetation conditions dating to 1912, and early studies evaluating the impacts of various levels of grazing pressure on ecosystems and individual plants, have led to the development of methods for rangeland restoration, including development and evaluation of plant materials and of plant establishment techniques. This body of work laid the foundation for management of range and associated lands to recover natural ecosystems, improve habitats, and mitigate adverse off-site effects on watersheds.

USDA Forest Service scientists initiated research at the Starkey Experimental Forest and Range in Oregon in the 1950s to improve rangelands and livestock grazing methods in mixed grassland and conifer forests. An ungulate-proof fence enclosing 104 square kilometers, along with interior fencing, provides control of the mix of large herbivores (cattle, mule deer [*Odocoileus hemionus*], and elk [*Cervus elaphus*]), so their interactions, herbivory effects, response to hunters and other visitors, and other topics can be examined experimentally. Research at Starkey is providing guidance concerning appropritate cattle stocking levels to minimize range and watershed degradation, the roles of hunting and viewing elk, and many other land management issues.

many of these sites also use associated USDA Forest Service satellite properties, such as the more than 250 research natural areas ranging in size from 15 to 4000 ha and dedicated to nonmanipulative research.

Records from meteorological and gauging stations and forest research plots in some experimental forests date back more than 90 years. The Priest River Experimental Forest in Idaho boasts uninterrupted daily weather records since 1911 and data on growth of forest stands dating back to 1912; the latter are used to develop and verify computer simulation models of forest growth. The earliest long-term plots in the Pacific Northwest were established in 1910 for forest growth and yield studies. Today, these are part of a regionwide network of 145 long-term plots, which spans several experimental forests as well as other areas used in both basic and applied forest ecology studies (Acker et al. 1998).

Several factors have facilitated the evolution of individual research properties into an interactive network, including common experiments and measurement programs, common protocols for data management and sharing (e.g., data harvester systems for climate and hydrology parameters), and cross-site synthesis of long-term records. Some of this intersite work began early in the history of the experimental forests and ranges, but the effort has increased substantially in recent decades. For example, sequences of experimental forests that cross environmental gradients are being used to examine effects of moisture and temperature on root decomposition in Oregon, and the much more extensive Long-term Intersite Decomposition Experiment Team (LIDET) study of fine litter decomposition spans 28 Forest Service, LTER, and other sites extending from the North Slope of Alaska to the Caribbean and Central America (see *www.fsl.orst.edu/lter/research/intersite/lidet.htm*).

Although they have a branching hierarchical organizational structure through which funds and directives flow, intersite science programs at experimental forests and ranges generally function as "small-world" networks (*sensu* Barabasi 2002). That is, scientists from various sites who share an interest in a particular science problem may collaborate voluntarily across diverse admin-

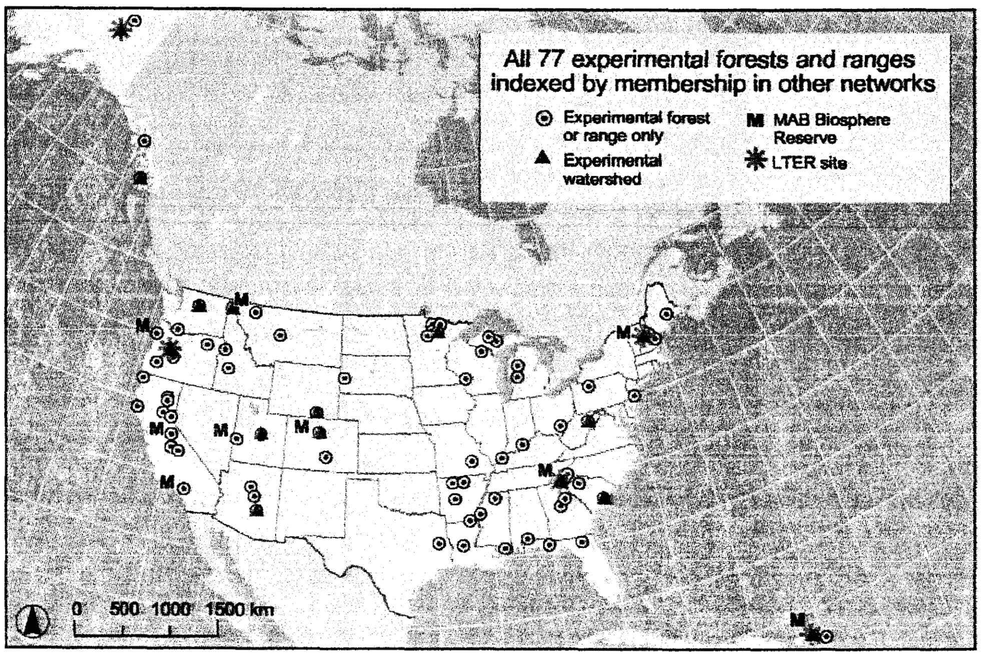

Figure 1. Geographic distribution of experimental forests and ranges, and of experimental watersheds, showing their designation as LTER (Long Term Ecological Research) sites, MAB (Man and the Biosphere) reserves, or both.

istrative units within the Forest Service. This distinction is important because the hierarchical organization supplies the basic support for operating the properties and core research programs, but the scientific excitement comes from working on common science questions in energized networks of scientists.

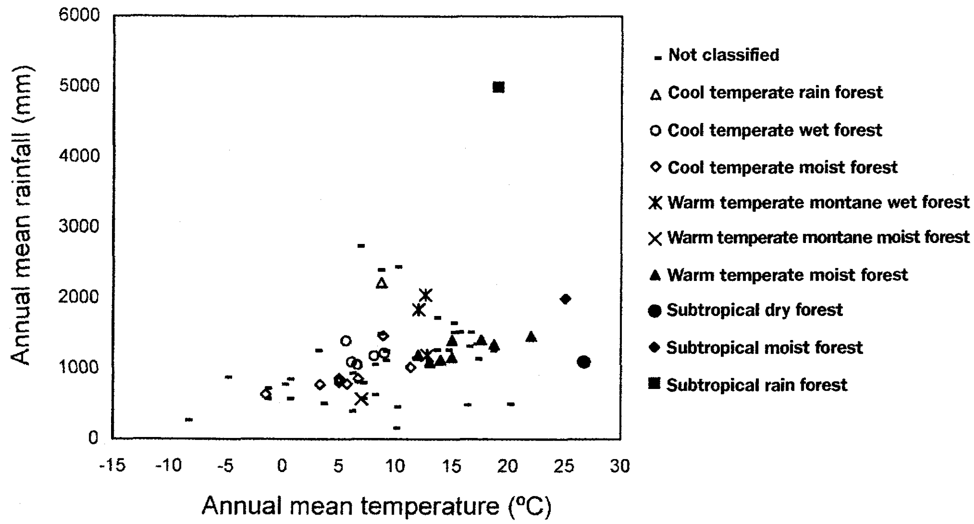

Figure 2. Relationship between annual rainfall (in millimeters) and temperature (in degrees Celsius) in the network of experimental forests and ranges. Notice the different climatic gradients for moist, wet, and rain forest life zones and for temperate and subtropical life zones. Data are from Adams and colleagues (2004); life zones are from Lugo and colleagues (1999).

US environments and ecosystems sampled by the experimental forests and ranges. The network of experimental forests and ranges spans broad geographic and environmental ranges, from St. Croix in the US Virgin Islands to Alaska (figure 1), extending well beyond conditions one typically thinks of as forest or grassland vegetation types. The elevation of these research properties ranges from 30 meters (m) (Silas Little Experimental Forest in New Jersey) to 3500 m in the alpine Glacier Lakes Ecosystem Experiments Site (GLEES) in Wyoming. This broad spread, including nearly 50 degrees of latitude, results in the system of experimental forests and ranges reflecting a great range of temperature and precipitation conditions (figure 2).

Several vegetation and ecosystem classification systems provide a useful base for characterizing vegetation represented by the experimental forests and ranges. The network contains representatives of 21 of the 25 forest cover types in the USDA Forest Service's forest type map of the United States (visit *www.fsl.orst.edu/lter/pubs/webdocs/reports/lugobiosci.cfm?* for data sources, analytical methods, maps, tables, and additional findings). The forest cover types most represented by experimental forests are oak–hickory (*Quercus–Carya*), loblolly–shortleaf (*Pinus taeda–Pinus echinata*), and ponderosa pine (*Pinus ponderosa*), which together represent 32% of the forests of the United States. The experimental forests and ranges occur in 26 provinces or ecoregions defined by Bailey (1995). These ecoregions cover more than 55% of the area of the United States. The greatest number of experimental forests falls within the Laurentian mixed forest ecoregion, which represents 4.1% of the area mapped. The conterminous United States has 38 Holdridge life zones (Lugo et al. 1999), of which at least 14 contain experimental forests or ranges (table 1). The network

Table 1. National representation of the 14 Holdridge life zones that are present in the experimental forests and ranges network of the USDA Forest Service.

Life zone	Area in kilometers (percentage)	Number of experimental forests or ranges (area in hectares)
Warm temperate moist forest	1,804,944 (23.24)	22 (31,107)
Cool temperate moist forest	1,259,616 (16.22)	12 (17,271)
Warm temperate dry forest	708,000 (9.11)	1 (1987)
Warm temperate thorn steppe	482,624 (6.21)	1 (5364)
Cool temperate wet forest	366,912 (4.72)	9 (16,932)
Warm temperate montane moist forest	255,920 (3.29)	4 (13,219)
Warm temperate subalpine wet forest	136,416 (1.76)	6 (27,826)
Cool temperate desert scrub	111,072 (1.43)	1 (22,500)
Cool temperate subalpine wet forest	105,520 (1.36)	4 (21,391)
Cool temperate subalpine rain forest	100,128 (1.29)	3 (5574)
Warm temperate montane wet forest	79,152 (1.02)	5 (7168)
Warm temperate alpine rain tundra	53,888 (0.69)	1 (600)
Cool temperate rain forest	47,376 (0.61)	2 (8431)
Warm temperate subalpine rain forest	29,872 (0.38)	1 (1200)
Total	5,541,440 (71.33)	72 (180,570)

Note: Data cover only the conterminous United States.

also includes six subtropical life zones in the Caribbean and several boreal ones in Alaska.

The current conditions of the vegetation at these sites reflect the history of natural disturbances and land management before their designation as experimental forests and ranges, as well as the more recent history of manipulative studies. Many experimental forests, especially those in western states, contain natural vegetation. This vegetation includes old forest established after wildfire, and forest plantations in a variety of age classes resulting from management since the establishment of the experimental forest. Some experimental forests, especially those in the eastern and southern United States, were established after a history of forest cutting, and in some cases farming and grazing; as a result, these forests represent abandonment of earlier land-use practices (e.g., Douglass and Hoover 1988). In at least one case (the Calhoun Experimental Forest, South Carolina), the site was picked to represent "the worst of the worst" in terms of past land-use impacts (Adams et al. 2004). Experimental ranges were generally representative of the regions in which they were established, and contained vegetation that was usually no more degraded than elsewhere in the locale. Plant communities on some experimental ranges represented grasslands, shrublands, and woodlands in very good condition. In all cases, the purpose of designating experimental forests and ranges was to learn how to restore and maintain forests so that the public could reap the full suite of products and services from forestlands.

Research at experimental forests and ranges

Research at many experimental forests and ranges involves a diverse portfolio of applied and basic studies with short- and long-term planning horizons. These studies employ a variety of approaches, including manipulative experiments, long-term observations, simulation modeling, and life history studies. The dominant research themes have focused on timely issues related to the utilization and conservation of natural resources (Adams et al. 2004). Among the major topics of applied research are (a) the effects of forest management practices, such as logging, grazing, road construction, prescribed fire, and soil fertilization, on streamflow, biogeochemical cycling, sediment yield, and water quality; (b) the effects of and ecological responses to insect and disease outbreaks; (c) the effects of floods, hurricanes, wildfire, and other natural disturbance processes on forests, stream biota, and streamwater quantity and quality; (d) wildlife population dynamics; and (e) life history traits and habitat requirements of plant and animal species of critical conservation concern.

Research programs at many individual experimental forests and ranges have changed progressively over time, with a general shift in focus from local, narrow, applied themes to a wider range of study themes of broad relevance, such as global and climate change science. For example, research at GLEES examines both (a) the effects of atmospheric deposition and climate change on alpine and subalpine aquatic and terrestrial ecosystems and (b) hydrology and biogeochemical balances in snow-dominated watersheds. Many experimental forest and range programs are now contributing long-term observations and studies on climate and atmospheric chemistry change, carbon dynamics, biodiversity, invasive species, ecohydrology, and land-use change. Hydrological and meteorological data collected at most experimental watersheds for decades, in some cases for as long as 70 years, are now easily accessed through a data harvester system (*www.fsl.orst.edu/climhy/hydrodb/*). Recent new analyses of these records from six experimental forests uncovered patterns of vegetation control on streamflow in diverse systems (Post and Jones 2001, Jones and Post 2004), and helped define an aspect of ecohydrology (Post et al. 1998).

As part of studies of carbon dynamics under the USDA Global Climate Change Program, scientists are linking intensive ground-based measurements of carbon stocks, forest growth, and climate from experimental forests with spatially extensive but coarse resolution measurements. Spatial data are acquired through remote sensing and forest inventory and linked to high-resolution measurements of carbon exchange between terrestrial ecosystems and the atmosphere made at AmeriFlux sites. Through this work, the investigators at the Bartlett Experimental Forest in New Hampshire, the Marcell Experimental Forest in Minnesota, the Fraser Experimental Forest in Colorado, and GLEES are linking landscape monitoring to carbon management at a scale relevant to local land management decisions.

The strong partnerships of agency and academic scientists have been an important factor in the evolution from a narrow focus on regional science to a broader perspective that also includes global change. These scientists have made it possible to conduct cutting-edge, interdisciplinary research on lands dedicated to long-term research missions. Strong working relationships among federal scientists, land managers, and academic scientists took root in the 1960s and 1970s (e.g., Douglass and Hoover 1988, Likens 2004). These partnerships grew in the 1970s, when several experimental forests and ranges became focal points for ecological research in the International Biological Program, and then in the 1980s, when LTER programs led to strong federal–academic science interactions.

At many experimental forests and ranges, strong partnerships between the research teams and land managers of the USDA Forest Service have been integral to the success of the science program and the flow of science findings to management. The science–management partnership is a two-way street. The land managers often have critical roles in implementing large experiments and identifying information research needs. The partnership also brings the science community into contact with current natural resource issues and with the public that is interested in them. Solutions to land management issues often call for interdisciplinary approaches to complex problems and involve trade-offs among different interests; addressing these types of issues pushes scientists to think more broadly. Scientists, for their part, bring a set of special skills and knowledge to the partnership.

Long-term applied studies of forest, watershed, and landscape management can be found on experimental forests and ranges. For example, adaptive management areas established under the Northwest Forest Plan (USDA FS/USDI BLM 1994) include two experimental forests and a 24,000-ha landscape management study conducted by modeling landscape change and actual land management (Cissel et al. 1999). Such shared activities build the science–management link so that new findings can quickly be applied over broad areas.

The sustained commitment of USDA Forest Service research properties to long-term ecological studies has resulted in experimental forests and ranges being the home of numerous notable, monumental experiments and observation platforms. In some cases, large-scale networks of science installations use experimental forests for the placement of instruments because of their security, commitment to research, and local staff to service equipment. Some of the developments initiated at USDA Forest Service sites operate at individual sites and others over multiple sites. Examples of research studies that originate at experimental forests and ranges include the following:

- Hundreds of silviculture experiments and long-term vegetation plots in unmanipulated forest stands throughout the experimental forest and range system
- Scores of paired experimental watershed studies (*www.fsl.orst.edu/climhy/hydrodb/*), including manipulations such as the one in the Fernow Experimental Forest in West Virginia, where an entire 34-ha forested watershed was treated with twice-ambient deposition of nitrogen and sulfur to evaluate the effects of elevated acidic deposition on forest ecosystem processes
- Long-term decomposition studies, such as the 10-year LIDET installed at many experimental forests (*www.fsl.orst.edu/lter/research/intersite/lidet.htm*) and the 200-year log decomposition study at the H. J. Andrews Experimental Forest (Harmon 1991)
- The Wind River Canopy Crane, a 76-m-tall construction crane that provides access for research within the canopy of Wind River Experimental Forest, a 2.3-ha, old-growth conifer forest in Washington (Shaw et al. 2004, Suchanek et al. 2004; *www.washington.edu/research/field/crane.html*)
- Long-term observational and experimental studies of soil restoration at the Calhoun Experimental Forest following abandonment after protracted agriculture for cotton (*Gossypium hirsutum*) and associated accelerated soil erosion (Richter and Markewitz 2001)
- Fencing at the landscape scale (e.g., 104 square kilometers) for experimental studies of species–species and species–habitat interactions involving herds of large mammals, such as elk (*Cervus elaphus*), deer (*Odocoileus hemionus*), and cattle (*Bos taurus*), and various forest and grazing management systems at Starkey Experimental Forest and Range (Adams et al. 2004; *www.fs.fed.us/pnw/starkey*)

Relevance to science, management, policy, and the public

These types of long-term studies have proved invaluable to both science and society because they have consistently produced new, important, and often unexpected findings (e.g., Likens 2004). Many environmental phenomena change gradually over time in response to natural forces, such as soil development and vegetation succession, and in response to human actions, such as changes in policies regulating natural resource management and chemical emissions to the atmosphere. The patterns and consequences of these incremental changes are revealed convincingly through long-term studies. The experimental forests and ranges network's long-term records of environmental change and experiments are proving to be a great resource for addressing contemporary science questions. New questions are addressed using new tools (e.g., chemical analyses, statistical techniques) on studies set up in the network decades ago for other purposes.

Natural resource management and policy at local, regional, and national scales has been profoundly affected by results of research from experimental forests and ranges. Studies that began as basic research, such as those on life history characteristics of individual species (e.g., the red cockaded woodpecker, *Picoides borealis,* and northern spotted owl, *Strix occidentalis caurina*), forest succession, air and streamwater chemistry, hydrological processes, the character of old-growth forests, the roles of dead wood in forests and streams, and hurricane disturbances, have yielded results of great social importance. Furthermore, important conceptual developments derived from studies at one location or in one forest type—for instance, variable density thinning in young stands to promote more complex structure—may find broad regional to national application. Even changes in federal legislation may have roots as simple as a chemical analysis of precipitation samples collected for decades at a backwoods rain gauge on an experimental forest (Likens 2004). The link between experimental forest research and public policy is significant enough to have encouraged an examination of the roles of experimental forest scientists in natural resource decision-making (Lach et al. 2003).

Public outreach is an integral part of any large research program today, and especially so if the work is close to the public's immediate interests. The public sees the national forests, drinks water from them, hikes in them, and hears debate about their use, so experimental forests and ranges can be a useful forum for communicating with the public about science and natural resources. Communication with the public can be as straightforward as the establishment and operation of an interpretive trail, such as the Management Loop Trail winding through an array of forestry and wildlife management demonstration areas of the Stephen F. Austin Experimental Forest in Texas (*www.srs.fs.usda.gov/wildlife/trail.htm*). Researchers and land managers working at experimental forests and ranges conduct thousands of tours annually for interested groups, communicate through the media, and create publications and Web sites for public use. Field tours and training programs for practicing forest and watershed managers and other interested members of the larger community are not only essential for communicating science findings but also important in helping the science and management communities to assess public attitudes about management issues.

Primary, secondary, postsecondary, and continuing education programs are integral components of experimental forest and range operations. College theses and dissertations are also a major component of the science work at experimental forests and ranges.

Overcoming barriers to developing a functional network of research sites

Several barriers hinder progress toward the goal of developing an integrated national network of research sites. These include (a) a limited history of network research, (b) chronic underfunding of research infrastructure and data management, (c) difficulties in accessing data from independent site files, (d) an absence of funding mechanisms for network research, and (e) mistrust of manipulative research at large scales. These five impediments are significant and cannot be ignored. However, they are not insurmountable, and must be resolved to assure that future research activity at networked sites is as effective in addressing current and emerging challenges as past research at individual sites was in solving earlier resource management problems. Overcoming these barriers will require cooperation and collaboration both within the Forest Service and with external partners and constituents.

In the past several decades, the Forest Service has made important advances in moving a subset of the experimental forests and ranges toward a functional network of ecological observatories. As we have commented, this has occurred mainly through cooperation with other networks (especially LTER, but also NASA). Notable accomplishments include data harvester systems (ClimDB, HydroDB), hydrological syntheses (Post et al. 1998, Post and Jones 2001, Jones and Post 2004), and cross-site decomposition experiments (Gholz et al. 2000). In these cases, the Forest Service contributed long-term experiments and data sets, and links with policy and management; the other research programs, principally involving academics supported by NSF funds, contributed the motivation and resources for intersite science. Both the Forest Service and collaborating programs contributed science staff.

Data management is a major challenge to all ecological research in the United States, one that is a priority for NSF in its LTER network. The Forest Service is collaborating with NSF to improve data management policies and procedures as both agencies focus on cross-site network research approaches. The NEON program affords a unique opportunity to improve data management protocols for ecological networks supported by both agencies. The limitation of research funding is a government-wide issue. Given the general state of federal funding for research, the most robust research networks will ultimately be built cooperatively across programs and institutions. Fortunately, the limited funding for network infrastructure has had little effect on archived long-term data in Forest Service custody and in established long-term field experiments.

Mistrust of manipulative studies often can be overcome with greater attention to public participation in the research enterprise when developing research objectives and design, implementing experimental treatments, and sharing the interpretation and application of study results. Citizens fully informed of the research goals and objectives of manipulative research, and invited to comment and participate in such research, have been supportive of research at experimental forests.

Strengthening existing research capacity and capitalizing on new initatives are factors that influence the path of future development of networks of ecological research sites. For the experimental forests and ranges themselves, we encourage developing the capacity of a selected subset of these forests and ranges, particularly through greater use by academics and other agencies and through improvements in data management and access. Recent initiatives by the chief of the Forest Service on alien species invasions, forest fires, unmanaged recreation, and loss of open spaces (Bosworth 2003, USDA FS 2004) all direct the Forest Service into cross-regional research programs with specific national-level objectives that should foster intersite research (USDA FS 2003, 2005). New initiatives, such as NEON and CUAHSI, will benefit greatly by capitalizing on the infrastructure of place, knowledge, and data from key experimental forests and ranges.

Conclusions

The network of experimental forests and ranges has many distinctive, valuable, and synergistic characteristics that could facilitate future broadscale research efforts. Many characteristics of these sites result from the management of research properties with a long-term perspective. Among the important characteristics are these:

- Long-term records of climate, vegetation, streamflow, and wildlife populations
- Archival records, knowledgeable staff, collections, and other information sources that collectively document the long-term history of these places and ecosystems
- Extensive geographic and ecological coverage in the United States and the Caribbean
- Close relations with a land management organization, the National Forest System, whose staff can help implement large-scale experiments and carry out land management operations, inform the science community of information needs, and test the use of the latest scientific findings
- The presence both of areas open to experimental manipulation and of control areas on most properties

- Long-term (multidecade), large-scale manipulative experiments
- A cadre of dedicated federal scientists and technical staff
- A land base formally designated for research and in operation for many decades, reflecting an institutional commitment
- Inclusion within other research and monitoring networks, which adds to the information base on the sites and their regional and global contexts
- Education and public outreach programs, which contribute to the two-way flow of information between the technical community and the public
- A commitment to keeping the network in the public domain, which means that it is open to the public and that collaboration with academia and other research organizations is encouraged

Research conducted in experimental forests and ranges has adapted over time in response to changing environmental challenges. The philosophy at the outset was to tackle land management problems at the local scale at which they occurred, as represented by the long-term experiments focused on different forest types and watersheds throughout the country. As the complexity of the environmental situation increased as a result of the larger-scale effects of human activity, research focused on whole landscapes and comparative studies across landscapes. We anticipate a future with even more complex challenges, involving climatic and global change, that force the biota and ecological processes of the world to adjust to the new environments created by human activity.

We believe the philosophy that created the experimental forests and ranges is just as relevant now as it was at the beginning of the 20th century. However, to tackle national and global issues at the proper scale will require the whole network to function as an integrated research platform. The network contains many environmental gradients, such as the climatic one illustrated in figure 2, and it is through long-term comparative research across those gradients that scientists will unravel the consequences of climate change and other global change. Developing such an integrated transcontinental program of long-term research, while maintaining strength at the local levels, is the next great challenge.

Critical emerging research themes for such a network will include the following:

- Long-term examination of the roles of global and climate change on carbon sequestration, water yield, changes in biodiversity, ecosystem productivity, and other ecosystem goods and services
- Long-term studies of silviculture, hydrology, fire ecology, and other aspects of vegetation change to explore alternative ways to balance wood extraction, carbon sequestration, development of specific habitat conditions for species of special interest, and restoration of degraded sites
- Landscape change detection analysis and studies to understand the causes and consequences of landscape change, such as fragmentation, urbanization, hydrological alterations, and patterns of species changes
- Research on the response of forests and rangelands to disturbances, both natural and anthropogenic, to provide greater insight when dealing with the expansion of invasive species

Through its network of experimental forests and ranges, the USDA Forest Service has provided significant opportunity for constructive blending of top-down funding support and oversight of a large, hierarchical organization, while permitting a great deal of research initiative by individual scientists, teams, and sites. The network of experimental forests and ranges serves as a useful model for development of long-term ecological and environmental observatories and as a prospective player in future networks.

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