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Forest Service Research and Development: Strategic Vision for the Experimental Forests and Ranges Network

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Cover: A wireless "Smart Forest" system, such as this installation at H.J. Andrews Experimental Forest in Oregon, allows real-time data and images from remote forest and stream sites to be transmitted to the Web. Photo by Sherri Johnson.

Abstract

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The 80 official experimental forests and ranges (EFR) administered by the U.S. Forest Service have provided a remarkable collection of research findings over the last 100 years, helping the agency address information needs related to forest and rangeland management. Long-term data sets are one of the most significant contributions of the EFR system, in particular, the ongoing, long-term studies of the effects of a changing climate on natural resources, streamflow, vegetation, and biogeochemistry from experimental watersheds. These data are crucial for examining ecosystem services from forests over time and are of sufficiently long duration now to be extremely valuable for quantifying the extent of changing climate. We describe a vision for building on the knowledge legacy of EFRs by joining them in a functional, coordinated research, outreach, and partnership network. We present a strategic analysis of options for implementing this network, including measurable criteria for evaluating the current and future potential of EFRs, identification of common minimum levels of infrastructure that could be shared by EFRs, and identification of the assets necessary so that the value of science and monitoring efforts can be maximized across a network of EFRs.

Keywords: Experimental forests and ranges, network, monitoring, data management, long-term database.

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Introduction

The 80 experimental forests and ranges (EFRs)[1] currently managed throughout the United States by the U.S. Department of Agriculture, Forest Service, are valuable assets. They have an impressive history of scientific contributions and are uniquely positioned to address current and emerging natural resource challenges. Our EFRs encompass an assortment of field sites covering more than 235,000 ha (580,000 acres). These sites (fig. 1) are located in almost every forested ecoregion in the Nation, and are found in 32 states and the Commonwealth of Puerto Rico. They offer a wide variety of historical data sets as old as 100 years, and have been used by hundreds of past and current Forest Service scientists, academic and other partners, and countless students pursuing undergraduate and graduate degrees. Basic and applied research activities on EFRs have provided a more thorough understanding of forested ecosystems and answers to pressing questions about how to manage public and private lands. They also have provided approaches to improve the effectiveness of management actions and better understand the potential unintended impacts of these activities, as well as strategies to mitigate or avoid these impacts. Most EFRs also have served as focal points for education and demonstration and as a venue for the interaction between land managers and scientists. These facilities offer some of the few places in the United States where ecological and land management research can be conducted over large areas and long time frames.

The leadership of the Forest Service's Research and Development (R&D) branch has important choices to make about EFRs. With the significant asset the EFRs represent comes both enormous potential and considerable responsibility. Until recently, each of the 80 EFRs was managed largely independently of the others, addressing issues of local importance. Recently, R&D has begun to recognize the potential of using networks of these sites (and those of collaborating partners) to address questions of regional to continental significance. Many of the sites already have prestigious reputations within the scientific community, but linking them in a network approach has large, untapped promise to explore scientific questions of broader significance.

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[1] In the draft revision to Forest Service Manual 4062—Experimental Forests, Ranges, Grasslands and Watersheds, these sites are technically referred to as "experimental areas." However, for purposes of this report, we will use the term "experimental forests and ranges," abbreviated as "EFRs."

Figure 1—Locations of Forest Service Research and Development facilities.

model, the existing buildings, scientific infrastructure, and research investments are maintained at considerable cost per site, with costs varying among EFRs. A more organized approach to scientific and facilities investment is required to realize the added value that these assets would offer as a network.

Purpose

This report represents a "Strategic Vision" for the future of the EFR network. Its goal is to evaluate an array of alternative paths that could be chosen for the future of the EFR network and present to Forest Service R&D leadership a recommended path. Each path carries with it different opportunities and associated required investments, and the six alternative paths presented offer a full spectrum of choices.

Scope and Format

To describe this strategic vision, we take a comprehensive look at the past, present, and future of the collection of EFRs and their potential as a functional network. It is intended to provide the full context for making important and difficult decisions about the future of this network. There are many different choices that Forest Service R&D leadership could make, and each choice carries significant implications for the future of each EFR, the network as a whole, and the rest of Forest Service research. We expect the array of information and data contained in this report to enable Forest Service R&D leadership to be well prepared to make the subsequent necessary decisions.

Background

History and Accomplishments

Our interest in managing and conserving forests dates back to the early years of the Nation. The reasons for this interest have evolved over time, but fundamentally we have always valued, and will continue to value, the wealth of what we now refer to as "ecosystem services" that come from forests throughout the United States. In 1882, in regard to fish and wildlife resources, prominent early zoologist and conservationist George Bird Grinnell explained this perspective as well as anyone might today: "No woods, no game; no woods, no water; and no water, no fish."

Early efforts to manage and conserve forests began before the turn of the 20th century. With these actions came the first steps toward learning how to manage forests. Academic institutions established schools dedicated to forestry and professional societies. The important contributions made and essential role performed by research in forest management were recognized very early on, as President Theodore Roosevelt stated in 1903 (Miller and Staebler 2004):

> I believe that there is no body of men who have it in their power today to do a greater service to the country than those engaged in the scientific study of, and practical application of, approved methods of forestry for the preservation of the woods of the United States.

The formal establishment of the Forest Service in 1905 was a milestone in our history of concern for the condition of our forests. The Forest Service initially hired many forestry graduates from universities to address the long list of challenges. Although the range of land and resource management challenges at the turn of the 20th century was quite different from the challenges managers now face in the early stages of the 21st century, the need for scientific information was already apparent, as was the importance of having a research arm to help guide management.

Although land and resource management challenges at the turn of the 20th century were quite different from the challenges that managers now face, the need for scientific information was already apparent, as was the importance of having a research arm to help guide management.

In the very early days of the Forest Service, as reported by Jeremy Young (2010), Raphael Zon, the first Chief of the Bureau of Silvics (the origin of the R&D branch of the Forest Service) argued for what he believed to be one of the Forest Service's most significant achievements in its early years, the creation of:

> … the experiment stations in the West … (which) are now building the scientific foundation upon which the future practice of American forestry is to rest (1913).

At the very onset of the Forest Service, Zon made the case to the first Forest Service Chief, Gifford Pinchot, that there was a need for data to support forest management recommendations (Young 2010). He developed a 23-page plan for creating "Forest Experiment Stations" that included a model new to the United States. Under it, experimental work would be carried out under independent direction through permanent forest experiment stations. Based on the ideas of Zon and Bernard Fernow (Chief of the Department of Agriculture Division of Forestry and later first Dean of the Cornell School of Forestry), and with Pinchot's leadership, the first experimental forest was established in 1908.

The legislative history pertaining to EFRs includes two significant milestones. Although several experimental forests had been previously established, the McSweeney-McNary Act in 1928 set the stage for designation of most of the experimental forests that now exist. The act authorized and directed the Secretary of Agriculture:

> … to conduct such investigations, experiments, and tests as he may deem necessary …. in order to determine, demonstrate, and promulgate the best methods of reforestation and of growing, managing, and utilizing timber, forage, and other forest products, of maintaining favorable conditions of water flow and the prevention of erosion, of protecting timber and other forest growth from fire, insects, disease or other harmful agencies, of obtaining the fullest and most effective use of forest land, and to determine and promulgate the economic considerations which should underlie the establishment of sound policies for the management of forest land and the utilization of forest products.

A full 50 years later, a more contemporary point of view was given to the legislative direction. With the passage of the Forest and Rangeland Renewable Resources Research Act of 1978, Congress found that:

> Scientific discoveries and technological advances must be made and applied to support the protection, management, and utilization of the nation's renewable resources. It is the purpose of this Act to authorize the

Secretary of Agriculture to implement a comprehensive program of forest and rangeland renewable resources research and dissemination of the findings of such research.

Section 4(a) of the act stated, "In implementing this Act, the Secretary is authorized to establish and maintain a system of experiment stations, research laboratories, experimental areas and other forest and rangeland research facilities."

Our ability to conduct scientific research, to apply our research findings on the public lands managed by the Forest Service, and to transmit the lessons we learn, sets us apart as a natural resource agency. The U.S. Fish and Wildlife Service and National Park Service once had a similar relationship between their research and management branches, but that was changed in the early 1990s when research was removed from these two bureaus and ultimately placed within a separate bureau, the U.S. Geological Survey. The National Park Service and Fish and Wildlife Service continue to aspire to re-develop their own research capabilities.

As a resource management agency, the Forest Service has unique and valuable opportunities to apply the findings of its R&D branch toward its land management responsibilities. The EFR network is central to the capabilities to achieve this application. The development of these sites and their respective accomplishments over the last 100 years, largely through very modest and uncoordinated financial and staff support, has been remarkable. Where will this irreplaceable asset be in another 100 years?

We must reexamine and further define our direction for the management and use of EFRs. We must also revitalize the relationship between the National Forest System (NFS) and Forest Service R&D branches to appropriately manage those lands designated as EFRs. This Strategic Vision provides a foundation from which we can take that important fresh and thorough look at the forest and range management challenges of today and tomorrow, and how we can strategically and effectively apply EFR assets to those tasks.

Overview of the Current EFR Network

We have 80 official EFRs; this designation includes all locations where "establishment records" have been prepared and approved by the Chief of the Forest Service according to FSM 4062 direction. The content of establishment records, and the process by which each is prepared and approved, are specifically described in FSM 4062.1. Six are titled to and managed solely by Forest Service R&D, eight are on state lands, two are on combinations of state and NFS lands, one is on Bureau of Land Management (BLM) land, one is on private land, and 62 are on NFS lands (table 1). Each of the EFRs is directed and managed by the research station in whose area it is located.

Of the 80 current EFRs, 65 were established by 1960; the first was Fort Valley EF in northern Arizona, established in 1908. Only 15 new EFRs have been added in the last 50 years; the most recent addition was Héen Latinee EF in southeast Alaska, established in 2009. Over 30 previously designated EFRs have been eliminated in the last 25 years as support for infrastructure maintenance and for collection and maintenance of long-term experiments and data sets has declined. Inadequate clarity of responsibilities between R&D and NFS has also diminished support. In addition, although there are advantages to decentralization of R&D management and operations, it is difficult to direct and execute a national network under the current organizational structure, in which each research station directs its own program.

Unlike the NEPA process typically conducted on National Forest System projects, a given research study is not one of several alternatives. Studies are designed to test specific hypotheses, and the only other alternative is not to do the study.

EFRs were established to promote and facilitate research. However, conflicting resource demands and growing complications in the area of land management administration threaten the viability of continued research opportunities on these EFRs. The challenges of managing the 80 EFRs differ around the country. Regulatory mandates for NFS lands are not designed for the special needs of EFRs (Adams et al. 2004), in that it can be difficult to navigate the National Environmental Policy Act (NEPA) and National Forest Management Act (NFMA) requirements for manipulative experiments. Authority for management decisions and the application of regulations has been uncertain; the respective roles of line officers in the NFS and R&D are often not clear. The application of NEPA on EFRs has a different contextual setting than on other national forest lands. First, R&D activities on EFRs do not implement forest plans. Rather, they implement selected research studies within the Forest Service R&D program areas. Research Work Unit Descriptions, in particular, usually have a 5-year time frame. A delay of 18 months to 2 years for initiating research and demonstration projects stemming from NEPA requirements adversely affects the ability to expeditiously implement research programs. In addition, unlike the NEPA process typically conducted on regular NFS projects, a given research study is not one among several alternatives that could be implemented. Studies are designed to test specific hypotheses, and the only other alternative is not to do the study.

Another issue is non-research use of EFRs (on NFS lands), which may conflict with the research mission for which EFRs were established. These non-research uses potentially affect existing studies and preclude future research opportunities. Often, regions, forests, or districts allow uses or make land use decisions that conflict with the research mission. This includes the encouragement of recreational activity and development of recreational attractions (e.g., trails) within EFRs. Current policy and provisions of the NFMA and regulations and directives pursuant to this act and others are impeding the ability of scientists to conduct research programs needed for prudent forest management on these experimental

Table 1—USDA Forest Service experimental forests and ranges (see fig. 3 for locations)

Number	Name	Station	Region	Land ownership/ managment	State or territory	Year established	Acres
1	Estate Thomas EF	IITF	None	IITF	U.S. Virgin Islands	1964	148
2	Luquillo EF	IITF	8	El Yunque NF	Puerto Rico	1956	27,890
3	Argonne EF	NRS	9	Chequamegon-Nicolet NF	Wisconsin	1947	6,499
4	Bartlett EF	NRS	9	White Mountain NF	New Hampshire	1931	2,600
5	Big Falls EF	NRS	None	Minnesota state land	Minnesota	1961	2,040
6	Coulee EF	NRS	None	Wisconsin state land	Wisconsin	1960	3,000
7	Cutfoot EF	NRS	9	Chippewa NF	Minnesota	1932	3,100
8	Dukes (Upper Peninsula) EF	NRS	9	Hiawatha NF	Minnesota	1926	5,500
9	Fernow EF	NRS	9	Monongahela NF	West Virginia	1934	4,700
10	Harshaw Farm	NRS			Wisconsin	1972	540
11	Hubbard Brook EF	NRS	9	White Mountain NF	New Hampshire	1955	7,750
12	Kane EF	NRS	9	Allegheny NF	Pennsylvania	1932	3,463
13	Kaskaskia EF	NRS	9	Shawnee NF	Illinois	1942	2,150
14	Kawishiwi EF	NRS	9	Superior NF	Minnesota	1931	116
15	Lower Peninsula EF	NRS	9	Huron-Manistee NF	Michigan	1954	3,400
16	Marcell EF	NRS	9	Chippewa NF, State of Minnesota, Itasca County, and private landowners	Minnesota	1962	2,219
17	Massabesic EF	NRS	None	NRS	Maine	1939	3,700
18	Paoli EF	NRS	9	WayneHoosier NF	Indiana	1963	632
19	Penobscot EF	NRS	None	University of Maine Foundation	Maine	1950	4,000
20	Pike Bay EF	NRS	9	Chippewa NF	Minnesota	1932	3,914
21	Silas Little EF (Lebanon)	NRS	None	State of New Jersey and FS	New Jersey	1933	590
22	Sinkin EF	NRS	9	Mark Twain NF	Missouri	1950	4100
23	Udell EF	NRS	9	HuronManistee NF	Michigan	1961	3800
24	Vinton Furnace EF	NRS	None	Ohio state land	Ohio	1952	1,201
25	Bonanza Creek EF	PNW	None	Alaska state land	Alaska	1963	12,486
26	Cascade Head EF	PNW	6	Siuslaw NF	Oregon	1934	12,424
27	Entiat EF	PNW	6	Wenatchee NF	Washington	1957	4,619
28	Héen Latinee EF	PNW	6	Tongass NF	Alaska	2009	25,595
29	H.J. Andrews EF	PNW	6	Willamette NF	Oregon	1948	15,852
30	Maybeso EF	PNW	10	Tongass NF	Alaska	1956	10,996
31	Pringle Falls EF	PNW	6	Deschutes NF	Oregon	1931	11,053

Table 1—USDA Forest Service experimental forests and ranges (continued)

Number	Name	Station	Region	Land ownership/ managment	State or territory	Year established	Acres
32	South Umpqua EF	PNW	6	Umpqua NF	Oregon	1951	650
33	Starkey EF&R	PNW	6	Wallowa-Whitman NF	Oregon	1940	27,506
34	Wind River EF	PNW	6	Gifford Pinchot NF	Washington	1932	10,811
35	Blacks Mountain EF	PSW	5	Lassen NF	California	1934	9,180
36	Caspar Creek EW	PSW	None	California state land	California	1962	2,243
37	Challenge EF	PSW	5	Plumas NF	California	1942	3,572
38	Hawaii Tropical EF	PSW	None	Hawaii state land	Hawaii	2007	48,228
39	North Mountain EF	PSW	5	BLM	California	1964	10,740
40	Onion Creek EF	PSW	5	Tahoe NF	California	1958	2,964
41	Redwood EF	PSW	5	Six Rivers NF	California	1940	1,240
42	Sagehen EF	PSW	5	Tahoe NF	California	2005	8,100
43	San Dimas EF	PSW	5	Angeles NF	California	1933	17,154
44	San Joaquin ER	PSW	None	PSW	California	1934	4,542
45	Stanislaus-Tuolumne EF	PSW	5	Stanislaus NF	California	1943	1,700
46	Swain Mountain EF	PSW	5	Lassen NF	California	1932	6,155
47	Teakettle EF	PSW	5	Sierra NF	California	1938	32,113
48	Black Hills EF	RMRS	2	Black Hills NF	South Dakota	1961	3,436
49	Boise Basin EF	RMRS	4	Boise NF	Idaho	1933	8,736
50	Coram EF	RMRS	1	Flathead NF	Montana	1933	7,326
51	Deception Creek EF	RMRS	1	Idaho Panhandle NF	Idaho	1933	3,520
52	Desert ER	RMRS	None	RMRS	Utah	1933	55,575
53	Fort Valley EF	RMRS	3	Coconino and Kaibab NF	Arizona	1908	5,261
54	Fraser EF	RMRS	2	Arapaho-Roosevelt NF	Colorado	1937	22,991
55	Glacier Lake Ecosystem ES	RMRS	2	Medicine Bow NF	Wyoming	1994	1,482
56	Great Basin ER	RMRS	4	MantiLaSal NF	Utah	1912	4,597
57	Long Valley EF	RMRS	3	Coconino-Sitgreaves NF	Arizona	1936	2,534
58	Manitou EF	RMRS	2	Pike San Isabel NF	Colorado	1936	16,692
59	Priest River EF	RMRS	1	Idaho Panhandle NF	Idaho	1911	6,397
60	Sierra Ancha ER	RMRS	3	Tonto NF	Arizona	1932	13,249
61	Tenderfoot Creek EF	RMRS	1	Lewis and Clark NF	Montana	1961	9,123
62	Alum Creek EF	SRS	8	Ouachita NF	Arkansas	1959	4,658
63	Bent Creek EF	SRS	8	Pisgah NF	North Carolina	1925	6,301
64	Blue Valley EF	SRS	8	Nantahala NF	North Carolina	1964	1,300
65	Calhoun EF	SRS	8	Sumter NF	South Carolina	1947	5,135

Table 1—USDA Forest Service experimental forests and ranges (continued)

Number	Name	Station	Region	Land ownership/ managment	State or territory	Year established	Acres
66	Chipola EF	SRS	None	Southern Research Station	Florida	1952	640
67	Coweeta Hydrologic Lab	SRS	8	Nantahala-Pisgah NF	North Carolina	1934	5,482
68	Crossett EF	SRS	8	Ouachita NF	Arkansas	1934	1,680
69	Delta EF	SRS	None	Mississippi state land	Mississippi	1945	2,580
70	Escambia EF	SRS	None	Cedar Creek Land and Timber, Inc.	Alabama	1947	3,000
71	Harrison EF	SRS	8	Desoto NF	Mississippi	1934	4,107
72	Hitchiti EF	SRS	8	Oconee NF	Georgia	1946	4,735
73	Henry R. Koen EF	SRS	8	Ozark-St. Francis NF	Arkansas	1950	720
74	Olustee EF	SRS	8	Osceola NF	Florida	1931	3,135
75	Palustris EF	SRS	8	Kisatchie NF	Louisiana	1935	7,500
76	Santee EF	SRS	8	Francis Marion NF	South Carolina	1937	6,101
77	Scull Shoals EF	SRS	8	Oconee NF	Georgia	1959	4487
78	Stephen F. Austin EF	SRS	8	Angelina NF	Texas	1945	2649
70	Sylamore EF	SRS	8	Ozark-St. Francis NF	Arkansas	1934	4290
80	Tallahatchie EF	SRS	8	Holly Springs NF	Mississippi	1950	3499
							609,893
Cooperating experimental forests and ranges:							
1	Caribou-Poker Creek RW	PNW	None	Alaska state land	Alaska	1969	25,688
2	Olympic Experimental State Forest			State of Washington	Washington	none	Washington state land
3	Baltimore Ecosystem Study	NRS	9	Diverse public, private and community lands	Maryland	1997	1,660,548
4	Howland Forest	NRS	None	Northeast Wilderness Trust	Maine	1984	558
5	Swanton Pacific Ranch	PSW	None	California Polytechnic State University	California	2015	3,200
							1,924,306

BLM = Bureau of Land Management; EF = experimental forest; ER = experimental range; NF = national forest; IITF = International Institute of Tropical Forestry; NRS = Northern Research Station; PNW = Pacific Northwest Research Station; PSW = Pacific Southwest Research Station; RMRS = Rocky Mountain Research Station; SRS = Southern Research Station.

sites. As a result, however, revisions to FSM 4062 are in progress and should improve Forest Service R&D's ability to manage EFRs for their intended purpose.

The past and current research and monitoring agendas of the 80 EFRs each reflect their individual purpose for being established. Over the history of EFR establishment, there was no intention or expression of a common template for all EFRs. Some have focused on one or two topics such as silviculture or genetics research. Others, especially the more recent additions, have a broader ecosystems orientation and tend to be larger in area. The size and configuration of the EFRs reflects these varying purposes. Figure 2 displays the range of size classes among the 80 EFRs. Of the total, 18 are smaller than 1000 ha (2,500 ac) while 16 are larger than 4000 ha (10,000 ac). Size and configuration clearly dictate what kind of research is possible. Three recent additions to the system, Sagehen EF, Hawaii Tropical EF, and Héen Latinee EF, demonstrate a trend toward larger experimental forests that have the capacity to examine questions at a landscape scale and thus address some of the emerging concerns of land managers that manifest at that larger spatial scale. There is also the dramatic need for a new research and monitoring frontier in long-term forest research along the entire rural to urban gradient, specifically the urban ecological community.

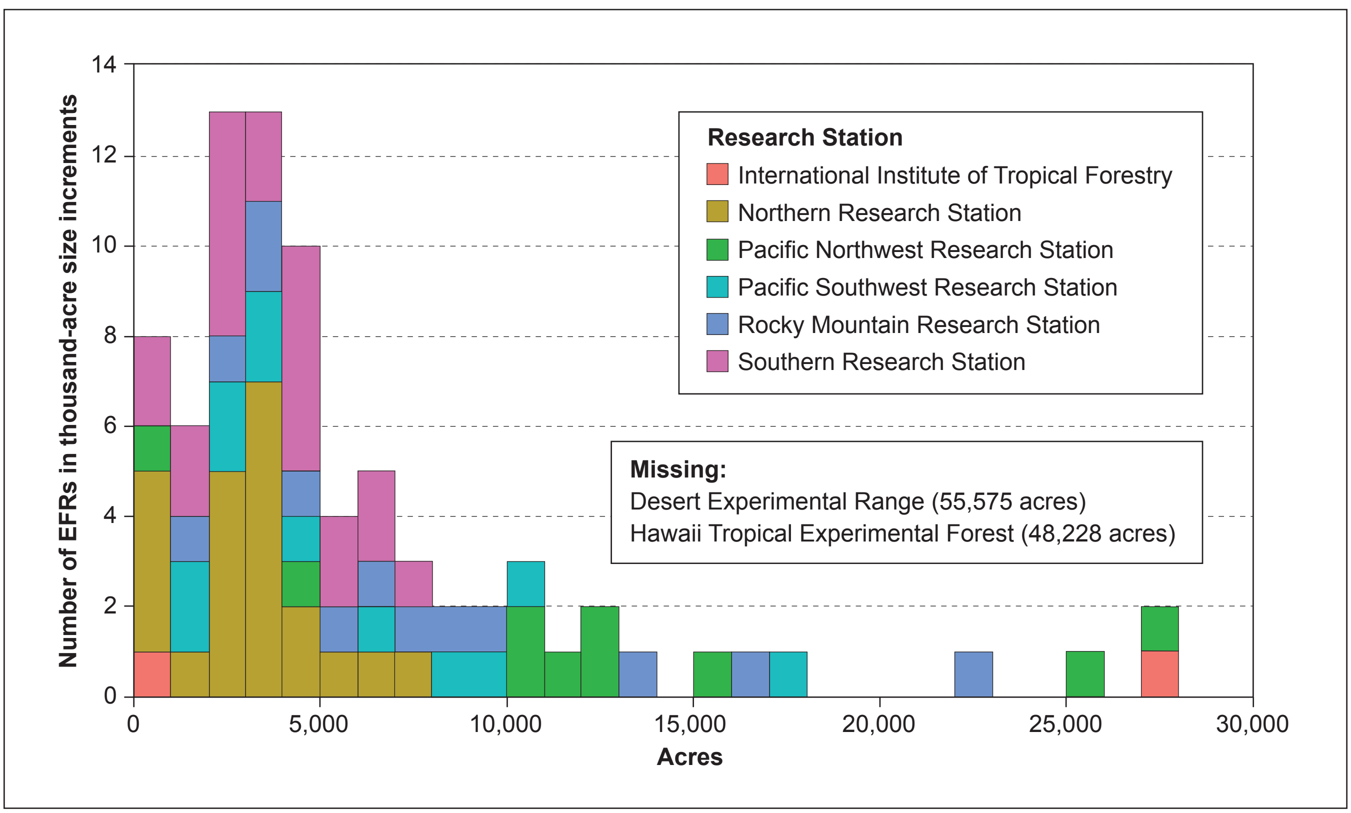

Figure 2—Range of size classes of the 80 experimental forests and ranges.

Ecosystem Diversity of EFRs

The diversity of ecoregion types represented by the existing 80 sites is remarkable. Under the Bailey Ecoregion schema (Bailey 1995) the United States includes four ecological domains, 25 ecological divisions, and 52 ecological provinces. The ecological domains level is too coarse for a meaningful examination of representation; however, the ecological division and ecological province scales provide insight into how well the 80 EFRs represent the ecological diversity of the United States.

Do the current 80 EFRs represent this ecological diversity? Figure 3 illustrates how the 80 EFRs are distributed amongst the ecological divisions and provinces. Among the 25 ecological divisions in the Bailey Ecoregion schema (which includes

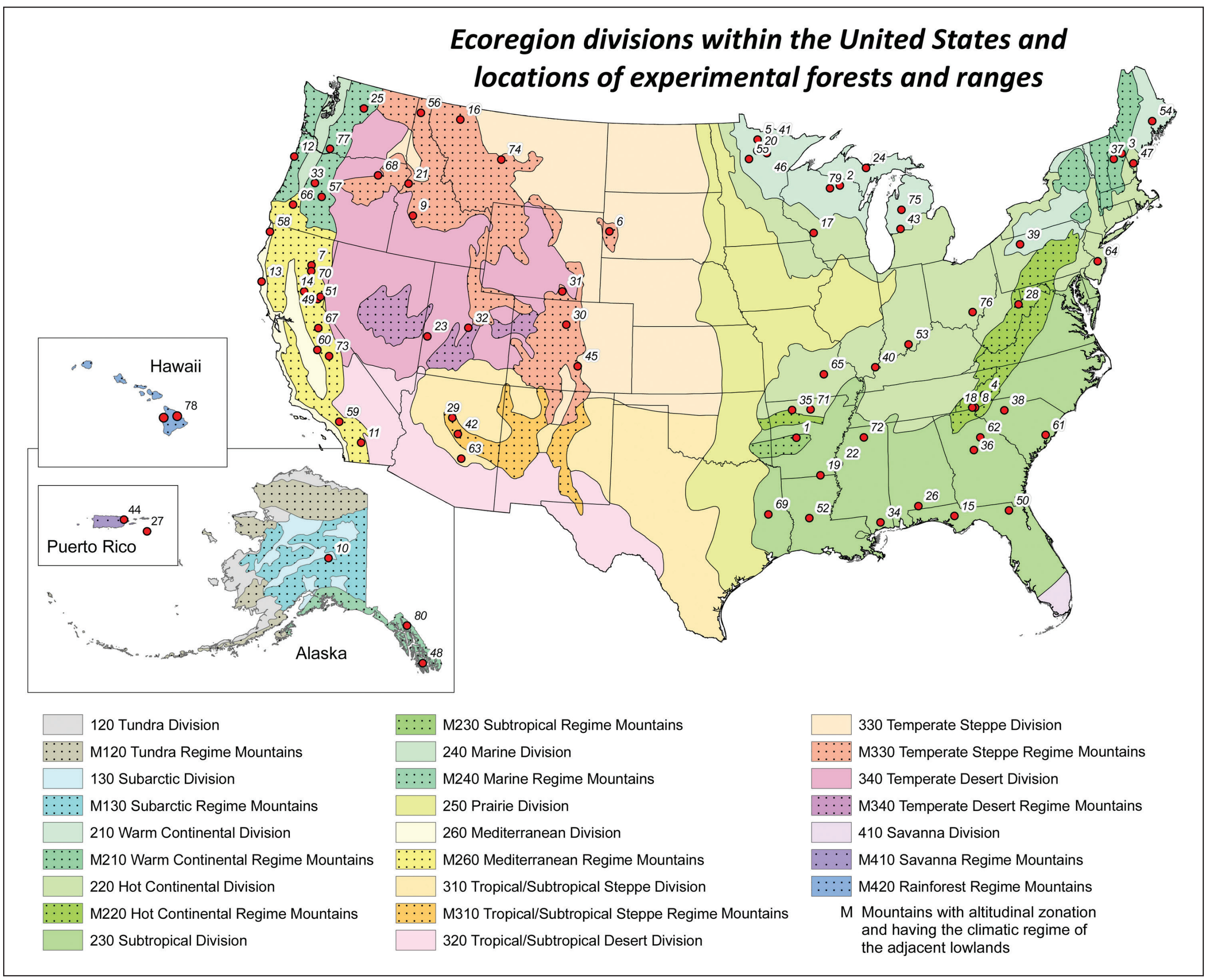

Figure 3—Distribution of experimental forests and ranges among the Bailey Ecoregion system of ecological divisions and provinces.

With the exception of the subarctic taiga forest type, a strong case can be made that, at the ecological division level, the distribution of existing EFRs well represents the diversity of forest and rangeland types throughout the United States.

both lowland and mountainous terrain as separate divisions) five are assumed to have little to no forest or shrubland and do not enter into this analysis (table 2). Of the remaining 20, only four, Subarctic, Hot Continental, Tropical/Subtropical Steppe, and Temperate Desert may be underrepresented (as defined by <1 EFR per 100,000 square km). The Hot Continental Division, essentially the lowland hardwood forests of the Midwest and East, is large and contains eight EFRs, but still is slightly underrepresented given the threshold (i.e., numbers of EFRs per unit area) defined above. The Subarctic Division is dominated by boreal forest. The other two divisions are sparse shrubland and each has one or more EFRs. With the exception of the subarctic taiga forest type, a strong case can be made that, at the ecological division level, the distribution of existing EFRs well represents the diversity of forest and rangeland types throughout the United States at this level of analysis.

Table 2—Ecoregion divisions in the experimental forests and range (EFR) network

Ecoregion division	Code	Area of division	Number of EFRs	Number per 100 000 km^2
		Square kilometers		
Subarctic	130	219 700	0	
Subarctic Mountains	M130	477 700	1	0.2
Warm Continental	210	381 507	12	3.1
Warm Continental Mountains	M210	112 924	2	1.8
Hot Continental	220	969 955	8	0.8
Hot Continental Mountains	M220	192 955	5	2.6
Subtropical	230	1 064 749	13	1.2
Subtropical Mountains	M230	22 792	1	4.4
Marine	240	38 591	0	
Marine Mountains	M240	303 807	7	2.3
Mediterranean	260	88 319	2	2.3
Mediterranean Mountains	M260	241 388	11	4.6
Tropical/Subtropical Steppe	310	657 342	1	0.2
Tropical/Subtropical Steppe Mountains	M310	130 018	2	1.5
Temperate Steppe	330	1 099 973	0	
Temperate Steppe Mountains	M330	585 081	9	1.5
Temperate Desert	340	689 458	3	0.4
Temperate Desert Mountains	M340	112 924	0	
Savanna Mountains	M410	9 583	2	20.9
Rainforest Mountains	M420	16 835	1	5.9
			80	

Divisions in boldfaced type: like a domain without appreciable forest or shrub cover.
Divisions in italic type: less than one experimental forest and range per 100,000 km^2, possible a deficit.
Note: Some divisions, those unlikely to have any forest or shrublands, are not included in this analysis: Tundra, 120; Tundra Mountains, M120; Prairie, 250; Tropical/Subtropical Desert, 320; and Savanna, 410.

At the Bailey (1995) ecological province level, perhaps the most appropriate level at which to examine representativeness, there are 52 ecological provinces across the United States. Nineteen of the 52 do not have an appreciable amount of forest or shrubland/rangeland and do not figure into further analysis. Of the 33 remaining, as many as 12 appear to be underrepresented (defined by <1 EFR per 100,000 km^2) or may have no EFRs at all (table 3). A closer look suggests that two of those 12, Eastern Broadleaf Forest (the lowland hardwood forests of the Ohio Valley and portions of the upper Midwest), and Intermountain Semidesert/Desert (the high desert portion of the Great Basin in Nevada and Utah) have five and two EFRs within them, respectively, and are close to the threshold (both at 0.7 per 100,000 km^2). Four of the 12 ecological provinces, Alaska Range, Lower Mississippi

Table 3—Ecoregion provinces in the experimental forests and range (EFR) network

Ecoregion province	Code	Area	Percentage of extent in United States	Number of EFRs within province	Number of EFRs per 100,000 km^2
		Thousands of square kilometers			
Arctic Tundra[b]	124	49.5	0.5	0	0
Bering Tundra (Northern)[b]	125	121.5	1.3	0	0
Bering Tundra (Southern)[b]	126	61.1	0.7	0	0
Brooks Range[b]	M121	263.1	2.8	0	0
Seward Peninsula[b]	M125	53.4	0.6	0	0
Ahklun Mountains[b]	M126	43.3	0.5	0	0
Aleutian[b]	M127	57.5	0.6	0	0
Yukon Plateaus Taiga[b,d]	131	145.3	1.6	0	0
Coastal Trough Taiga[b,d]	135	40.7	0.4	0	0
Upper Yukon Taiga[b,d]	139	33.7	0.4	0	0
Yukon Taiga–Meadow[c]	M131	142.5	1.5	0	0
Alaska Range[e]	M135	158.0	1.7	1	0.6
Upper Yukon Taiga–Meadow[c]	M139	177.2	1.9	0	0
Laurentian Mixed Forest[a]	212	381.5	4.1	12	3.1
Adirondack–New England[a]	M212	112.9	1.2	2	1.8
Eastern Broadleaf Forest (Oceanic)[e]	221	270.7	2.9	3	1.1
Eastern Broadleaf Forest (Continental)[e]	222	699.3	7.5	5	0.7
Central Appalachian[a]	M221	176.4	1.9	4	2.3
Ozark[a]	M222	16.6	0.2	1	6.0
Southeastern Mixed Forest[a]	231	499.9	5.4	6	1.2
Outer Coastal Plain Mixed Forest[a]	232	450.1	4.8	6	1.3
Lower Mississippi Riverine Forest[e]	234	114.7	1.2	1	0.9

Table 3—Ecoregion provinces in the experimental forests and range (EFR) network (continued)

Ecoregion province	Code	Area	Percentage of extent in United States	Number of EFRs within province	Number of EFRs per 100,000 km^2
		Thousands of square kilometers			
Ouachita[a]	M231	22.8	0.2	1	4.4
Pacific Lowland Mixed Forest[d]	242	38.6	0.4	0	0
Cascade[a]	M242	138.3	1.5	5	3.6
Pacific Coastal Mountains[a]	M244	103.6	1.1	1	1.0
Pacific Gulf[a]	M245	61.9	0.7	1	1.6
Prairie Parkland (temperate)[b]	251	565.1	6.1	0	0
Prairie Parkland (subtropical)[b]	255	207.5	2.2	0	0
California Coastal Chaparral[d]	261	26.7	0.3	0	0
California Dry Steppe[a]	262	49.7	0.5	0	0
California Coastal Steppe/Mixed Forest/ Redwood Forest[a]	263	11.9	0.1	2	16.8
Sierran[a]	M261	176.9	1.9	9	5.1
California Coastal Range[a]	M262	64.5	0.7	2	3.1
Great Plans Steppe and Shrub[b]	311	45.6	0.5	0	0
Colorado Plateau Semidesert[b]	313	195.0	2.1	1	0.5
Southwest Plateau/Plains Dry Steppe and Shrub[b]	315	416.7	4.5	0	0
Arizona-New Mexico Mountains[a]	M313	130.0	1.4	2	1.5
Chihuahuan Semidesert[b]	321	220.7	2.4	0	0
American Semidesert/Desert[b]	322	227.1	2.4	0	0
Great Plains/Palouse Dry Steppe[b]	331	752.9	8.1	0	0
Great Plains Steppe[b]	332	347.1	3.7	0	0
Southern Rocky Mountain[a]	M331	265.0	2.8	3	1.1
Middle Rocky Mountain[a]	M332	211.9	2.8	3	1.4
Northern Rocky Mountain[a]	M333	98.7	1.1	2	2.0
Black Hills[a]	M334	9.6	0.1	1	10.4
Intermountain Semidesert/Desert[e]	341	277.4	3.0	2	0.7
Intermountain Semidesert[e]	342	412.1	4.4	1	0.2
Nevada-Utah Mountains[d]	M341	112.9	1.2	0	0
Everglades[b]	411	20.2	0.2	0	0
Puerto Rico (also U.S. Virgin Islands)[a]	M411	9.6	0.1	2	20.9
Hawaiian Islands[a]	M423	16.8	0.2	1	5.9
Total		9 305.4		80	

[a] Likely sufficient representation.
[b] Likely an ecosystem type without appreciable forest or shrub cover.
[c] Unsure whether this ecosystem type should be considered.
[d] No representation.
[e] Perhaps a deficit of representation.

Riverine Forest, Colorado Plateau Semidesert, and Intermountain Semidesert, each have one EFR, but an argument could be made to consider adding another. Three of the 12 (Yukon Plateaus Taiga, Coastal Trough Taiga, Upper Yukon Taiga) are dominated by "taiga" or needle leaf forest, often referred to as boreal forest. The Taiga is the forested ecosystem most vulnerable to climate change.

The Holdridge life zone schema is another point of view from which to evaluate the ecological diversity of the current distribution of EFRs. This system provides an ecosystem classification approach that relies on simple and objective criteria of mean annual biotemperature, mean annual precipitation, and elevation to construct ecological units called life zones (Lugo et al. 1999). A primary advantage cited by some for using this schema is the empirical and objective-based criteria used to formulate the life zones. It also is based on climatic driving factors of ecosystem processes and recognizes ecophysiological responses of plants (Lugo et al. 1999). By using this approach, we find 38 life zones within the conterminous 48 states, including 1 boreal, 12 cool temperate, 20 warm temperate, four subtropical, and 1 tropical zone.

The total picture of the Holdridge life zones in the United States results in a somewhat different story of the distribution of EFRs across the country (fig. 4 and table 4). The warm temperate moist forest and cool temperate moist forest life zones occupy 23 percent and 16 percent of the continental United States, respectively. Each is well represented with 22 EFRs in the warm temperate moist forest and 12 EFRs in the cool temperate moist forest. However, many of the Holdridge life zones in the United States cover a very small proportion of the landscape. Most of the diversity in these life zones is found in the western United States where there is significant variation in elevation and humidity over relatively short distances. Approximately 30 of the 38 life zones are only found west of the Mississippi River and many of these (16) occupy less than 20,000 square kilometers. The ecological diversity of the western United States is clearly demonstrated using this ecoregional schema.

Nonetheless, EFR representation in life zones that are larger than 20,000 km^2 and have appreciable amounts of forest or scrub is still reasonably good. Four such life zones, however, contain no EFRs (fig. 4):

- Cool temperate subalpine moist forest (38,704 km^2)
- Warm temperate desert scrub (157,728 km^2)
- Warm temperate montane desert scrub (232,432 km^2)
- Warm temperate subalpine moist forest (149,520 km^2)

One could argue that none of these life zones represents landscapes with significant amounts of forest or rangelands; however, each of these life zones contains at

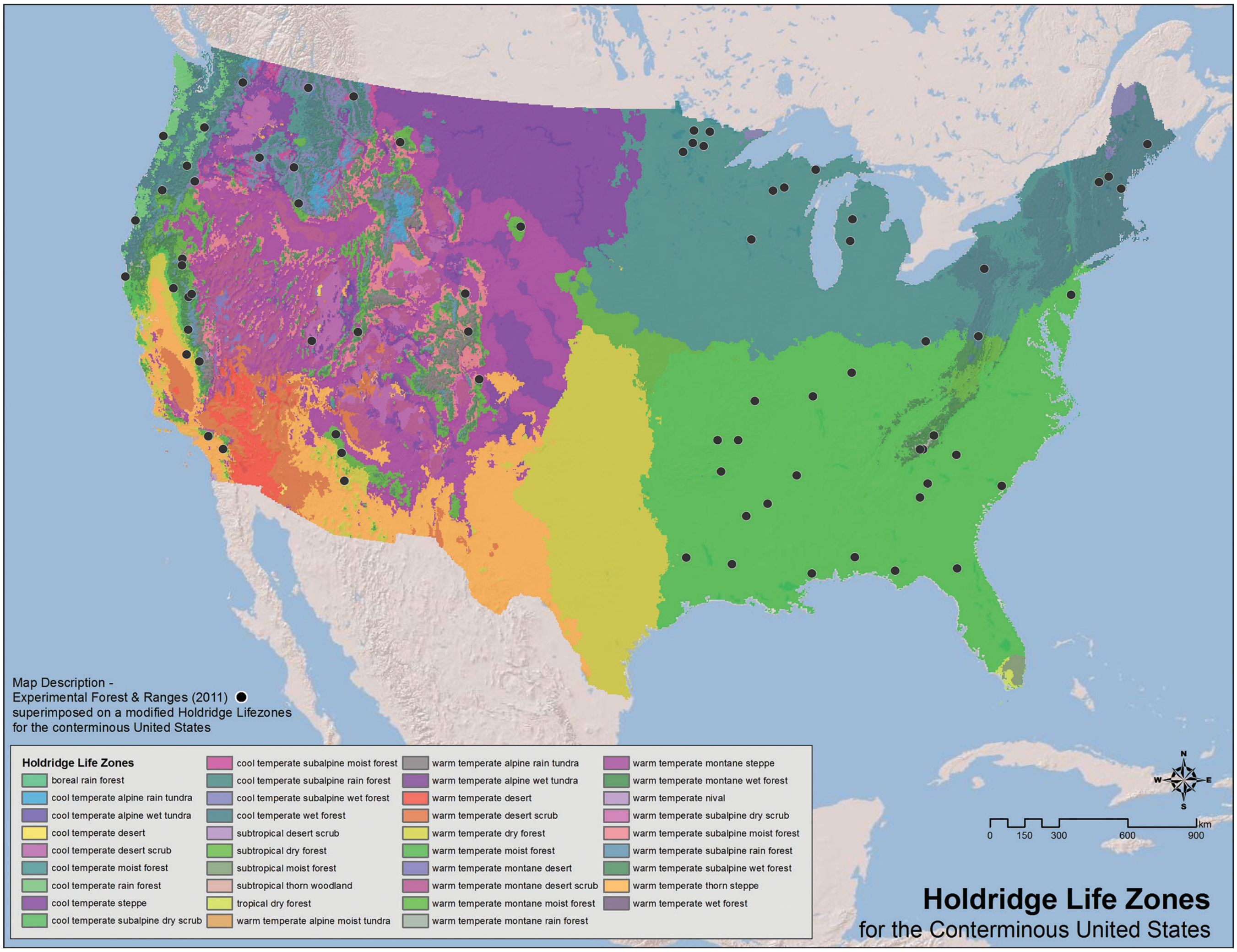

Figure 4—Distribution of experimental forests and ranges among the Holdridge Life Zones of the conterminous United States.

least modest amounts of shrub or tree cover. There are also two life zones that have one or two EFRs, but given their extent, may merit consideration for another EFR:

- Warm temperate dry forest (1 EFR on 708,000 km^2)
- Warm temperate thorn steppe (2 EFRs on 482,624 km^2)

Although the foregoing analysis using Holdridge life zones excludes the six EFRs found outside the contiguous 48 states, the schema for partitioning the landscape into Holdridge life zones can be applied to other localities. It is interesting to note that the Laupahoehoe Unit of the Hawaii Experimental Tropical Forest contains native-dominated forested landscapes from lowland forest at 2,300 feet (700 m) above sea level extending through four life zones to almost 6,200 feet (1890 m) in elevation. Héen Latinee in Alaska also has several life zones from sea level to high-elevation glaciers.

Facilities Assets on EFRs

Field research is the "bread and butter" of Forest Service R&D. The data that lead to the scientific findings, which fuel the publications that inform management and policy decisionmaking, are derived from spending time on the forests and ranges of the United States. Many logistical challenges to acquiring these data need to be considered when planning and executing research. These include:

- Traveling to field sites, sometimes long distances
- Accessing remote or difficult-to-reach field sites
- Selecting placement of study location sites
- Deploying instruments in the field
- Collecting the data (from deployed instruments or through direct observation)
- Consistency in how the data are collected and recorded
- Storing data in secure repositories
- Developing and executing safety procedures for employees
- Maintaining functional equipment
- Providing overnight facilities for field staff
- Converting data to accessible formats
- Adhering to field study protocols
- Ensuring safety in the field.

When a research program is designed, the focus is understandably on the scientific considerations of articulating the research question(s) or hypotheses, experimental and sampling design, anticipated data analyses, and expected applications of the results. None of this is possible, however, without logistical planning and execution. Facilities and other infrastructure have a profound influence on the ability of Forest Service research scientists and their collaborators to be successful.

The EFRs network has been incrementally built over time; each EFR has had to take an entrepreneurial approach to achieve what it can. Some have been notably successful in building a functional infrastructure with dormitories, laboratories, work buildings, and other facilities to support the research. Most EFRs have very modest facilities developed through one or two fleeting opportunities to establish a foundation for the field work. Because we have never had a comprehensive assessment of EFR facilities and other assets, we asked all research stations to assemble data on the facilities and capital equipment for each of their EFRs. The results of this survey are compiled in table 5.

Compiling such information is difficult. The success of such a call for data depends on an attentive and consistent response from dozens of different individuals or teams of scientists. Nonetheless, based on results through fiscal year 2011,

Table 5—Survey of investments and assets on experimental forests and ranges (EFRs), fiscal year 2011

Experimental forest or range	Salaries	Equipment	Materials and supplies	Travel	Fleet	G & A	Rent, communi-cations, utilities	Contracts	Training	Other personnel salary	Other	FRRE total
	FRRE research appropriated funds											
	Dollars											
International Institute of Tropical Forestry (IITF):												
Luquillo	957,433	12,905	210,508	3,796	29,280	166,780	—	—	—	—	—	1,380,702
Estate Thomas	9,000	None	3,766	3,000	—	—	—	—	—	—	—	15,766
IITF totals	966,433	12,905	214,274	6,796	29,280	166,780	—	—	—	—	—	1,396,468
Northern Research Station (NRS):												
Argonne EF	52,200	1,500	5,400	790	4,800	24,000	—	—	—	—	—	88,690
Bartlett EF	180,600	—	11,352	3,500	4,600	—	14,713	—	—	—	—	214,765
Big Falls EF	600	—	—	125	—	—	—	—	—	—	—	725
Coulee EF	675	—	—	250	—	—	—	—	—	—	—	925
Cutfoot EF	87,000	2,500	9,000	1,316	8,000	40,000	—	—	—	—	—	147,816
Dukes EF	20,400	500	1,800	263	1,600	8,000	—	—	—	—	—	32,563
Fernow EF	755,000	7,500	61,500	18,700	51,100	104,600	—	—	—	—	—	998,400
Harshaw EF	226,052	500	440,719			455,872	—	—	—	—	—	1,123,143
Hubbard Brook EF	500,900	31,527	34,624	12,667	13,300		10,489	—	—	—	6,576	610,083
Kane EF	174,362	1,000	4,799	—	8,111	12,000	—	—	—	—	—	200,272
Kaskaskia EF	—	—	—	—	—	—	—	—	—	—	—	—
Kawishiwi EF	1,975	—	—	—	—	—	—	—	—	—	—	1,975
Lower Peninsula EF	570	—	—	—	—	—	—	—	—	—	—	570
Marcell EF	423,000	10,000	90,000	500	25,000	70,000	—	—	—	—	—	618,500
Massabesic EF	105,410	—	4,206	1,000	6,700	15,000	1,629	—	—	—	—	133,945
Paoli EF	—	—	—	—	—	—	—	—	—	—	—	—
Penobscot EF	177,000	—	7,525	600	4,000	47,500	3,710	—	—	—	2,831	243,166
Pike Bay EF	17,400	500	1,800	263	1,600	8,000	—	—	—	—	—	29,563
Silas Little EF	287,031	25,247	15,000	8,000	6,800	128,000	—	—	—	—	—	470,078
Sinkin EF (long-term soil productivity study)	140,214	—	—	315	—	—	—	—	—	—	—	140,529
Sinkin EF	217,484	15,000	1,052	727	6,000	11,791	—	—	—	—	—	252,054
Udell EF	1,260	—	—	—	—	—	—	—	—	—	—	1,260
Vinton Furnace State EF	257,594	4,127	13,825	393	16,596	10,000	—	—	—	—	—	302,535
NRS totals	3,626,727	99,901	702,602	49,409	158,207	934,763	30,541	—	—	—	9,407	5,611,557

Table 5—Survey of investments and assets on experimental forests and ranges (EFRs), fiscal year 2011 (continued)

	FRRE research appropriated funds											
Experimental forest or range	Salaries	Equipment	Materials and supplies	Travel	Fleet	G & A	Rent, communi-cations, utilities	Contracts	Training	Other personnel salary	Other	FRRE total
							Dollars					
Pacific Northwest Research Station (PNW):												
Bonanza/Caribou O&M	43	—	919	—	—	—	—	—	—	—	—	962
Bonanza/Caribou Research	244,500	—		—	—	—	—	—	—	—	—	244,500
Cascade Head O&M	37,500	—	16,000	—	—	—	—	—	—	—	—	53,500
Cascade Head Research	12,500	—		—	—	—	—	—	—	—	—	12,500
Entiat O&M	35,631	6,892	7,489	967	1,922	6,400	—	—	—	—	—	59,300
Entiat Research	62,500	—	—	—	—	—	—	—	—	—	—	62,500
Héen Latinee O&M	12,500	—	—	—	—	—	—	—	—	—	—	12,500
Héen Latinee Research	31,250	—	—	—	—	—	—	—	—	—	—	31,250
H.J. Andrews O&M	55,832	—	—	—	—	130,000	—	—	—	—	—	185,832
H.J. Andrews Research	412,500	—	—	—	—	—	—	—	—	—	—	412,500
Maybeso O&M	775	825	—	—	—	—	—	—	—	—	—	1,600
Maybeso Research	31,250	—	—	—	—	—	—	—	—	—	—	31,250
Olympic	—	—	—	—	—	—	—	—	—	—	—	—
Pringle Falls O&M	—	—	—	—	—	—	—	—	—	—	—	—
Pringle Falls Research	150,160	10,600	150,160	21,545	14,840	43,491	—	—	—	—	—	390,796
South Umpqua O&M	—	—	—	—	275	—	—	—	—	—	—	275
South Umpqua Research	—	—	—	—	—	—	—	—	—	—	—	—
Starkey O&M	257,626	149,950	146,889	20,000	41,704	10,000	—	—	—	—	—	626,169
Starkey Research	456,459	—	—	—	—	—	—	—	—	—	—	456,459
Wind River O&M	4,775	—	11	1,143	56	—	—	—	—	—	—	5,985
Wind River Research	18,750	—	—	—	—	15,000	—	—	—	—	—	33,750
Corporate (PNW-wide)	30,000	—	—	—	—	—	—	—	—	—	—	30,000
PNW totals	1,854,551	168,267	321,468	43,655	58,797	204,891	—	—	—	—	—	2,651,628
Pacific Southwest Research Station (PSW):												
Blacks Mountain EF	—	—	—	—	—	—	—	—	—	—	—	—
Caspar Creek EW	—	—	—	—	—	—	—	—	—	—	—	—
Challenge EF	10,000	—	—	—	500	—	—	—	—	—	—	10,500
Hawaii Tropical EF	60,000	—	—	—	—	—	—	—	—	—	—	60,000
North Mountain EF	—	—	—	—	—	—	—	—	—	—	—	—
Onion Creek EF	—	—	—	—	—	—	—	—	—	—	—	—
Redwood EF	—	—	—	—	—	—	—	—	—	—	—	—
Sagehen EF	2,000	—	—	1,000	—	—	—	—	—	—	—	3,000
San Dimas EF	—	—	10,587	—	—	—	10,587	—	—	—	—	21,174
San Joaquin ER	59,159	—	11,271	—	—	—	11,271	—	—	—	—	81,701
Stanislaus-Tuolumne EF	102,000	—	—	1,000	3,500	80,000	—	—	—	—	—	186,500
Swain Mountain EF	—	—	—	—	—	—	—	—	—	—	—	—
Teakettle EF	33,886	—	80	—	5,000	—	80	—	—	—	—	39,046
PSW totals	267,045	—	21,938	2,000	9,000	80,000	21,938	—	—	—	—	401,921

Table 5—Survey of investments and assets on experimental forests and ranges (EFRs), fiscal year 2011 (continued)

	FRRE research appropriated funds											
Experimental forest or range	Salaries	Equipment	Materials and supplies	Travel	Fleet	G & A	Rent, communi-cations, utilities	Contracts	Training	Other personnel salary	Other	FRRE total
							Dollars					
Rocky Mountain Research Station (RMRS):												
Black Hills EF	—	—	—	3,363	—	—	—	—	—	—	—	3,363
Boise Basin EF	—	—	—	3,975	—	—	—	—	—	—	—	3,975
Coram EF	41,982	—	629	600	1,818	—	3,540	—	—	—	—	48,569
Deception Creek EF	—	—	—	1,988	—	—	—	—	—	—	—	1,988
Desert ER	46,237	—	500	1,062	—	—	—	—	—	—	—	47,799
Fort Valley EF	35,746	—	1,573	—	—	—	5,500	—	—	—	2,500	45,319
Fraser EF[a]	163,813	9,598	44,700	—	19,586	—	19,000	—	—	—	3,500	260,197
GLEES	63,267	—	2,799	3,000	25,200	—	7,221	14,521	1,000	—	—	117,008
Great Basin ER	26,235	—	844	909	—	—	—	—	—	—	—	27,988
Long Valley EF	—	—	—	—	—	—	—	—	—	20,000	—	20,000
Manitou EF[a]	—	—	79,316	—	—	—	—	—	—	—	—	79,316
Priest River EF	100,228	—	18,315	3,207	4,200	—	4,200	—	—	—	19,743	149,893)
Sierra Ancha EF	15,514	21,205	—	4,397	—	5,000	1,625	—	1,000	36,436	4,568	89,745
Tenderfoot Creek EF	—	—	565	7,500	4,764	—	—	10,285	1,500	—	47,916	72,530
RMRS totals	493,022	30,803	149,241	30,001	55,568	5,000	41,086	24,806	3,500	56,436	78,227	967,690
Southern Research Station (SRS):												
Alum Creek EF	50,643	3,000	500	—	2,204	15,000	—	—	—	—	—	71,346
Bent Creek EF	68,850		13,400	250	720		2,850	—	—	—		86,070
Blue Valley EF	1,000		—	—	75		—	—	—	—		1,075
Calhoun EF	—	—	—	—	—	—	—	—	—	—	—	—
Chipola EF	—	—	—	—	—		—	—	—	—	—	—
Coweeta EF	1,000,000	25,000	25,000	50,000	30,000	—	50,000	—	—	—	15,000	1,195,000
Crossett EF	233,460	12,908	21,770	5,403	16,232	—	5,500	—	—	—	3,500	298,773
Delta EF	3,000						500	—	—	—		3,500
Escambia EF	100,000	5,000	5,000	5,000	2,500	15,000	10,000	—	—	—	2,000	144,500
Harrison EF	87,960	48,000	10,000	—	9,000	—	13,030	—	—	—	2,000	169,990
Koen EF	12,000	200	—	500	400	—	3,000	—	—	—	—	16,100
Hitchiti EF	59,700	—	689	—	1,500	—	2,721	—	—	—	—	64,611
Olustee EF	—	—	—	—	—	—	—	—	—	—	—	—
Palustris EF	110,000	2,000	2,000	—	—	—	5,000	—	—	—	2,000	121,000
Santee EF	750,000	20,000	20,000	50,000	20,000	—	20,000	—	—	—	15,000	895,000
Scull Shoals EF	—	—	—	—	—	—	—	—	—	—	—	—
Stephen F. Austin EF	48,324	9,927	4,342	—	3,227	—	2,000	—	—	—	2,400	70,220
Sylamore EF	1,000		—	—	200		—	—	—	—	—	1,200
Tallahatchie EF	500	—	—	—	—	—	—	—	—	—	—	500
SRS totals	2,526,437	126,035	102,701	111,153	86,058	30,000	114,601	—	—	—	41,900	3,138,885
All stations totals	9,734,215	437,911	1,512,224	243,014	396,909	1,421,434	208,166	24,806	3,500	56,436	129,534	14,168,149

Table 5—Survey of investments and assets on experimental forests and ranges (EFRs), fiscal year 2011 (continued)

Experimental forest or range	FRF2 fire			Construction CM (incl. CMFC, FMCP09, CRRD, CRFR +)			All appropriated funding total	Outside funding
	FRF2	FRF2 G&A	FRF2 total	O&M	New	Total		
				Dollars				
International Institute of Tropical Forestry (IITF):								
Luquillo	—	—	—	175,000	—	175,000	1,555,702	1,600,000
Estate Thomas	—	—	—	—	—	—	15,766	—
IITF totals	—	—	—	175,000	—	175,000	1,571,468	
Northern Research Station (NRS):								
Argonne EF	—	—	—	—	—	—	88,690	—
Bartlett EF	—	—	—	41,468	—	41,468	256,233	—
BigFalls EF	—	—	—	—	—	—	725	—
Coulee EF	—	—	—	—	—	—	925	—
Cutfoot EF	56,000	—	56,000	—	353,559	353,559	557,375	—
Dukes EF	—	—	—	—	371,610	371,610	404,173	35,100
Fernow EF	43,000	—	43,000	12,000	—	12,000	1,053,400	88,600
Harshaw EF	—	—	—	1,000	—	1,000	1,124,143	190,614
Hubbard Brook EF	—	—	—	11,798	—		610,083	—
Kane EF	—	—	—	650	—	650	200,922	—
Kaskaskia EF	—	—	—	—	—	—	—	—
Kawishiwi EF	—	—	—	—	—	—	1,975	—
Lower Peninsula EF	—	—	—	1,000	371,610	372,610	373,180	100,000
Marcell EF	—	—	—	9,200	353,559	362,759	981,259	—
Massabesic EF	—	—	—	—	683,345	683,345	817,290	—
Paoli EF	—	—	—	—	—	—	—	28,212
Penobscot EF	—	—	—	15,394	—	15,394	258,560	
Pike Bay EF	—	—	—	—	353,559	353,559	383,122	92,500
Silas Little EF	—	85,000	85,000	—	—	—	555,078	—
Sinkin EF (long-term soil productivity study)	—	—	—	—	—	—	140,529	14,000
Sinkin EF	—	—	—	—	—	—	252,054	14,000
Udell EF	—	—	—	—	371,610	371,610	372,870	—
Vinton Furnace State EF	—	—	—	—	—	—	302,535	—
NRS totals	99,000	85,000	184,000	92,510	2,858,852	2,951,362	8,746,918	563,026

Table 5—Survey of investments and assets on experimental forests and ranges (EFRs), fiscal year 2011 (continued)

	FRF2 fire			Construction CM (incl. CMFC, FMCP09, CRRD, CRFR +)				
Experimental forest or range	FRF2	FRF2 G&A	FRF2 total	O&M	New	Total	All appropriated funding total	Outside funding
				Dollars				
Pacific Northwest Research Station (PNW):								
Bonanza/Caribou O&M	—	—	—	—	—	—	962	—
Bonanza/Caribou Research	—	—	—	—	—	—	244,500	—
Cascade Head O&M	—	—	—	—	—	—	53,500	—
Cascade Head Research	—	—	—	—	—	—	12,500	—
Entiat O&M	—	—	—	—	—	—	59,300	—
Entiat Research	—	—	—	—	—	—	62,500	—
Héen Latinee O&M	—	—	—	—	—	—	12,500	—
Héen Latinee Research	—	—	—	—	—	—	31,250	—
H.J. Andrews O&M	—	—	—	45,291	66,435	111,726	297,558	—
H.J. Andrews Research	—	—	—	—	—	—	412,500	—
Maybeso O&M	—	—	—	—	—	—	1,600	—
Maybeso Research	—	—	—	—	—	—	31,250	—
Olympic	—	—	—	—	—	—	—	—
Pringle Falls O&M	—	—	—	—	123,865	123,865	123,865	—
Pringle Falls Research	—	—	—	—	—	—	390,796	—
South Umpqua O&M	—	—	—	—	555,000	555,000	555,275	—
South Umpqua Research	—	—	—	—	—	—	—	—
Starkey O&M	—	—	—	32,300	28,357	60,657	686,826	—
Starkey Research	—	—	—	—	—	—	456,459	—
Wind River O&M	—	—	—	—	—	—	5,985	—
Wind River Research	—	—	—	—	—	—	33,750	—
Corporate (PNW-wide)	—	—	—	—	—	—	30,000	—
PNW totals	—	—	—	77,591	773,657	851,248	3,502,876	—
Pacific Southwest Research Station (PSW):								
Blacks Mountain EF	—	—	—	—	—	—	—	—
Caspar Creek EW	—	—	—	—	—	—	—	—
Challenge EF	—	—	—	—	—	—	10,500	74,000
Hawaii Tropical EF	—	—	—	—	—	—	60,000	—
North Mountain EF	—	—	—	—	—	—	—	—
Onion Creek EF	—	—	—	—	—	—	—	—
Redwood EF	—	—	—	—	—	—	—	—
Sagehen EF	—	—	—	—	—	—	3,000	—
San Dimas EF	—	—	—	—	—	—	21,174	—
San Joaquin ER	—	—	—	13,290	—	13,290	94,991	—
Stanislaus-Tuolumne EF	—	—	—	—	—	—	186,500	—
Swain Mountain EF	—	—	—	—	—	—	—	—
Teakettle EF	—	—	—	—	—	—	39,046	—
PSW totals	—	—	—	13,290	—	13,290	415,211	74,000

Table 5—Survey of investments and assets on experimental forests and ranges (EFRs), fiscal year 2011 (continued)

	FRF2 fire			Construction CM (incl. CMFC, FMCP09, CRRD, CRFR +)				
Experimental forest or range	FRF2	FRF2 G&A	FRF2 total	O&M	New	Total	All appropriated funding total	Outside funding
				Dollars				
Rocky Mountain Research Station (RMRS):								
Black Hills EF	—	—	—	—	—	—	3,363	—
Boise Basin EF	—	—	—	—	—	—	3,975	—
Coram EF	—	—	—	—	—	—	48,569	—
Deception Creek EF	—	—	—	—	—	—	1,988	—
Desert ER	—	—	—	—	—	—	47,799	480
Fort Valley EF	—	—	—	—	—	—	45,319	—
Fraser EF[a]	—	—	—	—	—	—	260,197	—
GLEES[a]	—	—	—	—	—	—	117,008	—
Great Basin ER	—	—	—	—	—	—	27,988	—
Long Valley EF	—	—	—	—	—	—	20,000	50,000
Manitou EF[a]	—	—	—	—	—	—	79,316	—
Priest River EF	—	—	—	—	—	—	149,893	—
Sierra Ancha EF	—	—	—	—	—	—	89,745	—
Tenderfoot Creek EF	—	—	—	—	495,000	495,000	567,530	—
RMRS totals	—	—	—	—	495,000	495,000	1,462,690	50,480
Southern Research Station (SRS):								
Alum Creek EF	—	—	—	—	—	—	71,346	
Bent Creek EF	—	—	—	—	—	—	86,070	
Blue Valley EF	—	—	—	—	—	—	1,075	
Calhoun EF	—	—	—	—	—	—	—	50,000
Chipola EF	—	—	—	—	—	—	—	50,000
Coweeta EF	—	—	—	—	—	—	1,195,000	250,000
Crossett EF	—	—	—	—	—	—	298,773	50,000
Delta EF	—	—	—	—	—	—	3,500	—
Escambia EF	—	—	—	—	—	—	144,500	—
Harrison EF	—	—	15,000	15,000	—	15,000	199,990	80,000
Koen EF	—	—	—	—	—	—	16,100	—
Hitchiti EF	—	—	1,022	1,022	—	1,022	66,655	—
Olustee EF	—	—	—	—	—	—	—	—
Palustris EF	—	—	—	—	—	—	121,000	—
Santee EF	—	—	—	—	—	—	895,000	—
Scull Shoals EF	—	—	—	—	—	—	—	24,000
Stephen F. Austin EF	—	—	—	—	—	—	70,220	—
Sylamore EF	—	—	—	—	—	—	1,200	—
Tallahatchie EF	—	—	—	—	—	—	500	—
SRS totals	—	—	16,022	16,022	—	16,022	3,170,929	504,000
All stations totals	99,000	85,000	200,022	374,413	4,127,509	4,501,922	18,870,092	1,191,506

a There are other categories that are not included such as rent, communications, utilities, training, contracts, and other personnel costs. Thus the total given for this unit is less than the true funding.

G & A = grants and agreements; O & M = operations and maintenance; EF = experimental forest; EW = experimental watershed; ER = experimental range.

we can see that the 80 EFRs are clearly not all functioning at the same capacity, something we certainly knew already. Of the 80 EFRs, 32 have no facilities of any note. Research done at these EFRs relies on access and support work (e.g., lab preparations, nursery activities, sleeping quarters, etc.) from offsite locations. Among the remaining 48 EFRs, there are roughly 90 buildings (offices, cabins, dormitories, and other space for human activities) for which Forest Service R&D has responsibility. Of these 48, most (roughly 40), have fairly substantial facilities (office buildings, cabins, bunkhouses, storage buildings, laboratories, workshops) onsite or nearby (i.e., accessible and of use to scientists working on the EFR). Sleeping facilities include roughly 325 beds, but most EFRs with sleeping facilities have between 2 and 10 beds. Four EFRs, H.J. Andrews (88), Luquillo (40), Priest River (26), and Manitou (23), account for over half of the total beds available. Some EFRs have substantial facilities for housing people, but they are operated by partner institutions (e.g., Hubbard Brook [Hubbard Brook Research Foundation], Sagehen [University of California at Berkeley], and Coweeta [University of Georgia]) and thus are not included in this assessment. Table 5 contains a compilation of data that roughly accounts for the facilities assets we have at our experimental forests.

Many of our facilities are quite old; inevitably, much of this inventory is in need of maintenance work. Some of these buildings, built in the 1930s and 1940s, have historical significance. There will be considerable challenges in the immediate future managing our portfolio of largely older infrastructure. Historical structures are more expensive and complicated to restore. Removal is a complicated process that takes time and money. Most of those that are not historical are also in need of typically expensive repairs. This issue will require careful thought to determine prudent solutions.

Information Assets on EFRs

Respondents to a survey thought that long-term research and its attending data sets (especially those from experimental forests) may be among the Forest Service's most valuable resources.

Information assets are a key legacy of any field-oriented research organization, whether biological field station, Long-Term Ecological Research (LTER) site, or EFR. The most familiar set of assets is the research data collected on the site. The significance of EFR research data was confirmed by a 2009 Customer Satisfaction Study conducted by the Claes Fornell International Group (CFI 2009) to assess satisfaction with FS R&D. Respondents were from both private and public sectors, with half (49 percent) self-identified as technical or professional and 15 percent as researchers. The study found that respondents thought long-term research and its attending data sets (especially those from experimental forests) may be among the most valuable resources that the Forest Service has. Despite this perceived importance, accessing these data can be very difficult even for scientists in FS R&D—as the problems associated with developing the air temperature series described in chapter 2 demonstrate.

Research data are increasingly recognized as valuable research products in their own right. For over a decade, EFRs participating in the National Science Foundation (NSF) LTER program have provided research data online in compliance with LTER network-wide data access policy. Recent developments illustrating this growing recognition include:

- NSF grant proposals must have a data management plan describing how data will be managed and shared after conclusion of the grant (2010)
- Joint Fire Sciences Program set a data management plan requirement similar to NSF, and created a program to archive data from previous JFSP projects (2011)
- USDA Scientific Data Management Committee and Working Group was created; the working group drafted a policy addressing the need to preserve and share USDA scientific data (2011).

Two other classes of EFR information assets are administrative data, including research project histories, and the EFR Web presence. The Web presence includes an internal component for communication among EFRs and an external component for communication with the global scientific community and the public. Each of these asset classes faces significant management challenges that the EFR community will need to address to maximize the success and impact of its research activities.

Current Costs of Operation

The collection of 80 EFRs presents a sizeable combined opportunity and challenge. These sites and their facilities have a significant capacity to enable the field results that are central to our mission. Our most successful EFRs have people dedicated to the activities of the site and well-developed facilities. The challenge comes from providing the staff to energize the activities on site and developing and maintaining the facilities, a considerable and continuous task.

The scientific staff necessary to support and energize an EFR varies from site to site. Not every site merits the same level of commitment, but we know from 100 years of experience that it is largely the initiative and drive of people involved in any given EFR that make an EFR successful. In this section, however, the focus is on the physical infrastructure that is so integrally important to the science that is achieved.

The physical infrastructure issues that need conscientious attention include:

- Maintenance of buildings
- Maintenance and updating of field instruments and other equipment
- Provision of utilities
- Road maintenance and access
- Fire safety
- Site security
- Safety of employees who use these facilities
- Communications (Internet access, telephone).

Based on the rather incomplete and inconsistent response to the national data call on recent annual investments in EFRs, we do not yet have a clear picture. Table 5 does convey, however, some insight into the level of investment in individual EFRs and EFRs as a group by research stations. Not surprisingly, estimates obtained from each research station show that Forest Service-wide expenditures on EFRs are declining.

Fiscal year	Forest and rangeland research expenditures	Construction expenditures
2010	$ 14,168,149	$ 4,501,922
2011	$ 12,074,825	$ 6,937,860
2012	$ 10,610,928	$ 913,539

Investments in construction and maintenance are also likely to decline, although they are more subject to the vagaries of need and opportunity. The American Recovery and Reinvestment Act recently provided an influx of funds in certain areas. In general, we expect this kind of funding to decline as well. Most of the Forest and Rangeland Research (FRRE) expenditures are in salaries, largely those of scientists who work at EFRs. Also included are support staff, site-management work, most equipment and supply purchases, and other things necessary to conduct research on the site. Although this measure of investment may be rough, it does suggest that currently all work on EFRs constitutes something less than 5 percent of the total R&D program. We did not previously have any quantifiable sense of this level of investment. Whether it is more or less than expected is worth pondering.

Investments parsed out by research stations also suggest some important insights. The Northern Research Station has the most EFRs (22 of 80—about 27 percent of the total) and invests about $5.6 million (FY 2010 figures), which is about 39 percent of the total in FRRE investments. The insight gained is that research stations have different business requirements and models for operating their respective stations and the EFRs within their area. There are some solid, explainable reasons for this (e.g., some research stations have several high-profile EFRs within their area) and it is also likely because of different priorities at each station.

Management Structure Supporting EFRs

The EFRs are managed by the respective research stations, each managing in its own way. This is a legacy of 100 years of managing EFRs as independent units.

There is also currently no independent budget line allocated to each individual EFR. Personnel, equipment, facilities, operation, and maintenance costs are accounted for as part of specific research projects or administrative costs at the research station level. We do have a job code assigned for EFR activities; however, the job codes are not mandatory to be used by scientists and administrative personnel who are conducting research or administrative tasks for the EFRs.

The EFRs are managed by the respective research stations, each managing in its own way. This is a legacy of 100 years of managing EFRs as independent units.

The Role of External Funding

Monies for operating the EFRs are largely from appropriated funds, but there are other sources that play an important role in the various aspects of EFRs. This includes both support for the scientific work (salaries, equipment, supplies, travel) and maintenance of the considerable physical infrastructure at the EFRs. The latter (e.g., facility repairs, utilities, etc.) is generally included in station or research program budgets, though the amount varies annually and across EFRs. Additional support for infrastructure maintenance on an EFR often comes from the host institution (typically a national forest). Funding for long-term studies on EFRs is allocated by the stations within program or work unit budgets. Forest Service scientists at EFRs are able to conduct long-term research and monitoring as long as the parent research stations are able to sustain this committed base funding. To the extent that the Forest Service supports EFR infrastructure, scientist and professional support salaries, and costs of data collection and publication, Forest Service scientists are able to engage in longer term research and monitoring projects than their university colleagues. This allows them to address management issues arising from natural or anthropogenic disturbances that may take many years, or longer, to appear.

Forest Service scientists can engage in longer term research and monitoring projects than their university colleagues, allowing them to address management issues arising from natural or anthropogenic disturbances that may take decades, or longer, to appear.

For many decades, Forest Service EFRs were funded almost exclusively with appropriated or base funds. Over the past 10 to 20 years, however, long-term research on EFRs has become increasing reliant on external funding. This is due to a number of factors, including shrinking operating budgets and the need to invest in research on emerging issues, which inevitably affects our ability to maintain the long-term studies that serve as the foundation of EFR work. This trend toward increasing reliance on external funding is underscored by research funded by the NSF through the LTER network. Of the 26 LTER sites, six are Forest Service EFRs (including Cooperating EFRs) that benefit directly and indirectly from NSF funding for the network. The annual funding support provided to these six EFRs is well over $10 million, which leverages additional millions of dollars of research and has resulted in many notable research results and significant contributions to the EFR network. Like the LTER program, there is also a new NSF initiative that involves several EFRs, the National Ecological Observatory Network (NEON). Although this program is just getting underway, it will bring some significant new work and attending investments to the seven EFRs that are involved in this program.

In addition to significantly reduced operating budgets, R&D has experienced a cultural shift toward greater emphasis on and reward for competitively awarded, external funds. There is a relatively recent organizational expectation that scientists will, to some degree, be self-funded, both because base funds are limited and because competitively awarded grants confirm the scientific merit of new work. In addition, the Research Grade Evaluation Guide acknowledges performance for scientists who have initiated original studies more than for those who are continuing studies initiated by their predecessors. In light of these factors, it is likely that the desire for and reliance on external funds for EFR work will increase in the future. This trend, however, will not enable the maintenance or additions needed for the infrastructure of our facilities. The support for facilities will likely have to continue coming from appropriated dollars.

The proportion of EFR budgets consisting of external funds is small overall (roughly less that 10 percent of the total EFR budget in FY 2011). Yet this amount varies across stations, ranging from 55 percent in IITF to 7 percent in RMRS and NRS. Although the majority of EFRs remains wholly Forest Service-funded, some receive a substantial portion of their funding (as much as 70 percent, but more commonly about 15 percent in FY 2011) from external sources. The use of external money is appropriate for LTER research and for newly initiated or short-term projects, but reliance on these sources of funding to cover expenses related to maintenance of long-term studies threatens the integrity of EFR research.

The value accumulated through past investments, and the importance of the EFRs to the Forest Service R&D portfolio, suggests that Forest Service R&D leadership will have important investment tradeoffs to consider. The long-term viability of EFRs will be affected by how we plan to balance the use and suitability of external and competitively awarded funds versus base funds. An evaluation of whether external money is necessary and desirable to support core EFRs research is warranted. There are significant risks if we cannot rely on the base research funding support to maintain the necessary infrastructure and long-term baseline monitoring.

Products and Services from EFRs

The evolution of research purposes on experimental forests and ranges— The original intent for EFRs was relatively uniform and simple. Sixty-four of the current 80 EFRs were established by 1960 and most were created for a basic, common set of information needs. Silvicultural knowledge was needed in all the regions of the country in the first half of the 20th century to aid forest managers in rehabilitating previously cutover stands and increasing timber production. Several of these original EFRs were also designed to address additional ecological questions tailored to local conditions and management challenges. The following summary highlights the trends in establishing EFRs by geographic region.

Seventeen current EFRs were established in the north-central and northeast areas of the country by 1960 in a variety of forest cover types. Sixteen had very common roots. Fundamental to their origin were silviculture, methods of cutting, stocking levels, regeneration, growth, and yield. However, the last EFRs established in this region prior to 1960 signified a new trend in EFR purpose: watershed research. The Hubbard Brook EF was established in 1955 with a primary purpose of studying the hydrology of forest systems. A few of the other sites also had the study of fire and effects on forest systems as part of their charge.

The EFRs in the southeastern portion of the country had similar origins. Of the 18 current EFRs established prior to 1960, the first 14 again had the same purposes of silviculture, cutting cycles, growth and yield, thinning, and reforestation. One exception was the Coweeta Hydrologic Laboratory. Established in 1934, it had a unique purpose for its time—collecting baseline measurements on climate, streamflow, and forest growth. Some also had ancillary purposes such as game habitat management and fire management in the fire-prone pine regions of the southeast United States. The last four established before 1960 once again marked a trend toward other purposes. The Tallahatchie, Chipola, Alum Creek, and Scull Shoals EFs were established to address such purposes as effects of flooding, flood prevention, restoration, watershed processes, and wildlife habitat.

Eleven EFRs in the Rocky Mountain/Intermountain region had been established by 1960. Once again silviculture, in ponderosa pine and other interior conifer types, was the driving purpose in seven of these 11 sites. However, with the establishment of experimental ranges (Great Basin, Sierra Ancha, and Desert), different purposes emerged. Range research that examined grazing, plant succession, revegetation, and nutrient cycling served important information needs for land managers of this region. Effects of watershed management and flash flooding were also important. At the Fraser EF in Colorado, investigations of snow accumulation, water yield, and watershed management issues dating from as early as 1937 anticipated important issues of today.

Reasons for establishing the 13 EFRs of the Pacific region prior to 1960 were consistent with those of the rest of the EFRs, although they included several additional research themes reflective of conditions in western coniferous forests—the effects of bark beetle infestations, response to periodic fire, and watershed health. Management of the various conifer types of the West, including mixed conifer, redwood, true fir, spruce-hemlock, and others, was generally focused on maintaining productivity to serve the forest products industry. The western states also have extensive range and shrublands, and three of the 13 EFRs (San Joaquin Experimental Range, Starkey EFR, and San Dimas EF) emphasize research on grazing, shrubland ecology, restoration after fire, and wildlife habitat improvement.

The original purpose of the EFRs was to serve the information needs of commodity-production forestry early in the 20th century. However, as the science of land management and public expectations began to change mid-century, the purpose of EFRs progressed toward a more ecological, multi-objective perspective.

The original purposes of the EFRs generally were to serve the information needs of commodity-production forestry for the first several decades of the 20th century. However, as the science of land management and corresponding public expectations began to change mid-century, there was a significant progression of purposes for the EFRs toward a more ecological, multi-objective perspective during the latter part of the century. The EFRs established since 1960 especially reflect this shift in emphasis. The 16 EFRs established since 1960 generally have a broader ecosystem management orientation with emphasis on themes such as soils and groundwater (Marcell EF), effects of forest management on streamflow and sedimentation (Caspar Creek EF), atmospheric deposition and climate variability in alpine ecosystems (Glacier Lake Ecosystem Experiment Site), interactions of climate and hydrology over a complete watershed (Héen Latinee and Sagehen EFs), and restoration of tropical ecosystems (Hawaii Tropical EF). This trend matches well with the movement toward broad provision of ecosystem services by the Forest Service and other land managers.

Managers are also being challenged to address adaptation to and mitigation of environmental changes on regional to global scales. The demand for new science is driven partly by shifts in climate. Managed forests will increasingly be valued as carbon sinks in response to both ecological needs and market demands. Whether or not national forests participate in carbon markets directly, they are sure to have a key role in regional management of carbon- and climate-related ecosystem services. For example, EFRs can be used to conduct training, provide demonstration sites for outreach, reach international networks and partners for workshops and field tours in cooperation with Forest Service international programs, and so forth. One could argue, the EFR network is significantly underutilized for these kinds of activities.

Among the most prestigious and productive EFRs the Forest Service possesses are a small handful of older ones that had an early vision for addressing a broad array of ecosystems services. The Coweeta Hydrological Lab (1934), the Fraser EF (1937), the H.J. Andrews EF (1948), the Hubbard Brook EF (1955), and Luquillo EF (1956) all share broad, multidisciplinary research and monitoring purposes. These sites have important affiliations with the scientific community through the LTER program, NEON, and other significant collaborative efforts. More recent additions to the EFR network have added to this standing within the scientific community with Bonanza Creek EF and Baltimore Ecosystem Study (a cooperating experimental forest), both part of the LTER network. Affiliation with the broader scientific community provides breadth that raises the capabilities and stature of those EFRs and the entire R&D program.

Distinction and advantages of experimental forests and ranges—

> "Field stations are places where we can read the book of life in the language in which it was written."
>
> *—James Kirchner, Director of the Sagehen Creek Field Station, University of California–Berkeley*

There are many field research sites around the Nation, sponsored and managed by a variety of research and educational institutions. The Organization of Biological Field Stations is one group that represents many of the field sites where ecological research is conducted (with 226 members currently), typically operated by universities. The mission of these field sites is to enable scientists to understand natural processes at every scale, from the molecular to the global, and from milliseconds to eons, and to help member stations increase their effectiveness in supporting critical research, education, and outreach programs. State and federal government agencies also have such facilities. Many states have field sites dedicated to conservation where research and monitoring activities are enabled. National parks, Fish and Wildlife Service refuges, and BLM lands, the primary federal lands managed for conservation purposes, also have some portion of their holdings dedicated to providing opportunities for research and monitoring. However, there are few sites in the United States that offer the conditions directly suited to scientific pursuit that can be found on EFRs.

Some key advantages of EFRs that are largely unavailable at other research field sites provide scientists with the ability to conduct research at durational and spatial scales unmatched by most field research sites:

- These are permanent facilities dedicated to research activities.
- Historical environmental records and research data span up to 100 years and provide a wealth of information from which new studies can draw.
- Long-term research is feasible and enabled.
- Manipulative field studies, such as testing management practices, are encouraged. This is one of the fundamental reasons for establishing these sites and sets them apart from almost any other field site.

Long-term data sets are one of the most significant distinctions of EFRs. Recent research findings affirm the value and significance of a long-term view of ecological systems through spanning the inherent spatial and temporal variability of the observed elements.

- Some work is designed and executed over fairly large geographic areas, more relevant to landscape management problems.
- New studies, complementing and conterminous with existing studies, are feasible and enabled.
- Both basic and applied research activities are encouraged and enabled.
- Land and resource managers are typically involved in articulating the research and monitoring questions as well as enabling the execution of the work through a variety of logistical support activities.
- Many sites provide demonstration plots or stands to illustrate the results of research findings for educational purposes.
- Logistical support (housing, meeting rooms, laboratories, data, maps, etc.) is available at many EFRs.
- Sites support "placed-based research" in which multiple disciplines and managers can be involved with research.

Long-term data sets are one of the most significant distinctions. Recent research findings affirm the value and significance of a long-term view of ecological systems through spanning the inherent spatial and temporal variability of the observed elements. There are very few comparable opportunities to capture this long term variability in forest and range systems. The value of these data sets is significant. Some data collection efforts stretch back 80 or 90 years; some are intended to continue for as many as 200 years. Forest Service R&D is almost the only entity capable of such a long research horizon.

The ability to conduct scientific research in-house, apply research findings on national forests, and transfer them to others for use on all of the Nation's forest land sets the Forest Service apart as a natural resource agency. No other agency or organization has such a significant land management responsibility and extensive land base for field research.

The ability to conduct scientific research in-house, apply research findings on NFS lands, and transfer them to others for use on all of the Nation's forest land sets the Forest Service apart as a natural resource agency. No other agency or organization has such a significant land management responsibility and extensive land base for field research combined with a strong and reputable research capability to provide guidance to land management. This level of capability to address natural resource challenges is unmatched worldwide.

Scientific discoveries—

One hundred years of field research and monitoring has developed a wide array of scientific results well suited to guiding land management decisions. Key discoveries with wide-ranging impact on environmental policy and natural resource management have emerged in a variety of research themes that have direct management implications. For over a century, EFRs have made significant contributions to the practical environmental processes and to the formulation of management approaches and policies that affect the use of our forests and the many natural resources they contain (Youngblood and Palik 2011). This significant body of work has had the ancillary benefit of training a large number of graduate students, many of whom represent the future workforce in forest management and natural resource conservation.

A brief summary of key scientific findings includes:

Silviculture and forest ecology—Many forest management strategies, employed on both public and private lands, have been based on knowledge gained from experimental forests. For example, loblolly pine management techniques were pioneered on the Crossett Experimental Forest in Arkansas. Impacts of diameter-limit cuts were developed on the Penobscot EF in Maine. Long-term research on the Pringle Falls EF in Oregon made significant contributions to development of management strategies to sustain the valuable ponderosa pine forests of the interior Pacific Northwest. Much of what is known about old-growth structure and function came from studies on the H.J. Andrews EF in Oregon and the Wind River EF in Washington. In particular, a key shift in management standards for streams in the Northwest occurred upon the finding that large woody debris was, in fact, an important ecological element of streams and should be retained rather than removed as prior management direction required (Sedell and Swanson 1984).

Current research is conveying knowledge of old growth into management of young, second-growth forests. Recent research on the Teakettle EF and the Stanislaus-Tuolumne EF in California is making significant contributions to restructuring Forest Service forest management policy toward variable-density thinning strategies throughout the Sierra Nevada.

Current research is conveying knowledge of old growth into management of young, second-growth forests. Recent research on EFRs in California is making significant contributions to restructuring Forest Service forest management policy toward variable-density thinning strategies throughout the Sierra Nevada.

Water—Clean water (and an adequate supply) is a critical resource and service that comes from our forests. Water is vital to all portions of the United States and especially acute in the western states, where cyclical droughts result in increasingly short supply of water for domestic and agricultural uses. Forests play a critical role in their relationship with watersheds, and many watershed management strategies are a result of findings from research on experimental forests. For example, the H.J. Andrews Experimental Forest was one of the first to examine the relationship between forest ecology and watershed function.

The Caspar Creek Experimental Watershed in California has yielded key information on how logging on steep slopes and riparian areas can affect sediment flows in watersheds. Long-term research at the Coweeta Hydrologic Laboratory in South Carolina has had a significant impact on our understanding of how forest vegetation affects site water balance, nutrient cycling, and water quality. Research on the Maybeso EF in Alaska has improved our under-

Silvicultural Research on the Crossett Experimental Forest

Loblolly–shortleaf pine forests cover 10 million hectares (25 million acres) of western Gulf coastal plain. Loblolly pine is a prolific cone producer, a reliable seeder, a fast grower, a generous wood producer, and a hardy dominator of practically any site. A stand of loblolly reduced to a bare one-third of its former abundance of trees can be fully restored in 15 years with the right silviculture.

Because most of the forestland in the South is held by private nonindustrial owners, sustainable and profitable timber management is important not only to landowners but to the Southern economy. The Crossett Experimental Forest was formally established in 1934 when the Crossett Lumber Company, owner of thousands of hectares of timber in southern Arkansas and northern Louisiana, leased 680 ha (1,680 ac) of its cutover timberland to the Forest Service for a research station. The company needed scientific support for managing the second-growth timber that was springing up on its logged lands.

By the 1930s, the old-growth forest was almost gone, and most companies had either gone out of business or moved to richer pickings on the West Coast. In 1937, a Farm Forestry study examining uneven-aged forestry began. Two 16-hectare (40-acre) research plots, now known as the Good Forty and the Poor Forty, had been heavily logged in about 1920 without any thought toward regeneration, and had recovered at different rates. By 1937, the Good Forty had good stocking of about 5,000 board feet of pine timber to the acre; the Poor Forty had less than half that amount. The Farm Forestry research showed conclusively that owners of small tracts of loblolly and shortleaf pine could manage their land profitably without clearcutting it—even if the forest is damaged from overcutting, ice storms, high winds, or pine beetles.

Today Crossett has the most complete long-term data on growth and yield of naturally regenerated loblolly–shortleaf pine stands in the South. Crossett's work continues to be relevant to managed forests throughout the South—not only on private lands, but also on public lands such as national forests, where values such as wildlife and aesthetics are often as important as timber.

Watershed Research on the H.J. Andrews Experimental Forest

The H.J. Andrews Forest is part of the vast, productive Douglas-fir region of the Pacific Northwest, where forests have shaped the region's economy and way of life. The coniferous forests of the western United States have three (at least) distinctive native features: big, old trees; cold, fast streams; and lots of dead wood.

When the Andrews Forest was dedicated in 1948, the main purpose of its research was to quantify the effects of commercial logging on watersheds and find ways to mitigate its environmental impacts, especially on streamflow and water quality. In the mid-1960s, researchers questioned the assumption that old-growth forest was nothing but overripe timber. The work of these scientists began to reveal old forests for what they are: complex ecosystems with processes of living and dying going on all the way from soil microorganisms to lichens at the tops of the tallest trees.

Researchers began probing the function of wood jams commonly found in old-growth forest streams. Common wisdom, backed by the latest fisheries research, said that dead wood choked the stream and blocked passages for fish. So loggers were routinely (and expensively) hauling all wood out of streams after a logging operation, even pieces that had been there before. Their studies showed, however, that dead wood provides calm pools where fish can rest, gravel bars for spawning, and cover from predators. And it harbors the insects that fish need for food. These findings resulted in a rapid about-face in standard forest practices. Further research on terrestrial old forest began a remarkable experiment in 1985 to look at decomposition processes in dead logs at the Andrews representing a broad range of decay rates.

The research was designed to last 200 years, unheard of at the time. More than two decades later, this study has begun to yield important findings about the role of dead wood in wildlife habitat, carbon dynamics, and nutrient cycling.

standing of how timber harvest practices affect ecosystem water use and availability. Acid rain, and its impact on trees, e.g., dry deposition, runoff, and forest soils, was discovered at Hubbard Brook EF in New Hampshire (Likens et al. 1972). Research from there and from Fernow EF in West Virginia demonstrated the effects of acid rain on forest soils, streams, and vegetation, as well as ways to mitigate these effects.

Fire—Wildfire can be a terribly destructive force, particularly where human habitation coexists with or borders forests and shrublands. However, fire is the driving ecological influence that has shaped forests and shrublands in the West for millennia. Organisms and the ecological systems in which they have evolved depend on periodic fire to regenerate their function and structure. After many decades of fire suppression, combined with the extensive wildland-urban interface that exists today, land managers face unprecedented challenges. Research on

Fire and Fuels Management Research on the Blacks Mountain Experimental Forest

When scientists installed a research project in 1996 at Blacks Mountain EF, they were hoping to better understand the role that stand structure and fire play in interior ponderosa pine forests. They also hoped to gain insight into the use of fire and thinning to make stands more resilient to fire and other disturbances. A fire that swept down from nearby Blacks Mountain in the dry autumn of 2002 gave the experiment a rigorous real-world test.

The fire roared through the crowns of the untreated parts of the forest, killing all the vegetation in its path. But when it reached plots that had been thinned, it dropped to the ground immediately. In plots where researchers had followed the thinning with prescribed burning, the fire was halted even more dramatically—in one instance expiring before it reached a firebreak. Before European-American settlement, ponderosa pine forests of the interior West tended to experience frequent wildfires. Evidence at Blacks Mountain, including rings from living and dead trees, suggested a pattern of frequent, extensive fires that left a mosaic of burned and unburned patches across a wide landscape.

The fire pattern is significantly different today because fires have been systematically excluded from most forested areas for over a century. Until the 2002 Cone Fire, Blacks Mountain had experienced no fire at all for 70 years. Its forests have responded by packing more vegetation into their understory.

Can human management—thinning, or burning, or both—effectively mimic natural fire? The research team at Blacks Mountain has evaluated the ongoing effects of treatments in both the areas hit by the Cone Fire and the areas spared. Treatments made a significant difference, and treatments that include both thinning and prescribed fire seem to have the most dramatic effect. More importantly for the future, the thinning and burning treatments seem to be jump-starting the growth of pines.

experimental forests has made significant contributions to our understanding of how fire operates and how management can work with this significant force. For example, a 2002 wildfire on the Blacks Mountain EF in California helped researchers understand the real effects of forest thinning.

Grasslands and ranges—Our network of EFRs includes five experimental ranges. The United States has roughly 419 million acres of shrublands (21 percent of its total cover) and roughly 290 million acres of grasslands (14 percent of total cover) (USEPA 2001). Clearly, this is a significant land resource and merits attention for land management considerations. Research on these experimental ranges has also led to important discoveries. For example, early trials to rehabilitate ranges on the Desert Experimental Range in Utah helped pioneer the discipline of range management throughout the West, and research on the Tenderfoot Creek EF in Montana helped increase understanding of the dynamic relationship among fire, water, and forest ecology through watershed research that examined changes in water (rain and snow) accumulation and runoff response to various levels of forest cover that results from fire or forest treatments.

Early trials to rehabilitate ranges on the Desert Experimental Range in Utah helped pioneer the discipline of range management throughout the West.

Grazing studies on San Joaquin Experimental Range in California provided important contributions to the development of sustainable grazing systems in California's oak woodland savannas. Long-term research at Great Basin Experimental Range in Utah has developed important findings regarding the impacts of relative levels of grazing pressure on ecosystems and individual plants, and rangeland restoration techniques including development and evaluation of plant materials and of plant establishment techniques.

Soil conservation—Soils have long been recognized as a crucial component of forest and range ecosystems. Soil-based variables offer our most effective and practicable indices of sustainable productivity (Powers 2002). Long-term observational and experimental studies of soil processes on the Calhoun EF in South Carolina have examined soil change at multiple time scales, from the decadal to millennial. This work documented soil recovery processes following abandonment after protracted agriculture for cotton and associated accelerated soil erosion, followed by planting to loblolly pine. Research on soils of oak-dominated, unmanaged forest stands in seven experimental forests that range along an historical and current acidic deposition gradient from southern Illinois (Kaskaskia EF) to central West Virginia (Fernow EF) discovered that differences in oak growth and mortality may be related to the differences in soil chemical status and soil nitrogen dynamics. This program provides an example of the way a functional network can address management-related questions across an environmental gradient.

Rangeland Research on the Desert Experimental Range

The Desert Experimental Range (DER) in Utah is located 260 km (160 mi) southwest of Provo, Utah. Despite its low public profile, the DER is a significant spot on the map for range ecologists, being a place where past ecological research is paying off in future-focused science. Data from long-established studies are helping scientists come to grips with two of today's pressing challenges: invasive weeds and climate change.

Composed of 22 500 ha (about 55,600 ac) of mostly treeless salt-desert shrubland, the DER is the largest of all the Forest Service's experimental forests and ranges. The sparse vegetation, minimal precipitation, and continental temperatures make the DER typical of an ecosystem that is widespread across the more arid parts of the Interior West. In 1933, the DER was set aside by presidential order as a place to investigate the economic and ecological impacts of grazing. Within two years, the first researchers had established 20 study paddocks of 100 to 130 hectares (240–320 acres) each, of which 16 had two, 4,000-m^2 (1-acre) fenced "exclosures," or control areas where livestock were not allowed to graze. Grazing treatments in these paddocks have been used to test the long-term effects of various combinations of grazing intensity and season.

A key discovery at the DER was that, from the standpoint of environmental impact, season of use matters more than grazing intensity. Research determined that grazing at a low to moderate level can occur without significant impact if grazing occurs during the cold part of the year, when plants are dormant. In contrast, when livestock graze in the spring, the most important period for active plant growth, plants are damaged and recovery is slow.

Today's research is focused on mechanisms of ecosystem stability in response to various sources of disturbance. The goal is to learn how the whole ecosystem responds to the combined effects of invasive weeds and climate change in the presence of livestock grazing. The salt-desert shrubland ecosystem is a good place to address that question, because it is a relatively simple ecosystem that can function as a model for more complex systems.

Scientists at Marcell EF in Minnesota were the first to demonstrate that soil compaction negatively affects future aspen productivity. Long-term studies on the San Dimas EF helped to address what people can and cannot do to prevent landslides and floods in the extensive chaparral stands of heavily populated southern California.

Scientists at Marcell EF in Minnesota were the first to demonstrate that soil compaction negatively affects future aspen productivity. Long-term studies on the San Dimas EF helped to address what people can and cannot do to prevent landslides and floods in the extensive chaparral stands of heavily populated southern California. The North American Long-Term Soil Productivity cooperative research program (LTSP), of which many EFRs are a part, is the world's most extensive coordinated effort to address questions of sustainable productivity in managed forests. Results illustrate the physical importance of organic soil cover in reducing soil erosion and maintaining favorable soil temperature and moisture relations during summer drought. Findings also show that the biological significance of soil compaction depends on soil texture.

Wildlife—Wildlife conservation is one of the important ecosystem services provided by forests and other wildlands. Research on a wide variety of wildlife species has increased significantly over the last 30 years. At least 16 EFRs have hosted field research on avian ecology, habitat use, censusing methods, and conservation, including both short-term, focused studies and studies integrated into a broad-based, interdisciplinary research program on ecosystem patterns and processes (Stoleson et al. 2011). Research findings have made significant contributions to conservation of endangered and threatened species such as red-cockaded woodpeckers (Escambia EF in Alabama, Hitchiti EF in Georgia, and Santee EF in South Carolina) and northern spotted owls (H.J. Andrews EF in Oregon). Avian community research looking at effects of forest management has been conducted at Fernow EF in West Virginia, Blacks Mountain EF in California, Coram EF in Montana, and Bent Creek EF in North Carolina (Stoleson et al. 2011). Definitive results from the Starkey EFR have given managers defensible options for managing off-road recreation, range allotments, and fuel treatments in relation to mule deer and Rocky Mountain elk populations (Wisdom et al. 2005). A major long-term focus of research on the Fort Valley EF was on the ecology and management of the Abert's squirrel (Sciurus aberti) and its relation to management of ponderosa pine.

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Atmospheric science and climate change—Until recently, scientists and managers could not have predicted that they would need to understand the effects of a changing climate on America's natural resources and associated ecosystems. Fortunately, we have long-term records from many experimental forests that document trends in temperature and precipitation. Records from the Coweeta Hydrologic Lab, H.J. Andrews EF, Desert Experimental Range, Fernow EF, Hubbard Brook EF, Marcell EF, Olympic Cooperating EF, San Dimas EF, and Crossett EF display mean annual air temperatures for over 50 years (L. Rustad, pers. comm.). Research at Marcell EF has helped demonstrate the role of forests in mitigating climate change through measurements of carbon flux into and out of peatland forests.

Kane EF in Pennsylvania was the site of a systematic inventory that replicated the original forest survey conducted in 1932. The inventory provided an

It is likely that all 80 experimental forests and ranges will be able to play a role in future climate change research.

opportunity to assess the feasibility of collecting the additional data required for a full carbon accounting as well as testing the carbon reporting capabilities of a key management tool, the Forest Vegetation Simulator (FVS) (Hoover and Rebain 2008). It is likely that all 80 experimental forests and ranges will be able to play a role in future research pertaining to climate change.

Climate Change Research on the Marcell Experimental Forest

Forests have been called the lungs of the planet, but peatlands—the swampy areas in northerly climates where soil is mostly organic and slow to decompose—equally deserve the title. Peatlands occupy a huge swath of territory north of the 45th parallel in North America, Europe, and Russia. Peatlands are carbon sinks, and highly efficient ones, because they pack away a disproportionately large amount of carbon dioxide (CO^2) relative to the land area they occupy.

Research at Marcell EF, which sits squarely in the peatland zone of northern Minnesota, suggests that a warming climate could hasten the decomposition of peat. Researchers are measuring gases flowing into and out of the peatlands at the Marcell, trying to find out what is happening there. Questions include: is peatland still storing carbon and how much is it storing? Has it become a source of CO^2, and if so how much of a source? If it is not a source, has its ability to sequester CO^2 lessened over time?

Researchers are also looking at the flux of methane, picking up where the studies left off in the early 1990s. Although less methane than CO^2 is present in the atmosphere, methane produces a stronger atmospheric greenhouse effect. In addition, researchers are analyzing the Marcell's collected data on dissolved organic carbon (DOC) which is a measure of carbon dissolved in the water flowing out of the peatlands.

With the help of funding from NASA, Marcell scientists are comparing their data with those from other research sites in the Rocky Mountains and the northeastern United States, trying to get a picture of carbon flux across the landscape. The goal is to combine plot-scale measurements and extrapolate them accurately up to larger areas—states, regions, even the whole world.

Better large-scale measures of carbon flux would improve the reliability of the computer models that monitor global climate. An important goal of research at the Marcell is to provide policymakers with insights on how to use the land in mitigating the warming of the planet.

Urban ecology/forestry and human uses—About 84 percent of the U. S. population (>308,700,00 as of 2010) (U. S. 2010 census) lives in the 366 metropolitan areas (cities with a core population of more than 50,000 people). Further, over 58 percent lives in large urban areas (defined as communities with more than 200,000 people). As this urbanization trend continues, interest in stewardship of urban natural resources and the effects of these resources on people's lives is growing rapidly. Today about 35 percent of all EFRs are within 50 miles of an urban area (defined as a community with more than 50,000 people) and 15 percent within 25 miles (Charnley and Cerveny 2011). These circumstances suggest a growing role for research that addresses both urban forestry/ecology and the social sciences of human uses and relationships with natural resources found in forests and rangelands. Researchers in the Baltimore Ecosystem Study (a cooperating experimental forest in the greater Baltimore region of Maryland) have examined interactions among urban forests, watersheds, soils, climate, and community well-being. Diversified recreation is likely to increase on public lands, and research at several EFRs is examining how these uses may affect wildlife and forests and range conditions (Charnley and Cerveny 2011). Even research on the traditional uses of wildlands by indigenous peoples have been researched in experimental forests (Oregon's Cascade Head and H.J. Andrews EFs). At Luquillo EF in Puerto Rico, scientists are studying how natural and anthropogenic disturbances interact to influence forest characteristics (Charnley and Cerveny 2011).

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Ecological restoration—With a growing interest in the provision of ecosystem services from our wildlands, ecological restoration has become a primary objective of the Forest Service. Land managers need scientifically sound guidance on the approaches they can take to accomplish restoration in a wide variety of ecosystems. Research at Luquillo EF in Puerto Rico documented the effects of hurricanes on Caribbean forests, setting the stage for understanding how disturbances influence tropical forests and how these systems can recover. Bent Creek EF in North Carolina was the site of some of the earliest experiments on regeneration of hardwood species on degraded lands after extensive logging. Ecological restoration through silviculture to restore the savanna ecosystem was conducted in Sinkin EF in Missouri. This effort demonstrated techniques and evaluated the efficacy of reducing overstory tree density and reintroducing fire to develop the tree composition, structure, and herbaceous complex typical of a savanna (Lowenstein and Davidson 2002). Exploitation of longleaf pine-dominated forests, an ecosystem that once covered an estimated 36 million ha (90 million ac), or two-thirds of the area in the Southeast, led to a steady decline of its acreage. Longleaf pine forest was considered the third most endangered ecosystem in the United States. Research on the

Escambia EF (Alabama) and other experimental forests in the Southeast develop the science needed for regeneration of longleaf pine forests.

There is a rich history of research and ecological monitoring conducted at EFRs, established decades ago, that are still active in some locations. The long-term data available at so many EFRs are fueling the research of tomorrow.

These examples demonstrate how sustained, interdisciplinary research at EFRs can lead to discoveries based on well-designed studies, long-term data collection, and even through simple serendipity. The experimental forests and ranges and the research groups working there in long-term collaborations are seedbeds for discovery (Lugo et al. 2006).

Experimental Forest and Range Community of Interest

For most of the century-long history of the EFR network, sites were selected and operated as stand-alone units to represent a broad array of forest and grassland types and conditions. EFR leaders in the 20th century interacted primarily through informal or scientist-to-scientist ties (Ryan and Swanson 2014). Each site has developed its own community of interest with scientists, collaborators, and information users. Some have had a notable history of accomplishment and active participation by a broad array of Forest Service scientists, university collaborators, and scientists from other state or federal organizations. Others have modest histories with relatively narrow involvement.

The community of interest for each of these facilities also varies quite a bit. Most are hosted on national forests and the logistical support and involvement by national forest staff is integral to their success.

Below is a brief summary of the different communities that are involved in the use, operation, and consumption of results from EFRs.

Use of EFRs by Forest Service Research—

Because of the individual histories of each EFR, the nature of the community of interest varies considerably among the EFRs. Many of the EFRs have a cadre of Forest Service scientists who devote most or all of their research interest to activities on the site. Some EFRs have little to no current research activity, although we have a designated "Lead (Forest Service) Scientist" for each of the 80 EFRs. Activity ebbs and flows. Some EFRs were highly active at different phases of this 100-year history and dropped off for a variety of reasons such as retirement of key scientists, changing priorities in the NFS or R&D, variable interest and support from the host institution (usually units of the NFS), and changing emphases of the public. Nonetheless, there is a robust record of Forest Service R&D scientists making significant use of the EFR network.

Value of EFRs to and collaboration with America's forests—
The Forest Service has what is now a unique association between a research organization and a land management organization. This relationship enables a world-class research staff to bring their expertise to bear directly and indirectly on about 80 percent of the critical land and resource management issues confronted by public and private land managers. The advantages of this connection should not be underestimated.

The ability of the R&D branch to conduct research on the EFR network is facilitated in large part by land managers, largely on ranger districts and national forests (62 of the 80 EFRs are on Forest Service land), who participate in the operation of an EFR. The most successful and productive EFRs achieve their accomplishments because land managers take an active role in defining information needs and executing many of the treatments. They also provide a myriad of types of logistical support that is absolutely crucial to making an EFR function effectively. There are a variety of management and maintenance requirements to enable these locations to function properly. Roads, culverts, law enforcement, fuels reduction to prevent wildfires, and NEPA planning and execution are among a long list of activities that require conscientious attention.

The most successful and productive EFRs achieve their accomplishments because land managers take an active role in defining information needs and executing many of the treatments.

There is also considerable value in the collaboration between researchers and land managers to define the questions that are most relevant to sound land management. Defining the specific questions in this iterative manner leads to the most meaningful research and useful results for land managers.

Use of experimental forests and ranges by collaborating scientists—
Collaboration with research partners from other institutions is one of the primary reasons for the success of many individual EFRs and the entire EFR network. The majority of our EFRs, particularly those with significant accomplishments, have regular participation by collaborating scientists from universities, other government agencies, nongovernmental organizations, and scientists from other institutions. Many EFRs have significant participation and, in some cases, active involvement in the administration of activities on the site by partners. Other EFRs host research stations from universities and with many researchers/faculty, graduate students, and classes who regularly visit and use the site for various purposes. Some important examples of collaboration include (but are not limited to):

- Sagehen EF—University of California–Berkeley
- Hawaii Experimental Tropical Forest—University of Hawaii
- H.J. Andrews EF—Oregon State University; University of Washington; others
- Hubbard Brook EF—a number of universities including Cornell University and Dartmouth College

- Wind River EF—University of Washington
- Fraser EF—Colorado State University; University of Colorado
- Bonanza Creek EF—University of Alaska Fairbanks
- Coweeta Hydrologic—University of Georgia; Virginia Tech
- Luquillo EF—University of Puerto Rico and a host of other universities
- Baltimore LTER—University of Maryland Baltimore County, Cary Institute of Ecosystem Studies
- Penobscot EF—University of Maine

Collaboration with other research institutions is crucial to EFRs. These institutions bring people, equipment, and intellectual resources along with funding from a variety of sources, including the NSF. Many research or monitoring efforts have participation by a variety of partners, and that creates a rich and productive intellectual environment.

Our EFRs also have productive collaborations with other network research initiatives such as the NSF's LTER program and the planned National Ecological Observatory Network (NEON) program.

Of the 26 LTER sites across the United States, six involve EFRs (includes one cooperating EFR):

- H.J. Andrews EF
- Baltimore Ecosystem Study (Cooperating Experimental Forest)
- Bonanza Creek EF
- Coweeta Hydrologic Laboratory
- Hubbard Brook EF
- Luquillo EF

Of the 20 NEON domains planned across the country, six involve EFRs (one cooperating EFR and three which include a "relocatable" NEON site):

- NEON Domain 1 (Northeast)—Bartlett Experimental Forest (relocatable site)
- NEON Domain 13 (Southern Rockies–Colorado Plateau)—Fraser EF (relocatable site)
- NEON Domain 16 (Pacific Northwest)—Wind River EF (core site)
- NEON Domain 16 (Pacific Northwest)—H.J. Andrews Experimental Forest (relocatable site)
- NEON Domain 17 (Pacific Southwest)—San Joaquin Experimental Range (core site)
- NEON Domain 19 (Taiga)—Caribou-Poker Creeks Cooperating EF (core site)
- NEON Domain 20 (Pacific Tropical)— Hawaii Tropical EF (core site)

Experimental forests and ranges participate in numerous other scientific networks. These are detailed in chapter 4 where we discuss, in detail, the scientific questions that we are contending with both in current research and monitoring as well as future research and monitoring opportunities.

Value of research results from EFRs for private landowners and industry—
As stated earlier, the Forest Service has a direct and indirect role on about 80 percent of America's forests along a complex rural to urban gradient; most of these lands are nonfederal in ownership. Science plays a crucial role in stewardship of these private lands, as well the national forests and grasslands. The research work done on EFRs has a steady focus on informing policy and land-management decisions for all forest and rangelands, including the approximately 485 million acres of private forest lands in the United States. The researchers work independently and with a range of partners, including other agencies, academia, nonprofit groups, and industry. The information and technology produced through basic and applied science programs is available to all of the public for its benefit and use.

Use of information generated at EFRs—
EFRs, like the rest of R&D, serve customers that include all Forest Service resource mission areas (NFS; State and Private Forestry; and International Programs), other government agencies, the global science community, and many segments of the American public.

Many of the influential scientific findings described in chapter 5 have had a profound impact on land management. There is an increasing demand to encapsulate research findings derived from EFRs and other sites into forms more easily applied to land management issues. A variety of efforts have been explored to accomplish this through venues such as general technical reports (GTRs), demonstration sites, brochures, and technical transfer mechanisms. As a 2010 GAO assessment of R&D noted, there is substantial room for improvement in this across R&D; EFRs provide an excellent platform for testing and deploying new ideas in this arena.

Public interest in EFRs—
Although EFRs are not generally thought of as public use areas, some, especially those with facilities, offer excellent opportunities for outreach to diverse students and publics. All of the LTER programs hosted by EFRs (six) have educational components as part of their mission. For example, the Research Experiences for Teachers in the Experimental Forests (RET-EF) program is a joint effort between the Forest Service and the Hubbard Brook Research Foundation (HBRF). The primary aim of the RET-EF program is to provide K–12 science teachers with sustained, hands-on experience in environmental science research. The program serves three

major purposes: science content, science teaching, and science communication. Another example involves the Sagehen EF and the activities of the Sagehen Creek Field Station of the University of California–Berkeley. Here the station manager hosts a variety of school and local community field trips and summer youth camps that enable children and adults from the nearby Truckee community an opportunity to experience and learn about all the wonders of a forest and a multi-faceted research program in that watershed. The opportunities for enhancing this kind of activity are huge. Education is a strong partner of research, and each of the 80 EFRs has possibilities for establishing or expanding these opportunities.

Education is a strong partner of research, and each of the 80 EFRs has possibilities for expanding collaboration with educational institutions, as well as provideing demonstration sites that provide on-the-ground evidence of new, innovative management techniques to Forest Service personnel.

Use of EFRs also includes the opportunity to provide demonstration sites as educational tools for Forest Service personnel, such as demonstration plots, which provide on-the-ground evidence of new, innovative management techniques. This enables land managers, foresters, and district rangers and others to see tangible evidence of how management objectives and the scientific underpinnings behind those objectives are expressed in the field. Field tours to visit demonstration sites prove very valuable for conveying research results.

There is an important and growing interest in research that addresses human uses of urban forests and other ecological systems in and near urban/suburban communities and the ecosystem services provided by those systems. We live in an increasingly urbanized society and thus the benefits and amenities provided by urban ecosystems are growing in importance. The EFRs distributed around the country offer a resource for both education and research concerning the relationship between people and their natural environment. This represents a large community of interest that, for the most part, does not yet exist. With emerging interests in these areas it appears that there will be a growing role for education and research that involves the interests of the human communities. The Baltimore Ecosystem Study, a cooperating experimental forest, is a noteworthy example of the emergence of this field of research.

Despite the various success stories that we can refer to, Forest Service R&D does not have the staff to manage any kind of public use activities. Nonetheless, as highlighted above, a number of EFRs, with the significant participation by one or more of the collaborating institutions, are able to provide meaningful educational opportunities for K-12 schools, undergraduate and graduate programs, and community connections.

Chapter 2: Looking to the Future

The Need for a Networked Organization

What are the information needs of forest, rangeland, and resource managers today? What are information needs of the future that we may not currently anticipate? These are important questions that Forest Service Research and Development (FS R&D) is challenged by to optimize the service we provide to land management and policy communities both within the Forest Service and outside.

Forest Service R&D works on a wide array of research and monitoring activities that address many of these information needs. The core of our research is founded in the many individual research projects conducted by our more than 500 research scientists at seven research stations distributed around the United States. This body of research can be organized and communicated in many ways, depending on the audience we want to reach. Individual research initiatives will continue to be an important portion of the objectives and anticipated accomplishments derived from experimental forests and ranges (EFRs).

Ecosystems have changed more in the last 50 years than at any other time in human history, largely as a result of factors operating at multiple spatial and temporal scales (MEA 2006). It is now clear that local processes affect broad-scale ecological dynamics, and also that broad-scale drivers can overwhelm local patterns and processes. Understanding these cross-scale interactions requires a conceptual framework based on connectivity in material and information flow across scales (Peters et al. 2008). Connectivity has been altered in unprecedented ways through human transport of propagules, toxins, and diseases, as well as anthropomorphic disturbances and changes in land use (MEA 2006). Understanding global connectivity and its consequences requires the creation of research and monitoring across ecological networks for observation and experimentation (Peters et al. 2008).

Ecosystems have changed more in the last 50 years than at any other time in human history, largely as a result of factors operating at multiple spatial and temporal scales. Local processes affect broad-scale ecological dynamics, and broad-scale drivers can overwhelm local patterns and processes. Understanding these interactions requires a conceptual framework based on connectivity in material and information flow across scales.

Concurrently, the science of landscape-scale ecology has evolved rapidly in the last two decades and has had a significant impact on the perspective that land managers have developed about planing and executeing management action. New analytical tools such as geographic information systems (GIS) and remote sensing have emerged in tandem with the growing awareness and attention to scaling issues in forest landscapes. Managers have turned their attention to managing landscapes at multiple scales for the sustainability of a broad assortment of ecosystem functions (Bradford et al. 2009).

These circumstances have spawned a considerable new array of questions that span substantially larger spatial and time scales than were previously considered by land managers. Issues such as climate change, invasive species, continued changes in land use and land status, and many others have bred numerous critical questions to which managers seek answers. These challenges will require additional and novel sampling designs coupled with innovative, state-of-the-art scientific infrastructure to gather the necessary data. The Forest Service collection of 80 EFRs offers a platform for addressing many of these needs.

Applying the term "network" to EFRs needs to be done carefully because "networks" associated with EFRs have taken many forms. Scientists at EFRs have a long history of collaborating in formal and informal ways with many partners, including scientists at universities, other agencies, and other EFRs, and with land managers and policymakers (Swanson et al. 2010). EFR programs and scientists have participated in other networks, some interagency, such as the Long-Term Ecological Research (LTER) network and the National Atmospheric Deposition Program (NADP), and some international, such as UNESCO's Man and Biosphere (MAB) Program. Understanding the nested sets of networks within which EFRs operate helps to give perspective on what kinds of linkages different network approaches foster among sites and what additional actions may be needed to make EFRs a functioning research network. Ryan and Swanson (2014) broadly categorized networks in which EFRs have participated to illustrate the kinds of relationships each has created among its members, including participating EFRs.

- **Networks-in-Name.** These provide recognition, but little or no significant network functionality for their members. For example, nine EFRs have been named Biosphere Reserves of the UNESCO MAB Program (http://www.georgewright.org/mab.html#Anchor-Are-35882), recognizing them as members of an international group of significantly intact ecosystems set aside for study, with some opportunities for experimentation. Membership indicates that these sites have high intrinsic value for understanding natural and managed ecosystems, but beyond occasional scientist-to-scientist contacts, the MAB Program does little to create significant interactions among its member sites, including participating EFRs. We refer to these as "**informal networks**."
- **Environmental Monitoring Networks.** EFRs have participated for many years in a variety of environmental monitoring networks, primarily as sites for collecting observational data. Data gathered through these networks such as the NDAP usually follow standard protocols; data management, analysis, interpretation, dissemination, and publication are usually done by organizations that produce relatively little interaction among the participating sites, including EFRs. We refer to these as "**observational networks**."

- **Experimentation Networks.** EFRs have been connected by scientists who have collaborated on cross-site experimentation and observational programs. The focus has usually been one-time or fixed-term studies even though some individual experiments may run for a long time, in some cases for decades. Some experiments are designed and contained within a subset of the EFR system and other studies have been organized by scientists partially or entirely outside the EFR system. We refer to these as "**experimentation networks**." This can also include use of ecological gradients as a "treatment" effect. With the broad geographic distribution of EFRs across the landscape of the United States, there are many potential ways to implement these "natural experiments."
- **Integrated, Long-Term Research Networks.** These are composed of study sites, collaborating research programs, and a social network of scientists from across sites in which participants are committed to sharing ideas and cooperating on multiple long- and short-term projects. Linking together the science capacity of individual sites makes it possible to address network-scale questions corresponding to the extent of the network. Both LTER and EFRs are attempting to reach a high level of research-network functionality, although both were initially set up as a collection of sites rather than as a functioning network. The National Ecological Observatory Network (NEON) is a proposed network that has received some funding through NSF. It is explicitly intended to collect data over a long term at sites representing the ecological domains of the United States. Research networks combine aspects of environmental monitoring, experimentation, and synthesis. Critical ingredients for network science include a culture that encourages and rewards network science, support for network projects, management of collaborations that build and sustain a strong and open community, and infrastructure for cross-site investigations, especially information-sharing systems. We refer to these as "**synthesis networks**."

We use this typology of networks to organize and present the current portfolio of research and monitoring initiatives in which EFRs participate.

Ongoing research and monitoring projects involving the EFR network—Some of the greatest values of the EFR system are the ongoing, long-term studies of the effects of a changing climate on natural resources, streamflow, vegetation, and biogeochemistry from experimental watersheds. These data are crucial for examining ecosystem services from forests over time and are of sufficiently long duration now to be extremely valuable for quantifying the extent

Some of the greatest values of the EFR system are the ongoing, long-term studies of the effects of a changing climate on natural resources, streamflow, vegetation, and biogeochemistry. These data are crucial for examining ecosystem services from forests over time and are of sufficiently long duration to be extremely valuable for quantifying the extent of changing climate at multiple sites across the country.

of changing climate at multiple sites across the country and long-term responses for forest management. Emphasis is added here to the importance of having baseline environmental data. Such data are crucial in the use of indicators and assessing changes over time, e.g., as is being done in the National Climate Assessment. EFRs generally provide high-quality data across a broad range. The lessons to be learned from these records are absolutely critical to informing traditional management issues of the Forest Service and to the contemporary issues of climate change and other forms of environmental change. The evolving interest by leadership in upgrading the Forest Service Inventory, Monitoring, and Assessment efforts draws more attention to the value of an effective baseline monitoring program.

A number of cross-site research projects have been conducted on EFRs. These projects have largely been initiated by "bottom-up" collaborations of individual scientists and staff at scattered locations across the country. Much has been fueled by funding from other organizations such as the LTER program, but the accomplishments can be attributed to grassroots efforts and the energy and enthusiasm of individual scientists. These ad-hoc efforts have been productive, but also can suffer from inadequate cross-site coordination and from the risk of being discontinued should resources continue to decline or new initiatives supplant them, or when key personnel retire or move to new positions. The organization must determine how it can effectively keep researchers connected so that networking does not end when key people leave the organization.

A strategic and comprehensive look at these current initiatives is important to give us a full picture of what we are learning and how that information can be applied to current and future scientific challenges. Few or perhaps none of us can comprehend the full, long-term scientific contribution of these many activities. We have compiled a master list of the current research, monitoring, and synthesis work to form a foundation for our future. In doing so, we have organized these activities into a matrix: one that describes the types of work being done and the themes of topics to help understand an array of activities this large. The types of work could be organized in a variety of ways, but we have chosen to use fairly conventional categories (described above), which are comparable to ways other research organizations view their portfolio of work:

- **Informal Networks** (networks in name only)
- **Observational Networks** (environmental monitoring)
- **Experimentation Networks** (research studies)
- **Synthesis Networks** (integrated, long-term networks where data are being compiled and synthesized)

After partitioning the current work into these categories, we further parse the work into the following six general topical themes. These categories can also be cross-walked roughly to Forest Service R&D Strategic Program Areas (SPA), which are used for reporting accomplishments and organizing outputs:

- **Biodiversity** (wildlife, fish, other organisms)—Wildlife and Fish SPA
- **Disturbances** (fire, floods, climate change, invasive pests and pathogens)—Fire SPA
- **Water and watersheds** (soil, hydrology, water quality, and regional ecosystem services)—Water, Air, Soil SPA
- **Climate and land use change** (atmosphere and global ecosystem services—Water, Air, Soil SPA
- **Resource management** (land use and management issues, including vegetation management that influences carbon)—Resource Management and Use SPA
- **Social sciences** (recreation, arts and humanities, urban influences)—Recreation SPA

Obviously, some of the ongoing projects overlap more than one of these categories, but this list should provide an easily understood class for each ongoing project. Table 6 summarizes all known activities within this four-by-six matrix. The list of these ongoing research or monitoring activities is provided in table 7. Appendix 2 provides descriptions of all projects.

This array of current initiatives covers a number of the key priorities for informing conservation and management policy in the United States as forecast by Fleishman et al. (2011). A large panel of distinguished scientists in the land and resource conservation community carefully considered a wide range (more than 500) of possible questions and ultimately selected a “top 40 priorities” for multidisciplinary research directed toward informing some of the most important current and future decisions about biological conservation and ecological processes in the

Table 6—Current research and monitoring network activities on experimental forests and ranges (EFR)

EFR network ongoing activities	Biodiversity	Disturbances	Water and watersheds	Climate and carbon	Resource management	Social sciences	All themes
Informal networks	—	—	3	39		34, 35	4
Observational networks	7, 11, 14, 16	—	2, 5, 13, 37, 38	1, 6, 8, 9, 10, 12, 31	15	—	17
Experimentation networks	—	—	32, 36	33	—	—	—
Synthesis networks	29	—	19, 22, 30	18	20, 23, 25, 26, 27, 28	—	21, 24

Table 7—Ongoing research and monitoring activities

Project number	Cross-site activity	Type of data collection	Theme of data collection	Secondary theme	Partner organizations
1	Clim DB	Observational	Climate and carbon	—	—
2	Hydro DB	Observational	Water and watersheds	—	—
3	Watershed directory	Informal	Water and watersheds	—	—
4	EcoTrends	Informal	All	—	—
5	Stream Chem DB	Observational	Water and watersheds	—	—
6	AmeriFlux	Observational	Climate and carbon	—	—
7	Federal pollinator network	Observational	Biodiversity	—	—
8	Forest Service climate tower network	Observational	Climate and carbon	—	—
9	Monitoring climate change impacts on EFRs	Observational	Climate and carbon	—	—
10	Clean air status and trends network (CASTNET)	Observational	Climate and carbon	—	—
11	National ecological observatory network (NEON)	Observational	Biodiversity	Climate and carbon	National Science Foundation
12	National atmospheric depositions program (NADP)	Observational	Climate and carbon	—	—
13	Soil climate analysis network (SCAN)	Observational	Water and watersheds	Climate and carbon	—
14	USA National phenology network (NPN)	Observational	Biodiversity	Climate and carbon	—
15	Forest Inventory and Analysis on EFRs	Observational	Resource management	Biodiversity	—
16	Phenocam	Observational	Biodiversity	—	Harvard University
17	Regional environmental sensor network	Observational	All	—	—
18	EFR climate synthesis	Synthesis	Climate and carbon	—	—
19	Hydroclimatic effects on ecosystem response	Synthesis	Water and watersheds	Climate and carbon	—
20	Integrating landscape-scale forest measurements	Synthesis	Resource management	Climate and carbon	—
21	Long-term ecological research (LTER)	Synthesis	All	—	—
22	Long-term soil productivity study (LTSP)	Synthesis	Water and watersheds	Resource management	—
23	Long-term stand responses to silviculture	Synthesis	Resource management	—	—

Table 7—Ongoing research and monitoring activities (continued)

Project number	Cross-site activity	Type of data collection	Theme of data collection	Secondary theme	Partner organizations
24	Quantifying uncertainty in ecosystem studies (QUEST)	Synthesis	All	—	—
25	U.S. Forest Service management intensity demonstration plots	Synthesis	Resource management	—	—
26	Systematic experimental forest inventory data as a signal of forest change	Synthesis	Resource management	Biodiversity	—
27	Long-term regeneration research for the development of the Forest Vegetation Simulator (FVS)	Synthesis	Resource management	—	—
28	Decomposition on the forest floor: soil productivity studies	Synthesis	Resource Management	Water and Watersheds	—
29	Vegetation dynamics across EFRs	Synthesis	Biodiversity	Resource management	—
30	Water supply sensitivity and ecosystem resilience to land use change, climate change, and climate variability	Synthesis	Water and watersheds	Climate and carbon	—
31	International cooperative program on assessment and monitoring of air pollution effects on forests	Observational	Climate and carbon	—	—
32	Long-term inter-site decomposition experiment team (LIDET)	Experimentation	Water and watersheds	Biodiversity	—
33	Lotic inter-site nitrogen experiment (LINXII)	Experimentation	Climate and carbon	—	—
34	Maps and locals (MALS)	Informal	Social Sciences	Water and Watersheds	—
35	Engaging arts and humanities	Informal	Social Sciences	all	—
36	Detritus input and removal treatments (DIRT)	Experimentation	Water and watersheds	Biodiversity	—
37	Nutrient network (NutNet)	Observational	Water and watersheds	—	—
38	Snowpack telemetry (SNOTEL)	Observational	Water and watersheds	Climate and carbon	NRCS
39	Basic meteorological station	Informal	Climate and carbon	—	—
40	Long-term ecosystem productivity study	Experimentation	Biodiversity	Climate and carbon	—

Table 7—Ongoing research and monitoring activities (continued)

Project number	Cross-site activity	Type of data collection	Theme of data collection	Secondary theme	Partner organizations
41	Forest ecosystem response to regeneration treatments for upland hardwoods (sustaining oaks)	Experimentation	Resource management	—	—
42	U.S. regional climate reference network (USRCRN) station	Observational	Climate and carbon	—	—
43	Wood decomposition experiment	Experimentation	Resource management	—	—
44	Remote assessment of forest ecosystem stress (RAFES)	Experimentation	Resource management	—	—
45	Groundwater survey	Observational	Water and watersheds	—	—
46	Longleaf pine restoration and ecosystem productivity	Experimentation	Resource management	—	—
47	FACE (free-air carbon dioxide enrichment) experiment decomposition studies	Experimentation	Climate and carbon	—	—
48	Smithsonian global program for long-term, large-scale forest research	Observational	Biodiversity	—	—

United States. Among these 40 key questions are seven that are especially relevant to forest and range management:

- What quantity and quality of surface and groundwater will be necessary to sustain U.S. human populations and ecosystem resilience during the next 100 years?
- How do different strategies for ecosystem management across the gradient of development intensities affect human health in urban areas?
- How do different strategies for growing and harvesting biomass or biofuels affect ecosystems and associated social and economic systems?
- How do different strategies for managing forests, grasslands, and agricultural systems affect carbon storage, ecosystem resilience, and other desired benefits?
- What are the ecological and economic effects of different methods of restoring forests, wetlands, and streams?
- What are the reliable scientific metrics for detecting chronic, long-term changes in ecosystems?
- What are the relative ecological effects of increasing the intensity versus spatial extent of agriculture and timber production?

Each of these key questions is being addressed in some way with the various ongoing monitoring, research, and synthesis activities on our EFRs. Having a network of localities contributing long-term and focused monitoring and research data on these topics is a truly significant contribution to the ecological health of our country.

In addition to the wide range of potential applications to these current activities, it is apparent that collecting and maintaining these data will lead to future uses and corresponding questions that we cannot currently anticipate. There are many applications of historical data sets that are now reaping value for addressing emerging environmental questions. These longitudinal studies consisting of repeated observations of the same variables over long periods will be one of the hallmarks for which Forest Service EFRs will be recognized.

Challenges to implementing and sustaining these activities—
It is clear that the efforts described above have emerged through ad hoc action with minimal, primarily one-time resources supporting the effort. One can argue that these bottom-up initiatives are well developed ideas with a strong scientific foundation. The scientists involved typically are quite dedicated to the success of their research and invest much intellectual capital toward that success. However, these efforts cannot come close to realizing their potential without more dedicated investments from the Forest Service to address the many requirements (infrastructure maintenance, data management, dissemination of results, etc.) typically associated with successful research and monitoring activities. An excellent case study to illustrate this issue is the recent effort to assemble basic temperature data from EFRs to provide the Chief of the Forest Service with a synopsis of temperature records that tell a story about our warming climate.

This synthesis effort was the first systematic evaluation of EFR climate data, to examine patterns and trends across all EFR sites using a consistent framework and methodology. In this initial analysis, the focus was on only air temperature. Many EFRs have been collecting air temperature, precipitation, and other climate data (e.g., relative humidity, windspeed) for decades; several have conducted in-depth analysis of climate trends within their own sites, and a few studies have been initiated to evaluate climate change impacts across a subset of EFRs. The expectation was that owing to the anticipated ease and consistency in measuring air temperature (e.g., daily readings from a maximum/minimum thermometer), a large proportion of the 80 EFRs would have a long-term temperature record of suitable quality, duration, and accessibility for statistical analyses. This expectation was not borne out; only 16 sites had useable long-term data sets.

One other consideration that needs to be acknowledged is the current forest management policy environment that many EFRs find themselves in at this time.

A critical element in defining the value—past, present, and future—of EFRs is the ability to do manipulative research at meaningful scales. As we move into the future, the outcomes of such research will become more and more important in informing policy and in providing options and practices for landowners and land managers. However, any proposed work on an EFR is necessarily subject to the National Environmental Policy Act (NEPA) process. In recent years, many Forest Service management projects have been challenged by the public through appeals and sometimes legal action. This has included some proposed research work that has delayed or stopped some projects from going forward. This creates significant uncertainty in planning and executing rigorous experimental design and poses a threat to a scientist whose career depends on timely execution of scientifically defensible field research.

While good relationships with local national forests and stakeholders can potentially limit delays or stops, it cannot prevent them. Addressing these concerns can significantly increase the costs (both upfront and in litigation) of trying to carry out manipulative research on EFRs. The costs and risks associated with this need to be stated upfront and taken into account when considering research project development. We cannot assume that a well-designed research project can stand solely on its scientific merits. Careful consideration of the potential public concerns and sometimes extensive public outreach must be factored into project design and execution.

New ecological initiatives (research or monitoring) that the EFR network is positioned to address—

In addition to the value we stand to garner from sustaining existing network activities, there are many new potential initiatives that could have a meaningful impact on future land management issues. Forest Service R&D staff has identified a number of potential activities that could be added to our portfolio of research and monitoring activities using the EFR network. Table 8 summarizes the ideas assembled to date (app. 2 provides a short description of each idea). This includes ideas solicited from various NFS technical experts including:

- Regional wildlife biologists
- Regional silviculturalists
- Regional geneticists
- Regional vegetation ecologists
- Regional range conservationists

There will be many ideas for adding new initiatives and these are not all necessarily separate, independent activities. Many of these tasks could be operated through complementary efforts. Once the necessary equipment has been acquired and deployed, a small number (but critical mass) of well trained staff may be

Table 8—New ecological initiatives

Project number	Cross-site activity	Type of data collection	Theme of data collection	Secondary theme
1	EFR meta-database of site information and content	Informal	All	
2	Quaking aspen growth, yield, and mortality across the United States	Experimentation	Resource management	
3	A comprehensive reassessment of stand development and timber management guidelines in the northern Lake States	Synthesis	Resource management	
4	Development of modeling tools for predicting smoke dispersion from low-intensity fires	Synthesis	Resource management	
5	National silvicultural synthesis: long-term compartment study outcomes	Synthesis	Resource management	
6	Nontimber forest product ecology and response to disturbance: insights from EFR long-term data sets	Synthesis	Resource management	
7	Wood decomposition and its role in the forest carbon cycle across the conterminous United States	Experimentation	Climate and carbon	
8	Airborne LiDAR Surveys of vegetation and topography	Observational	Resource management	
9	Disturbance monitoring; protocols to measure intensity, severity, and extent of major disturbances	Observational	Disturbances	
10	Vegetation monitoring; assess declines and advances of dominant plant species	Observational	Biodiversity	
11	Wildlife monitoring; assess declines and advances of common wildlife species (birds, mammals)	Observational	Biodiversity	
12	Carbon inventory; sample all carbon pools using long-term plots and standardized protocols	Observational	Climate and carbon	
13	Biophysical drivers; augment standard weather measurements with other biophysical processes measurements	Observational	Climate and carbon	
14	Indicator species monitoring; a standard set of biological indicators to monitor magnitude and trends	Observational	Biodiversity	
15	Biomonitors			
16	Invasive species			
17	Climate variability			
18	Common garden experiments to assess key plant species adaptation to climate change	Experimentation	Climate and carbon	Biodiversity
19	EFR science synthesis of biological responses to stream nutrients			
20	Legacy study using the long-term ecosystem productivity (LTEP) experiments implemented on Olympic State Forest, in the greater H.J. Andrews EF area, and near Cascade Head EF			
21	Continental-scale questions for EFRs			

Table 8—New ecological initiatives (continued)

Project number	Cross-site activity	Type of data collection	Theme of data collection	Secondary theme
22	Understanding the controls on clean water delivery from headwater forests—synthesizing long-term data from USFS experimental forests	Synthesis	Water and watersheds	
23	Experimental management of riparian wind buffers to provide for both riparian habitat functions and commodity production			
24	Understanding changes in ecosystem function at continental scales: monitoring in the EFR network with permanent vegetation plots	Observational	Biodiversity	
25	Understanding ungulate herbivory as a chronic disturbance interacting with episodic disturbance	Experimentation	Biodiversity	
26	Evaluating fuel, vegetation, and disturbance dynamics using the irregular uneven-aged silvicultural system within different forest structure stages on the Black Hills EF			
27	Landscape-scale management experiments to test effectiveness of riparian management practices based on historical range of natural variability	Experimentation	Resource management	
28	Testing different silvicultural techniques for creating and maintaining structurally complex forests	Experimentation	Resource management	
29	Accumulation of heavy metals in watershed soils and their subsequent removal during postfire erosion events leading to contamination of drainage sediments			
30	Develop guidelines for eastern shortleaf pine natural and artificial regeneration in the Southern Appalachians			
31	Animal damage control (ADC) on the Chippewa National Forest			
32	Ecological site development for the Caddo National Grasslands, north-central Texas			
33	Spruce reforestation techniques			
34	Developing guidelines for assisted migration of populations within major tree species in the Eastern United States			
35	Impacts of herbicide use on forest land to control vegetation			
36	Region 1 and RMRS draft adaptive management research framework (AMRF)			
37	Ground water survey			
38	What is the effect of a wide range of management strategies on long-term ecosystem productivity?	Experimentation	Biodiversity	
39	A sentinel monitoring network for detecting the hydrologic effects of climate change on headwater stream ecosystems and biological indicators	Observational	Biodiversity	Water and watersheds

capable of efficiently collecting and managing the data across the network. We will need to assess a number of factors that will, in total across all activities at a given site, dictate the resources needed to accomplish each:

- Acquisition of samples/data (periodicity, geographic location, technical expertise needed to ensure consistent data quality)
- Maintenance of equipment (frequency, costs)
- Processing of samples (costs, periodicity)
- Management of data (input into electronic storage, archiving, and access)

Undoubtedly, many of these routine data collection efforts could overlap in ways that can realize economies of scale and thus reduce overall costs (e.g., centralize sample analysis of soil or water in one location as a service for other EFRs). Careful evaluation of which research or monitoring is needed combined with an evaluation of how to most efficiently design field protocols will lead to an assessment of what resources will be necessary.

Social science issues and the arts/humanities that could be addressed through the EFR network—

When the first EFRs were established not long after the turn of the 20th century, no one imagined or planned for a future in which the United States population would exceed 300 million, or that more than 80 percent of these people would live in urban areas. There was little to no concern about issues such as the quality of human uses or the impacts of human activities. It is a much different landscape today and many new issues exist that now involve topics such as economics, historical studies, human population and land-use change, human values, and interdisciplinary social-ecological studies (Charnley and Cerveny 2011). These trends have opened a new avenue for the social sciences to take advantage of EFRs. Interestingly, more than 35 percent of the EFRs in the United States are within 50 miles of urban areas (i.e., cities of more than 50,000 people) (Charnley and Cerveny 2011). The potential exists for many new lines of research on the network of EFRs.

When the first EFRs were established, no one imagined a future in which the U.S. population would exceed 300 million, or that more than 80 percent of these people would live in urban areas. Today, many issues involve topics such as economics, historical studies, human population and land-use change, human values, and interdisciplinary social-ecological studies.

Engagement of arts and humanities in these public places dedicated to learning is also just beginning. In part, this reflects recognition that management of public forest lands takes more than "scientific forestry;" it is a profoundly social and cultural enterprise and the beauty and dynamism of many parts of our EFR system are powerful and inspirational (Swanson 2008). A very interesting and rich body of arts and humanities works is emerging from several of our EFRs. The disciplines involved include humanities (creative writing, environmental philosophy, environmental history), the arts (visual arts, dance, music, drama/theater), and sciences (ecology, earth and social sciences).

Education and community involvement are also facets of the EFR portfolio emerging as an important activity. While many of these activities are largely ad hoc and generated by individuals who have a particular interest, it is quite possible that these activities could become a more formal part of future initiatives at EFRs. Notwithstanding the efforts that have occurred at a number of EFRs, there is enormous untapped potential for education and outreach activities at most of our EFRs.

All of these emerging activities will involve segments of our society that heretofore have had little to no participation in what happens at EFRs. With continuing demographic trends toward a more urban society, it will be important for the EFR network to embrace this additional role in the future. This could become an important facet of work at many EFRs in the near future.

Chapter 3: The Future of the EFR Network

The 80 experimental forests and ranges (EFRs) across the United States offer an abundance of special opportunities for addressing key land management issues for the Forest Service, other research and land management institutions, and the general public. A significant portion of the accomplishments and future opportunities of the EFRs across the United States continues to lie with the site-by-site research that addresses local questions of interest. However, here we define and focus upon the directions that are suggested to specifically take the collection of EFRs, the network, into the future.

For most of the century-long history of the EFR system, EFR sites were selected and operated as stand-alone units to represent a broad array of forest and grassland types and conditions. In the first century of EFRs, their leaders interacted primarily through informal or scientist-to-scientist ties with no explicit intention of networking them (Ryan and Swanson 2014). We have already discussed some of the significant achievements that have come from the research and monitoring done on EFRs. However, we have just begun to capitalize on the possibilities of networking EFRs to address many of the pressing issues of today and tomorrow.

A significant portion of the accomplishments and future opportunities of EFRs across the United States lies with site-by-site research that addresses local questions of interest. Here we define and focus upon the directions that are suggested to specifically take the EFR network into the future.

Why a Network?

Evolving societal expectations and science questions call for increasingly broad-scale and interdisciplinary ecological research (Lugo 2006). The kinds of environmental challenges we face today require greater innovation from the research, management, political, environmental, and resource-use communities. The evolution of land and resource management scientific information needs has progressed to include the arena of “macro systems biology.” This new demand for broader ecological insight includes research on biological systems at regional to continental scales. This approach requires quantitative, interdisciplinary, systems-oriented research on biosphere processes and their complex interactions with climate, land use, and invasive species. There are important new programs being initiated by other organizations (NSF, USGS, NASA, NOAA, NEON, etc.) and other scientific disciplines (meteorology, public health, sustainable agriculture, etc.) to get out in front of these issues. It is important that we capitalize on efficiencies in our existing network and any future investments to translate results and opportunities to knowledge that informs forestry and natural resources management.

The obvious implication is that we need sites strategically distributed across geographic domains and along environmental gradients, sampling a full complement of locations that are representative of the diversity of environments in question. 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). Many of the questions that are important today, or that we anticipate to be important tomorrow, are addressed only with this kind of sampling array. It is also essential that Forest Service R&D be in a position to "share a usable network" with other capable scientists who need, but do not have access to, the wealth of data offered by the EFR network.

The goal of forming EFRs into a more functional research network is to enhance their combined scientific capacity to address pressing, regional-to-continental environmental issues, such as predicting the effects of climate change, altered atmospheric chemistry, or urban growth on forests and grasslands.

The goal of forming EFRs into a more functional research network is to enhance their combined scientific capacity to address pressing, regional-to-continental environmental issues, such as predicting environmental effects of widespread influences including global climate change, altered atmospheric chemistry, or urban growth on forests and grasslands. Through better coordination and less duplication of effort, a network could also make better use of the long-term investment in scientific research that the Forest Service has made at these sites. It has already been recognized that an information-sharing infrastructure to facilitate access to, and synthesis of, cross-site data will be an integral component of the foundation for a research network (Ryan and Swanson 2014). A more functional network will also play a vital role in the Inventory, Monitoring, and Assessment initiative of the entire Forest Service. Review appendix 2 for details on the kinds of networks in which the EFRs across the country are currently participating.

What Is the Niche for the EFR Network?

Ecological research and monitoring is the domain of many government, educational, and private institutions. As scientific information needs continue to evolve, these institutions adapt to meet those needs. Competition, while not a purposeful part of the process, results from different organizations attempting to position themselves to garner support and funding.

The competition is fiercer than we are likely to acknowledge, particularly with declining agency budgets and the zeal to capture and identify with emerging and increasingly broad ecological issues. The need for information is acute and organizations whose mission it is to deliver such information need to be responsive. Nonetheless, the types of information needed require certain kinds of expertise and facilities to obtain and deliver reliable results. The competitive advantages of the EFR network were reviewed in chapters 1 and 2. These are significant and clearly suggest where the appropriate niche of the EFR network may lie. Again, it all depends on the kinds of questions that are to be addressed.

Of the many information products that society demands of its scientific infrastructure, a certain subset fall more closely within the niche of experimental forests and ranges, and set an effective research and monitoring network apart from other options:

- A robust legacy of data collection and research results
- Access to high-quality baseline data
- Long-term control of large forested landscapes
- Stability and longevity of sites
- Landscapes with a well known and documented history
- Richness of prior research and access to those findings
- Sentinel sites for monitoring strategies or where one can conduct experiments and test management approaches
- Adequate representation across ecological gradients of interest
- A connection between research initiatives and management priorities
- Logistical support and access
- Cooperation and support from site managers and other research institutions.

An array of possible scientific questions suited to the EFR network is considered in chapter 4. Which ones are these facilities best suited to address? Some of these environmental questions require intensive data collection. The National Ecological Observatory Network (NEON) was designed to detect and enable forecasting of ecological change at continental scales over multiple decades. NEON will use distributed sensor networks, coordinated airborne observations, and experiments linked by advanced cyber infrastructure to collect ecological data across the continental United States, Alaska, Hawaii, and Puerto Rico.

NEON has partitioned the United States into 20 ecoclimatic domains, each of which represents different regions of vegetation, landforms, climate, and ecosystem performance. In those domains, NEON will collect site-based data about climate and atmosphere, soils and streams and ponds, and a variety of organisms.

A second example of intensive ecological monitoring and research is the Long-Term Ecological Research program (LTER). Twenty-six research sites constitute a loosely integrated LTER network at present. The network includes a wide range of ecosystem types spanning broad ranges of environmental conditions and human domination of the landscape. The geographic distribution of sites ranges from Alaska to Antarctica and from the Caribbean to French Polynesia, and includes agricultural lands, alpine tundra, barrier islands, coastal lagoons, cold and hot deserts, coral reefs, estuaries, forests, freshwater wetlands, grasslands, kelp forests, lakes, open ocean, savannas, streams, and urban landscapes.

The budget and focus of NEON and LTER are very different than what can be expected of the EFR network. NEON and LTER are concentrated at a relatively few strategically located sites, and the data collection efforts are broadly focused. The EFR network of sites could provide information on the considerable variability around these sites, greatly enhancing the scope of inference and facilitating the application of research results at a scale appropriate to land managers. On the other end of the spectrum are data collection efforts that are extensive (i.e., many and widely distributed) but have a narrow, limited focus. For example, the Forest Inventory and Analysis (FIA) program reports on status and trends in forested area and location; in the species, size, and health of trees; in total tree growth, mortality, and removals by harvest; in wood production and utilization rates by various products; and in forest land ownership. A combination of remotely sensed data collected for thousands of points across the United States combined with field plots taken at a subset of these points provides annual inventory data on the condition of our forests. These data can be used for a variety of analytical purposes, but are limited to some basic forest composition and structure data and thus limited in what questions can be addressed with them. Another example is the U.S. Geological Survey daily stream gauge values. Over 25,000 sites across the country have daily flow records for representing the daily mean, median, maximum, minimum, and other derived values regarding streamflow. Again this represents extensive raw data that can be used to analyze a variety of streamflow questions, but it is limited by the narrow scope of the data.

The EFR network occupies a niche that is somewhere between these two ends of the spectrum. EFRs can augment existing efforts. The 20 NEON domains do not cover enough geography to represent all ecological systems. EFRs also augment existing monitoring networks such as the National Atmospheric Deposition Program sites (NADP) by not only having monitoring locations, but having the distinct advantage of having such specific measurements collocated with baseline environmental measurements, such as stream water chemistry. This is a huge benefit to these existing partner networks.

We are not aiming to address the kinds of questions and obtain the level of funding support to which the NEON and LTER programs aspire. However, there is a suite of important environmental challenges and questions that are well suited to what can be accomplished with relatively modest investments and with the kinds of facilities and landscapes on which we are working. Chapter 4 presents a set of choices that include both ongoing research and monitoring activities as well as a noteworthy array of possible new initiatives for which a network of EFRs could be employed.

There is a lot of natural resource information being gathered, but someone has to understand the forest management questions and translate the emerging complexity of data into answers that land and resource managers can put into application. Forest Service R&D is best situated to accomplish this. Through the expertise and focus of R&D scientists and staff, combined with our proven ability to work with other research organizations, we are best positioned to serve the needs of the Forest Service and many other organizations that are responsible for managing land through well documented, credible science.

Priorities and Expectations

The existing and emerging environmental challenges facing humanity require a research focus capable of addressing complexity at the scales of time and space in which the problems are rooted (Lugo et al. 2006). The research that traditionally entails studies focused on individual sites and local research objectives will continue to be a priority for all EFRs. The successes of the EFR system have been founded on these efforts and will continue to be a mainstay of R&D. Here we forecast a body of work that will take increasing advantage of networks of sites across broad temporal and geographic environmental gradients. Lugo et al. (2006) summarized the characteristics of the EFR network that could facilitate future broad scale research efforts. These characteristics should be familiar and are well documented in earlier sections of this report:

- 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 (multi-decade), 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 that 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 and realized.

Lugo et al. (2006) cited several barriers that hinder progress toward the goal of developing an integrated national network of research sites. These include:

- A limited history of network research
- Chronic underfunding of research infrastructure and data management
- Difficulties in accessing data from independent site files
- An absence of funding mechanisms for network research, and
- Mistrust of manipulative research at large scales.

They correctly acknowledge that these impediments are significant and cannot be ignored but further maintain that they are not insurmountable. The public depends on professional research and land management institutions like the Forest Service to forge solutions that will 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.

The existing assemblage of experimental forests and ranges, albeit cobbled from 80 individual sites, has all the makings of a model for development of long-term ecological and environmental observatories and as a prospective player in future networks. Chapters 4 and 5 provide a roadmap for accomplishing this.

Managing and Exploiting EFR Facilities and Information Assets

Managing our information assets—

Many EFRs have not implemented modern management for their information assets and suffer from lost or compromised paper records and isolated storage of electronic records. This poses a challenge to the EFR network and Forest Service R&D. Regardless of the level of scientific questions addressed by EFRs, improved management of these assets is critical to EFR network success and relevance in the 21st century. This section describes these key EFR information assets (table 9). Chapter 4 discusses how to extract the untapped value of these assets; it provides assurance that there is a way forward to obtain the benefits described below. Later in this report we discuss options for organizing an improved data management infrastructure for the network.

Table 9—Summary of potential value of information assets

	Asset type			
	Research data			
Asset value description	Historical	Modern	Administrative data	Web presence
Enhances productivity and research impact	X	X		
Facilitates new science via re-use	X	X		
Adds credibility to research articles		X		
Adds value and richness to future research	X	X		
Provides educational tools at multiple levels	X	X		X
Facilitates cross-site research	X	X	X	X
Increased partnering opportunities		X	X	
Improves site management			X	X
Provides historical context for EFRs	X		X	
Marketing for FS R&D, EFRs, and Network	X	X	X	X
Ancillary benefits for FS R&D	X	X		X

FS R&D = Forest Service Research and Development.
EFRs = experimental forests and ranges.

Historical research data—
There are few substitutes, if any, for the data collected by EFRs over the past 100 years. They continue to be relevant for supporting their original research purpose, but as we have seen with the use of weather series for climate change research, data re-use is not always linked to the original collection purpose. Historical data also provide context for understanding results from new research on the site.

Some data sets are available in modern digital formats; however, many data sets are still stored on paper in file cabinets. EFR principal scientists believe that the file cabinets hold a rich and unique lode of content to mine. This view is supported by occasional forays into these data by both Forest Service and external scientists. Also buttressing this view is the positive response received by scientists at EFRs who have made research data available online. However, knowledge of file cabinet and old media contents are imprecise and these historical studies lack the necessary documentation, or metadata, required to be fully useful.

Many EFR principal scientists believe that data sets stored in file cabinets hold a rich and unique lode of content to mine.

As the recent report to the Chief of the Forest Service on temperature trends on EFRs exemplifies, if historical research data were available across all EFRs, there would be significant opportunities for cross-site synthesis research. Such research would be simplified if the data were available without having to rely on the goodwill and time availability of very limited (or nonexistent) local EFR staffs to assemble and organize the needed data for each project. Instead, synthesis work could simply access and then cite the available data products.

Modern research data—

Few modern projects performed by FS or external researchers on EFR sites have data management plans or resources to hire information managers and provide for information system development. Thus, over time, these data are at risk of becoming as inaccessible as current historical data sets—locked in obsolete formats and lacking the documentation needed to understand how to use them.

EFR sites are also starting to deal with the very large quantities of data produced by modern sensor equipment. Effective management of these data streams will require more advanced data management systems and practices, as sites like Silas Little can attest based on North American Carbon Program work.

Administrative data —

EFR administrative data form an important, if underutilized, collection of content that includes:

i. Research-oriented data—maps of the EFR site and information, including spatial extent, about past and current studies. These data are not project-specific; rather, they broadly support site research and site management (e.g., reporting to hosting landowners).
ii. Operations-oriented data—how to run the site, lessons learned for processes like National Environmental Policy Act (NEPA) analyses and national forest permit processes, etc.
iii. General administrative—correspondence, establishment reports, etc.

Knowing where studies have been conducted can be important for establishing new studies. For example, the Hawaii Experimental Tropical Forest has used knowledge of past study locations to help scientists rule out sites that would not be appropriate for a new research project because of the effects of past research there.

Sharing lessons learned across time (staff changes) and space (EFR sites) can improve facilities management and conduct of administrative activities. For example, an organized site history can also be useful when infrequent activities need to be performed. From a network perspective, lessons learned by one site can be useful to another site dealing with a similar situation, preventing frustration or bad decisions.

Web presence—
The public Web presence is how we market EFRs and their accomplishments to the public and to scientists who might conduct research on our sites. The collective value of information available on a Web site, from both EFRs and FS R&D, should not be underestimated. The current collection of websites is broadly variable in visual style, uneven in terms of both quality and quantity of content, and does not cohere as a network. Overall, the sites do not deliver on their potential.

The internal Web presence is a tool for communication among EFRs that has been underutilized. This is beginning to change, as the EFR Coordinator and the eResearch EFR project manager work to create a SharePoint site that could increase user access and availability of key information.

Chapter 4 provides more detail on how to extract the value from the main asset types; addresses how to obtain value from a sub-type of asset that the network currently has very little of (i.e., cross-site research data); and discusses how investing in EFR data management yields benefits to the rest of FS R&D.

Managing Our Facilities Assets

Forest Service R&D has a significant challenge in maintaining a functional physical infrastructure to serve the needs of a research organization. The aging assets we have across the country combined with evolving needs and technological changes clearly suggest that we are sorely in need of "Facilities Master Planning." Such planning would help develop near-term recommendations and priorities that are essential to achieving the intended long-term goals and objectives of the R&D mission. It would also influence, and shape the forecasted development, disposal, major alteration, and renovation needs essential to supporting the EFR network's immediate and long-term goals.

The primary problem is that most of our facilities were constructed in the 1950s and 1960s and are worn out. There are insufficient resources to maintain them let alone upgrade them to current standards. Many of our facilities were constructed when R&D had a much larger workforce and some of those facilities are no longer needed. Other facilities are critical to achieving our mission and require maintenance and reconstruction.

Forest Service R&D leadership needs a strategy for the care and feeding of these facilities. To say that we can maintain all of them to an acceptable standard is not realistic. An additional problem is the disposition of some of our buildings that are recognized as historical. Some should be repaired or restored, whereas others should perhaps be disposed of. We currently do not have a clear vision of how we should approach these infrastructure challenges.

Chapter 4: Strategy for Moving EFRs Forward

The considerable successes of EFRs are well documented in the scientific literature. But we have to ask: how do we support this enterprise and continue these successes? There is still robust energy and scientific output at many of our EFR sites and there are significant opportunities to enhance the productivity that both individual sites and especially the network could achieve. What does Forest Service R&D leadership need to do to support continued value from these sites? We must keep in mind that past accomplishments at a given EFR have typically been a result of the entrepreneurial efforts by one or a few individuals. Once these individuals move on, sites have often languished, especially those not receiving outside institutional support such as LTER sites. As a collection of individual sites there is no institutional structure that provides the glue of a network. Although this did not impede the success of individual EFRs, at least when a given site benefited from the energy of an enthusiastic research scientist, this model will not serve the objectives of a research or monitoring network going forward.

As a collection of individual sites, there is no institutional structure that provides the glue of a network. This did not impede the success of individual EFRs when a given site benefited from the energy of an enthusiastic research scientist, but this model will not serve the objectives of a research or monitoring network going forward.

Broad Approach to Achieveing Objectives

We describe here a vision of what is possible with a functional network of EFRs distributed across the country. A fully functional and integrated EFR network can have the capability to effectively address scientific questions concerning the implications that are relevant to policy and management of emerging, large-scale environmental issues on the nation's forest and grassland ecosystems. The network can accomplish this goal by building working relationships among scientists doing research throughout the EFR network. The foundation of the network can be a culture of cooperation that encourages, facilitates, and rewards EFR scientists working together. EFR scientists can have a strong community that fosters mutual trust and facilitates interactions among EFR sites and their programs of research. For example, the EFR network can enhance cross-site interactions by sponsoring network-wide events similar to those of the LTER network. The EFR network can hold periodic EFR all-scientists meetings to build community by serving as a forum for collaboration on topics of major interest to scientists, and serve as a seedbed for multi-site research projects. Gatherings of EFR scientists can also include, when appropriate, non-Forest Service cooperating scientists and EFR network science users including representatives of the policy and management communities.

EFR sites and their research programs can have the scientific capacity to be a critical mass capable of participating at a high level in major EFR network science topics. Not all EFR sites can have full capability on all topics, but together, subsets of sites can have the capacity to address national-scale questions related to vegetation dynamics, biogeochemistry, or hydrology.

The network can provide selected services that enhance science programs throughout the network. Common protocols can be established for environmental data collection and documentation. Information sharing capacity can be developed that enables scientists to build upon science done across the entire network and can be readily shared with the larger scientific community and the public. EFRs can participate in research networks managed by other institutions, such as LTER, NEON, and NADP, which can extend the reach and inferences of findings from EFRs and share lessons learned about networking processes. Dedicated administration and leadership can be in place to support network science with an appropriate mix of top-down and bottom-up approaches. Funding and resources for network science can be sufficient to provide a reliable and merit-based process to sustain a significant level of cross-site science to address major, large-scale issues for forests and rangelands.

Current Situation and Challenges

The foregoing discussions illustrate that we have serious challenges to optimizing the value of our EFR network. Going from current conditions to the vision set forth above will require a significant commitment. A brief summary of these challenges include:

Support for data collection—
It is a constant and increasingly difficult struggle to sustain important long-term research initiatives or initiate new research or monitoring at even the most high-profile of our EFRs. Shrinking budgets and loss of capacity through attrition is clearly decreasing our capacity to sustain, let alone expand, research and monitoring data collection. Lest we forget, this is the lifeblood of this organization.

Support for data management—
We have enormous challenges related to managing our data resources. There is a significant backlog of data requiring attention. This crucial aspect of the EFR program is in need of resources to bolster our capacity. Without meaningful attention to this issue, we stand to lose or never archive substantial amounts of the raw data that we know are very important to our mission.

Support for synthesis—
Although many individual researchers have been collecting and publishing their data at sites for decades, collaborations across the EFR network are fairly new. Cross-site syntheses of existing data are beginning to occur. Having syntheses conducted collaboratively by those who have familiarity with sites is important, in part to help promote EFRs, but more importantly because of the nuances of

interpreting the data. Some of the most interesting research with the highest impact results comes from synthetic evaluations of our data. Multiple efforts are underway, for example:

- Sherri Johnson (PNW), Chuck Rhoades (RMRS), and Steven Sebestyen (NRS) are leading the stream chemistry synthesis and ChemDB group.
- Lindsey Rustad (NRS) and Jim Vose (SRS) are leading the analysis of long-term climate data collected on EFRs.
- AmeriFlux is a network of sites that provide continuous observations of exchanges of carbon dioxide, water and energy. These sites also provide detailed environmental data (air and soil temperatures, precipitation, solar radiation, soil moisture) as well as ecological measurements including forest leaf area index and foliage nutrient content.
- NADP sites, collecting data on precipitation chemistry, began operations in 1978 with the goal of providing data on the amounts, trends, and geographic distributions of acids, nutrients, and base cations in precipitation.
- The USA National Phenology Network brings together scientists, federal, state, and local agencies, nonprofit groups, and educators and students to monitor the impacts of climate change on the phenology of plants, animals, and landscapes in the United States.
- LTSP research focuses on the joint role of soil porosity and site organic matter and their effect on the site processes that control productivity.

Identifying and Promoting Our Competitive Advantages

Earlier in this report we addressed what is distinctive and unique about EFRs. These features provide particular competitive advantages for the network of EFRs in certain key areas compared with other ecological research institutions. Elaborating on this list we can further make the case for how EFR work stands out:

- EFRs were established through formal congressional authorities provided to the Chief of the Forest Service and are designated for research as their primary purpose. Generations of researchers can count on these locations being there in the long term. With rare exceptions (for small localities), other agencies and universities do not have any such facilities.
- Data have been collected on these sites for decades, in many instances for up to 100 years. These data provide a wealth of information from which new studies can draw. Very few other research sites have this length of data record on stable sites. The value of long-term data with known land use history is becoming increasingly important to the research community.

- Many data collection efforts are co-located with other data collection efforts, enabling analysis of attribute changes in one measurement of one factor with changes in ecosystem structure and function.
- Long-term research is feasible and enabled. Universities do not have access to any particular location for more than generally 5 to 10 years with the exception of some small locations such as natural reserves or a limited number of experimental sites.
- Manipulative field studies, testing management ideas, are encouraged. Most field sites used for ecological research are largely limited to observational research, which does not permit land disturbance. Research that requires long-term study of management alternative such as forest treatments cannot be done on virtually any other research sites, university, or other state (natural reserves, state parks) or federal sites (e.g., National Park Service or U.S. Fish and Wildlife Service lands).
- New studies, complementing and conterminous with existing studies, are feasible and enabled. New researchers have distinct advantages when they can draw upon other background data sets and site characteristics to complement new research initiatives. Many research sites can claim this advantage; few have the depth and breadth of data like EFRs.
- Both basic and applied research activities are encouraged and enabled. EFRs were established to enable research to address management problems. All EFRs have a strong legacy of applied research covering many years. Most also have a variety of basic research investigation which provide important scientific insights which add important value to the overall mission of each EFR.
- The cooperation and collaboration with the land and resource management community is a key foundation of all EFRs. Land and resource managers are typically involved both in articulating the research and monitoring questions as well as enabling the execution of the work through a variety of logistical support activities. No other network of research sites has this direct connection between the research and management community.
- There is significant value for both the management community and the public to have an opportunity to obtain a firsthand view in the field. Many EFR sites provide demonstration plots or stands to illustrate the results of research findings for educational purposes. Few other research sites have the capacity to provide a research-results demonstration site that managers can visit and learn from.

- Field research has many logistical challenges. Sites are generally far from communities of researchers and productivity is directly proportional to the ability of research staffs to access and get around a site. Logistical support (housing, meeting rooms, laboratories, data, maps, etc.) is available at many EFRs. Some other research sites have these capabilities but they are mostly limited. Many EFRs have excellent logistical support.

The basic infrastructure of the EFR network, providing for the array of advantages described above, is partly in place. Some improvements are needed and these are addressed in the next chapter. However, the 100-plus years of investments represented by the current network would be next to impossible to put in place today. The significant advantages of the EFR network for addressing our strengths in field research and monitoring are abundantly clear.

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Evaluating Our Current EFRs: Criteria for EFR Tiers

The Forest Service is aware of the range of conditions and uses found on our EFRs across the country. Each of these locations has a different history of research and monitoring activities; different levels of investment in scientific instrumentation, research facilities, and other infrastructure; and varying levels of support from collaborators. That these exceptional sites have unique histories is not a condemnation of the inherent value that each has for R&D on its own or as part of a larger EFR network, but simply recognition of the varying conditions that developed over time.

As we move forward with plans to identify our research and monitoring opportunities across a network of official and cooperating EFRs, we will be forced to consider priorities for future investments. It will be to our advantage to provide some criteria for positioning our portfolio of EFRs for what we believe is needed to maximize the science and monitoring that we can execute across such a network. Having relevant and measurable criteria for evaluating the current and future potential of our EFRs can benefit the full network of EFRs in two ways: (1) to identify common minimum levels of infrastructure that should be shared by EFRs (e.g., a modern meteorological station with comparable data), and (2) to identify assets necessary to be part of a network so that the value of science and monitoring efforts can be maximized across a network of EFRs. Below, we offer some criteria for placing each EFR into one of four categories, or tiers, that will signify what we can expect from them and, in turn, what we should be investing in them.

Clearly these conditions can change, and targeted activities and investments can make that happen. Here, we mean to inform leadership and the participants in the EFR network of the current range of options and opportunities that each EFR offers. As we further develop scientific questions and determine how the network will be able to serve those questions, we will make case-by-case decisions on which EFRs will be involved in any given research or monitoring activity.

The following criteria provide a measure of the current activity and production of each EFR. Collectively, these metrics will give us a means for classifying EFRs and placing each into the appropriate tier. We suggest that each criterion could be assigned a qualitative value such as high, medium, or low and that some of these criteria could be weighted to reflect a higher level of importance relative to others.

- **Scientific merit and activity**—Number of research studies, demonstrations, and monitoring activities ongoing.
- **Partnerships**—Ability to leverage research funding and involvement from participants from collaborating agencies, research institutions, nongovernmental organizations, or other potential partners
- **Available scientific infrastructure**—Number and quality of scientific instrumentation that will support independent research activities such as meteorological stations, stream gauges, permanent plots, etc.
- **Site facilities and management**—Includes management viewpoint institutional cooperation, organizational structure and decisionmaking, logistical support and communication. Logistical support and communication involves lodging, housing, office space, T1 line/digital subscriber line/telephone ground line, wireless phone access, coverage by FS radio network, etc.
- **Research products generated at EFR**—Count of refereed and nonrefereed publications that have provided knowledge on ecological function, composition, and structure; list of demonstrations, field tours, videos, and other science delivery products.
- **Local to regional applications**—Are research results from a given EFR being applied in the local area or region? Do these results provide a model for managers to adopt and apply to their local management challenges?
- **Cross-site, regional, and international activities**—How much activity at the site is devoted to working with other EFRs or other comparable field sites, regional/continental/international collaborations on research or monitoring questions, and general collaboration with scientists from other institutions?
- **Access**—Road network, trails, administrative support tools such as GIS, maintenance of access infrastructure, clear boundaries recently surveyed.
- **Data management**—Past data collected at the site are available, with metadata and digital formats for use by other researchers. Includes performance in information systems, metadata development, quality control systems, administrative interface, website, system administration, and data access.

- **What is the quality of the data sets at the site?** Are they useful for other researchers or for networking with other sites?
- **Ecological importance**—Is the EFR located in an ecological province (Bailey Ecoregions) that has no other representation (or is underrepresented)?
- **Education and outreach activities**—Number and scope of activities that contribute to education and outreach across the spectrum, from K-12 to university to public and technical transfer of scientific findings to management and policy makers.
- **Support from national forest (or other host)**—Does the facility enjoy support by the host institution for law enforcement, NEPA preparation, road maintenance, and other necessities for project implementation and day-to-day operations?
- **How far is the EFR site from a staffed location?**
- **How much staffing (scientist time, support staff time, etc.) is assigned to an EFR?**
- **What are the major research topics studied at each EFR** (e.g., wildlife, silviculture, hydrology, carbon budgets, etc.). How long have they been under study? How do the primary areas of research fit within/contribute to a network context?

Collectively these criteria can help guide where we put our limited investments in the future. Some EFRs will clearly rise to the top as places where we can observe the benefits of continued support. Others will reflect the need to consider whether R&D should continue to support the site, for likely obvious reasons.

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Tier 1. Model EFRs that have excelled in scientific accomplishment and promise to do so into the future. They score highly in all ranking criteria; staff is in residence; work center/office space is in good condition; lodging exists for researchers and visitors; basic instrumentation is modern and operational; good access to Internet and phone networks; many active research studies on site and linked to other sites.

Tier 2. EFRs with notable past and present accomplishments, and plans for future research and monitoring activities. These sites score highly in more than half of the ranking criteria and provide current promise for improving in all.

Tier 3. EFRs with notable past accomplishments, and promise for future research or monitoring activities. Current activities are minimal or none. No one is located at the site, mothballed buildings exist, utilities are not active, and only primitive rest room facilities are available.

Tier 4. EFRs with no notable activity for many years and no plans for future activity. No one is on site; no buildings for work or lodging are on site; no Internet service; difficult access. Essentially, the EFR is in caretaker status.

Addressing availability of limited funding for EFRs is a difficult but necessary step. We have to be objective and careful as we examine the full roster of EFRs and determine how we administer them in the future. The intent of these tiers is to characterize the current or anticipated status of each EFR and provide some guidance regarding investments for the near term. Inevitably, some of the EFRs will logically be placed in Tier 4 and essentially be mothballed for the time being or, in some cases, even dis-established. This does not mean that we would not attempt to gather the historical data from these sites and archive them, as deemed necessary, as we intend to for all 80 EFRs. It is merely recognition of the reality of current circumstances and the pragmatic management decisions that we will face. As circumstances change, the rating of any one of these EFRs can be reevaluated and adjusted accordingly.

Networking and Marketing

Many of the long-term monitoring and research studies, including stream gauging of small streams and watershed-based research are distinctive to the Forest Service and could benefit from increased “branding.” This is appropriate for a number of reasons, including the fact that recognition of these contributions and the conscious linkage and credit to Forest Service R&D could translate into increased resources needed for maintaining these long-term data records and for post-doctoral researchers and others to help with synthesis efforts. Other national networks do not have such a foundation of land and facilities to build on. The Long Term Ecological Research (LTER) program, known for long-term studies, has built on the investment of the Forest Service for the longest term data collections at its shared sites. NEON has only begun to collect data and is decades away from having comparable record diversity and duration. If we are to enhance our position within the scientific community and the connection to management relevance, it is essential that we sustain this body of work.

For many decades agencies like Forest Service R&D were provided a reasonable budget and simply expected to fulfill their mission. There was relatively little public scrutiny and the reputation of the organization was sustained through quality publications and long-term productivity. So much has changed in the last two to three decades. We now find ourselves in a very different socioeconomic arena in which we must tap into new skills and abilities. We must be able to effectively communicate the value and practical application of the science we produce. No longer can we rely upon passive, unstructured practices of managing our work. This includes developing more structured approaches to record collecting, managing data properly (Quality Assessment/Quality Control, archiving), and making the data publicly accessible.

Identifying and Working With Partners

We long ago reached a point at which it was clear that an organization like Forest Service R&D, with an asset like the EFR network, could not meet its aspirations by working alone. There is a range of partners and collaborators who are essential to the success of the mission embodied in the EFR network. First and foremost is the relationship with the NFS and the many people, from the district level to the Washington Office, who both enable much of the work and use the results. Most EFRs are designated within national forests (62) and depend on a variety of services and cooperation from the districts, forests, and regions that hosts these sites. Furthermore, the wide array of research or monitoring conducted on EFRs has direct or indirect implications for land management. Cooperation with the NFS is crucial to the success of the EFR network. Swanson et al. (2010) provided useful guidance on effective research-management collaboration at long-term environmental research sites. Fundamentally, it depends on mutual understanding and respect, a shared commitment to the land base, interest in learning, a common program of work, and a spirit of partnership. The many examples of good collaboration associated with long-term research sites serve as models for what can occur more widely (Swanson et al. 2010).

Long ago it became clear that an organization like Forest Service R&D, with an asset like the EFR network, could not meet its aspirations by working alone. A range of partners and collaborators is essential to the success of the mission embodied in the EFR network.

We also have the tremendously important relationship with our research partners. Our most successful and productive EFRs are those with a strong and visible collaboration with one or more universities. These partnerships allow leveraging of limited resources, share in defining the research agenda, assist in obtaining research funding, aid in developing the facilities which are ultimately shared by all parties, administer the activities on the site, and manage the scientific and logistic resources that support the research and monitoring. Examples include the H.J. Andrews EF (Oregon State University), Hubbard Brook EF (Dartmouth University, Cornell University, others), Sagehen EF (University of California–Berkeley), etc. Partnerships offer enormous advantages and opportunities to achieve much more with fewer resources.

There is also a broad community of those who value and use the scientific findings that are derived from EFRs (see the section on the community of interest on EFRs for details). Support to operate these EFRs comes largely internally and from our partners in research and management. However, we also have examples of external support from organizations like the Rocky Mountain Research

Foundation (at Starkey EFR) and the Hubbard Brook Research Foundation (at the Hubbard Brook EF). With the expansion of research initiatives and growing interest in initiatives such as climate change monitoring and research, we can see these partnerships with beneficiaries of our research products growing.

We are seeing more and more examples of what we can accomplish through collaborations than we can individually. It will be a significant priority of this program to continue to nurture and build new collaborations and sources of support that can be associated with our overall EFR network.

Education and Outreach Opportunities

Over the 100 years of activities on EFRs there has been tremendous achievement by the large number of students, particularly graduate students who do their graduate research on EFRs. Forest Service R&D has collaborated with universities over the decades to include students on these research sites and to take advantage of the many opportunities EFRs present.

Education and outreach activities were not an explicit purpose of the EFR network or any individual EFR when each was established. But the last two to three decades have brought a tremendous increase of public interest in how forest ecosystems are structured and how wildlands are managed.

Education and outreach activities were not an explicit purpose of the EFR network or any of the individual EFRs when each was established. Times have changed, and the last two to three decades have brought a tremendous increase of public interest in how forest ecosystems are structured and how wildlands are managed in this country. Many kinds of interest groups have emerged; people have become much more informed about the complex issues of land management. There is also a growing demand to enable educational/informational exchanges between researchers and professionals in the land/resource management community and local public officials. We are also seeing growth in international collaborations and opportunities to exchange expertise.

This has introduced a new and now potentially important element to the mission of EFRs. However, this also presents a new, unfunded duty for most EFRs, one that is largely impossible for many. This opportunity is something that will have to be developed as the capabilities emerge through partnerships and other dedications of interest, both internal and external.

Nonetheless, the opportunities are almost endless and the potential reward is significant, both for the external benefits that education and information can provide to a broader audience as well as internal benefits of recognition for all the accomplishments at EFRs. A sample of some of the existing and effective educational and outreach activities at EFRs include:

Sagehen Experimental Forest—

Sagehen EF hosts workshops and courses like Geomorphic and Ecological Fundamentals for River and Stream Restoration and public events like the Summer Science Speaker Series. Online media includes the Sagehen News blog, Sagehen

TV videos, podcasts and a Sagehen Forest Project blog. Other outreach and education programs or events include:

- Adventure-Risk-Challenge program held at Sagehen Creek Field Station, the Sedgewick Reserve and Yosemite National Park.
- The Highway-89 Stewardship Team Transportation Ecology Outreach Program.
- K-12 programs for local and state-wide school kids.
- Fish Cam (a web cam for the fish house to observe wild fish behavior).
- Hosting the University of California—Davis Graduate Group in Ecology's new graduate student "Odyssey." http://ecology.ucdavis.edu/news_events/odyssey.html

Coweeta Hydrologic Lab—

Coweeta LTER scientists and staff provide middle school, high school, and community college students "hands-on" field and laboratory research experience. The Schoolyard Initiative has been funded since the 1998–1999 school year by an annual supplemental grant from the National Science Foundation to the core Coweeta LTER grant. The purpose of the Schoolyard Program is to formally provide instruction, field research, and data summary and analysis experiences to K-12 students and instructors using Coweeta LTER research projects as an example.

The program coordinated by researchers at Coweeta Hydrologic Laboratory includes students from Mountain View Intermediate School, Macon Middle School, and Macon Early College in Franklin, NC, as well as students from Rabun Gap–Nacoochee School in Rabun County, GA.

H.J. Andrews Experimental Forest—

In collaboration with the LTER program on the site, the H.J. Andrews EF has numerous and varied education and outreach programs and activities geared toward K-12 students and teachers, visiting scholars, undergraduates and graduate students, Forest Service and other natural resource professionals, and the general public. The following list is just a small sample of the offerings:

- Research Experience for Teachers (RET)
- Outdoor School, McKenzie School District
- Research Experience for Undergraduates (REU)
- Andrews LTER Graduate Student Research Awards
- Environmental Leadership Program, University of Oregon
- Undergraduate/graduate classes and courses
- Post-doctoral trainees
- Field workshops and tours

- Visiting Scholars Program
- Workshops and tours organized by Central Cascades Adaptive Management Program (CCAMP)
- Oregon State University Extension and Outreach Partnerships
- Interpretive trails for the public

Hubbard Brook Experimental Forest—

The Hubbard Brook Research Foundation (HBRF) and the Forest Service have joined efforts to develop a Research Experiences for Teachers in the Experimental Forests (RET-EF) program. The primary aim of the RET-EF program is to provide K-12 science teachers with sustained, hands-on experience in environmental science research. Additionally, the RET-EF program supports participating scientists by providing them with summer research assistance and, at the same time, a mechanism to extend the broader impacts of their work. The RET-EF program aims to improve public awareness of environmental science research and the role of the USDA experimental forests.

Clearly, education and outreach can be an extremely useful and relevant part of the EFR mission. With limitations in available resources to support the core research mission of the EFR network it is likely that the support and encouragement by Forest Service R&D leaders be largely from in-kind resources. Nonetheless, we stand to reap significant benefits from including education and outreach as an integral component of EFR activities.

Addressing the Status of Our Facilities Assets

Given the need to take a comprehensive look at the condition of and needs of our facilities it would serve Forest Service R&D well to form a national team to assess the EFR facilities. The kinds of issues that need attention include:

- What is the purpose for the site? Internal research only, collaboration, education, conference center, etc.?
- Are we duplicating the same types of research facilities in multiple locations? Is there sound reasoning for this?
- Should we put emphasis on developing a few, state-of-the-art conference centers such as H.J. Andrews and Bent Creek and not try to develop those types of facilities at multiple locations?
- Are there obsolete buildings on the site that should be removed or changed to another use?
- What is our use of the site? Is it only occasional use or regular and needed use? Should we be spending limited funds on sites that have very little usefulness?

- Should we be building new facilities when we have old ones in disrepair?
- Are some EFR facilities that were purposeful 50 years ago still relevant today?

These are tough questions for many reasons, but a comprehensive evaluation of our complete inventory of facilities assets is necessary to make smart decisions. From the results of such an assessment, through a complete Facilities Master Plan for EFRs, we will have the information needed to make informed decisions about this crucial and largely neglected concern.

Safety Considerations

No Forest Service strategy should go forward without addressing safety concerns for our employees. The work we do on experimental forests and ranges often takes us to remote places where we contend with obstacles and risks of all kinds. The innumerable safety concerns that come with field work are taken seriously by everyone. Numerous precautions have been devised to help our employees avoid accidents, as have procedures for responding to them, including job hazard analyses for field activities, emergency evacuation plans, safety and first aid training, and tailgate sessions to provide reminders (most especially to our relatively inexperienced seasonal work force) of the hazards one is likely to encounter on any given day. These practices have become part of Forest Service culture and will remain in place.

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Development of new innovations to improve the safety of our work environment (both field and office) will continue to be a priority. We continue to have more opportunities to devise better procedures. One area where we stand to both improve the quality of the science we do as well as reduce exposure to hazardous conditions is through technological innovations. The development of a "virtual experimental forest" at many of our experimental sites could have a profound impact on lessening our environmental impact and, at the same time, increasing safety. By minimizing the person-hours driving to sites and traversing difficult terrain to access study areas, and reducing the need to provide access roads, we decrease impacts on soils and water, and reduce disruption of wildlife. By limiting the need for frequent on-the-ground field trips we reduce hazards to field crews. Much of the field sampling conducted in EFRs, especially under hazardous conditions such as during storms, is wasteful and potentially dangerous. Routinely visiting unconnected instrumentation sites to verify that they are functioning properly and download data is inefficient and is hit or miss from the standpoint of data quality.

New technology has emerged that enables deployment of sophisticated data collection equipment and the networking of those instruments to create more effective and more efficient research and monitoring tactics. Clearly these measures will also reduce exposure to potentially dangerous conditions and result in a safer environment for our employees. As the EFR network moves forward, special attention can be given to developing these sensor networks at all EFRs where it is affordable and feasible.

Relationship to the Greater Forest Service Inventory Monitoring and Assessment Program

The framework for the new planning rule process consists of a three-part cycle: assessment, plan revision or amendment, and monitoring. These phases of the planning process are complementary, and intended to allow the Forest Service to adapt management to changing conditions and to improve plans with more frequent amendments based on new information and monitoring. The planning process would require developing an understanding of the landscape-scale context for unit-level management. Assessments, in particular, are designed to create an understanding of conditions, trends, and stressors both on and off NFS lands to guide the development of plans to manage resources on the unit.

The planning rule also creates a two-tiered strategy for monitoring at the unit level and at a broader scale. Monitoring is a central part of both plan content and the planning process, allowing responsible officials to test assumptions, track changing conditions, measure management implementation and effectiveness in achieving desired outcomes, and feed new information back into the planning cycle so that plans and management can be changed as needed.

With the increased emphasis on executing a scientifically credible inventory, monitoring, and assessment program, including targeted efforts at a landscape scale, there is a clear nexus with what a network of EFRs can offer. Close coordination between R&D and the NFS as this program is put into operation will clearly improve the reliability of efforts related to the planning rule. We can reduce redundancy, realize savings, improve scientific robustness, and make more efficient use of our limited staffing.

Data Archiving and Sharing

Data that extend over long periods of time can greatly enhance the value to EFRs in addressing new questions or long-term trends. But to be valuable beyond those who are intimately involved in their collection, these data need to be archived and well documented with standardized metadata descriptions. Archives will be most effective if they extend beyond hardcopy or digital storage by individual scientists; this could include centralized servers or academic and interagency partnerships. This challenge and the direction we hope to go in is discussed subsequently in Chapter 5.

One of the most difficult and awkward issues in research, particularly for a federal agency funded by public tax dollars, is procedures for sharing data. Data collected using appropriated funds is part of the public domain. At what stage of the data collection process should and can data be made available to other interested parties? What kinds of data should be shared? What is the responsible approach to making data available?

The National Institutes of Health (NIH), for example, has a policy for support of the concept of data sharing. Their position is that data sharing is essential for expedited translation of research results into knowledge, products, and procedures to improve human health. The NIH endorses the sharing of final research data to serve these and other important scientific goals. The NIH expects and supports the timely release and sharing of final research data from NIH-supported studies for use by other researchers. The NIH requires a data-sharing plan as part of the grant writing plan.

Data and metadata can be shared through multiple venues, and scientists at EFRs have developed a range of methods and protocols. Some sites designate specific data as core data and make it publicly available as digital files over the Web, often through research partners, as soon as possible after collection. Core data often include hydrologic or climatic parameters that are used by many researchers at the site and beyond. Some sites do not have partners that can provide access to servers and the Web. Shared harvester sites have been developed (such as Hydro/ClimDB, an integrated database of basic streamflow and weather data that pools information from cooperating sites throughout the country) that allow these sites to submit some types of data for sharing and dissemination on the Web. Data that are not collected digitally often have much longer lags before distribution, or exist only as hardcopy.

Tracking use and interpretation of data is challenging once it is available on the Web. Most EFRs scientists ask that the research group or agency be acknowledged if the data are used in a publication, but follow-through on acknowledgments is spotty. Data that are not available on the Web can often be obtained by contacting the researcher at a site. However, it can be challenging to know what types of data are collected or available as well as to identify who to contact for various types of data. Some EFRs managers request proposals about potential use of data before releasing it. This allows site researchers to become involved in analysis and interpretation of the data and often to be co-authors or acknowledged in publications that may result. Other sites have protocols ensuring that once the data are published the data can then be released.

Depending on the EFR and type of data, shared data can be provisional with very limited quality control or checking, while in other situations, data are subjected to rigorous quality assessment/quality control (QAQC) before being released. Data sharing through the Web or through individual contact both require scientists to take extra steps to make the data understandable by others, similar to those taken to archiving data for long-term use. However, these steps are generally not recognized as essential or "rewarded" in scientific circles unless a publication results. Some journals and scientific societies are encouraging dissemination and archiving of data by attributing a citation to "published" datasets.

This issue is part of the bigger challenge of data management, addressed below, and is directly related to staff capacity and our ability to process and check increasingly large volumes of data. Not all data can or should be considered "high" quality for any particular use. What is important is that the quality be documented. Plans for addressing information management will include this issue.

Information Management: Strategies for Moving Forward

Management of information and data is a challenging issue; it is both mundane and crucially important. This is part of a complete issue with broader ramifications for policy and procedures for how federal agencies maximize the quality, objectivity, utility, and integrity of information disseminated by federal agencies. Our EFRs have substantial information assets of significant untapped value. To make that value available, EFRs need a more effective information management (IM) infrastructure. There are many ways to design such an infrastructure. Four approaches that span the spectrum of options are: (1) fully decentralized; (2) fully decentralized but with central coordination; (3) partially decentralized but with substantial central coordination and support; and (4) fully centralized.

Approach 1: Fully Decentralized

All IM activities are handled by the individual site's staff; so each site has at least one information manager. The information manager is responsible for research data, administrative data, and Web content. The work includes deciding what activities are appropriate and what standards, if any, are used. This is the approach that has been used for most of the history of EFRs, except that many sites do not have a formal information manager.

Approach 2: Fully Decentralized With Central Coordination

All IM activities are handled by the site's staff, so each site has at least one information manager. The activities that staffs engage in and how the activities are executed are partially determined by a central coordinating group. The central group also sets standards and provides training. Implementation of standards is left up to the local units. This is the approach used by the LTER network, with the central coordinating group role being filled by the LTER Network Office. For example, the LTER Network Office sets IM standards, but each of the 26 sites implements the standards independently.

Approach 3: Partially Decentralized With Substantial Central Coordination and Support

IM activities are handled in a hybrid manner. Some sites have information managers—when local resources and interest support such a position. A central coordinating group sets standards and provides training, but also supports and coordinates implementation of information management strategies. Candidates for central group support include:

- Cross-site and multi-investigator studies
- Site-based support for EFRs that cannot support a local information manager
- Temporary site-based support for sites with an information manager when dealing with spikes in demand or when the manager is on leave
- Projects that are long-term for the network, but short-term for a given site; for example, converting sometimes fragile paper documents into modern digital formats
- Network-level websites
- Common applications or components across EFR websites

The central group, which may be geographically dispersed, does much of its work by creating, deploying, and maintaining IT systems that assist site scientists, technicians, and administrative staff in their work. In addition to IT tasks, the central group might house a science writer to create content for both the network and local site Web pages.

Approach 4: Fully Centralized

All IM management activities are handled by a central group; this group may be geographically dispersed. There are still data technicians at the sites collecting data and transferring to the central systems, and potentially assisting in writing/maintaining metadata to reflect changes in field data acquisition techniques.

The current norm across the EFR network is a mix of Approach 1 (this continues to be the primary system) and Approach 3 (for activities managed by the eResearch EFR IM project or by the Data Archive). However, because most sites do not currently have dedicated information managers as does the LTER, the quality of IM tends to be relatively undeveloped.

Each approach has its advantages and disadvantages, and each might be the most appropriate type to deploy—depending on overall objectives. For example, Approach 1 places a high premium on local control; its disadvantages are a lack of consistency across the collection of sites and a relatively high cost. Approach 2 trades some local control for increased cross-site consistency; the deployment cost remains relatively high owing to the need to have an information manager at every active site. It is also a relatively cumbersome system for cross-site research, particularly if budgetary constraints do not permit stationing an information manager at every site participating in the research. It works very well for LTER because of NSF funding for full-time information managers and because there is relatively little cross-site research performed (in part because of the variety of ecosystems represented—polar to prairie). It also seems to be an effective way to balance goals when working across the many institutions that house LTER sites. Approach 4 places a high premium on consistency of practice and will tend to be very efficient and effective; its primary disadvantages are a tendency toward rigidity, creation of a single locus of failure, and a distancing of IM from the people for whom the information is being managed.

Approach 3 can be structured in at least two styles. The "hierarchical" style uses strong partitioning of responsibilities between the central group and the site-based group. The "team" style uses a looser partitioning, wherein the central group does its work and the site-based group participates in that work on a less than full-time basis. A key to success for the latter approach is to set it up such that the work done by site-based people in association with the central group is not considered to be collateral duty. Rather, it is part of their normal responsibilities. The team style captures most of the advantages of Approach 4, without being as brittle. The resilience flows from the site-based group being able to keep systems running if the central group becomes dysfunctional, and vice versa. The systems don't run as well in those two situations; the idea is to have the systems run well enough to survive while the dysfunction is being identified and addressed. Either structure helps to keep IM systems better anchored to the needs of the scientists and technicians who rely on them.

Other Business Management Considerations

Based on an analysis by the University of California–Davis Graduate School for Management, conducted in 2011, some independent observations offer ideas for potential improvements. Administration of EFRs is not strictly a business proposition; however, there are some business management insights from this analysis that Forest Service R&D leaders should evaluate.

First, consider establishing a cost unit at the research station level to capture all costs related to EFRs, including research activities and operational and administrative functions. The cost data could be useful for each EFR for the following:

- Inventory accountability: Each EFR should maintain a list of equipment and facilities with values assessed in accordance with R&D valuation methodology, and with projected annual maintenance and replacement costs.
- Budget planning: This is necessary for maintenance of equipment and facilities, and possible expansion of the EFR's existing structure.
- Performance measurement: Tracking of research activities conducted at each EFR will provide management insights into its performance.

In addition, it would be useful to have a clear classification of funding sources, whether from the federal government or outside entities such as universities. Currently, external funding for equipment and facilities is roughly estimated or unaccounted. With detailed information of funding sources and amounts, we can better account for inventories and determine the level of partnership cultivation needed for each EFR.

Furthermore, to capture accurate cost data, plan budgets, and evaluate performance measures, it would be useful for each research station, in conjunction with national guidance, to provide consistent business management operations and oversight. Led by national guidance, as we have seen executed by the Forest Inventory and Analysis (FIA) program, research station-level business managers would help implement revenue and cost structure to the entire EFR network. The research station business managers could also work with on-site managers to implement these strategies and work with them to improve EFR efficiency and performance on an operational level.

Chapter 5: Strategic Path Alternatives for EFRs

Previous chapters provided a foundation for the purpose and need for an EFR network and a framework for considering how R&D might best use its 80 EFRs. This chapter condenses the spectrum of possible strategic uses into six major alternative paths for the future of these critical assets. These paths are each described using eight characteristics of a successful experimental network. No matter which path is chosen, each starts from current conditions. Inevitably it will take time to reorient to whatever new trajectory that is followed and to make specific tactical decisions that will begin to move it forward. Note that an optimal path may blend two or more of the alternative paths. Once a strategic path is chosen, follow-up planning will flesh out implementation details. The amount and type of planning will depend on the path chosen.

Each primary path has a very rough cost estimate. We have not developed these ideas sufficiently to have more precise cost estimates, and project planning experience reminds us that estimates are likely to change. Nonetheless, they do provide reasonable qualitative guidance on the relative cost of achieving different EFR research outcomes and benefits.

The eight common characteristics for each potential path are:

- **Science:** What kinds of scientific challenges, both current and future, are we able and best situated to address utilizing our EFRs?
- **Portfolio**: What course we will take for expansion, contraction, status quo, or selective focus of the ecological representativeness of our EFRs?
- **Infrastructure:** What course we will take for expansion, contraction, status quo, or selective focus for EFR building and research infrastructure?
- **Data management:** How will we archive our legacy data, manage our collection of data in the future, and effect data standardization for cross-site analyses?
- **Personnel:** What kinds of new or different positions will be required to fuel and support current and new activities?
- **Organization:** What is the most effective overall organization for EFRs, both nationally and at the station level (i.e., staffing, leadership and direction, investment strategies, etc.)?
- **Partnerships:** To what extent and how do we intend to attract, engage, and interact with partners?
- **Outreach**: How do we engage in outreach, technology transfer, and education? How do we cultivate a support community to bolster the recognition and value of this enterprise?

Once direction is given—based on this strategic plan and the following descriptions of alternative paths—finer details can be developed. It is recommended that a team, consisting of a national coordinator, leadership, and scientists, be formed to develop a detailed work plan for implementing the selected direction.

The optional paths are titled (1) Limited Capacity, (2) Status Quo Plus, (3) Experimentation Network, (4) Synthesis Network, (5) R&D Core Research Platform, and (6) Experimental Ranger Districts. These paths are summarized in table 10.

Table 10—Summary of consequences of the six paths

Path	Consequences
Path 1—Limited Capacity:	
Implications for science	Science will continue to be organized solely at the local level, with cross-site studies continuing to have little or no corporate support
Implications for the EFR portfolio	Each station director will determine what to continue to support, all others will be mothballed
Implications for the building infrastructure	Focus will be on periodic, strategically selected maintenance needs, meted out to facilities on an as-needed basis
Implications for data management	This path relies on the national Research Data Archive to coordinate and manage a slow migration of historical EFRs research data out of file cabinets and create the necessary Web infrastructure for EFR data delivery; $250,000
Implications for personnel/workforce	No new positions will be identified or filled
Implications for the Forest Service organization	The organization will remain as is, with each research station director managing the station EFRs as they choose
Implications for partnerships	Individual EFRs and station leaders determine how to allocate resources for existing or new partnerships
Implications for outreach	Individual EFRs and station leaders determine how to allocate resources for existing or new outreach opportunities
Total estimated cost (additional dollars)	$250,000
Path 2—Status Quo Plus:	
Implications for science	No new projects, slow decline in existing projects
Implications for the EFR portfolio	No new EFRs, mothball 20 percent of existing
Implications for the building infrastructure	Many existing facilities are in serious disrepair and thus some work is needed simply to avoid loss of assets. The national focus will be on periodic, strategically selected maintenance needs; $ 1,000,000
Implications for data management	There is a need to minimally equip EFRs for the demands of modern research data management; $600,000
Implications for personnel/workforce	No new personnel, replace one of every two losses
Implications for the Forest Service organization	Fully decentralized, all decisions and guidance from stations
Implications for partnerships	Support existing, no efforts to build more
Implications for outreach	Minimal support
Total estimated cost (additional dollars)	$1,600,000

Table 10—Summary of consequences of the six paths (continued)

Path	Consequences
Path 3—EFRs as an Experimentation Network:	
Implications for science	Most science will continue to be organized solely at the local level, addressing local/regional issues; however, a limited number of short- and long-term, cross-site studies will be actively encouraged via a national competitive proposal process; $1,500,000
Implications for the EFR portfolio	Establishing new EFRs remains primarily a station director's decision; however, there may be some changes to facilitate effective cross-site research. A careful review of the 80 EFRs will be performed to determine the current status of each based on the tier system
Implications for the building infrastructure	The national focus for the next 5 to 10 years will be on periodic, strategically selected maintenance needs, meted out to facilities on an as-needed basis; $1,500,000
Implications for data management	Improve data management for all Tier 1 and Tier 2 EFRs to handle research and administrative data; support new data management needs for a limited number of strategic cross-site research projects as needed; $1,000,000
Implications for personnel/workforce	Five new data managers, five new technicians, $500,000 (in addition to data management needs); replace as people leave
Implications for the Forest Service organization	Fully decentralized, all decisions and guidance from station directors; national coordinator will chair the cross-site competitive proposal process and coordinate other national-level activities and support
Implications for partnerships	Support existing, no efforts to build more
Implications for outreach	Minimal support, encourage existing efforts of individuals and partners
Total estimated cost (additional dollars)	$4,500,000
Path 4—EFRs as a Synthesis Network:	
Implications for science	Concerted effort to build the network; pursue the current set of networked research and monitoring activities; solidify existing efforts; develop selected new initiatives; pursue the "Smart Forest" initiative, costs covered in other categories (personnel, data management), one-time costs for new equipment estimated at $3,500,000
Implications for the EFR portfolio	Identify options for new EFRs. "New" EFRs can take four forms: (1) standard EFR establishment; (2) expand or reconfigure an existing EFR to add ecosystems or scale; (3) "reboot" a Tier 3 or Tier 4 EFR to active status; or (4) establish a Cooperative EFR
Implications for the building infrastructure	R&D engineer, in collaboration with station directors and station engineers, will develop a maintenance priority list for all facilities and develop a queue and schedule; $2,000,000
Implications for data management	Work with four teams: the science team, the research data team, the administrative team, and a team of teams—the network team. Pair with modern information technology systems to achieve the objectives; $2,000,000
Implications for Personnel/workforce	Establish new positions in data managers (see item 4), field technicians at research stations (10), network office technicians (3), field site managers (5), and outreach; $2,500,000

Table 10—Summary of consequences of the six paths (continued)

Path	Consequences
Implications for the Forest Service organization	Develop a national organization that provides national guidance, execution of work at the station and EFR level, and promotes networked research and monitoring addressing the key scientific and management questions of today and tomorrow
Implications for partnerships	Actively support existing partnerships, aggressively pursue new partnerships
Implications for outreach	Develop and active, participatory effort in outreach and education, support local activities; $200,000
Total estimated cost (additional dollars)	$10,200,000
Notes	This cost includes a one-time cost of $500,000 for new equipment purchases
Path 5—EFRs as R&D's Core Research Platform:	
Implications for science	EFR network becomes the focal point of the Forest Service R&D organization. R&D research and monitoring activities focus on what new initiatives can be pursued using the EFR network as the test bed for questions and management strategies; $3,500,000
Implications for the EFR portfolio	Efforts will begin to establish up to five new EFRs, as needed, within the next 3 years; also seek to identify potential partnerships with other institutions to designate up to five new "Cooperating Experimental Forests" in strategic locations; $100,000
Implications for the building infrastructure	Maintenance needs will be assessed for all EFRs in the network. A schedule for the next 5 years will be developed to address the backlog of maintenance needs; provide recommendations for new facility initiatives for EFRs, as needed; $3,000,000
Implications for data management	Strong level of IM support for Tier 1 and 2 EFRs; aggressively convert all historical data into digital formats; enable the network to pursue Grand Challenge-scale research using historical and modern data; make EFRs a compelling proposition for hosting external research; $7,000,000
Implications for personnel/workforce	Additions of staff described in Path 4 are included plus up to 10 additional research grade-scientists with the explicit assignment to develop research and monitoring projects in affiliation with a given EFR; $4,000,000
Implications for the Forest Service organization	Essentially as Path 4, a small national office would oversee the operations of the network, day-to-day activities would continue to be executed by the respective research stations.
Implications for partnerships	We will aggressively seek and support partnerships for collaborations on existing and future EFRs; seek and encourage strategic additions to the EFR network through use of the provision for "Cooperating Experimental Forests and Ranges;" $500,000
Implications for outreach	Provide active support for an array of outreach and education activities through six new positions, five at the research stations and one in the national coordinator office; $1,000,000
Total estimated cost (additional dollars)	$19,100,000
Notes	This cost includes a one-time cost of $500,000 for new equipment purchases

Table 10—Summary of consequences of the six paths (continued)

Path	Consequences
Path 6—Experimental Ranger Districts:	
Implications for science	With a particular emphasis on selected EFRs on ranger districts, there will need to be a shift of resources to support these efforts; research and monitoring ideas and initiatives will be developed collaboratively; $3,500,000
Implications for the EFR portfolio	Strategic additions to the network will be explored. Initially we will seek to identify one suitable ranger district per region that has a functional EFR on it to serve as the hub for expanded activities; $100,000
Implications for the building infrastructure	Maintenance needs will be assessed for all EFRs in the network. A schedule for the next 5 years will be developed to address the backlog of maintenance needs; provide recommendations for new facility initiatives for EFRs, as needed; $3,000,000
Implications for data management	Strong level of IM support for Tier 1 and 2 EFRs; aggressively convert all historical data into digital formats; enable the network to pursue Grand Challenge-scale research using historical and modern data; make EFRs a compelling proposition for hosting external research; $7,000,000
Implications for personnel/workforce	In addition to carrying forward ideas from Path 4 and 5, personnel from the selected ranger districts will be collaborating on the full array of duties to execute this path. They will remain, of course, as National Forest System (NFS) staff and will not affect the personnel needs of this path. Collaboration with ranger districts and forests will be the approach for development of new research or monitoring initiatives; $2,500,000
Implications for the Forest Service organization	Oversight and direction will be similar to Path 4 and 5 with the significant addition of NFS staff at all levels
Implications for partnerships	On this path, the emphasis is on expanded experimental areas within national forests and addressing issues of common interest with the NFS. We will continue to support partnerships with universities and other research institutions for collaborations on EFRs; $350,000
Implications for outreach	Provide active support for an array of outreach and education activities through six new positions, five at the research stations and one in the national coordinator office; $1,000,000
Total estimated cost (additional dollars)	$17,450,000
Notes	Does not include costs and other requirements for the ranger districts to become integrated into this approach

Path 1: Limited Capacity

This path is essentially the current situation and keeps the EFRs as an unevenly resourced informal network. It reflects a choice to maintain current priorities within the Forest Service. Thus, for the immediate future, few additional national resources are assigned to the EFR system. A key expectation of this path is that, over time, additional EFR sites are highly likely to slide into the Tier 3 and Tier 4 levels.

Science

Science will continue to be organized solely at the local level, with cross-site studies continuing to have little or no corporate support. Work will continue to be conducted by current field staff and supported by existing resources. Some initiatives will likely cease over time as staff availability diminishes, equipment deteriorates, and overall capabilities decline. Many current initiatives will be fueled by ad hoc efforts without targeted budgets. Some of these projects will drop out over time. Science direction will continue to be determined by the priorities and efforts of individual scientists and by station managers based on the needs of their clients.

Projected annual costs over current: $0

Portfolio

Establishment of new EFRs will be rare and will only occur if a station chooses to make the investment. A number of existing EFRs will be, by default, put in a "Tier 4" status, which essentially means indefinite "mothballing" where no work is accomplished and all facilities are shut down. Each station will determine what can continue to be supported; all others will be mothballed. Some may be identified for removal from the system, as determined by the lead research station.

Projected annual costs over current: $0

Infrastructure

Individual stations will determine whether to invest in new construction. The national focus will be on periodic, strategically selected maintenance needs, meted out to facilities on an as-needed basis. The R&D Engineer, collaborating with station directors and station engineers, will develop a maintenance priority list for all facilities and develop a queue and schedule. Some facilities will be identified for demolition.

Projected annual costs over current: $0

Data Management

Even without targeted initiatives there will be requirements for a greater investment to meet modern research data management requirements. Therefore, this path relies on the national Research Data Archive to coordinate and manage a slow migration of historical EFR research data out of file cabinets and create the necessary Web infrastructure for EFR data delivery. The archive is also interested in making the movement of new research data from scientists' desktops to the archive system as smoothly as possible. To that end, EFRs will be significant participants in the archive's broader efforts to create tools and processes to improve R&D's management of research data during the course of large and long-term studies.

Projected annual costs over current: $250,000

Personnel

No new positions will be identified or filled. Decisions on whether to replace people as they leave will be made by station directors based on local resource constraints. Over time, this process can be expected to result in mothballing of some currently active sites.

Projected annual costs over current: $0

Organization

The organization will remain as is, with each research station managing the EFRs in its area as chosen.

Projected annual costs over current: $0

Partnerships

Individual EFR managers and station directors will determine how to allocate resources for partnerships, existing or new.

Projected annual costs over current: $0

Outreach

Individual EFR managers and station directors will determine how to allocate resources for outreach opportunities, existing or new.

Projected annual costs over current: $0

TOTAL annual national costs: $250,000

Anticipated Consequences of Path 1

This path concedes the likelihood of a static or declining budget and acknowledges that no concerted effort will be made to support or further build an EFR network. Some EFR initiatives will continue as station directors and individual EFR managers choose and are able to sustain those efforts. Most EFR activities will decline and some will drop out of the portfolio of Forest Service R&D over time. Historical data will continue to deteriorate and much will be lost. Opportunities to harvest the scientific values of an EFR network will be limited.

Path 2: Status Quo Plus

This path also keeps the EFRs as an unevenly resourced informal network. However, it retains and slightly augments the work currently being done to address critical infrastructure maintenance needs and create a somewhat more robust network infrastructure. Although budgets are declining and costs are increasing, limited investment to bolster certain facets of the network is determined to be prudent for R&D and the Forest Service as a whole. Key areas for support include selected facility upgrades, data management improvements, and support for selected existing networked activities that are currently supported only by ad hoc efforts at individual EFRs. For the foreseeable future this path will require little to no additional resources to be dedicated to the EFR network. A key expectation is that, over time, additional EFR sites are highly likely to slide into Tier 3 and Tier 4 levels. However, while still in Tier 1 or Tier 2 status, a site will be better resourced to manage its information, and R&D will be better positioned to preserve its accumulated knowledge of the site.

Science

Science will continue to be organized solely at the local level, with cross-site studies continuing to have little or no formal corporate support. Work will continue to be conducted by current field staff and supported by existing resources. We will endeavor to sustain all productive and in-demand ongoing activities; however, some initiatives may cease over time as staff availability diminishes, equipment deteriorates, and overall capabilities decline. Strategic discussions will reveal which ongoing initiatives require more stable, long-term support. A review of these ongoing activities will carefully consider which activities R&D should sustain as part of the national research and monitoring program of the EFR network. We will acknowledge an EFR network, albeit modest and limited in scope.

Projected annual costs over current: $0

Portfolio

New EFRs will be established only if a station director chooses to make the investment. A careful review of the 80 EFRs will be performed to determine the current status of each based on the tier system described above. Research station directors will assign the appropriate tier for each of their EFRs. Some sites may be identified for disestablishment, as determined by the lead research station director. This will enable a focus on those EFRs that are active and currently performing, thus prioritizing future investments.

Projected annual costs over current: $0

Infrastructure

Individual station directors will determine whether to invest in new construction. Many existing facilities are in need of repair and thus some work is needed simply to avoid loss of assets. The national focus will be on periodic, strategically selected maintenance needs, meted out to facilities on an as-needed basis. The R&D Engineer, collaborating with station directors and station engineers, will develop a maintenance priority list for all facilities as well as a queue and schedule. Some facilities will be identified for demolition.

Projected annual costs over current: $1,000,000

Data Management

As in Path 1, there is a need to equip EFRs for the demands of modern research data management. Even this austere path requires a greater investment in data management than has historically been made to meet current demands and expectations of the scientific community and public. Thus, the five national investments will be:

- Periodic migration of historical research data from file cabinets and creation of the necessary Web delivery infrastructure, managed by the research data archivist
- Develop/maintain a data management capability for each Tier 1 and Tier 2 site
- Develop/maintain shared research management/administration tools
- Develop/maintain an internal SharePoint site for collaboration and knowledge sharing, facilitating the use of the network as a loose support structure
- Update all EFR websites to reflect the new network information architecture; use data availability to market the EFR research platform

Projected annual costs over current: $600,000

Personnel

Existing staff associated with EFRs will continue to do their current work, as directed by their station director. In general, when people leave through retirement or take other jobs, some positions will be refilled; others not. Responsibilities of the vacant position will be redistributed among remaining staff, potentially at other locations, or dropped from the job description. No new positions will be identified or filled. Decisions on whether to replace people as they leave will be made by station directors based on local resource constraints. Over time, this process can be expected to result in mothballing some currently active sites.

Projected annual costs over current: $0

Organization

The organization will remain as is, with each research station managing the EFRs in their area as it chooses.

Projected annual costs over current: $0

Partnerships

Individual EFR managers and station directors will determine how to allocate resources for partnerships, existing or new.

Projected annual costs over current: $0

Outreach

Individual EFR managers and station directors will determine how to allocate resources for outreach opportunities, existing or new.

Projected annual costs over current: $0

TOTAL annual national costs: $1,600,000

Anticipated Consequences of Path 2

This path acknowledges value in our array of EFRs and attempts to capitalize on these opportunities with modest support of existing resources and minimal additional investments. It will be hard to maintain all existing EFR network initiatives. Over time, some will have to be dropped. Some historical data will be lost. Strategic decisions will attempt to retain our most productive and useful activities. No new initiatives will be possible and thus strategic scientific opportunities that could be addressed through a network of field sites will be forgone. We will rely on the high performing EFRs and their ancillary sources of support to further the potential of individual EFRs. The EFR network will be largely unrealized. The Forest Service will turn to other facets of the R&D program as its primary source of noteworthy accomplishments.

Path 3: EFRs As an Experimentation Network

This path seeks the research value expected from shifting from an informal network to an experimentation network. Choosing this path affirms that cross-site (i.e., larger scale) research is critical to addressing the land management problems of the 21st century, and that the potential and value of a functional network of EFRs is to handle these challenges. Allocating the additional resources required by this path would ensure relevant and high-impact research. Key areas for support include selected facilities upgrading, data management improvements, and support for selected existing networked activities that are currently supported only by ad hoc efforts at individual EFRs. In the short-term this will involve additional resources dedicated to operating an EFR network and the research and monitoring activities that the network is uniquely positioned to address. Some resource reallocation is likely as the cross-site proposal process is instituted and funded.

Science

Most science will continue to be organized solely at the local level, addressing local/regional issues; however, a limited number of short- and long-term cross-site studies and monitoring activities will be encouraged via a national competitive proposal process. Work will continue to be conducted by current field staff and supported by existing resources. Strategic discussions will reveal which ongoing initiatives require more stable, long-term support. We will endeavor to sustain all productive and in-demand ongoing activities; however, some local initiatives may cease over time as staff availability diminishes, equipment deteriorates, and overall capabilities decline. A review of these ongoing activities will carefully consider which activities R&D leaders should sustain as part of the corporate research and monitoring programs.

Projected annual costs over current: $1,500,000

Portfolio

Establishing new EFRs remains primarily a station director's decision; however, the EFR network may also propose changes to facilitate effective cross-site research. A careful review of the 80 EFRs will be performed to determine the current status of each based on the tier system described above. Research stations will assign the appropriate tier for each of their EFRs. This will enable a focus on those EFRs that are active and currently performing, thus prioritizing future investments.

Projected annual costs over current: $0

Infrastructure

The national focus for the next 5 to 10 years will be on periodic, strategically selected maintenance needs, meted out to facilities on an as-needed basis. The R&D engineer, collaborating with station directors and station engineers, will develop a maintenance priority list for all facilities, and will develop a queue and schedule. Some facilities will be identified for demolition. After the backlog of maintenance issues is addressed, the focus will turn to strategic investments in new facilities. Such investments will be rare and carefully considered. Elimination of facilities that are not needed will be considered first.

Projected annual costs over current: $1,500,000

Data Management

The objectives are:

- Update all EFR websites to reflect the new network information architecture; use data availability to market the EFR research platform
- Improve data management for all Tier 1 and Tier 2 EFRs to handle research and administrative data
- Support new data management needs for a limited number of strategic cross-site research projects as needed
- Create data-oriented marketing pitch for researchers to use EFRs
- National investments:
    - Aggressive effort to make historical research data available on the Web
    - Develop/maintain a data management capability for Tier 1 and 2 sites
    - Develop/maintain shared research management/administrative tools
    - Develop/maintain an internal SharePoint site for collaboration and knowledge sharing, facilitating the use of the network as a loose support structure
    - Update all EFR websites to reflect the new network information architecture; use data availability to market the EFR research platform
    - Provide national-level data management support for cross-site studies, as needed.

Projected annual costs over current: $1,000,000

Personnel

A very limited number of new positions will be filled, solely for data management improvements. A small number (five estimated) of data management specialists will be added to provide national support (probably housed with a core group supporting EFRs nationally, see “Data Management” above). An additional five technicians will be added to cover shortfalls in technical support of existing efforts that are expected to emerge as critical ad hoc support of important network monitoring or research activities from personnel at field sites inevitably abates. Existing scientists, technicians, site managers, and administrative staff will continue to do their current work.

Projected annual costs over current: $500,000 plus investments described in “Data Management” section.

Organization

For local research not considered to be strategic at a national scale for R&D, the organization will remain essentially as is. The national coordinator position will be supported as a part of the national support network. The coordinator will chair the cross-site competitive proposal process and coordinate other national-level activities and support.

Projected annual costs over current: $200,000

Partnerships

Individual EFR managers and station directors will determine how to allocate resources for partnerships, existing or new. We will continue to endorse and support existing partnerships with existing resources and external funds.

Projected annual costs over current: $0

Outreach

Individual EFR managers and station directors will determine how to allocate resources for outreach opportunities, existing or new. The efforts required to effectively achieve these objectives will continue to be done as ad hoc activities by Forest Service or non-Forest Service staff at EFRs based on their interest and capabilities. This is largely viewed as an ancillary task that is performed as time and interest permits. Under this option it will continue to be an opportunistic activity unless prioritized by a lead station.

Projected annual costs over current: $0

TOTAL annual national costs: $4,700,000

Anticipated Consequences of Path 3

This path reflects limited investments that will focus on improving conditions in our ability to support ongoing work through adequate facilities and data management. Existing EFR activities will be sustained through existing mechanisms, largely through the efforts and decisions of each research station and with external funds. Some activities will likely be dropped over time as other priorities and inflation constrains capacity. A concerted effort to archive as much of our historical data as possible will be pursued. Strategic decisions are necessary to determine if limited new investments in scientific activities will be used to sustain projects over time or explore emerging new issues. There will be very limited capacity to pursue new high-priority research or monitoring initiatives that are particularly suited to a distributed network of field facilities if deemed important. The EFR network will meet a limited scope of expectations.

Path 4: EFRs As a Synthesis Network

This path is designed to provide meaningful support to existing EFR programs as well as to serve as the foundation of a well-coordinated EFR network. Key existing initiatives will be recognized and solidified and long-term provisions will be established to sustain these efforts. A limited number of new initiatives, considered by R&D leaders to be central to the mission of the organization, will be identified and initiated as part of the network. A formal network will be recognized and branded as a cornerstone of the R&D organization. Minimal central support for the network will be established to enable the EFRs to function as a network in an effective and reliable manner. As planning begins for the future, the recommendations contained herein will be built into the R&D budget.

Science

Demand is growing for information about the physical and chemical environment of the natural systems that support the Nation's forests and ranges. Historically, the collection of these "baseline" data has been labor intensive and expensive, but recent advances in environmental sensor technology, wireless communications, and software have enabled the development of low-cost, low-power, multifunctional sensor networks that can communicate data to researchers, managers, and the public in near real time.

Under this path there will be a concerted effort to build the network. First, we will continue to pursue the current set of productive networked research and monitoring activities. Existing activities will be carefully evaluated and the core efforts will be confirmed. The requirements to stabilize and provide a solid foundation for the future will be determined. The majority of work will continue to be conducted by current field staff and supported by existing resources. Additional needs will be identified and those requirements will be supported by a combination of additional support to research stations and development of a core staff that provides support to all EFRs nationwide. Consistent applications for existing activities will be supported at the station level as well as through a central support office. Models for administration and support (e.g., FIA program and LTER network) will be examined and elements identified for adoption by EFRs.

A select number of new network-wide monitoring and research initiatives will be identified and efforts put in motion to begin a set of these. Table 8 includes an initial set of ideas collected from Forest Service scientists as well as NFS science specialists. Priorities will be established by the EFR science community with substantial input from stakeholders. Proposals to address the priority research areas will be solicited; a competitive evaluation process will select a limited number of new projects to fund nationally as network research. These efforts are intended to create a network research agenda that is relevant to land and resource managers and supported by robust experimentation on the ground.

Path 4 also includes a specific intention to pursue a "Smart Forest" initiative (see app. 1). Demand is growing for information about the physical and chemical environment of the natural systems that support the Nation's forests and ranges. The collection of these "baseline" environmental data has historically been labor intensive and expensive. However, recent advances in environmental sensor technology, wireless communications, and software applications have enabled the development of low-cost, low-power, multifunctional sensor networks that can communicate environmentally sensed data to researchers, managers, and the public in near real time. When combined with plot-level data about forest structure, composition, and dynamics, these wireless sensor networks (WSNs) can provide information on unprecedented temporal and spatial scales, and offer new opportunities for research, monitoring, and environmental warning systems.

The objective of the EFR "Smart Forest" initiative is to develop a strategic and cost-efficient approach to updating and modernizing environmental data collection and delivery tied to information about forest and range conditions at EFR sites across the country, effectively creating an integrated nationwide wireless sensor network to measure, monitor, and enable assessment of environmental change at the continental scale. Key components of this initiative must include:

- Provision of national-level data management support for cross-site studies, as needed
- Clear articulation of scientific and societal needs and questions for which baseline ecological and stand-level data are required
- Identification of specific data needed to address these questions
- Determination of spatial and temporal resolution needed to address these questions now and in the coming decades
- Evaluation of hardware and software needed to collect these data
- Determination of how to deliver data most effectively and efficiently from the field to the repository for storage and subsequent analysis
- Design of a system with maximum flexibility for expansion as new environmental concerns emerge and novel environmental sensors and measures of vegetation plot dynamics are developed.

The objective of the "Smart Forest" initiative is to develop a strategic and cost-efficient approach to modernizing collection and delivery of data about forest and range conditions at sites across the country, effectively creating an integrated nationwide wireless sensor network to measure, monitor, and enable assessment of environmental change at the continental scale.

Success will depend on strategic selection of new initiatives, promoting the values garnered from these sites, and a sound investment strategy. Investments will include staffing, a network office, equipment, and data management. Equipment is addressed here (largely one-time costs); staffing, network office, and data management are addressed in other sections.

Projected annual costs over current:

- $3,000,000 science funding (for new initiatives)
- $500,000 one-time equipment cost (for the Smart Forest initiative)

Portfolio

The 80 EFRs will be evaluated and assigned to appropriate tiers using the criteria contained in this document. Each station, in collaboration with a national team (e.g., the EFR Working Group) for EFRs, will conduct this evaluation. This information, plus an assessment of site needs for the priority research areas, will be used to identify options for decommissioning of obsolete sites and identification of potential new EFRs. "New" EFRs can take four forms: (1) standard EFR establishment; (2) expand or reconfigure an existing EFR to add ecosystems or scale; (3) "reboot" a Tier 3 or Tier 4 EFR to active status; or (4) establish a Cooperative EFR with interested parties.

Projected annual costs over current: $ contained in other categories.

Infrastructure

Periodic, strategically selected maintenance needs, meted out to facilities on an as- needed basis, will be addressed. The R&D engineer, in collaboration with station directors and station engineers, will develop a maintenance priority list for all facilities, and will develop a queue and schedule. Some facilities will be identified for demolition. Station directors will direct their engineers to provide recommendations for new facility initiatives for EFRs, as needed. These proposals will be given high priorities for the Choosing by Advantage (CBA) process for new facilities funding. Modernizing facilities on EFRS will be a priority for R&D. New facilities will be considered but will require compelling evidence.

Projected annual costs over current: $2,000,000 plus periodic new facilities projects through the CBA process.

Data Management

Objectives: (1) create a strong level of data management support for Tier 1 and 2 EFRs to handle research and administrative data; (2) aggressively convert all historical data into digital formats that are preserved and shared via the R&D data archive; (3) enable the network to pursue Grand Challenge-scale research using historical and modern data, while retaining capability to engage in locally focused research; (4) make EFRs a compelling proposition for hosting external research.

The formation of a data management team for the entire EFR network will help to not only place importance on data collection, but also ensure an approach to research data management that is consistent across sites. The team will have four functions: (1) develop, maintain, and promote data management standards for the network; (2) develop data management tools for use by EFR staff (scientists, data managers, and site managers); (3) be the steward for data collection standards developed by the network; (4) provide direct data management support for sites that lack this capability (this encompasses back-up support for sites with data managers, e.g., for when the data manager is on leave).

The organization of the team should follow the team style described for approach 3 in chapter 4, which is modeled by the national research data archive—EFR-wide in scope, with staff embedded in the field using the national partner model in place for the data archive, eResearch, and the EFR coordinator. It is important that this team not lose touch with the EFR community's needs; being in the field helps with that. Members of the team who are providing direct support to sites could be co-located with an EFR or be more virtual; they could be organized to be responsible for sites in a given geographical area, for sites with common support needs (e.g., relying on a geographic information system, doing hydrology, etc.), or some mix of these. Regardless of the organizational structure, it will be important for the team to maintain a broad view and understanding of EFRs data management needs, and not adopt a narrow view based on the subject matter or geographical area they happen to work with most intensely. Overall, how to organize the establishment of data management team members is a tactical decision that should be delegated to the EFR science community to work through with cross-station leadership (e.g., Assistant Director Team). The community will need to gain experience with group decisionmaking and this will be a good network component for such practice.

A related issue is how the EFR data management infrastructure will interact with the national research data archive. There is overlap in roles and requirements that could be leveraged to reduce overall data management costs to R&D (and the R&D data archive staff is excited about the idea of continuing to work closely with the EFR community). Or the EFR network could be afforded the same status as Forest Inventory and Analysis (FIA), handling internal and external aspects of its data management with minimal interaction with the archive.

National investments:

- Historical data are migrated expeditiously and are available via the R&D Data Archive; this includes all data gathered by other investigators on each site
- Work to standardize data collection and reporting methods
- Create cross-site databases and cross-site data queries; support internal research products and public communication
- Develop/maintain a data management capability for Tier 1 and 2 sites by
  - Providing national-level data management support for EFRs
  - Developing shared research management/administrative tools

  - Developing active Information Technology infrastructure support for data linkages with external networks such as HydroDB, Consortium of Universities for the Advancement of Hydrologic Science (CUAHSI) for hydrology research, etc.
- Develop/maintain an internal SharePoint site for collaboration and knowledge sharing, helping to build and maintain the social network aspects of the network
- Update all EFR websites to reflect the new network information architecture; use data availability to market the EFR research platform
- Establish an EFR science board, analogous to the board used by LTER, to provide high-level oversight/direction for the data management team.

Although all items on the investment list pertain to EFR information management, their execution could be distributed across a data management team and a Web team, or managed together as has been the case for the eResearch EFR project.
- Estimated staff increases: 16 (team leader, developers, database managers, Web content staff, and data managers)
- Projected annual costs over current: $2,000,000 (for current system of ≈40 active sites; costs rise with more sites).

Personnel

In this option there is a clear intent to increase the capacity of the EFR network through strategic selection of additional personnel. Critical needs for personnel include data management specialists (see above), field technicians, site managers, and the support of a national network organization. The data management requirements are covered above. Field technicians will include funding/staff assigned to each research station as well as a limited core staff from a national network office. The rationale is to provide trained expertise in the field to deploy and manage field equipment and provide scientist support for field monitoring and experiments. We also will have a small network office team with highly trained technicians and support staff to provide guidance and assistance to the entire network and the field staffs of all EFRs. This will promote consistency and efficiency in use of high-tech equipment and standardization of data collection protocols and equipment use.

Administering effective field sites requires diligent attention to myriad details. Most sites currently rely on scientists or scientific support staff to execute the painstaking details of site administration. Some additional staff will be allocated for this crucial task to both better execute the job of site management and relieve scientists and key support staff from these duties.

The few site managers we have currently exercise a lot of independence and, in effect, run their own small business operation. Although most if not all of these appear to be run exceptionally well, other EFRs may lack the same level of activity and most lack a site manager altogether.

An EFR-wide business development position will be established to help train and educate site managers on strategies for running an effective and successful EFR. By helping site managers create a list of metrics to evaluate their revenue, costs, assets, etc., site managers will be better equipped to run an efficient EFR.

Existing scientists, technicians, site managers, and administrative staff will continue to do their current work. As people leave through retirement or to take other jobs, most positions will be refilled. Responsibilities of the vacated position will be redistributed amongst remaining staff or dropped from the job description.

Estimated staff increases:

- Data managers (see "Data Management" section)
- Field technicians at research stations: 10
- Network office technicians 3
- Field site managers at research stations 5

Projected annual costs over current: $2,500,000 (plus data management accounted separately).

Organization

The current organization for EFRs is solely through each station director's choice for organization and oversight of the EFRs. On this path there will be two key changes. First, a national organization of EFRs will be further developed to provide consistent and standardized management and procedures similar to the manner in which the Forest Inventory and Analysis (FIA) program is currently administered. FIA provides national guidance and oversight for each of the regional units that coordinate and execute the inventory and analysis work. FIA has three levels of internal management: an **executive level** involving senior executives from the Forest Service and state forestry agencies, who provide broad policy guidance; a **management level** consisting of field program managers from the Forest Service and states responsible for implementing the program on a day-to-day basis; and a **technical level** consisting of groups of technical specialists drawn from the Forest Service and states, who develop, document, and review program procedures. Each region maintains its own internal set of regional customers and partners who collaborate in program implementation.

This option adopts a similar organizational structure for EFRs that will consist of an executive level of oversight, led by perhaps two members of the FS Research

Executive Team (FSRET) and the EFR national coordinator, a management level of oversight led by representatives from each research station, and a technical level of oversight led by the current EFR Working Group, which already has a charter (which will require updating) and includes two members from the NFS. This organization will provide guidance and the individual EFRs will execute this guidance, under the current supervision of research stations.

The second change in organization will entail development of a social network that involves staff (e.g., lead scientists from all EFRs) from all the stations. This network will enable frequent communication and collaboration among the involved players and promote more effective collaboration on the array of research and monitoring activities that are part of the network. Social networking tools (e.g., SharePoint sites, Facebook sites, Twitter, etc.) will be employed as well as traditional methods of periodic meetings, symposia, and websites.

Projected annual costs over current: $0 (assumes that a national coordinator position continues to exist and any needed support staff for a national coordinator's office is embedded in the items above).

Partnerships

We will continue to encourage and support partnerships for collaborations on existing and future EFRs. We will actively seek relationships with logical partners at selected EFRs that currently have none. We will actively promote the use of EFRs by collaborating scientists and explore opportunities to foster relationships through mutually beneficial arrangements. We will actively seek support from partners in operating our EFR facilities as well as offering EFR facilities for full use by partners.

As demonstrated by a number of EFRs (e.g., H.J. Andrews EF or Sagehen EF) an effective strategy is to promote EFRs as dedicated research centers where students and faculty can conduct their research projects. Tactics include getting involved with scientific clubs and gatherings, posting on university websites, and reaching out to department heads and faculty.

We will also seek and encourage strategic additions to the EFR network through use of the provision for cooperating experimental forests.

Projected annual costs over current: $0 (there will be marginal to significant costs i.e., investment of time for many participating R&D employees who make the efforts to pursue and execute these ideas).

Outreach

On this path, outreach and education become explicit objectives of the EFR network. We will continue to provide encouragement and existing staff support for all existing outreach and education activities carried out by both Forest Service staff as well as staff from collaborating institutions. In addition, we will provide active support for all such activities through development of a new position in the national coordinator's office to do the following tasks:

- Promote transfer of knowledge garnered at EFRs
- Develop educational activities at EFRs with schools and for land managers
- Assist in the development of demonstration sites at EFRs
- Develop community involvement activities at EFRs
- Work with collaborating institutions to promote all outreach and education activities done on EFRs by the collaborating institution

Site managers can also develop their own websites to promote their EFR in the community and create opportunities for school and volunteer participation.

Projected annual costs over current: $ 200,000

TOTAL annual national costs: $9,700,000 plus $500,000 one-time costs

Anticipated Consequences of Path 4

This path provides a sound foundation for the present and future of EFRs. Significant new financial and logistic investments will be required. Facilities and scientific infrastructure will be maintained/upgraded, to enable the ongoing research and monitoring activities to continue successfully. Important new scientific initiatives will be pursued and R&D findings will address emerging relevant land and resource management issues. We will be able to strategically expand our portfolio to include underrepresented ecoregions and provide thorough coverage of forests and rangelands in the United States. Key advances in data management and field instrumentation will make our work more available and improve the efficiency and reliability of our data collection efforts. Much of our historical data will be retrieved and put in digital form for long-term archiving. Crucial adjustments to our organizational structure and our ability to partner with other scientific institutions will significantly improve scientific capabilities and particular attention to outreach consideration will advance our visibility to partners and the public.

Path 5: EFRs as R&D's Core Research Platform

The gate on this path is unlocked by a business decision that the EFR network becomes the focal point of the Forest Service R&D organization. If this path is chosen it will require a concerted commitment that will require concessions in other areas of the R&D program.

This change will bring R&D research back to the land base it regularly used in previous decades. R&D research and monitoring activities will focus on what can be done using the EFR network as the test bed for questions and management strategies. All components of the previous options are included in this option. The emphasis here is to optimize the value and opportunities of the EFR network through targeted investments into research and monitoring that happens on EFRs. Not all work done by R&D will be aimed at EFRs, of course, but we will seek to take every advantage available with these assets.

National investments:

- Work with collaborating institutions to promote all outreach and education activities done on EFRs by the collaborating institution
- Selected/majority of EFRs (at least those in Tiers 1 and 2) have at least one active scientist and at least five active cross-site research projects
- Every EFR site has coverage by a full-time information manager
- Every EFR site has strong administrative support
- An EFR network office is established to provide IM support to sites. This includes sensor hardware support, central data management and data management tools, a common Web infrastructure, and tools for site administration. The office coordinates information management (IM) training and maintains the internal and external network websites.

Science

A number of EFRs currently have one or more scientists who dedicate the majority of their research effort on the EFR site. The results of their efforts clearly demonstrate the production and value the investment that a dedicated scientist can generate. Not all EFRs are suited to this level of investment (e.g., those in Tier 3 and especially Tier 4) but there are a number of EFRs that currently have no scientist(s) or staff dedicated to working on the site. In this option we provide more emphasis to EFRs through redirection of some existing staff, as feasible, and hiring of new staff to selected EFRs. The national office, in coordination with the EFR Working Group and AD station representatives, will work together to identify the 10 highest priority EFRs that could use a dedicated scientist. R&D will use some combination of reassignments and new hires to fill these 10 spots. New research initiatives will be developed by these scientists to take advantage of the opportunities available on the individual site and as part of a regional or national network.

Projected annual costs over current: $3,000,000 for new initiatives.

Portfolio

As in path 4, strategic additions to the network will be explored. Efforts will begin to establish up to five new EFRs, as needed, within the next 3 years. Each station director, in collaboration with a national team for EFRs, will conduct this evaluation. The existing 80 EFRs will be evaluated using the criteria contained in this plan and each will be assigned to the appropriate tiers. This information will be used to set funding and other support levels for all EFRs.

We will also seek to identify potential partnerships with other institutions to designate up to five new cooperating experimental forests in strategic locations. These will be added to the EFR network through memorandums of understanding (MOUs) between the appropriate station director and the cooperating institution.

Projected annual costs over current: $100,000 for the array of administrative costs for handling new EFRs.

Infrastructure

Maintenance needs will be assessed for all EFRs in the network. A schedule for the next 5 years will be developed to address the complete backlog of maintenance needs. The R&D Engineer, in collaboration with station directors and station engineers, will develop a maintenance priority list for all facilities, and will develop a queue and schedule. Some facilities will be identified for demolition.

Station directors will direct their station engineers to provide recommendations for new facility initiatives for EFRs, as needed. These proposals will be given high priorities for the Competition by Advantage process for new facilities funding. New facilities and modernized facilities on EFRs will be a priority for R&D.

Projected annual costs over current: $3,000,000.

Data Management

Objectives: (1) create a strong level of IM support for Tier 1 and 2 EFRs to handle research and administrative data; (2) aggressively convert all historical data into digital formats that are preserved and shared via the R&D data archive; (3) enable the network to pursue Grand Challenge-scale research using historical and modern data, while retaining the capability to engage in locally focused research; (4) make EFRs a compelling proposition for hosting external research.

Although a structure similar to that described for Path 4 could be used, for this level of investment a system more like the LTER approach is described. Under this scenario the intention is to make a LTER-caliber information manager available to every site (at least Tier 1 and 2 sites); establish a fully functional EFR network office; and provide for administrative support staff to all EFR sites so that scientists have none of these duties.

Projected annual costs over current: $7,000,000.

Personnel

The personnel additions discussed in Path 4 are folded in here. These additions should be helpful and complementary to the key feature of this option, additional scientific capacity. In this option there will be up to 10 additional research grade scientists to be brought into the Forest Service with the explicit assignment to develop research and monitoring projects in affiliation with a given EFR. These scientists will work in tandem with the IM support, technicians, and field site administration to carry forward existing research and monitoring as well as develop new projects. Collaboration with partner institutions will be actively fostered and existing partnerships sustained. New initiatives can be drawn from the ideas presented in table 8 as well as original ideas. Working closely with NFS staff will be written into the position descriptions of these new positions.

Projected annual costs over current: $4,000,000 ($ 2,500,000 carried forward from Path 4 plus $1,500,000 for up to 10 new scientist positions).

Organization

The current organization for EFRs is through each station director's choice for organization and oversight of the EFRs. This option is largely the same as Path 4. It will consist of an executive level of oversight, led by two members of FSRET and the national coordinator, a management level of oversight led by representatives from each research station, and a technical level of oversight led by the current EFR Working Group which already has a charter (which will require updating) and includes two members from the NFS.

A somewhat larger national office will oversee network operations, although day-to-day activities will continue to be executed by the respective research stations.

Projected annual costs over current: $0 (assumes a national coordinator continues to exist and any support staff for the coordinator is embedded in the items above).

Partnerships

We will aggressively seek and support partnerships for collaborations on EFRs. We will actively seek relationships with logical partners at selected EFRs which currently have none. We will actively promote the use of EFRs by collaborating scientists and explore opportunities to cement relationships through mutually beneficial arrangements. Seed money for encouraging these kinds of collaborations will be provided through requests for proposals that feature research partnerships.

We will actively seek support from partners in operating our EFR facilities as well as offering EFR facilities for full use by partners. We will also seek and encourage strategic additions to the EFR network through use of the provision for cooperating experimental forests.

Projected annual costs over current: $150,000 for a full time partnership coordinator (there will be marginal to significant costs for many participating R&D (existing) employees who make the efforts to pursue and execute these ideas), and $350,000 for seed money to enable partnerships and begin new initiatives.

Outreach

For this path, as for Path 4, the scope of outreach and education is expanded and becomes an explicit objective of the EFR network. We will continue to provide encouragement and passive support for all existing outreach and education activities carried out by both Forest Service staff as well as staff from collaborating institutions. In addition, we will provide active support for all such activities through six new positions, five at the research stations and one in the national coordinator's office to do the following tasks:

- Promote transfer of knowledge garnered at EFRs
- Develop educational activities at EFRs with schools and for land managers
- Assist in the development of demonstration sites at EFRs
- Develop community involvement activities at EFRs
- Work with collaborating institutions to promote all outreach and education activities done on EFRs.

Projected annual costs over current: $1,000,000

TOTAL annual national costs: $18,600,000 plus 500,000 one-time costs.

Anticipated Consequences of Path 5

This path makes a conscious shift toward a significantly greater investment in EFRs as part of the complete EFR research and monitoring portfolio. The advantages of Path 4 will be brought forward and, in addition, there will be an increase in scientific capacity at selected EFRs. A greater emphasis of the R&D organization will be placed on the work done at EFRs and new scientists will be able to discover and capitalize on what can be accomplished on EFRs. Partnerships will expand and the network of EFRs will increase to enhance capacity. A significant increase in our outreach and education capabilities will also be a notable feature of this path. Overall, EFRs will become a notable and recognized cornerstone of the Forest Service R&D activities.

Path 6: Experimental Landscapes

This path represents a new departure in our EFR enterprise that will require some fundamental shifts in both the NFS and Forest Service R&D. There are likely some significant administrative hurdles to realizing this approach, but it is an idea with merit that is worthy of discussion. This approach has many obstacles under current circumstances within the agency, however, a case on its behalf is presented here for consideration.

The concept for Path 6 is that (1) most existing EFRs are too small to carry out research at a landscape scale, (2) the management challenges of today and beyond require work across broader temporal and spatial scales, and (3) the most productive research applied to contemporary land management problems is done with a committed participation from the land management community.

The concept for this path is anchored to three fundamental thoughts; (1) most existing EFRs are too small to carry out research at a landscape scale, (2) the management challenges of today and beyond require work across broader temporal and spatial scales, and (3) the most successful and productive research applied to contemporary land management problems is done with a committed participation from the land management community. Thus, the approach of this path is to strategically identify a few suitable locations where these three principles could be realized in collaboration between national forest systems and R&D. Perhaps this could be accomplished using some of our most accomplished EFRs throughout the United States, located in a variety of ecological regions, as anchors for expanded experimental sites. In either case it will require large landscapes where restoration and other contemporary land management objectives can be experimented with over large areas. This would entail dedication of large areas of NFS lands, such as an entire ranger district (RD), committed to management activities but conducted through a partnership with R&D. Initially this would involve one or two per region to begin developing the approach.

The objective will be to form a strong collaborative bond between the RD/national forest and the research staff from the corresponding research station, with a focus on carrying out landscape-level experimental management to examine existing or new management strategies. The experiments will focus on needed land management actions and employ contemporary management techniques. They will be done, however, in an adaptive management context, in which scientifically robust treatment designs are executed as a partnership between management and research at a landscape scale.

There are a number of compelling motives for suggesting this approach. Adaptive management has long been regarded as a transparent strategy for acknowledging the uncertainty in all land management that is performed on lands administered by the Forest Service. This approach also recognizes that a closer and more earnest working relationship between research and management can be viewed by the public as holding significant merit. Public scrutiny of land management efforts by the Forest Service is at a level never before seen. Scientifically defensible management actions are required to support bold, innovative land management initiatives. Furthermore, this approach will blend well with the new Forest Service planning rule. This new rule embraces the principles of adaptive management through explicit recognition of the assessment/implementation/monitoring cycle that is intended to iteratively lead to more scientifically sound land management.

Of course, this path will require unprecedented cooperation and perhaps procedural changes to designate portions of national forest lands as locations for experimental landscapes. Certainly there will need to be a strong will on the part of both management and research to form this enhanced partnership. However, if this can be accomplished, even incrementally with some pilot areas, the level of potential accomplishments is intriguing. We have seen what can be accomplished with smaller projects within the confines of existing EFRs. A number of EFRs currently have this level of cooperation between research and management and that has led to some of our most noteworthy and meaningful achievements within the Forest Service. Such experimental areas can set a new level of achievement that other districts and forests within a region will find significant benefit.

Of course, this path will require unprecedented cooperation and perhaps procedural changes to designate portions of national forests as locations for experimental landscapes.

Science

With a particular emphasis on selected EFRs on RDs there will need to be a shift of resources to support these efforts. A number of EFRs currently have one or more scientists who dedicate the majority of their research effort to the EFR site. The results of their efforts demonstrate the value of the investment a dedicated scientist can generate. Many of these most noteworthy EFRs have developed in tandem with the curiosity and dedication of NFS staff who work with research to craft research needs and implement experiments. A particular advantage of this path is synergy between research and management. Research and monitoring ideas and initiatives will be developed collaboratively. New research initiatives will be developed by these scientists to take advantage of the opportunities available on the individual site and as part of a regional or national network. Funding will be used to spark ideas and request proposals in a competitive manner.

Projected annual costs over current: $3,000,000 for new initiatives.

Portfolio

As in Path 4, strategic additions to the network will be explored. Initially we will seek to identify one suitable RD per region that contains a functional EFR to serve as the hub for expanded activities. Each station and region, in collaboration with a national team for EFRs, will conduct this evaluation. The existing 80 EFRs will be evaluated using the criteria contained in this plan and each will be assigned to the appropriate tiers. This information will be used to set funding and other support levels for all EFRs.

We will also seek to identify potential partnerships with other institutions to designate up to five new cooperating experimental forests in strategic locations. These will be added to the EFR network through MOUs between the appropriate station director and the cooperating institution.

Projected annual costs over current: $100,000 for the array of administrative costs for handling new EFRs.

Infrastructure

Maintenance needs will be assessed for all EFRs in the network. A schedule for the next 5 years will be developed to address the complete backlog of maintenance needs. The R&D engineer, in collaboration with station directors and station engineers, will develop a maintenance priority list for all facilities, and will develop a queue and schedule. Some facilities will be identified for demolition.

Station directors will direct their station engineers to provide recommendations for new facility initiatives for EFRs, as needed. These proposals will be given high priorities for the Competition by Advantage process for new facilities funding. New facilities and modernized facilities will be a priority for R&D on EFRs.

Projected annual costs over current: $3,000,000.

Data Management

Objectives: (1) create a strong level of IM support for Tier 1 and Tier 2 EFRs to handle research and administrative data; (2) aggressively convert all historical data into digital formats that are preserved and shared via the R&D data archive; (3) enable the network to pursue Grand Challenge-scale research using historical and modern data, while retaining capability to engage in locally focused research; (4) make EFRs a compelling proposition for hosting external research.

Although a structure similar to that described for Path 4 could be used, for this level of investment a system more like the LTER approach is described. Under this scenario the intention is to make a LTER-caliber information manager available to every site (at least Tier 1 and 2 sites); establish a fully functional EFR network office; and provide for administrative support staff to all EFR sites so that scientists have none of these duties.

Projected annual costs over current: $7,000,000.

Personnel

The personnel additions discussed in Path 4 and 5 are folded in here. These additions should be helpful and complementary to the key feature of this option, additional capacity through larger experimental areas. Personnel from the selected

RDs will be collaborating on the full array of duties to execute this path. They will remain, of course, as NFS staff and will not affect the personnel needs of this path. Collaboration with RDs and national forests will be the approach for development of new research or monitoring initiatives. Collaboration with partner institutions will also be encouraged. New initiatives can be drawn from the ideas presented in table 8 as well as original ideas.

Projected annual costs over current: $2,500,000 carried forward from Path 4 or 5.

Organization

The current organization for EFRs is overseen through the discretion of each station director. This option is largely the same as Path 4 and 5. It will consist of an executive level of oversight, led by two members of FSRET and the EFR national coordinator. It will also include a member from the NFS leadership team. Management level of oversight will be led by representatives from each research station, and a technical level of oversight led by the current EFR Working Group which already has a charter (which will require updating) and includes two members from the NFS.

A somewhat larger national office will oversee network operations, although day-to-day activities will continue to be executed by the respective research stations.

Projected annual costs over current: $0 (assumes that a national coordinator position continues to exist and any support staff for the coordinator is embedded in the items above).

Partnerships

On this path the emphasis is on expanded experimental areas within national forests and addressing issues of common interest with the NFS. We will continue to support partnerships with universities and other research institutions for collaborations on EFRs. We will actively promote the use of EFRs by collaborating scientists and explore opportunities to cement relationships through mutually beneficial arrangements. Seed money for encouraging new research initiatives will focus on national forests and our partnership with NFS. We will actively seek support from partners in operating our EFR facilities as well as offering EFR facilities for full use by partners.

We will also facilitate strategic additions to the EFR network through use of the provision for cooperating experimental forests and ranges.

- Projected annual costs over current: $350,000 for seed money to enable partnerships on national forests and begin new initiatives.

Outreach

For this path, as for Path 4 and 5, outreach and education become explicit objectives of the EFR network. We will continue to provide encouragement and passive support for all existing outreach and education activities carried out by both Forest Service staff as well as staff from collaborating institutions. In addition, we will provide active support for all such activities through six new positions, five at the research stations and one in the national coordinator's office to do the following tasks:

- Promote transfer of knowledge garnered at EFRs
- Develop educational activities at EFRs with schools and for land managers
- Assist in the development of demonstration sites at EFRs
- Develop community involvement activities at EFRs
- Work with NFS to promote all outreach and education activities done on EFRs, particularly those activities that have a bearing on management of NFS lands.

Projected annual costs over current: $1,000,000.
TOTAL annual national costs: $16,950,000 plus $500,000 onetime costs.

Anticipated Consequences of Path 6

This path combines some of the more aggressive features of other paths in expanding our capacity to do research and monitoring on EFRs. However, the key feature is the expansion of experimental areas to encompass selected locations on national forest land for research at a landscape scale. This path will take time to implement and will have an impact on the work plans of forests that are selected to dedicate an RD as part of an experimental area. There will be institutional and cultural barriers to overcome. Incremental implementation will be prudent to develop and test this concept and enable both R&D and NFS to build confidence in the operation of the program. The anticipated benefits are potentially enormous. Needed landscape treatments would be planned and conducted in an adaptive management framework. These sites could be demonstration forests for embracing the fundamental concepts in the new Forest Service planning rule. Much of the public would likely find this approach refreshing and honest, accepting and embracing the uncertainty in management of our forests and ranges. It is very possible that this assertive action will raise the level of confidence of the public in the Forest Service.

A summary of these six paths and their anticipated consequences is represented in table 11.

Table 11—Anticipated consequences of each of the six paths

	Potential accomplishments	Estimated costs (over current)	Deliverables
Path 1	Minimal	$250,000	Caretaking status
Path 2	Minimal	<$1 million	Modest care of historical work
Path 3	Modest	$4.5 million	Address key needs in data and facilities
Path 4	Meaningful	$10 million	Expand to the demand for data, modern technology, instrumentation, facilities
Path 5	Significant	$19 million	Featured asset of R&D
Path 6	Ground-breaking	$17.5 million[a]	Redefines Forest Service and the role of R&D

[a] Refers to additional costs to the National Forest System.
R&D = Research and Development.

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Appendix 1: Smart Forests for the 21st Century—A New Initiative to Develop Cyber Infrastructure

The Issue—Rapid Environmental Change

The 21st century is emerging as a time of great environmental change, including a rapidly changing climate, continued inputs of atmospheric pollutants, and current and projected shifts in demographics and land use. Together, these challenges threaten the health and sustainability of the Nation's natural resources. The demand for information to understand and monitor these environmental changes and to expeditiously communicate this information among scientists, to policymakers, land managers, and the concerned public has never been greater.

Box 1
Examples of Environmental Sensor Applications

Physical
- Climate (temperature, precipitation, relative humidity, windspeed, etc.)
- Hydrology (stage height, soil moisture, groundwater table, etc.)

Chemical
- Air pollution (O_3, nitrous and sulfur oxides, etc.), deposition
- Water quality (pH, nitrates, dissolved carbon quality and quantity, etc.)
- Atmospheric CO_2

Optical
- Phenology (canopy greenness and duration)
- Bird and animal movements

Acoustical
- Presence or absence of endangered species

Early Warning Systems
- Fire
- Floods
- Droughts

The Opportunity—New Advances in Cyber Infrastructure

Recent advances in environmental sensor technology, wireless communications, and software applications have enabled the development of low-cost, low-power multifunctional environmental sensors and sensor networks that can communicate environmental conditions to researchers, managers, and the public in real time. This emerging technology generates information at unprecedented temporal and spatial scales, and offers **transformational opportunities** to better understand the physical, chemical, and biological "pulse" of both terrestrial and aquatic ecosystems. These real time "windows on watersheds" also provide compelling new ways to engage the public, and provide novel tools for resource managers (see box 1).

The EFR Network—Long-Term History of Environmental Monitoring and Discovery

The U.S. Forest Service operates a network of 80 experimental forests and ranges (EFRs) across the continental United States, Alaska, Hawaii, the U.S. Virgin Islands, and Puerto Rico. These sites are located along broad gradients of climate, vegetation, soils, and land use that are representative of most National Forest System (NFS) lands. EFRs have a long history of research and environmental monitoring. At some EFR sites, environmental records date back more than 100 years. These long-term data sets are critical for detecting patterns and trends in climate, forest and range health and productivity, and response to natural and human induced environmental change. Individually, these sites serve as **benchmarks** against which further change can be gauged. Together, they have the potential to serve as a regionally distributed, long-term multisite, multisensor platform for detection of short- and longer-term environmental change for forests and rangelands of the United States.

The Need—Updated Cyber Infrastructure

To meet the information and discovery needs of the 21st century, the Forest Service must invest in new technology and cyber infrastructure within its network of EFR sites. Many EFRs still record basic information such as precipitation, temperature, and streamflow using circa 1950s mechanical devices attached to paper and pen charts; the charts are collected at weekly or monthly intervals by forestry technicians, transcribed by hand into electronic databases, then analyzed, sometimes years later, by scientists. These systems, although reliable, are labor-intensive; delivery of data to end users is slow; they have limited capacity for expanded data collection in time and space; they cannot respond to environmental crises in real time; and, in many cases, are so obsolete that replacement parts are no longer available. At other sites, scientists and managers have begun to invest *ad hoc* in new technology. These are often one-time purchases that address single aspects of a complete wireless sensor network (WSN) system (e.g., electronic data collection but not transmission or real-time delivery to the Internet), and funds are often not available or inadequate for replacements parts or training of competent staff. A vision for a comprehensive redesign and standardization of environmental data collection and delivery at Forest Service EFR sites is critically needed.

The Solution: "Smart Forest" Initiative

The EFR "Smart Forest" initiative offers a strategy to update and modernize cyber infrastructure for the collection and delivery of environmental data at EFR sites across the country. EFR Smart Forests will provide an integrated technological platform to monitor and respond to environmental change at local to continental scales. The basic objectives of this initiative will be to:

- Improve or standardize cyber technology for collection of and wireless transmittal to the Internet of a foundational set of environmental measurements at, initially, a core set of Smart Forest sites. These sites will be strategically distributed across major geographic, climatic, and vegetation gradients.
- Identify, evaluate, and deploy solutions to provide real-time access to environmental sensor data from core sites to a **single point of entry** website.
- Apply emerging visualization and outreach tools to engage researchers, resource managers, educators and the public with Smart Forest data.

Considerable groundwork for this initiative has been laid and real-time data access and viewing are available at a growing number of EFR sites (see fig. 1). Examples of current applications include continuous monitoring of climate variables, streamflow, water quality, ground water tables, sap flow, and trace gas flux; installation of webcams to improve quality and frequency of phenological measurements and observations of animal behavior; and installation and use of radio collars for tracking wildlife movements across the landscape. As the processing power of sensors and computers continue to improve at an exponential rate, as energy requirements and costs continue to come down, and as the world becomes increasingly globalized and connected, WSNs will assume an increasingly common role in our everyday lives, as much or more so than do present-day personal computers and cellular telephones. It is critical for the Forest Service to make a sound and strategic investment in this technology now to create the "smart forests" of the future.

Section I: Foundational Principals for Smart Forests

Implementation of the Smart Forest Initiative will require the formation of a planning committee to include a multidisciplinary team of scientists, resource managers, information managers, hardware and software engineers, education and outreach specialists, and administrators. The keys to its success will be modularity and flexibility. By modular, we mean developing a basic unit and its communications hardware and software that can be deployed at multiple locations within a site or across sites, and which can accommodate an expandable suite of sensors of different types. By flexible, we recognize that the basic unit will need to be adapted to individual sites, reflecting potential implementation barriers (such as complex terrain, remote access, harsh conditions, and the availability of power or trained personnel), as well as different resource and management needs. Developing this technology with the limited resources available to individual EFR sites is daunting, and yields only site-specific applications and insights. Developing this technology with the resources available to the U.S. Forest Service, providing this to individual EFR sites, and developing new "middleware" to stream data from multiple sites to a single point of access, where it can be made available to a range of end users and used to develop synthesis products in real time, is an exciting and attainable goal. Below, we outline several features that should be considered in the development of the Smart Forests Initiative.

I. Key Components and Considerations

For this initiative to succeed and gain wide acceptance, the following issues must be addressed.

- **Clear articulation of initial scientific and societal needs and questions for which baseline ecological data are required.** An initial set of needs and questions that can be addressed only by a multisite, multisensor cyber technology platform delivering data to end users in real time must be identified, coupled with clear and timely deliverables.
- **Identification of specific data needed to address these questions.** Careful consideration must be given to specific data needs to address the questions identified above. Scientists, modelers, resource managers, educators, and the public should be consulted to verify that the appropriate set of measurements is identified.
- **Determination of spatial and temporal resolution needed to address these questions now and in the coming decades.** New techniques for processing and storing "Big Data" are being advanced daily, and these aspects of cyber infrastructure are no longer major barriers to deployment of these systems. Data collections should be predicated on research, modeling, management, and outreach needs.

- **Evaluation of hardware and software needed to collect these data.** Considerable effort has already been spent to identify and evaluate hardware and software needed for this initiative, both by Forest Service scientists as well as scientists within other agencies (e.g., NOAA, USGS, NSRC). A review of these efforts should be a starting point for the Smart Forests Initiative. The question of whether to use identical hardware and software at all sites (NEON model) or allow individual sites to develop their own systems but mandate common data quality and delivery objectives (LTER model) must be addressed.
- **Determination of how to deliver data most effectively and efficiently from the field to the repository for storage and subsequent analysis.** A range of options now exist for real-time data delivery, including cell phones, satellite, radio telemetry, meteor bursts, and regular manual downloads. This is an area in which site factors will determine technological solutions.
- **Designing a system with maximum flexibility for expansion as new environmental concerns emerge and novel environmental sensors are developed.**

II. Principles for Managing This Initiative:

Although the vision for the EFR Smart Forest Initiative is expansive, it is also necessary to maintain focus and manageability. The following principles will thus help guide this initiative:

- The initiative is aimed to serve the entire EFR network. However, it may not be possible or desirable to implement the approach at each EFR, at least initially. A selection approach will be adopted to strategically determine which EFRs should be part of the initial implementation of the effort. This will be rooted in the information objectives of the overall effort.
- The fundamental purpose of this initiative is to develop credible scientific data and analyses to inform land and resource management decisions. Strategic partnerships will be developed with other federal, state, and private agencies when possible to share the cost and benefits associated with this initiative.
- The basic intention for this initiative is to provide for data integrity and access. Data collection protocols, accuracy, and precision will be the highest priority to enable pooling of the data and cross-site analyses involving the entire network.
- A fundamental shift in scientific data sharing and “ownership” will be required to make this initiative a success. It will be important to develop

and foster a culture of collegiality and collaboration that involves all 80 EFRs and any partner agencies and facilities.

- It must be recognized that this is an investment in the future and requires a relatively significant short-term investment followed by a long-term commitment to maintain the system.

III. Strategic Investment Requirements

The success of this initiative will depend on careful planning, a sound and robust investment strategy, and a commitment to adopting and maintaining this technology as part of our mission statement. Achieving the objectives of this initiative will require investments in **all** of the following:

- **People.** Skilled technicians, trained in the deployment and use of the equipment, will be needed. These technicians need not be site-specific but may service several sites in a station or region.
- **Network Office.** Direction from a central network office will be critical to effectively manage this initiative on a national scale. Trained staff to provide support for data oversight, delivery, and synthesis will be important to maximize the benefits of this continental-scale observational platform and to provide support for individual nodes of the national network.
- **Equipment.** Selected, state-of-the-art equipment will replace the outdated, inefficient equipment that is currently in use. Careful planning is required to determine what best fits both the individual requirements of each site as well as the needs of the network.
- **Data Management.** The entire EFR network is currently being evaluated to determine data management requirements that optimize archiving, storage, and retrieval of the large and growing body of data. This initiative needs to be imbedded in that larger overall strategy. Innovative and effective means are needed to deliver the data from the field to the end user.

Section II: First Smart Forests

As discussed previously, it will not be feasible, affordable, or desirable to deploy cyber technology in all EFRs at the outset of implementation. Here we suggest a set of **First Forests** (table 12; fig. 2). Selection criteria include the following:

- Location: EFRs selected for the initial set of Smart Forests are distributed across the geographic and climatic gradients of the entire EFR network, with First Smart Forests in all nine Forest Service regions and their associated research stations.

- Vegetation Types: First Smart Forests include a variety of forest and range types.
- Existing Cyber Infrastructure and Trained Personnel: for expediency and economy, most of the First Smart Forests were chosen to have robust existing cyber infrastructure and trained personnel. One (Héen Latinee) was selected to demonstrate feasibility to build a Smart Forest with little existing cyber infrastructure, no trained personnel, and a remote location.
- Historical Record: the initial Smart Forests effort will focus on climate and hydrology. Therefore, those sites with long-term meteorological and hydrological records were given priority (e.g., Fort Valley and Crossett EFs).

Section III: Initial Infrastructure and Measurements

We expect to convene a panel of experts to provide input to the First Smart Forests design and implementation. Here we propose an overview of what we anticipate to be key components of this initiative.

Given that physical measurements are the most developed and given the need for climate data at the local and continental scale, especially for extreme weather events, we will focus the First Smart Forests efforts on (1) developing the cyber infrastructure "backbone" for each First Smart Forest site, (2) deploying a vertical array of sensors to measure and monitor a suite of climate variables, (3) transmitting these data to a base station, (4) transferring data from the base station to a single point of access in near real time (defined here as within 24 hours of data collection), and (5) developing interactive visualization, graphical, and downloading capabilities. Considerable effort will be devoted to both quality assurance and quality control, from routine sensor calibrations through automated streaming QC and gap filling algorithms, to human screening of final data products.

The cyber backbone for each site will consist of:

- Individual sensors
- Power sources (AC, DC, solar, other)
- Data loggers for data collection and storage
- Telemetry system to transmit data to base station
- Base station connected to the Internet

We expect to tailor this infrastructure to meet individual site needs without compromising our ability to pool the data from all sites. The systems will be designed for maximum flexibility to accommodate additional sensors as funding or technology becomes available. Many of the sites listed in table 12 have existing infrastructure and need support only for upgrades, replacement parts, and maintenance.

Table 12—Suggested initial experimental forests and ranges (EFRs) for the First Smart Forest initiative

Experimental forest	State or territory	Forest Service region	Research station	Cyber infra-structure	Climate tower network	EFR climate synthesis	Other feature
Baltimore	Maryland	9	NRS	***	X	X	LTER
Bartlett	New Hampshire	9	NRS	***	X		NEON
Bonanza Creek	Alaska	6	PNW				LTER
Coweeta	North Carolina	8	SRS	***	X	X	LTER
Crossett	Arkansas	8	SRS			X	
Fort Valley	Arizona	3	RMRS			X	Long record
GLEES	Wyoming	2	RMRS	***	X	X	
Hawaii Tropical	Hawaii	5	PSW	***			Remote, RAWS
Héen Latinee	Alaska	6	PNW	None			Remote
H.J. Andrews	Oregon	6	PNW	***		X	LTER
Howland	Maine	9	NRS	***	X		Ameriflux
Hubbard Brook	New Hampshire	9	NRS	***		X	LTER, SCAN, USGS
Luquillo	Puerto Rico	12	IITF			X	LTER
Marcell	Minnesota	9	NRS	***	X	X	
San Dimas	California	5	PSW			X	Long record
Silas Little	New Jersey	9	NRS	***	X		
Wind River	Washington	6	PNW	***	X		

NRS = Northern Research Station; PNW = Pacific Northwest Research Station; SRS = Southern Research Station; RMRS = Rocky Mountain Research Station; IITF = International Institute of Tropical Forestry; PSW = Pacific Southwest Research Station; GLEES = Glacier Lakes Ecosystem Experiments Site; LTER = Long-Term Ecological Research; NEON = National Ecological Observatory Network; RAWS = Remote automated weather station, operated by the National Interagency Fire Center; SCAN = Soil Climate Analysis Network; USGS = U.S. Geological Survey.

We propose the following vertical suite of core measurements for each site (to be collected at 30-minute intervals).

1. Aboveground Climate: We propose the standard suite of measurements following NOAA protocols:
   - Air temperature (mean, minimum and maximum for interval)
   - Relative humidity
   - Windspeed
   - Wind direction
   - Total precipitation

2. Belowground Climate: We anchor the soil climate measurements at an upper 2 cm depth and a lower 50 cm depth. The middle two depths are arrayed according to site-specific rooting depth.

    - Soil temperature (5 cm, mid rooting zone, bottom of rooting zone, 50 cm)
    - Soil moisture (5 cm, mid rooting zone, bottom of rooting zone, 50 cm)

3. Hydrology—Sites with existing hydrology programs will additionally measure:
    - Stage height
    - Stream temperature

4. Webcam—Two webcams will be installed at each site: one for high-frequency phenological measurements and one for capture of charismatic species or vistas for outreach and education purposes.

Identical sensors will be used for all measurements at all sites, facilitating quality assurance controls, inter-site comparisons, and network level technical and scientific information sharing. We will adapt NEON's plug-'n'-play model, where each sensor has a unique identifier, recognizable anywhere in the Smart Forests network system.

Section IV—Initial and Continuing Costs

It is not the purpose of this document to provide a detailed budget for this initiative at this time. However, it is possible to provide preliminary insights on costs based on current efforts at EFRs across the country. These are shown in table 13. For sites with no known cyber infrastructure, start-up costs are estimated at $25,000 per site for the suite of measurements in Section III. For sites with existing Forest Service Tower Network (FSTN) or cyber infrastructure of similar quality, start-up cost is pro-rated to $5,000 per site for belowground climate and/or hydrological sensors. Maintenance costs will differ, depending on the complexity of the site sensor network, with less maintenance associated with a single weather station, and more with networks of weather and stream gaging stations. Here we use an average of 0.5 person days per week (about $4,160/yr), and $3,000 per site per year for equipment maintenance and upgrades.

Appendix 2: Cross-Experimental Forest and Range Research and Monitoring

The following is a list of ongoing or proposed projects associated with EFRs at the time of this writing. Since no formal network has been established, each project is operating on an ad hoc basis.

Part 1—Current Cross-EFR Research and Monitoring (table 7).

1 and 2. ClimDB and HydroDB

Objectives—

The National Science Foundation's Long-Term Ecological Research (LTER) program and many U.S. Forest Service research stations compile and maintain extensive, long-term ecological databases including streamflow and meteorological measurements. These databases have been widely used in inter-site comparisons, modeling studies, and land management-related studies, and continue to grow more valuable for addressing large-scale questions (both temporally and spatially). To facilitate inter-site research among the network sites, information managers have developed a prototype to provide climatic summaries dynamically over the Internet (http://www.fsl.orst.edu/climhy). Individual sites maintain local climate data in local information systems, while a centralized site continually harvests, updates, and provides access to all site data through a common database. Common distribution report formats and graphical displays have been established to meet specific needs of climate data users.

Sixteen EFRs are participants in the ClimDB/HydroDB project, along with additional research sites from LTER, the U.S. Geological Survey (USGS), and other research areas within the Forest Service. The following are participants: Baltimore Ecosystem Study (Cooperating EF), Fernow EF, Hubbard Brook EF, and Marcell EF.

The EFRs that have long-term weather and hydrologic data are a perfect fit for this project. Note however, that even those EFRs that have long-term weather data, but no hydrologic data, (e.g., no gaged watersheds) can still participate in this project.

Application of R&D results—

This is a good example of making data available for cross-site studies, and of good partnering with other agencies (in this case, LTER and USGS). These data have applicability to questions related to climate change, to changes with changing land use, and other questions addressing temporal issues. These data also have applicability for people who are interested in making comparisons across forest types or ecosystem types.

3. Watershed Directory

Objectives—

The objective of this online directory was to provide a searchable tool that would facilitate networking and cross-site research among Forest Service (and eventually other) researchers. The directory is a product of the national Silviculture and Range Synthesis Workshop held in 2000. Researchers at the workshop realized that they did not know enough about each other's research watersheds; the Directory of Watershed Context allows users to look for research watersheds with particular characteristics. Within NRS, the following are participants: Fernow EF, Hubbard Brook EF, and Marcell EF.

Application of R&D results—

The Directory of Watershed Context is intended as a networking tool, and a means to further watershed research. It is currently undersubscribed, underadvertised and underutilized, but could be quite useful within the EFR network, and ultimately to outside collaborators and cooperators as well. For more information: http://www.fs.fed.us/research/efr/fs_watershed/ws_all_watersheds.htm

4. EcoTrends

Objectives—

The EcoTrends project is a collaborative effort among state and federal agencies and institutions, primarily in the United States, to make long-term ecological data easy to access, analyze, and compare within and across sites. The project's website is a portal to a collection of standardized long-term ecological datasets and their metadata; data synthesis tools; and information about participating research sites and their agencies. The goal of the project is to make simplified versions of datasets, called derived datasets, easily accessible and understandable to a large audience in common formats on a single website.

Participating sites are Baltimore (Cooperating EF), Fernow EF, Hubbard Brook EF, and Marcell EF.

Application of R&D results—

The intent of EcoTrends is to promote synthesis activities and the use of long-term data, not only by scientists, but also more generally by students, teachers, and decisionmakers.

5. Stream Chem DB

Objectives—

Many Forest Service watershed research sites maintain extensive, long-term ecological databases, including streamflow and meteorological measurements, which are available through the ClimDB/HydroDB Web harvester (http://www.fsl.orst.edu/climhy). Most of these EFRs also measure stream chemistry on these same gaged watersheds. Chem DB is an effort to create similar data availability for the stream chemistry data from a variety of sites, with the goal to develop a Web-accessible portal to data for synthesis projects and data sharing. Because of differing analysts, and analytical techniques, among others, creating a common format and database structure is more complex than for streamflow and meteorological data. Individual sites choose to participate, including partners in the LTER program. The following are participants: Fernow EF, Hubbard Brook EF, and Marcell EF.

Application of R&D results—

With an overarching goal to document ecosystem conditions, identify environmental problems, and assess effects of landscape-level management decisions, these data have applicability to questions related to climate change, to changes with land use, and other questions addressing temporal issues. These data also have applicability for people who are interested in comparing across forest types or ecosystem types. For more information: http://web.fsl.orst.edu/streamchem/

6. AmeriFlux

Objectives—

AmeriFlux is a network of sites that provides continuous observations of exchanges of carbon dioxide, water, and energy. These sites also provide detailed environmental data (air and soil temperatures, precipitation, solar radiation, soil moisture) as well as ecological measurements including forest leaf area index and foliage nutrient content. Sites feature one or more instrumented towers extending through the plant canopy. For more information and data, see http://public.ornl.gov/ameriflux/.

The purpose of these measurements is to improve understanding of ecosystem function, especially forest carbon and water cycles.

Science questions—

The network role is to address the scientific uncertainties associated with global change. Our focus is to address these scientific questions:

1. What are the magnitudes of carbon storage and the exchanges of energy, carbon dioxide (CO_2), and water vapor in terrestrial systems? What is the spatial and temporal variability?
2. How is this variability influenced by vegetation type, phenology, changes in land use, management, and disturbance history, and what is the relative effect of these factors?

3. What is the causal link between climate and the exchanges of energy, CO_2, and water vapor for major vegetation types, and how does seasonal and interannual climate variability and anomalies influence fluxes?
4. What is the spatial and temporal variation of boundary layer CO_2 concentrations, and how does this vary with topography, climatic zone and vegetation?

Application of R&D results—
These data have proven useful in determining the response of forests to climate variation, management activities, and disturbance. AmeriFlux data are also being used to develop and test models of ecosystem function, and for ground-truthing remote sensing products.

7. Federal Pollinator Network

Objectives—
To monitor the status and trends of pollinating insects.

Bees are the primary insect pollinator in almost all North American environments. They collect and move pollen to provision their nests and in so doing pollinate 30 to 60 percent of all plants in a given environment. There are approximately 4,000 species of bees in the United States.

There is an international perception that populations of pollinating insects in North America are in decline. Despite this perception, we have no ability to measure the status or trends of native bees in the United States.

This project, which was initiated in 2010 and expanded to 23 EFRs in 2011, is a collaboration between the U.S. Geological Survey and U.S. Forest Service, and is in response to a federal meeting and task force on the topic of insect pollinators.

EFs participating in this ongoing, national cross-EF monitoring project include:

- Fernow (West Virginia, Thomas Schuler)
- Marcell (Minnesota, Randall Kolka)
- Massabesic (Maine, Mariko Yamasaki)
- Penobscot (Maine, Laura Kenefic and John Brissette)
- Vinton Furnace (Ohio, Daniel Yaussy)

Application of R&D results—
Findings of this study would inform land management and conservation bureaus about the status and trends of native and introduced bees and other pollinating insects, and are critical for evaluating the veracity of the perceptions of a North American insect pollinator decline. The experimental forests and ranges are ideally suited for this effort owing to their spatial distribution and, in most cases, colocation of meteorological stations.

8. Forest Service Climate Tower Network

Objectives—

The Forest Service supports climate change and carbon cycle research at a range of experimental forests and other sites across the country. At many of these locations, towers extending above the surrounding forest are used to sample climatic conditions and to measure the transfer of CO_2 or other greenhouse gases between the atmosphere and the forest (carbon sequestration research). The climate tower network uses precision temperature and precipitation measurement equipment (equivalent to that found in NOAA's Climate Reference Network) to detect trends in environmental factors across a range of sites. A stable and consistent environmental data record is needed to interpret trends in forest growth, water use, and other factors.

Application of R&D results—

A subset of the network is instrumented with precision CO_2 analyzers. These analyzers have several unique capabilities, including the ability to reliably discriminate small concentration differences, and the ability to monitor the concentration of a stable isotopic version of ordinary CO_2. These capabilities mean that this network would help resolve the east-west atmospheric gradients in CO_2 that develop from photosynthetic uptake and fossil fuel emissions. These gradients and estimates of the source regions assessed by these analyzers would contribute directly to quantifying carbon sequestration by our nation's forests. The unique ability of this network to continuously measure CO_2 isotope content would be used on a regional scale to assess photosynthetic stress and allow for estimates of root and soil contributions to respiration. This information would significantly improve the accuracy of model projections of future forest carbon uptake and storage.

Research questions being addressed by the network include:

- How are environmental conditions (temperature, rainfall, snowfall) changing in our forests?
- How do trends in environmental factors above forests compare to measurements made at NWS and Climate Reference sites?
- How much carbon is being stored by our forests and surrounding regions?
- Sites: Baltimore (Cooperating EF), Bartlett EF, Howland (Cooperating EF), Marcell EF, Silas Little EF, Willow Creek EF, Coweeta EF, GLEES, and Wind River EF

9. Monitoring Climate Change Impacts on EFRs

Objectives—

Climate change is expected to have major impacts on forests in the next century. However, there is research and speculation that silvicultural intervention can mitigate impacts of climate change. For example, density control may improve site moisture balance and reduce impacts of drought. Assessing forest changes and predicting future impacts requires measurements that are expensive and difficult to fund with external grants. Measurements must be both **detailed** (e.g., individual tree growth/mortality, fine spatial scales) and **frequent** (every 1 to 3 years.). Detailed annual measurements of tree establishment, growth, and mortality are rare in most forests; the lack of these data represents a clear knowledge gap in our understanding of how forests would respond to changing climate. Forest Service research is uniquely positioned to fill this knowledge gap, because of our network of existing long-term silvicultural studies on experimental forests and our ability to sustain detailed, consistent forest measurements over long time horizons. We propose a new effort to strengthen the capacity of the Forest Service to quantify the impact of climate change on forests. Our specific objectives are:

1. Establish an efficient long-term monitoring protocol for repeated annual or near annual measurements to quantify tree establishment, growth, and mortality.
2. Install a network of monitoring plots on experimental forests to collect annual demographic data.
3. Use dendrochronological methods (tree cores) to estimate establishment, growth, and mortality for the recent past on each plot, providing useful background information—almost as though the monitoring efforts were started years ago.
4. Relate annual demographic responses to climatic variation.

The primary questions to be addressed with this research are: (1) how variable are tree growth and mortality in response to climatic variation and (2) how do different silvicultural treatments that influence density, structure, and composition, influence responses?

Application of R&D results—

This research would enable the Forest Service to address complicated climate change issues, including long-term sustainability of forests under different silvicultural approaches. Data generated would be used to parameterize and validate prediction models, to assess the efficacy of silvicultural approaches for mitigation of climate change, and as a "canary in the coal mine" to detect climate change impacts in managed forests. As such, this study would be important to climate change researchers, silvicultural scientists, forest managers, and policymakers. It would also demonstrate to our various stakeholders that the Forest Service is working to detect climate change impacts, but more importantly, examining how on-the-ground forest management, a bread and butter activity of the NFS, might be used to mitigate impacts.

10. Clean Air Status and Trends Network (CASTNET)

Objectives—

CASTNET is a regional long-term environmental monitoring program administered and operated by the Environmental Protections Agency's Clean Air Markets Division (CAMD). The regional monitoring network was formed to assess trends in acidic deposition associated with emission reduction regulations, such as the Acid Rain Program (ARP) and NO_x Budget Trading Program (NBP). CASTNET has since become the nation's primary monitoring network for measuring concentrations of air pollutants involved in acidic deposition affecting regional ecosystems and rural ambient ozone levels. Presently there are a total of 86 operational CASTNET sites located in or near rural areas and sensitive ecosystems collecting data on ambient levels of pollutants where urban influences are minimal.

Application of R&D results—

CASTNET provides long-term monitoring of air quality in rural areas to determine trends in regional atmospheric nitrogen, sulfur, and ozone concentrations and deposition fluxes of sulfur and nitrogen pollutants to evaluate the effectiveness of national and regional air pollution control programs.

11. National Ecological Observatory Network (NEON)

Objectives—

NEON's goal is to contribute to global understanding and decisions in a changing environment using scientific information about continental-scale ecology obtained through integrated observations and experiments.

NEON will create a new national observatory network to collect ecological and climatic observations across the continental United States, including Alaska, Hawaii, and Puerto Rico. The observatory network would be the first of its kind designed to detect and enable forecasting of ecological change at continental scales over multiple decades.

Application of R&D results—

NEON has partitioned the United States into 20 ecoclimatic domains, each of which represents different regions of vegetation, landforms, climate, and ecosystem performance. Data would be collected from strategically selected sites within each domain and synthesized into information products that can be used to describe changes in the nation's ecosystem through space and time.

The data NEON collects and provides will focus on how land use, climate change, and invasive species affect biodiversity, disease ecology, and ecosystem services. Obtaining integrated data on these relationships over a long-term period is crucial to improving forecast models and resource management for environmental change.

These data and information products would be readily available to scientists, educators, students, decisionmakers, and the public. This would allow a wide audience, including members of underserved communities, to use NEON tools to understand and address ecological questions and issues. The NEON infrastructure is a means of enabling transformational science and promoting broad ecological literacy.

12. National Atmospheric Depositions Program (NADP)

Objectives—

Sites in the NADP precipitation chemistry network began operations in 1978 with the goal of providing data on the amounts, trends, and geographic distributions of acids, nutrients, and base cations in precipitation. The network grew rapidly in the early 1980s. Much of this expansion was funded by the National Acid Precipitation Assessment Program (NAPAP), established in 1981 to improve understanding of the causes and effects of acidic precipitation. Reflecting the federal NAPAP role in the NADP, the network name was changed to NADP National Trends Network (NTN). Today, the NADP is SAES National Research Support Project - 3. The NTN network currently has 250 sites.

Application of R&D results—

NADP monitoring data show that wet sulfate deposition has decreased by an average of 30 percent since the early 1990s in the eastern United States. The largest decreases occurred in Maryland, New York, Virginia, West Virginia, and Pennsylvania. Nitrogen deposition has decreased as well, but to a lesser extent.

Legislative mandates, federal government programs, and environmentally friendly changes in fossil fuel use in electrical power plants have successfully lowered the emission of sulfur dioxide (SO_2) and NO_x and the resulting acid deposition in the United States since the 1980s. However, the problem still exists. Scientists continue to try to fully understand acid rain and its long-term effects on the environment and on human health.

13. Soil Climate Analysis Network (SCAN)

Objectives—

This is a national program run by the Natural Resources Conservation Service. It began as a pilot project in 1991 with 21 stations in 10 states. The purpose was to determine the feasibility of a nationwide soil-climate monitoring system. The program uses meteor burst communication to acquire remote station data; 1999 SCAN began with Natural Resource Conservation Service and cooperator funding.

The current network has 115 stations in 39 states. SCAN provides hourly data and makes them available via the NWCC Web page. Stations send data via meteor burst or line of sight. Most stations have standard parameters, but some are for special studies and have additional sensors. Belowground monitoring includes soil moisture at 2-, 4-, 8-, 20-, and 40-inch depths and soil temperature at 2-, 4-, 8-, 20-, and 40-inch depths.

Application of R&D results—

National resource management issues for which long-term soil/climate information is needed include:

- Input to global circulation models.
- Predicting, monitoring, and verifying droughts.
- Developing new soil moisture accounting and risk assessments.
- Monitoring and predicting changes in crop, range, and woodland productivity in relation to soil moisture-temperature changes.
- Predicting regional shifts in irrigation water requirements, which may affect reservoir construction and groundwater levels.
- Predicting shifts in wetlands.
- Predicting changes in runoff that affect flooding and flood control structures.
- Verifying and ground-truthing satellite and soil moisture model information.
- Predicting the long-term sustainability of cropping systems and watershed health.

14. USA National Phenology Network (NPN)

Objectives—

The USA National Phenology Network brings together scientists; federal, state, and local agencies; nonprofit groups; and educators and students to monitor the impacts of climate change on the phenology of plants, animals, and landscapes in the United States. The network depends on the involvement of educational institutions and volunteers to motivate and organize people of all ages to observe and learn about seasonal changes of the ecosystems around them.

Application of R&D results—

The USA National Phenology Network encourages people to observe and record phenology as a way to discover and explore the nature and pace of our dynamic world. The network makes phenology data, models, and related information available to empower scientists, resource managers, and the public in decisionmaking and adapting to variable and changing climate and environments. The network promotes a broad understanding of plant and animal phenology and its relationship with environmental change.

15. Forest Inventory and Analysis (FIA) on EFRs

Objectives—

(1) Improve landscape-scale assessment of the effects of climate variability, and natural and management disturbances, on ecosystem demographics and carbon stocks and fluxes; (2) Develop a monitoring approach and establish permanent monitoring locations at experimental forests for early detection of impacts of climate change on ecosystem processes and function. The general approach is to link intensive monitoring of ecosystem processes at experimental forests with FIA's extensive monitoring and remote sensing. This strategy complements the existing three-phase FIA sampling strategy, such that sampling at intensive sites may be consider a fourth sampling phase involving measurements made at fine spatial and temporal scales.

The EFR network broadly represents forest conditions and management/disturbance history of the nation's forests, and is suitable for both intensive and destructive sampling in contrast to the FIA network. Participants include Baltimore (Cooperating EF), Bartlett EF, Hubbard Brook EF, Marcell EF, and Silas Little EF.

Application of R&D results—

The additional detailed measurements enhance the FIA plot-based carbon estimates by providing more complete and accurate estimates of the different carbon pools and their rates of change. This research is important to land managers and decision-makers who need information to decide on policies regarding how climate and land use change influence ecosystem carbon pools and feedbacks to the atmosphere. In the end, we would provide FIA and the public with tools to better assess patterns in long-term carbon sequestration in forest ecosystems in the United States.

Note that these studies are linked to several other initiatives, providing for strong leveraging of funds. NASA-sponsored studies are using experimental forests as ground-truth for landscape-scale monitoring and assessment. And studies funded through the Forest Service Global Change Program are using experimental forests for developing advanced monitoring techniques for carbon and climate change detection.

16. PhenoCam

Objectives—

Phenological events such as spring leaf emergence and autumn senescence exert strong control on primary productivity, hydrologic processes, nutrient cycling, and feedbacks to the climate system. Phenology has been shown to be a robust integrator of the effects of year-to-year climate variability and longer term climate change on natural systems (e.g., recent warming trends). Experimental studies have shown how other global change factors (e.g., elevated CO_2 and N deposition) can also influence phenology. The PhenoCam network uses high-resolution, Internet-connected digital cameras to provide automated, near-surface remote sensing of canopy phenology across the United States with a special concentration in the Northeast and adjacent parts of Canada.

Application of R&D results—

Research questions being addressed include the following:

1. How does phenology regulate spatial and temporal variability in ecosystem function (e.g., photosynthesis, respiration, net carbon sequestration, and transpiration)?
2. How well is MODIS able to capture phenology and what is the nature and magnitude of uncertainty in moderate resolution space-based estimates of phenological events?
3. What are the environmental factors regulating phenology (e.g., forcing temperatures, chilling, and day length) in different ecosystems? How would phenology respond to projected future climate change scenarios?

This project is directed by Dr. A. Richardson of Harvard University. More information is available at: http://klima.sr.unh.edu/info.html.

Sites: Bartlett EF, Howland (Cooperating EF), Hubbard Brook EF, and Silas Little EF.

Scope: National (other EFs include Coweeta and Wind River).

17. Regional Environmental Sensor Network

Objectives—

Electronic environmental sensors and associated data logging have been with us for nearly three decades. They have become standard in environmental monitoring and research, but remain a challenge to deploy and "do right." Within the past decade, the selection and capabilities of sensors have advanced rapidly, and transmission of data to the world in real time has become commonplace. To keep abreast of this quickly shifting electronic landscape, the Northeastern States

Research Cooperative (NSRC) has funded a new regional working group on environmental sensors. The goal of this group is to inform, assist, and support researchers at long-term ecological research sites in the northeastern United States on basic to advanced sensor deployment, data acquisition, and real-time transmission. In addition to this "clearinghouse" function, participants in this project would team up to advance the understanding of environmental processes and response to global change through integrated planning and deployment of state-of-the-art sensor systems. The working group would also engage the public with an easy to understand real-time website. NRS EFs involved in this effort include: Bartlett, Hubbard Brook, and Marcell.

Application of R&D results—

This project would allow members of the research community to assist each other in basic measurements and programming, sensor choices, and keeping abreast of the rapidly changing sensor landscape. In so doing we hope to more fully exploit the potential of new-generation environmental sensors to facilitate process understanding and response to change, and communicate findings to the public. Beyond their scientific relevance, "real-time" data from environmental sensor networks can be used as a teaching and outreach tool to engage the public with real-time images of charismatic species (e.g., birds, moose), weather and phenological events, and live data streaming from a forested ecosystem.

18. EFR Climate Synthesis

Objectives—

The objectives of this project are to (1) identify EFR sites with long-term (>40 year) temperature and precipitation records, (2) evaluate statistical trends in long-term data sets, and (3) assess accessibility of the data. (Note: this is a project initiated by the EFR Working Group, in response to a request from the Chief following his meeting with Mary Beth Adams last year).

NRS sites that provided data for this effort are: Baltimore (Cooperating EF), Fernow EF, Hubbard Brook EF, Marcell EF, and Vinton Furnace State EF.

Application of R&D results—

This effort would (1) highlight long-term climatic research across the EFR network, (2) identify continental-scale climatic trends, (3) identify gaps in our knowledge, and (4) provide a basic framework for designing a future network of weather/climate stations at EFR sites. Results would be provided to the Chief. This is also a pilot case study for accessibility of FS EFR data.

19. Hydroclimatic Effects on Ecosystem Response

Objectives—

Pulses of sulfate (SO_4) in streams have been linked to the severity of drought at sites within southeastern Canada and the northeastern United States. However, the extent to which this process occurs across the entire region is unclear. Furthermore, at sites that do show a response, the extent of the SO_4 response to drought has not been compared. Therefore, questions still remain regarding the significance of this process at the regional scale. The aim of this study was to address these questions to better understand the regional significance of drought on S biogeochemistry.

Long-term climate, discharge and stream chemistry data are included in this study from 22 watershed research sites throughout the southeast Canada/northeast U.S. region. Hubbard Brook and Fernow EFs are involved in this study.

Application of R&D results—

Results suggest that drought has a substantial effect on temporal trends in annual SO_4 concentrations across the northeastern United States/southeastern Canada region and that the presence of wetlands in a catchment is an important driver of SO_4 drought response. This information can help explain the apparent response (or lack of response) to air pollution controls. This information is useful to policymakers and to scientists modeling pollution response by ecosystems, and by land managers.

20. Integrating Landscape-Scale Forest Measurements

Objectives—

How do spatially extensive, but coarsely resolved, measurements made through remote sensing and forest inventories compare to the spatially intensive and highly resolved measurements made at intensive monitoring sites such as those in the AmeriFlux network? How do measurements made using independent methods over disturbance and recovery cycles, such as those resulting from insect infestations, fire, or harvesting, compare over annual and multi-year time scales?

As part of the North American Carbon Program, we are integrating intensive ground-based measurements, remote sensing, and modeling approaches at seven landscape-scale research sites across the United States to compare and contrast estimates of carbon stocks and fluxes. Each study site consists of a diverse landscape that reflects the effects of natural disturbances or forest management activities on carbon stocks and productivity. Flux tower locations include Bartlett EF in New Hampshire, Silas Little EF, the Cedar Bridge site and Fort Dix in New Jersey, and the Marcell EF in Minnesota. Other sites include a clearcut and mid-rotation Loblolly pine plantation in North Carolina, Glacier Lakes Ecosystem Experiments Site in Wyoming, and Niwot Ridge in Colorado. A network of plots centered around each eddy flux tower includes measurements of carbon pools, soil respiration, litterfall, and branchfall fluxes. The intensive ground-based biological data includes 16 nested Forest Inventory and Analysis (FIA) style plots arranged in a grid pattern within a 1 km^2 area which are embedded within plots located in a 9 km^2 area. This project involves a number of experimental forests that have eddy flux and biometric measurements in place (these include Silas Little, Marcell, and Bartlett EFs and Howland Cooperating EF). This project also integrates with a number of sites in the SRS, and RMRS (GLEES).

Application of R&D results—

The main products of this research include precise statistical estimates and maps of carbon stocks and productivity for a variety of forest landscape conditions, improved process-based models for simulating forest carbon dynamics at stand to ecoregion scales, and decision-support tools for land managers interested in carbon management. By estimating these for managed or disturbed forest stands in various stages of development, we would improve the ability of land managers to update or project stand-level inventories of carbon stocks for reporting to greenhouse gas registries. Reference data from these sites can be used by the scientific, policy, and land management communities. This project is evolving into a larger network of landscape-scale monitoring sites, including the two new sites in Mexico.

21. Long-Term Ecological Research (LTER)

Objectives—

The LTER Network is a collaborative effort involving more than 1,800 scientists and students investigating ecological processes over long temporal and broad spatial scales. The Network promotes synthesis and comparative research across sites and ecosystems and among other related national and international research programs.

Participating sites are: Baltimore (cooperating EF) and Hubbard Brook EF.

Application of R&D results—

LTERs provide the scientific community, policymakers, and society with the knowledge and predictive understanding necessary to conserve, protect, and manage the nation's ecosystems, their biodiversity, and the services they provide.

22. Long-Term Soil Productivity Study (LTSP)

Objectives—

- Determine what factors controll forest site productivity.
- Assess how forests can be managed sustainably over the long term.
- Develop soil monitoring standards for national forest managers.
- Evaluate forest practices to enhance productivity.

LTSP research focuses on the joint role of soil porosity and site organic matter and their effect on the site processes that control productivity. This study is being carried out through a standard series of experimental treatments designed to create varying degrees of stress and to provide measures of biological response and soil recovery. The work centers on national forest lands in the United States and dedicated sites in Canada covering major forest and soil types. Nationally, many of these research sites are located in experimental forests. There are three LTSP study sites, and most are affiliated with experimental forests: West Virginia (Fernow EF, Middle Mountain), Great Lakes (Marcell EF, plus national forest land in Minnesota and Michigan), and Missouri (Sinkin EF).

Application of R&D results—

The LTSP is an international study, providing dedicated research sites and opportunities in a variety of forest types. The outcomes of this research are of particular interest to national forest managers (indeed, the National Forest System was the original partner in establishing these study sites), and to land managers interested in managing forests over the long run. These sites are also the location for very intensive experimental monitoring, and the national level effort at collaboration in publications and research opportunities continues to be vital.

23. Long-Term Stand Responses to Silviculture

Objectives—

This study's research objectives are to (1) quantify the influence of stand structure, composition, site characteristics, and climatic factors on response to silvicultural treatment within and between forest types represented by selected EFs; and (2) identify (through variance components analysis) the sources of variability in this growth response. Ecological questions are: How do growth responses to silvicultural treatment differ at the regional, EF, treatment, stand and/or plot levels? Can this variability be explained with existing stand, site, or climatic data? This project would increase collaboration among EF managers in the Northern Research Station, and improve the accessibility of high-quality, long-term EF data through the creation of a relational database for a subset of studies on selected EFs.

Application of R&D results—

Results from this study would provide a working hypothesis concerning the variability of growth response from geographically separate stands with similar silvicultural prescriptions. This study is important to resource managers applying silvicultural treatments in a variety of forest types, and would improve the consistency of results by identifying sources of variation in treatment response. In addition, the associated multiple-EF "pilot" database would test the feasibility of a standardized format for EF data, and increase future collaboration and data availability. Collaborators include University of Maine faculty and a graduate student and University of Minnesota faculty.

This project is being conducted in the Northern Research Station and includes the Birch Lake Study and Argonne and Dukes EFs in Wisconsin, Michigan, and Minnesota; the Fernow EF in West Virginia; the Kane EF in Pennsylvania; the Penobscot EF in Maine; the Sinkin EF in Missouri; and the Vinton Furnace ESF in Ohio. The study also includes other participating station scientists.

24. Quantifying Uncertainty in Ecosystem Studies (QUEST)

Objectives—

Ecosystem nutrient budgets often report values for pools and fluxes without any indication of uncertainty, which makes it difficult to evaluate the significance of findings or make comparisons across systems. QUEST is a research network that has evolved around the idea that uncertainty analysis should be an accepted and expected practice in the construction of ecosystem budgets.

Right now we are conducting a cross-site comparison of input-output budgets in several watersheds throughout the United States. We are currently funded through an NSF LTER working group with the participation of 12 long-term study sites, and we also have submitted a proposal to NSF to develop a Research Coordination Network. http://www.quantifyinguncertainty.org/.

Principal investigators: USDA Forest Service, SUNY-ESF, Plymouth State University, U.S. Geological Survey, and Cary Institute.

QUEST Collaborators: USDA Forest Service, Cary Institute, Oregon State University, Harvard University, SUNY-ESF, University of New Hampshire, University of Colorado, and U.S. Geological Survey.

The following EFRs are involved: Hubbard Brook, Marcell, and Fernow. Other EFRs from other stations include: Luquillo, H.J. Andrews, and Coweeta.

Application of R&D results—

Collaborators represent forested sites (generally forests, but not exclusively) with long-term ecosystem data, in particular input-output fluxes. The results of this working group would have implications for policymakers, for other research scientists, and for land managers, as we put confidence bounds on our currently unbounded ecosystem nutrient budgets.

25. U.S. Forest Service Management Intensity Demonstration Plots

Objectives—

Originally, the Management Intensity Demonstration (MID) plots were installed over a half century ago on experimental forests throughout the northeast and north central United States to serve as stand-alone demonstrations of forest management practices rated as "excellent," "good," "fair," and "poor." Today the MIDs represent a rare opportunity to synthesize forest development across forest types and ecoregions following a range of forest management practices. The original value-laden treatment names have been more descriptively named (i.e., using silvicultural terminology) because the preconceptions about each practice were overly simplistic. Because the MIDs were small and used for demonstration purposes, treatments and measurements have been continued to the present in most locations.

Application of R&D results—

The results of this study would help identify how forests respond to a range of management choices across a broad region. In addition, this work represents an important advance toward quantifying forest response to altered environmental conditions related to atmospheric deposition, invasive species, herbivory, and climate change. Although these factors are likely confounded at any one site, the broad regional and long-term nature of this project would better allow us to isolate the effects of environmental change.

This project was initiated in 2008. The Bartlett, Dukes, Fernow, Kane, and Penobscot EFs, and Vinton Furnace Experimental State Forest, in New Hampshire, Michigan, West Virginia, Pennsylvania, Maine, and Ohio respectively, contributed data for initial exploratory analysis. Partners willing to contribute and participate in the effort were identified at each location. Data management issues were identified and similarities and differences in treatments were described. Preliminary analysis focused on the growth rates and biomass accumulation of different forest types following exploitive harvest. The network of willing scientists, active experimental forests, and similar MID areas represents a unique opportunity to continue this effort in ways that would address critical environmental issues. Supplementary funding, through R&D or external (grant) sources, would likely be required to make significant new progress.

26. Systematic Experimental Forest Inventory Data as a Signal of Forest Change

Objectives—

This research and development project has three overarching objectives to determine:

- How many EFRs have had systematic inventories conducted at least twice.
- If data from systematic inventories of EFRs at the landscape scale can be used to make thoughtful observations about long-term changes in vegetative communities.
- If data from systematic inventories of EFRs can bridge the gap between FIA-level estimates of stocks and accumulation rates of carbon and site-specific estimates of carbon stocks and accumulation rates.

At least two EFRs were inventoried using a systematic sampling scheme at or about the time of EFR establishment (Kane EF and Bartlett EF). In both these forests, the inventory plots have been remeasured at least once, usually fairly recently. Leak and Yamasaki (2010) and Leak and Smith (1996) examined the remeasurement data from the Bartlett EF to determine long-term trends in species composition and forest change; more recently, Hoover (in review) used data from both forests to detect patterns of carbon accumulation throughout the 60+ year period between early measurements and remeasurement. Hoover (in review) found that the carbon accumulation patterns were strongly influenced by age (time since last disturbance) in both forests, paralleling the observations others have made about the maturation of the eastern deciduous forest's role as an important carbon sink in global circulation models.

These preliminary results suggest great promise in expanding this kind of review to more forests where similar systematic inventories may have been undertaken, and in further investigation of the existing data.

Application of R&D results—

The study has potential value to both policymakers and land and resource managers. Detection of change in patterns of forest growth, species composition, and structure at a scale coarser than an experimental plot, but fine enough to incorporate detailed metadata about natural and management disturbance patterns, may be invaluable for detecting climate change and other signals of forest change and accommodation.

Partners currently include only the Bartlett and Kane EFs. Other partnerships are expected to emerge.

27. Long-Term Regeneration Research for the Development of the Forest Vegetation Simulator

Objectives—

This research and development project has three overarching objectives, to determine:

- If data from long-term studies of natural regeneration in eastern forests can be synthesized into a common format and set of models that are compatible with the Forest Vegetation Simulator (FVS).
- If long-term data from the Forest Inventory and Analysis Pennsylvania Regeneration Study can be used to develop a model for imputing advance regeneration from overstory attributes, and be calibrated for other eastern forests types.
- If both the advance regeneration predictions and regeneration models can be integrated with predictions of climate change impact on eastern tree species to improve local projections and those used in national forest long-term planning.

Many EFRs in the eastern United States host studies of natural regeneration processes. Loftis (Southern Research Station [SRS]) developed a regeneration modeling framework to integrate such studies into predictors of future stands based on a stand inventory of regeneration sources before a disturbance. The SRS and the FVS team are linking regeneration models (e.g., Loftis-type) to FVS, widely used in both project and forest-level planning. The question driving this suite of studies is whether these regeneration studies, with a wide variety of data formats, can be integrated into the same modeling framework based on universal ecological principles as expressed in competitive hierarchies of regeneration sources to predict future forests in the eastern region. This research seeks to identify and quantify emergent, unifying principles of regeneration processes using long-term data from EFRs.

Application of R&D results—

The study is of immediate importance to national forests of the Eastern United States required by forest planners to simulate forest change using model stands over periods longer than a typical rotation. This project would allow planners to replace local expert assumptions with research-based models of regeneration. As the regeneration models are integrated with imputation models for advance regeneration and models of likely species by habitat impacts of climate change, the importance of the study and the breadth of use would increase. Forest planners and policymakers would benefit from this study, and society at large would benefit from improved understanding of future forests leading to better planning for adaptation and mitigation. Partners include several eastern EFRs, notably including the Bent Creek EF

(SRS), the Bartlett, Massabesic, Kane, Sinkin, and Fernow EFRs (NRS), the Forest Management Service Center, FVS staff, NRS FIA, Virginia Tech, University of Missouri, and Pennsylvania State University. Other partnerships are expected to emerge.

28. Decomposition on the Forest Floor: Soil Productivity Studies

Objectives—

Soil organic matter is key to maintaining site productivity because of its roles in soil water availability, nutrient supply, soil aggregation, and disease incidence or prevention. A number of studies have shown a strong relationship between organic matter decomposition rates and site productivity. Forest management practices can greatly impact organic matter decomposition, which could affect tree growth and site productivity. Consequently, organic matter decomposition is being used as an index of forest management effects (both positive and negative) in long-term soil productivity studies being conducted in various parts of North America and Canada. Of the various types of organic substrates that can be used in a decomposition study, wood seems best suited for mineral soil. Wood is a normal component of mineral soil (e.g., coarse roots), and the slow decomposition rate of wood allows it to remain in the soil for at least several years. A number of study sites investigating wood decomposition have been established across the United States, Canada, and internationally. However, few of these sites exist within the Northern Research Station. This research would take place at the three NRS LTSP sites, the Baltimore LTER site, and a wetland restoration site (ARS) in eastern Maryland. The objectives of this study are to:

1. Evaluate the effects of soil chemical, physical, and biological properties on wood decomposition rates and microbial decay patterns across a range of soil types and climatic regimes within the Northern Research Station.
2. Estimate the impacts of a variety of land management practices (e.g., timber harvesting, site preparation, urbanization, and wetland restoration) on wood decomposition in the forest floor and mineral soil within the Northern Research Station.
3. Assess the relationship of microbial diversity to the rate and degree of wood decomposition under varying soil moisture, temperature, and nutrient conditions within the Northern Research Station.
4. Provide input to carbon sequestration and cycling model of the Northern Research Station.

Application of R&D results—

The information would be useful in calibrating carbon cycling models, and would also address local research questions about decomposition and site productivity.

29. Vegetation Dynamics Across EFRs

Objectives—

Research questions and hypotheses include: How has plant species dominance changed across EFRs over time in undisturbed and disturbed sites, in the overstory and understory (native/nonnative species)?

- We expect greater change at lower latitudes: higher disturbance, higher temperatures, and increased rainfall.
- We expect introduced species to be more prevalent in disturbed sites.

Additional question: What is the variation within and among sites? This would address alpha (species) and beta (community or ecosystem) diversity.

Application of R&D results—

This research would provide information about vegetation dynamics and the effects of climatic gradients and change agents at multiple temporal and spatial scales, thus informing management and policy.

EFs participating in this project include:

- Hubbard Brook
- Silas Little
- Fernow
- Marcell
- Baltimore Ecosystem Study (cooperating EF)
- Coweeta
- H.J. Andrews
- Bonanza Creek
- Santee
- Crossett
- Fraser
- Niwot
- Luquillo
- Tenderfoot
- San Dimas
- HETF
- Caspar Creek
- Sierra Ancha

30. Water Supply Sensitivity and Ecosystem Resilience to Land Use Change, Climate Change, and Climate Variability

Objectives—

Use data from long-term climate and hydrology studies in the LTER and related networks to assess ecosystem water use responses and resilience to climate variability and the effects of many processes on water supplies and society.

This study uses long-term climate and stream flow data from a number of LTER, EFR, USGS and other networks, and from sites in Canada, to assess ecosystem water yield sensitivity to past land use change and climate variability since 1950. The following are participants: Fernow EF, Hubbard Brook EF, and Marcell EF.

Specifically, questions asked were:

1. How are potential and actual evapotranspiration related?
2. How is streamflow correlated with long-term climate indices?
3. What trends have occurred since 1950 in temperature, precipitation, streamflow, and runoff rations?
4. What are the ecological and social implications of observed and predicted changes?

Application of R&D results—

This study used existing, available long-term data to evaluate questions related to climate change and land use change effects on streamflow and climate. This information would be useful for forest land managers within (and outside) the Forest Service as they make decisions about managing forests to provide clean, abundant water. This project also provides information based on experiences of a large number of collaborators working across agency boundaries to bring forward such a synthesis.

31. International Cooperative Program on Assessment and Monitoring of Air Pollution Effects on Forests

Objectives—

The main objective of the proposed network is to strengthen the role of EFRs by providing more internationally standardized data that would benefit the entire EFR network. The network would contribute to a better understanding of the relationships between the condition of forest ecosystems and anthropogenic (in particular air pollution) as well as natural stress factors through intensive monitoring on a number of selected permanent observation plots and to study the development of important forest ecosystems. Further, the network would provide a deeper insight into the interactions between the various components of forest ecosystems by compiling available information from related studies, and in close cooperation with the ICP on modeling and mapping, would contribute to the calculation of critical level/loads and their existence in forest ecosystems.

Application of R&D results—
Eleven EFRs and seven LTERS were selected in FY2007 for this study. Research from this study would improve collaboration with other environmental monitoring programs and would contribute to the monitoring activities to other aspects of relevance for forest policy at national and global levels, such as effects of climate changes on forests, sustainable forest management, and biodiversity in forests. The network would also provide policymakers and the general public with relevant information to make informed decisions.

32. Long-Term Inter-Site Decomposition Experiment Team (LIDET)

Objectives—
The primary objective of this study is to examine the control that substrate quality and macroclimate have on patterns of long-term decomposition and nitrogen accumulation in above- and belowground fine litter. Of particular interest would be the degree to which these two factors control the formation of stable organic matter and nitrogen after extensive decay.

Application of R&D results—
Understanding ecological systems on the global scale would require an increase in preplanned, long-term, multi-site studies. This leaf, wood, and root decomposition study is being carried out at 28 LTER sites that span a wide array of ecosystems, from tundra to warm desert to short-grass steppe to moist tropical forest. The duration of the study is designed to be approximately 10 years at temperate zone sites and approximately 3 years at tropical zone sites because of higher decomposition rates. The same decomposing materials, litter bags, and study design are used at all sites to facilitate inter-site comparisons. A team composed of field collaborators oversees the study at particular sites; modelers predict C, N, and P dynamics and validate models from the field study; and a central analysis group performs chemical analysis, data management, and preliminary analysis.

33. Lotic Inter-Site Nitrogen Experiment (LINXII)

Objectives—
This experiment involves an intensive, inter-site study of the fate of nitrate in streams. Research would evaluate whether streams are important sites of N retention in the landscape and, more importantly, how human disturbances affect that retention. This experiment and its measurements would allow the

testing a variety of hypotheses dealing with the impacts of human disturbances on streams, including effects on channel morphology, hydraulics, biological activity, and N retention.

Application of R&D results—

Proposed research integrates across a large range of spatial scales, from the microscale to stream reaches to landscapes of diverse biomes. The research would have broader implications to society by explicitly evaluating the effects of human disturbance on N retention in stream networks, contributing the knowledge needed for a more sustainable management of watersheds.

34. Maps and Locals (MALS)

Objectives—

The MALS project is a collaborative effort to develop common methods for research on social-ecological systems at the LTER network scale. The project seeks to research changing social-ecological systems using a mixed-methods, comparative approach. MALS will address a challenge for both applied and theoretical ecology of discerning past human effects on ecological systems and distinguishing anthropogenic from non-anthropogenic drivers of change. Although most LTER sites have assembled historical data on land cover, climate, vegetation, and other ecological attributes, less is known about historical resource management practices and other human influences. In many cases, social data are available for human communities of LTER regions, but are not well compiled. The objective in this collaborative research project is to develop methods and capacity for research into social-ecological systems both at individual sites and at the network scale.

Application of R&D results—

A cross-site collaborative effort would use spatial representation of land cover and land use to identify patterns of landscape change in regions in and around LTER sites; integrate local ecological knowledge (LEK) and other existing social data into theories and models of ecological change and their implications for human livelihoods.

35. Engaging Arts and Humanities

Objectives—

The H.J. Andrews EF Long-Term Ecological Research group; the Spring Creek Project for Ideas, Nature, and the Written Word; and the U.S. Forest Service are collaborating in a program that brings creative writers, humanists, and ecosystem scientists together at the Andrews and in other natural venues in the Pacific

Northwest. This program, called Long-Term Ecological Reflections, supports writers and humanists in their efforts to explore human/nature relationships as they evolve over many lifetimes.

The Spring Creek Project, an independently funded program in Oregon State University's Department of Philosophy, is dedicated to bringing together the wisdom of the environment sciences, the clarity of philosophical analysis, and the creative expressive power of the written word, to find new ways to understand and re-imagine our relation to the natural world. Dr. Kathleen Dean Moore, professor of philosophy and Spring Creek's director, is author of *Riverwalking*, *Holdfast*, and *Pine Island Paradox*, books of essays on nature and family.

36. Detritus Input and Removal Treatments (DIRT)

Objectives—

The DIRT is a long-term study of controls on soil organic matter formation. The goal is to assess how rates and sources of plant litter inputs control the accumulation and dynamics of organic matter and nutrients in forest soils over decadal time scales.

Application of R&D results—

Results from field data and inter-site soil incubations suggest that aboveground inputs exert a stronger influence on soil organic matter (SOM) mass, but root inputs have a stronger effect on its quality. The pool of turning over N is slow, having a different dynamic than the faster mineralizable carbon (C) pool. Metabolism of roots and rhizosphere organisms is more temperature-sensitive than bulk soil organisms. Exclusion of roots had a greater effect on microbial processes than either doubling or excluding aboveground inputs. Declining decomposition rate accompanied by increasing soil C in the double annual aboveground litter treatment suggests long-term nonlinear changes in soil microbial activity, which could lead to increased long-term soil C storage beyond expectations. Changes in above- and belowground plant inputs and their influence on temperature-controlled processes would be significant in determining the effects of a warmer world on the net flux of carbon from soils to atmosphere.

37. Nutrient Network (NutNet)

Objectives—

NutNet is a globally replicated experiment investigating the effects of resources and consumption on ecosystem processes. Two of the most pervasive human impacts on ecosystems are alterations of global nutrient budgets and changes in the abundance and identity of consumers. Fossil fuel combustion and agricultural fertilization have doubled and quintupled, respectively, global pools of nitrogen and phosphorus relative to preindustrial levels. Concurrently, habitat loss and degradation, and selective hunting and fishing disproportionately remove consumers from food webs. At the same time, humans are adding consumers to food webs for endpoints such as conservation, recreation, and agriculture, as well as accidental introductions of invasive consumer species. In spite of the global impacts of these human activities, there have been no globally coordinated experiments to quantify the general impacts on ecological systems. The Nutrient Network is a grassroots research effort to address these questions with a coordinated research network comprised of more than 40 grassland sites worldwide.

Application of R&D results—

Research questions for NutNet include:

a. How general is the current understanding of productivity-diversity relationships?
b. To what extent are plant production and diversity co-limited by multiple nutrients in herbaceous-dominated communities?
c. Under what conditions do grazers or fertilization control plant biomass, diversity, and composition?

The goal of NutNet is to collect data from a broad range of sites in a consistent manner to allow direct comparisons of environment-productivity-diversity relationships among systems around the world. This is currently occurring at each site in the network and, when these data are compiled, would provide new insights into several important, unanswered questions in ecology. Additionally, to implement a cross-site experiment requiring only minimal investment of time and resources by each investigator, but quantifying community and ecosystem responses in a wide range of herbaceous-dominated ecosystems (i.e., desert grassland to arctic tundra).

38. Snowpack Telemetry (SNOTEL)

Objectives—

SNOTEL is an automated system of snowpack and related climate sensors operated by NRCS. There are over 600 SNOTEL sites in 13 states, including Alaska. The sites are generally located in remote high-mountain watersheds. All SNOTEL sites measure snow water content, accumulated precipitation, and air temperature. Some sites also measure snow depth, soil moisture and temperature, windspeed, solar radiation, humidity, and atmospheric pressure. These data are used to forecast yearly water supplies, predict floods, and for general climate research.

Application of R&D results—

Installation of SNOTEL began in the mid-1970s. Its use in climate forecasting was not originally envisioned, but it has become the standard climate data for western U.S. locations that are elevated sufficiently to have at least a seasonal snowpack. With 50 to 80 percent of the water supply in the West arriving in the form of snow, data on snowpack provide critical information to decisionmakers and water managers throughout the West. SNOTEL provides a reliable and cost-effective means of collecting snowpack and other meteorological data needed to produce water supply forecasts and support resource management activities.

39. Basic Meteorological Station

Objectives—

A basic meteorological station contains instruments and equipment for observing atmospheric conditions to provide information for weather forecasts and to study the weather and climate. The measurements taken include temperature, barometric pressure, humidity, wind speed, wind direction, and precipitation amounts.

Application of R&D results—

A variety of land-based meteorological station networks have been set up globally. Some of these are basic to analyzing weather fronts and pressure systems, while others are more regional in nature.

40. Long-Term Ecosystem Productivity Program (LTEP)

Objectives—

Concerns expressed by scientists, managers, and citizens about the potential impact of management activities on long-term productivity led to the formation of the LTEP research program in 1990. A major component of the LTEP program is a network of sites where field experiments are conducted.

Application of R&D results—

Many important questions concerning long-term productivity were evaluated to develop the experimental design. Two general hypotheses were thought to have a continuing, long-term effect on forest development and productivity, and could be addressed in a large, stand-scale field experiment. The first of these states that early- and late-successional species affect productivity differently than do mid-seral species. Modern plantation management has sharply reduced the time that early- and late-seral species occupy the land relative to historical patterns. The second general hypothesis is that removal of organic matter from a stand affects long-term productivity. Concerns about potential negative effects of organic matter removal on nutrient supply, soil structure, and wildlife lie behind this hypothesis.

The study is designed to evaluate how to sustain long-term ecosystem function and productivity by examining the interrelationships among species composition, soil properties and organic matter over several rotations. The treatments are being assessed and compared in many ways by scientists and resource managers representing biological, physical, and economic and social sciences. Vegetation, wildlife, soils, special forest products, climate, economics, public perception, and special concerns are being examined.

41. Forest Ecosystem Response to Regeneration Treatments for Upland Hardwoods (Sustaining Oaks)

Objectives—

Upland, mixed-oak forests occupy more than 50 percent of the forested land base in the central hardwood region of the United States, where oaks play a pivotal role in forest ecology, wildlife ecology, and economics. Yet the sustainability of oak forests is threatened by widespread oak decline and regeneration failure. Widespread oak decline is threatening eastern U.S. oak forests. The restoration of southern forest ecosystems has become increasingly important to ensure future water quality, wildlife habitat, and other ecosystem services provided by forests. Restoration and management provides landowners and managers with knowledge and tools to help restore, enhance, and manage forests in a changing environment.

Application of R&D results—

A study of the ecosystem response (e.g., regeneration response of oak and other hardwood species, and plant diversity) to treatments that alter light and hardwood competition is being conducted. Additionally, wildlife response to these oak regeneration treatments is also being conducted. Results would be used to develop guidelines for sustainable oak ecosystem management within southern upland hardwood forests, and help ensure that these forests continue to provide valuable economic and ecological services.

42. U.S. Regional Climate Reference Network (USRCRN) Station

Objectives—

The lack of high-quality surface measurements of precipitation and air temperature historically has hampered the ability of climate scientists to fully characterize the national and regional climate signals with confidence. The USRCRN provides the nation with a climate-quality benchmark observing system for real-time measurements of air temperature and precipitation that meets national commitments to monitor climate of the U.S. for the next 50 to 100 years. The USRCRN also provides a platform opportunity to add additional sensors (i.e., soil moisture, soil temperature, relative humidity, wind, pressure) for future climate monitoring activities.

Application of R&D results—

The USRCRN consists of 114 stations in the 48 contiguous states and an additional seven stations installed in extreme environments in Alaska, Hawaii, and Canada. Each station is strategically placed away from urban and suburban influences to avoid any possible misinterpretation of changes observed. The USRCRN reports multiple observations per hour for temperature and precipitation. This temporal resolution of the data provides additional climate information, such as precipitation intensity and duration of extreme events.

43. Wood Decomposition Experiment

Objectives—

This study is designed to examine the control that substrate quality and climate have on patterns of long-term decomposition and nitrogen accumulation in above- and belowground fine litter. Of particular interest would be the degree to which these two factors control the formation of stable organic matter and nitrogen after extensive decay.

Application of R&D results—

The 28 sites involved in the study cover all major biomes in North America. The major factors considered in this experiment are site, species of and type of litter (leaves vs. roots vs. dowels) and time. Twenty-eight sites, representing a wide array of moisture and temperature conditions, would be used for litter incubations.

44. Remote Assessment of Forest Ecosystem Stress (RAFES)

Objectives—

The southern United States has experienced significant droughts over the past several years that have increased the susceptibility of southern forest ecosystems to insect outbreaks, disease, and wildfire. Weather data collected with traditional approaches provide an indirect measure of drought or temperature stress; however, the significance of short-term or prolonged climate-related stress varies considerably across the landscape as topography, elevations, edaphic (soil) conditions, and antecedent conditions vary. This limits the capacity of land managers to anticipate and initiate ecosystem-specific management activities that could offset the impacts of climate-related forest stress. In addition, drier and warmer conditions predicted with climate change models are likely to significantly affect forest ecosystems over the next several decades.

Application of R&D results—

Decision support tools are needed that allow fine-scale monitoring of stress conditions in forest ecosystems in real time to help land managers evaluate ecosystem specific response strategies. Researchers are developing a stress monitoring and decision support system (RAFES) across multiple sites and ecosystems in the Eastern United States that: (1) provides remote data capture of environmental parameters that quantify climate-related forest stress across the network of sites, (2) links remotely captured data with physiologically-based indices of tree water stress, and (3) provides a PC-based analytical tool that allows land managers to monitor and assess the severity of climate-related stress in specific ecosystems.

45. Groundwater Survey

Objectives—

The use of appropriate methods, models, tools, techniques to investigate, inventory, assess or quantify the quality and the volume of ground water resources underlying NFS lands is very important in achieving success in such endeavors. Temporal and three-dimensional spatial scales are also critical elements in these processes.

46. Longleaf Pine Restoration and Ecosystem Productivity

Objectives—

Reliable restoration and management systems for sustaining longleaf pine ecosystems are needed. Longleaf pine ecosystems once occupied over 90 million acres in the South. Today less than 3 million acres remain, with many of the remaining acres in an unhealthy state, owing partially to the exclusion of fire. The longleaf ecosystem figured prominently in the cultural and economic development of the South. Today, these forests and landscapes represent significant components of the region's ecological diversity and offer new economic opportunities for many private landowners. They also provide essential habitat for many rare animals and plants. Restoration efforts at various spatial scales are now underway on former longleaf sites. In addition, plantings have recently increased on private lands in the former range as a result of voluntary incentives and improved seedling and planting technology. A major impediment to restoration and management efforts is the lack of reliable models and supporting databases which can accurately predict the regeneration, growth, yield and mortality of longleaf under a range of site conditions and management regimes which include even-aged, two-aged, uneven-aged, and also natural and artificial regeneration systems. Also lacking is an understanding of how fire regulates ecological processes and structures in longleaf ecosystems and how this knowledge can be translated into prescriptions and user guidelines.

Application of R&D results—

Three areas of research need to be studied:

(1) Interruption of natural fire regimes in the Southeast has resulted in alteration of native plant abundance to a degree that threatens long-term longleaf pine ecosystem sustainability. These altered ecosystems have become increasingly vulnerable to destruction by catastrophic fire and invasion by noxious weeds and undesirable woody plants. Restoring periodic fire as a disturbance agent is fundamental to the ecological restoration and maintenance of longleaf pine ecosystems. Reliable information concerning the appropriate fire frequencies and seasons needs to be determined for the wide range of site conditions.

(2) The reintroduction of fire through prescribed burning is frequently proposed as the principal means for restoring and maintaining these ecosystems. However, if ecosystem degradation has progressed beyond key biophysical thresholds, then effective restoration would likely not be achieved simply by the reintroduction of fire. Fire would also be ineffective in restoring the longleaf pine ecosystem wherever its fundamental elements of composition are absent. Therefore, restoring healthy longleaf pine ecosystems on sites that have been degraded beyond key biophysical thresholds would likely require mechanical, chemical and/or biological treatments. These techniques may often be needed as initial treatments as a prerequisite for the safe eventual reintroduction of prescribed fire and need to be evaluated.

(3) Developing silvicultural systems that successfully regenerate longleaf pine seedlings is crucial to the long-term viability of longleaf pine management and to the survival of the ecosystem itself. Artificial regeneration may not always be an economically viable option for lands receiving lower-intensity management.

47.Free-Air Carbon Dioxide Enrichment Experiment

Objectives—

Free-Air Carbon Dioxide Enrichment (FACE) is a method used by ecologists and plant biologists that raises the concentration of CO_2 in a specified area and allows the response of plant growth to be measured. Experiments using FACE are required because most studies looking at the effect of elevated CO_2 concentrations have been conducted in labs and where there are often factors other than CO_2 concentration affecting growth, for example, the pot effect. Measuring the effect of elevated CO_2 using FACE is a better way of estimating how plant growth would change in the future as the CO_2 concentration rises in the atmosphere as a result of anthropogenic emissions. FACE also allows the effect of elevated CO_2 on plants that cannot be grown in small spaces (trees for example) to be measured.

Application of R&D results—

FACE circles have been used across parts of the United States in temperate forests and also in stands of aspen in Italy. The method is also used in agricultural research. For example, FACE circles have been used to measure the response of soybean plants to increased levels of ozone and carbon dioxide at research facilities at the University of Illinois at Urbana-Champaign. FACE technologies have yet to be implemented in old-growth forests, tropical forests, or boreal forests, but future research projects would probably include these areas. TasFACE is investigating the effects of elevated CO_2 on a native grassland in Tasmania, Australia. The National Wheat FACE array is presently being established in Horsham, Victoria, Australia as a joint project of the Victorian Department of Primary Industries and the University of Melbourne.

A FACE experiment began at Duke University in June 1994. The Blackwood Division of the Duke Forest contains the Forest-Atmosphere Carbon Transfer and Storage facility. This consists of four free-air CO_2 enrichment plots, which provide higher levels of atmospheric CO_2 concentration, and four plots that provide ambient CO_2 control. There have been 253 publications reporting on the findings of the experiment.

48. Smithsonian Global Program for Long-Term Large-Scale Forest Research

Objectives—

The Center for Tropical Forest Science (CTFS) is a global network of forest research plots committed to the study of tropical and temperate forest function and diversity. The multi-institutional network comprises more than 40 forest research plots across the Americas, Africa, Asia, and Europe, with a strong focus on tropical regions. CTFS monitors the growth and survival of about 4.5 million trees of approximately 8,500 species.

CTFS conducts long-term, large-scale research on forests around the world to:

- Increase scientific understanding of forest ecosystems
- Guide sustainable forest management and natural resource policy
- Monitor the impacts of climate change
- Build capacity in forest science

Ecologists at the Smithsonian Tropical Research Institute established the first plot on Barro Colorado Island, Panama, in 1980. There they pioneered long-term tree-census techniques that scientists replicated throughout the tropics, creating a network of forest research plots that would eventually become the Center for Tropical Forest Science. Before 1980, scientists had never attempted to measure tropical forests so intensively and at such a large scale. Today the scale and intensity of the CTFS research program remain unprecedented in forest science.

CTFS plots involve hundreds of scientists from more than 75 institutions worldwide. Individual forest plots are led and managed in each country by one or more partner institutions. CTFS coordinates plots in Asia through partnerships with host-country institutions and the Arnold Arboretum of Harvard University.

Common plot structure and scientific methodology unify the CTFS network. In each plot, which are typically 25 to 50 hectares, all free-standing trees with a diameter at breast height of at least 1 cm are tagged, measured, identified to species, and recensused approximately every 5 years. Because each plot follows the same methodology, scientists can directly compare data collected from different forests around the world and detect patterns that would otherwise be impossible to recognize.

Part 2A. Ideas from R&D Scientists for Potential Future Cross-EFR Research and Monitoring (table 8).

1. EFR Meta-Database of Site Information and Content

Objectives—

To construct a searchable database of EFR site information and research activities. This database would enable EFR scientists to better understand who is doing what research in what location, share expertise and data, conduct syntheses, and better address requests for proposals (RFPs) as they become available. This is not a data repository. Further efforts, similar to those of the NSF LTER sites, are also needed to make high-quality EFR data readily available to EFR scientists and the public.

Application of R&D results—

The EFR network is perhaps unparalleled in the world relative to its number of sites (more than 80), geographic distribution (continental United States, Puerto Rico, U.S. Virgin Islands, and Hawaii), long-term history of research and monitoring activities (more than 100 years), number and quality of scientists associated with the sites, both Forest Service scientists and collaborating scientists from universities and other research institutions (hundreds of people), land ownership (more than 600,000 ha), and relatively stable funding for scientist salaries and site operating costs (annual support). This network of sites offers a tremendous opportunity to serve as a continental-scale observatory network for local, regional, and national environmental and societal change. However, to realize these opportunities, a full and accessible inventory is needed of site characteristics, infrastructure, research priorities, datasets, and contacts. Some of this information is available in various existing documents. However, we know of no single repository to currently access this information.

a. To whom is the study important? All EFR scientists, staff, and administrators; other agency and university scientists, staff and administrators.
b. What benefits would clients and the public receive if the study is successful? It would clarify involvement by partners and collaborators, and would provide rapid access to current research in the EFR network as well as a platform for data synthesis activities and future research collaborations and proposals.

Status (ongoing or future potential): Proposed. Some of this information is available through EFR websites, ClimDB, the current EFR climate synthesis project, the searchable directory of watershed content database, and the network office.

2. Quaking Aspen Growth, Yield, and Mortality Across the United States

Objectives—

To assess the status of quaking aspen (*Populus tremuloides* Michx.). Quaking aspen is the most widely distributed tree species in North America and one of the most highly utilized species in the United States. Sudden as well as long-term decline and dieback of this species in regions of the country have garnered considerable attention over the last few decades, but regional analyses have not been linked to assess the national scope of the problem and potential overlap in primary and secondary stressors, particularly climatic variables. Furthermore, many of the aspen growth and yield equations used today were developed during the early part of the last century, prior to documented declines and dieback, when wildfire and exploitive logging created ecologically ideal conditions for the species to establish and grow. Given the spatial extent of quaking aspen in the United States, it represents an ideal species around which to build a standard monitoring and research program to assess **current** trends in growth, yield, and mortality. Specific objectives of such a program may be to: (1) measure growth, yield, and mortality of aspen in natural and managed stands of varying complexity; (2) test existing regional growth and yield equations against the range of current growing conditions; (3) develop a standard protocol for revising/developing regional growth and yield equations, and (4) assess the growth, yield, and mortality of aspen root systems—a potential long-term carbon sink. These questions could be addressed in detail on a few EFRs in each region with supplemental data provided by the Forest Inventory and Analysis program (FIA) or on all EFRs with an aspen component.

Application of R&D results—

The proposed study would establish a standard framework for defining and refining growth, yield, and mortality information at a national scale while maintaining regional specificity. Aspen is an important commercial tree species, but it is perhaps more important as forage and habitat for wildlife, for its aesthetics and recreational values, and for the watershed protection it provides. These factors combined with its above- and belowground carbon sequestration potential and use as a renewable biofuel make the findings useful to a wide range of stakeholders. The FIA program, for example, relies on regional volume equations to estimate live and standing dead tree biomass and carbon stocks. If yield equations do not accurately reflect tree volume, biomass and carbon stock estimates will not be accurate. The differences may be negligible at the tree level, but regional and national differences may be substantial. These differences have implications for state and local government agencies and industrial partners who rely on FIA data for growth and yield projections, energy utilities that rely on biomass estimates to inform bioenergy supply assessments, and forest carbon market-based mechanisms that rely on carbon stock information to address climate change and other environmental issues. Furthermore, documenting regional trends in aspen growth, yield, and mortality may lead to management strategies that mitigate stress factors and decline and dieback in other regions, which, in turn, may result in increased carbon storage, better water yield in dry environments, and improved recreational opportunities and aesthetics. Potential partners include but would not be limited to local EFR personnel, the USDA Forest Service FIA program, and affiliated universities.

3. A Comprehensive Reassessment of Stand Development and Timber Management Guidelines in the Northern Lake States

Objectives—

To develop updated and improved management guidelines for timber production, such as stocking guidelines and site index equations, by reevaluating current and future trends in forest stand development under current and future global change conditions.

Ecological question to be addressed: How have changes in atmospheric composition and climatic conditions, e.g., length of growing season, temperature and precipitation, affected stand dynamics and stocking in the last 50 to 100 years?

The EFRs should provide long-term records that provide insight into changes in stand development, and should be a readily available source for destructive sampling.

Application of R&D results—

The ultimate products would be a new suite of forest management guidelines, and along the way would address important theoretical issues related to global change.

a. The study will be important to scientists and forest managers.
b. The study would improve the efficiency of timber production on a diminishing land base, and provide global change modelers with data describing trends in forest development.

4. Development of Modeling Tools for Predicting Smoke Dispersion from Low-Intensity Fires

Objectives—

Can recent developments in fine-scale atmospheric dispersion modeling be used to produce more accurate smoke management tools for low-intensity fires? How well do predictions from a range of models compare to "fireflux" experimental data collected during prescribed fires?

We are using intensive field measurements made during prescribed fires to evaluate several state-of-the-art, fine-scale atmospheric dispersion models, with emphasis on their performance in simulating local-scale flows and near-surface conditions. Models and measurements aim to improve our understanding of the influence of forest vegetation layers and local terrain-induced circulations on smoke emissions, dispersion, and transport within and above forest canopies. In parallel, we are developing Web-based, user-friendly decision support tools for land managers, air quality regulators, and other users for planning prescribed burns.

The Forest Service and the experimental forests need to demonstrate that hazardous fuel reduction treatments can be conducted without causing significant environmental damage, including impacts to air quality. Other EFRs and national forests can use these tools, and would probably be involved in model testing in the future. Silas Little EF scientists have led this effort because they have the capacity to conduct fireflux experiments owing to their highly productive relationship with the New Jersey Forest Fire Service, expertise in building and operating eddy flux towers, extensive experience with fuel consumption measurements, and long-term measurements of forest carbon dynamics.

Application of R&D results—

This project represents a cost-effective way to build much-needed tools for smoke management by taking advantage of the rapid advancement in fine-scale atmospheric dispersion modeling for emergency response in the post 9/11 era. The Web-based decision support tools would benefit wildland fire managers, air quality regulators, and others who plan and conduct prescribed burns. These groups would be better able to plan fires to accomplish hazardous fuel reduction targets, while minimizing non-attainment of local, state and federal air quality standards. Because these tools would be location independent, they would benefit land managers worldwide.

5. National Silvicultural Synthesis: Long-Term Compartment Study Outcomes

Objectives—

To determine commonalities in stand response to silvicultural treatment over the long term across a variety of forest types. This work would investigate trends in composition and structure following application of similar treatments in the Forest Service's large-scale "compartment" studies. These studies, which comprise replicated, stand-level silvicultural treatments, were commonly installed on experimental forests nationwide in the mid 20^{th} century. Because they were based on a "pilot plant" or operational-scale model of research advocated by the Forest Service at the time, there are similarities in experimental design, measurement protocol, and treatment type across experimental forests and research stations. The remaining compartment studies present the unique opportunity to investigate the outcomes of like treatments on a national scale. This work would expand the spatial scope of current "pilot" (meta-analysis and regional synthesis) projects described earlier.

Application of R&D results—

The results of this study would help us identify universal truths about stand responses to certain types of treatments. We anticipate that we would be able to identify responses, in terms of structure, composition, and biomass and carbon accumulation, that consistently occur following application of a given treatment across forest types and climatic gradients, as well as those responses that are unique to given locales. As such, this research would improve our understanding of sustainable forest management, and allow greater certainty in prediction of treatment effects. Forest managers, as well as policymakers setting guidelines for acceptable practice, would benefit from the outcomes of this work. Collaborators would include university cooperators.

To date, work on this effort has been limited to an informal survey of EFR points of contact, to determine which sites have compartment studies. Potential participating sites identified so far include: the Argonne EF in Wisconsin (NRS, Brian Palik and Christel Kern), Bent Creek EF in North Carolina (SRS, Tara Keyser), the Boise Basin EF in Idaho (RMRS, Theresa Jain), the Crossett EF in Arkansas (SRS, Jim Guldin and Don Bragg), the Escambia EF in Alabama (SRS, Dale Brockway), the Fernow EF in West Virginia (NRS, Thomas Schuler), the Hitichie EF in Georgia (SRS, David Combs), and the Penobscot EF in Maine (NRS, Laura Kenefic and John Brissette). This research would be contingent upon the participation of a sufficient number of scientists from EFRs with compartment studies, as well as their willingness and ability to share data. Supplementary funding, through R&D or external (grant) sources, would likely be required to accomplish this work.

6. Nontimber Forest Product Ecology and Response to Disturbance: Insights from EFR Long-Term Data Sets

Objectives—

How do culturally and economically important nontimber forest products (NTFPs; vascular and fungal species used for food, medicine, and other purposes) respond to disturbance, including overstory manipulation? Although some NTFPs are derived from trees, most are from understory species about which relatively little is known. The proposed research would analyze EFR long-term datasets including detailed nutrient, soils, and overstory and understory inventory data to address three gaps in ecological understanding of selected economic and cultural keystone species:[1]

1. Site characteristics associated with the species,
2. Population dynamics over time in undisturbed sites, and
3. Population responses to disturbance.

EFRs long-term datasets constitute unique and potentially powerful existing resources for filling gaps in understanding NTFP ecology. Where comparable datasets are available, the national extent of the EFR network provides an exceptional opportunity to examine variation in population distribution and dynamics throughout a species' range. This information is critical to formulation of sound conservation policy at the local, state, and national levels.

Application of R&D results—

Study results would be of interest to diverse stakeholders interested in NTFP use and conservation:

- Native American tribes—Enhanced understanding of the ecology of cultural keystone species would help assure supplies of species needed to preserve traditional ceremonies and lifeways and provide tribes with a scientific foundation to complement traditional ecological knowledge in management.
- Forest managers and landowners—Information about the responses of NTFPs to management would enhance the capacity of U.S. forests to provide continuous (if modest) income streams.
- Land management agencies and conservation organizations—Data on habitat preferences and responses to disturbance would provide a scientific basis for NTFP conservation policies that is largely unavailable today. Results would help target inventory and monitoring programs, inform NTFP harvest guidelines, and inform vegetative management strategies to enhance NTFP populations.

[1] Species central to the cultural practices of Native Americans and other cultural groups.

- Climate change scientists and policy makers—NTFPs, many of which respond more quickly than trees to changes in precipitation and soil and atmospheric temperature, have promise as early indicators of local climate change impacts. Longitudinal data on the location of species could provide an empirical basis for locally tailored mitigation programs.

7. Wood Decomposition and its Role in the Forest Carbon Cycle Across the Conterminous United States—A Unified Assessment Using the EFR Network: The FACE Wood Decomposition Experiment (FWDE)

Objectives—
(a) Characterize fungal and invertebrate colonization and succession, decay rates, and fluxes of carbon from wood across a continental gradient of temperature, moisture, and soil conditions; (b) Use closed-system microcosms to quantify abiotic factors (temperature and moisture) and biotic factors (brown rot vs. white rot, presence and absence of termites) that influence decomposition rates and the ultimate fate of carbon in a system (e.g., released into the atmosphere or sequestered in the soil); (c) Model carbon movement through a complex food web among fungi and termites into the soil and atmosphere.

Our objective would be to integrate a large-scale field experiments (on a network of EFR sites), controlled microcosm experiments, and modeling to develop a mechanistic understanding of the wood decomposition and the development of soil organic matter under different abiotic conditions.

Dead wood is the largest detrital component of forests, comprising a significant portion of the total carbon pool. Despite its importance as a carbon pool, there is insufficient information on the factors affecting wood decomposition, and there are no mechanistic models that effectively simulate wood decay across North America. The basic approach for this study would be to incubate a common substrate (loblolly pine, birch, and maple wood) at locations with different temperature and moisture regimes in order to assess the interactions of physical conditions with biological processes mediating wood decomposition. The significant and unique aspect of this study would be that it employs loblolly pine grown in the Duke University FACE experiment and the Michigan Technological University FACE experiment; this wood has a distinct ^{12}C:^{13}C signature which would facilitate tracing the flux of carbon into the air, soil and water. As a result, this study would be able to partition the detrital sources of C through decomposition processes and organic matter pools; specifically it would allow quantification of the contribution of wood to soil C pools, greenhouse gas emissions (including trace gases), and illuminating the biogeochemical processes affecting decay. This study would capitalize on the Forest Service's experimental forest network, which provides sites across the country that have a strong foundation of supporting data and research that would augment this work. Our intent would be to establish a long-term (>50 year) experimental framework that can serve as a foundation for the study decomposition processes in wood.

Application of R&D results—

This study would engender companion studies that build on this foundation, and would enhance collaboration among scientists in the Forest Service and collaborating institutions. Results could be used by scientists and managers interested in climate change, carbon sequestration, insect and disease outbreaks, and biogeochemistry. If successful, this study would deliver critical information on how climate change would influence biotic processes in forest and rangelands. Partners and collaborators for this study would be from universities, industry, and other research stations.

8. Airborne LiDAR Surveys of Vegetation and Topography Across EFRs

Objectives—

EFRs comprise a network of sites representing valued vegetation, wildlife, hydrological, ecological, and cultural resources across the United States. The EFRs support a broad range of research and management applications in forestry, hydrology, ecology, etc., by scientists and professionals within R&D as well as academic research partners. The purpose of the study would be to establish baseline topographic and vegetation surveys of EFRs with Light Detection and Ranging (LiDAR). Objectives phrased as questions could include the following:

1. Can consistently derived metrics of canopy structure related to EFR plot data be used to predict biomass/carbon stores in our EFRs landscapes, then be applied in the national forests and grasslands for more informed carbon sequestration? Standardized canopy metrics across all vegetation types could be used to develop generalized models for regional biomass inventory and monitoring.
2. Can heterogeneity in canopy fuel structure in EFRs be used to simulate fire behavior dynamics following alternative experimental silvicultural treatments? Detailed, 3-D information on heterogeneous fuel distributions could constrain the range of probable fire behaviors for a given fuel condition.
3. Can canopy interception of light and precipitation be used to dramatically improve watershed-level models of water, energy, and carbon budgets? LiDAR can provide for accurate accounting of light and precipitation

interception by the canopy, for more accurate estimates of surface runoff, infiltration, transpiration, photosynthesis, and other biosphere-atmosphere exchanges of mass and energy.

Application of R&D results—

The goal of surveying all EFRs with LiDAR is already happening organically and may be about 50 percent complete, driven by the demand for LiDAR for many natural resource management applications. LiDAR is relevant to all forest and rangeland managers who stand to benefit from the more accurate topographic and vegetation information that only cutting-edge LiDAR technology can provide. Examples of LiDAR-derived products include 1-m resolution digital terrain models (DTM) and highly resolved canopy height and density data that can be used to facilitate virtually any environmental project at the regional, landscape, and watershed levels. Research Forester Hudak in Moscow already collaborates with national forests (Boise, Clearwater, Idaho Panhandle, Malheur, Nez Perce, Payette), private industry (Potlatch Forest Holdings, Bennett Lumber Products), and research universities with natural resource programs (University of Idaho, University of Montana, Oregon State University, Idaho State University) in the Interior Northwest. The EFRs provide R&D with an opportunity and a responsibility to take a leadership role among this suite of partners and collaborators to develop standardized LiDAR products as baseline information for strategic environmental measurement and monitoring at a national level.

9–17. Standard Inventory and Monitoring Protocols for Disturbance Effects: Vegetation, Wildlife, Carbon Inventory, Biophysical Drivers, Indicator Species, Biomonitors, Invasive Species, and Climate Variability Within EFRs

Objectives—

Develop a set of protocols to measure intensity, severity, and extent of major disturbances within an EFR. Collect data that could be compared across EFRs to assess the level of disturbance and its impact on other ecological monitoring data (hydrology, eddyflux, etc.). Many types of data could be collected and compared across EFRs to assess declines and advances of various plant and wildlife species. A set of plants or animals could be identified for monitoring across the United States. Populations, extent, health, and damage to these species could be recorded. Life cycles and population data could also be recorded. Stand level characteristics could be monitored and summarized upwards to an EFR using remote sensing. Additionally, each EFR could install a set of plots that would sample all carbon pools, where changes in fuels across components over time across the United States could be monitored. Standard weather measurements could be augmented with other instantaneous measurements meaningful to biophysical processes. A set of biological indicator species could be developed and monitored at each EFR to determine magnitude and trend information. For example, stonefly larvae could be used to monitor water quality. Lastly, generic generalist plants could be planted throughout the United States to monitor for a number of characteristics. Plants are great integrators of climate and ecological change. Standard protocols could be developed for how and when updates for EFRs data are done in response to disturbance. In particular, develop a standardized process for documenting fire severity for prescribed fires and wildfires that occur within EFRs. These standard protocols could build on previous work. Also, examine invasive processes for exotic species and examine vegetative productivity response to climate variability/drought.

Application of R&D results—

Study results would be used to measure and assess the intensity, severity, and extent of major disturbances across the United States, as well as within an EFR.

18. Common Garden Experiments to Assess Key Plant Species Adaptation to Climate Change

Objectives—

We conducted interviews with a number of current and past Rocky Mountain Research Station scientists as part of a study to gather anecdotal information on observed effects on climate change in experimental forests and ranges. We also talked about new relevant climate change research that could be done.

Application of R&D results—

On the biological side, several participants talked about networked common garden experiments, involving a gradient of EFRs, as a way to look at adaptation. More on the social side, participants talked about a need to “get a handle on” the effects of recreation on EFRs and NFS land as a whole. Road closure came up a couple of times as an issue that is going to be increasingly important and contentious so EFRs could be a place to test social and ecological responses to road closures (or any other relevant changes in policy toward recreation on NFS land).

Also, there would be an opportunity to (1) apply proposed adaptation strategies on the ground and measure outcomes/results and (2) simultaneously engage the public in thinking about management as experimentation (as in the adaptive management model) and measure outcomes/results.

19. EFR Science Synthesis of Biological Responses to Stream Nutrients

Objectives—

Synthesize EFR data, metadata, and publications to answer the research question: What are biological responses to stream nutrients? Draw upon the wide range of studies that have been done at sites across the EFR network to answer how the living component of stream ecosystems responds to nutrients in streams. Responses could be in aggregate (i.e., ecosystem-wide measures such as standing biomass, net photosynthesis, stream respiration, etc.); at the community level (e.g., measures such as species diversity); or at the population level (e.g., individual species or guild population responses). Coverage would include all EFRs that have a history of stream ecology studies. Responses could also be differentiated by other useful characteristics such as by region, forest type, or management practice. The purpose would be to respond to a request by members of the state and federal water quality regulatory community to make the body of EFR research on this topic more useful in their work of setting water quality standards for forestry practices. EFRs are eminently suited to this purpose because they were originally designed to study effects of forestry practices and there are very few places outside of EFRs where high-quality data and controlled studies have been done on effects of forestry practices on water quality that are comparable with those done on EFRS. EFR studies also provide examples in most major forest types across the country.

Application of R&D results—

This synthesis would be published and made available on the Web via the Clim/Hydro/StreamChemDB Web harvester suite and would provide water quality regulators (and any other users interested in biological responses to stream nutrients) with a well-articulated and thought-out analysis of what research and monitoring has been accomplished on this topic at EFRs and what EFR data/metadata are available. Results of the synthesis would also point out critical gaps for answering questions on this topic and may potentially identify important new areas/methods for future research or monitoring across the EFR network. (a) This synthesis would be directly important to the water quality regulatory community and more generally to stream ecologists, fisheries managers, drinking water utilities operators, and forest land managers. (b) Water quality regulators would benefit directly from better access to EFR data/metadata and study results that are of higher quality and more relevant to forest management than are generally available elsewhere for setting water quality standards and developing models to support those standards. The Pacific Northwest Research Station has led direct discussions (via webinar on

March 3, 2011) with water quality regulators from five states and three EPA regions across the country, jointly sponsored by NCASI, research arm of the forest products industry. This project is a direct response to a request from the regulators at that discussion for a comprehensive science synthesis of EFR research, data and metadata on this specific topic. A working group, including representative regulators, is currently writing an outline for a synthesis and would develop a proposal to seek funding for its development.

20. Legacy Study Using the Long-Term Ecosystem Productivity (LTEP) Experiments Implemented on Olympic Experimental State Forest, in the Greater H.J. Andrews EF Area, and Near Cascade Head EF

Objectives—

- What is the effect of a wide range of management strategies on long-term ecosystem productivity, where LTEP is evaluated with long-term above and belowground net primary production and soil fertility changes along with production of various ecosystem services?
- What role do hardwoods and early-seral vegetation play in long-term growth of conifers?
- Would leaving residual woody biomass benefit ecosystem production?
- How would treatment responses interact with fire and wind?
- How would older mature conifer stands (80 to 110 years old) respond to thinning?
- What are the biodiversity consequences of the various strategy elements (hardwoods, woody debris, mature-conifer thinning)?

With 15-acre treatment areas, replication, and extensive pre- and post-treatment measures and archived (especially soil) samples, renewed monitoring of LTEP experimental units would provide long-term data on ecosystem changes (since 1993) unavailable by other means. Recent monitoring of a fourth LTEP site (not affiliated with an EF, on the Rogue River–Siskiyou National Forest) demonstrated that significant changes in soils and vegetation can be obtained on these sites. The distribution of these experiments on or near EFRs in western Oregon and Washington, combined with the Siskiyou experiment, give a broad array of environmental conditions of Douglas-fir-dominated forests.

Application of R&D results—

The forward thinking applied in the design of this study is remarkably well suited to today's pressing questions on effects of management on carbon, rates of Npp, and ecosystem services. The treatments implemented also happen to represent major, different ways to manage given possible climate change. The large experimental units (15-acres) also represent key opportunities to evaluate satellite and plane-based (LiDAR) remote sensing of leaf area, productivity, and many other response variables across a wide range of adjacent or nearby treatments. Other studies in EFRs nationwide with similar measurements might constitute a network for such testing.

This study would provide empirical data on key questions currently unavailable, with direct inference (1) to past and future management practices and (2) to intervening lands throughout the Pacific Northwest region. Scientific credibility of modeled projections needs this empirical grounding.

Collaborators include the Pacific Northwest Region of the Forest Service (study instigator), various national forests, the Washington Department of Natural Resources (landowners), and various universities, including Western Washington University, Oregon State University, and the University of Washington (researchers).

21. Continental-Scale Questions for EFRs

Objectives—

A critical load is the pollution threshold that can be deposited into a specified ecosystem without causing significant adverse environmental effects. Data requirements include atmospheric deposition rates, nutrient cycling, water quality, soil chemistry, target organism condition, and other environmental data. EFR scientists often collect these data for the same location and have done so for long periods of time (≥10 years, sometimes ≥50 years) allowing for trend analyses and the development of a baseline to assess ecosystem responses to environmental change over decades. Nineteen EFR sites have received preliminary funding to establish ICP Level II plots, which roughly coincide with P3 or P4 plots used to monitor forest health by FIA. Although these funds have enabled the purchase of the needed equipment, the operation of the plots has been left up to individual projects. At a recent workshop a list of operational needs was developed for these sites. Some are applicable within the scope of this proposed initiative and include an ICP czar who would be responsible for training, protocols, quality assessment and quality control; the purchasing of missing equipment; data management (perhaps link with FIA P3 plot database and other efforts such as the National Research Data Management effort); and other activities central to the operation of the network. This czar position could also serve other national EFR efforts in database development and management, or facilitate the development of protocols for core data that all EFRs adopt (of course, taking into consideration existing protocols, etc.). Finally, an ICP or data czar could be an active participant in the new Integrated Monitoring and Assessment (IM&A) effort by all three deputy areas of the Forest Service and fully endorsed by leadership.

Another initiative related to EFRs and CL assessments would be a comparison of the different models used to calculate CLs for various climate, soil, and vegetation types. Individual EFR sites could serve as "point data" for using these models in calculating critical loads and thus provide data to validate the models. EFRs are well suited for this exercise because of the co-located data and the ability to validate models back in time. This modeling exercise would be done in partnership with NFS Air Program, NADP's Critical Loads Science Committee (CLAD), EPA, and the National Park Service as part of phase II of the FOCUS (Focal Center Utility Study) project.

Application of R&D results—

Critical Loads questions: What is the effect of land use and population change on the environment and do these changes affect the sensitivity of forest ecosystems to atmospheric pollution (deposition load and ambient level) and, more broadly, forest ecosystem health?

1. What is the effect of climate change on stream and air temperature in forest ecosystems at a multiple scales (local, regional, and continental)?
2. How do changes in stream and air temperature relate to vegetation type, plant physiology, presence of invasive species, etc.?
3. How do environmental changes related to climate and land use change affect carbon and nutrient cycling and, ultimately, the sensitivity of forest ecosystems to atmospheric pollution?
4. What are the responses of forest ecosystems to atmospheric pollution along various environmental gradients such as elevation, longitudinal, latitudinal, urban-to-wildland, industrial centers, soil types, and third-order to first-order streams?

Other questions:

1. Effect of climate change on phenology of forest understory and main forest tree species.
2. Effect of climate change on snow melt and vegetation physiology, effect on surface and groundwater hydrology. (This has been done at Frasier EF, but could be expanded to other snow EFRs).
3. Impacts of local and regional topography on smoke behavior patterns.
4. Effect of climate change on organic matter decay (already proposed; we support).

22. Understanding the Controls on Clean Water Delivery from Headwater Forests—Synthesizing Long-Term Data from USFS Experimental Forests

Objectives—

Clean water for multiple uses is one of the primary ecosystem services provided by headwater forests. Of the total miles of streams, most are located in headwaters, the terrain in which the majority of NFS lands are found. Owing to their relatively pristine condition, headwaters are sensitive to forest change associated with insects, wildfire, forest harvest, atmospheric inputs, climatic extremes, and natural forest succession. Such changes increase stream nutrient concentrations and temperature and sediment and nutrient output. Because disturbances cascade through ecosystems and affect downstream users, standards have been established to protect water quality during forest management activities. Forest Service Research and Development is uniquely positioned to examine the water quality responses to resource management, natural disturbance and climate-related change using existing long-term data from EFRs. Researchers have studied stream hydrology and solute chemistry in manipulated and untreated watersheds at experimental forests across the country for decades. These sites exist across gradients of precipitation, atmospheric nitrogen deposition, nutrient limitation, and vegetation and soil types.

Application of R&D results—

This synthesis would:

- Increase understanding of water quality responses to forest disturbance across a range of environmental conditions throughout the nation. With increasing concerns about climate change, forest management and water quality, this type of synthesis is extremely timely.
- Increase visibility of experimental forests and Forest Service research scientists by providing information that is relevant to managers, agencies, other scientists, interested public, and downstream consumers.
- Provide findings that are useful in forest planning documents and water quality criteria.

The proposed synthesis would capitalize on substantial efforts made to date to compile long-term cross-site streamwater chemistry data and assess the compatibility of these data across sites of the EFR network. Three synthesis products proposed would address: (1) Are water quality trends over time at EFR sites across North America responding similarly over time and with changing climate? (2) What abiotic and biotic factors most influence the magnitude and duration of water quality responses to forest disturbances, both natural disturbances (hurricane, insect outbreak, fire) and forest harvest? (3) How do long-term EFR stream chemistry data from headwater basins compare to state and national guidelines for stream nutrient criteria?

23. Experimental Management of Riparian Wind Buffers to Provide for Both Riparian Habitat Functions and Commodity Production

Objectives—

- What are the extents and the stand characteristics of wind buffers needed to maintain riparian forest integrity?
- How should timber in the wind buffers be harvested without compromising the ecological functions of the riparian forests?
- How does empirical data on windthrow in managed stream buffers differ from the projections of existing windthrow models?

Application of R&D results—

Relevance to Washington State Department of Natural Resources (WADNR) management needs: About one-fifth of the Olympic Experimental State Forest (OESF) is within riparian wind buffers. These buffers can be actively managed to potentially contribute to commodity production and enhanced ecological functions. Currently, they are generally not considered for active management mainly because of uncertainty about the use of forest management to achieve conservation objectives.

Wind is a major natural disturbance force in coastal forests of the Pacific Northwest. Its effect is greatly influenced by topography, stand conditions, and proximity to the ocean. Similar experiments in other EFR network locations could make an interesting and useful cross-site comparison study to test the influence of these factors.

WADNR is currently developing a long-term status and trends monitoring for riparian areas in the OESF. Both aquatic and riparian habitat conditions would be monitored, including managed and unmanaged wind buffers.

WADNR is using a windthrow risk model, developed by the University of British Columbia, to plan management in the OESF and WADNR-managed lands in southwest Washington. The model is based on previous research conducted in British Columbia coastal forests. Comparison of OESF empirical data with windthrow models or data from other EFRs (especially those subject to coastal wind storms like Luquillo EF in Puerto Rico) might also be of interest.

24. Understanding Changes in Ecosystem Function at Continental Scales: Monitoring in the EFR Network with Permanent Vegetation Plots

Objectives—

How are the functions of different ecosystems changing in response to changes in climate, disturbance, and management? A network of permanent plots with consistent measurements is the most effective way to detect changes in vegetation establishment, growth, and mortality at regional and national scales. Establishing such a network on EFRs provides a sample of the important vegetation types across the nation and a way to link in-depth knowledge of EFRs to the more extensive national grid of Forest Inventory and Analysis (FIA) plots. The EFR network samples vegetation gradients ranging from tropical to boreal, coastal to continental, and lowland to montane. Having comparable measurements across these gradients would vastly improve the scope of inference beyond the ubiquitously-studied vegetation types (e.g., Douglas-fir and ponderosa pine forests in the West).

How do the controls on ecosystem function vary across local, regional, and national scales? Understanding of hydrologic and climatic variation and their controls on vegetation productivity is rudimentary, particularly in mountainous terrain. Synchronous measurements of abiotic controls (e.g., microclimate and soil moisture) and biotic processes (e.g., transpiration and nutrient cycling) across local topographic gradients and regional and national climatic gradients would greatly enhance this understanding. Tying these measurements to permanent plot measurements of ecosystem structure and function would improve our ability to parameterize models of ecosystem function and its response to changes in climate.

Application of R&D results—
Forest management is increasingly focused on the maintenance of ecosystem services, including clean water, carbon sequestration, and wildlife habitat. Managers are also seeking guidance on strategies to deal with future changes in climate. The combination of existing and past management and watershed studies in EFRs with a consistent network of coupled climate and vegetation process measurements on permanent plots would allow better models coupling climate and vegetation response to hydrology and anticipate habitat changes and responses to likely future climate scenarios.

This project would take advantage of the considerable infrastructure in the national FIA program in terms of protocols, field expertise, and database management. Funding to the FIA program in FY 2010 and 2011 has been used to establish intensified plot networks in an initial set of EFRs and synthesize existing information and studies in the EFR network. The FIA program has established programs of quality control and assurance and the use of consistent measurement devices (e.g., sampling design, plot design, and instruments) would be key to ensuring comparability of results to answer questions across multiple EFRs.

25. Understanding Ungulate Herbivory as a Chronic Disturbance Interacting with Episodic Disturbance.

Objectives—

1. To evaluate the effects of ungulate herbivory on a variety of response variables including understory development and composition, particularly the dynamics of palatable versus unpalatable shrubs and trees, invasive species, and fire risk; ungulate diet selection and diet nutrient quality as influenced by changes brought about by ungulate herbivory; effects on nutrient availability that influences forest productivity; impacts to other organisms (small mammals, neotropical migrants).
2. To evaluate ungulate herbivory under episodic disturbance such as fuels reduction, wild fire, timber harvest, insect or disease mortality in contrast to sites not disturbed.
3. To use the results to refine and parameterize conceptual models regarding ungulate effects on forest development.

The proposed research is of fundamental interest to managers of forest ecosystems who are charged with delivery of sustainable forest products, sustainable forage for livestock, and management of a suite of associated watershed, wildlife, and recreational resources on public forests. Benefits to managers include the development of models that provide science-based options for management of multiple use forests where ungulates are important agents of chronic disturbance that alter successional trajectories.

Application of R&D results—

Ungulate herbivory is ubiquitous across forest landscapes in the United States. Yet mention of herbivory in management documents is rare. Research from the Kane EF illustrates the magnitude of the issue of herbivory effects on forest composition and biodiversity. Important questions are:

1. How does ungulate herbivory affect alien plant invasions and the composition, life forms, species richness, cover, and structure of plant communities in forest understories?
2. Are there thresholds of ungulate herbivory
3. How is forest productivity affected by ungulate herbivory; both directly (nutrient redistribution) and indirectly through changing the composition of both understories and overstories?
4. How do the effects of ungulate herbivory influence the productivity of the ungulates themselves?

26. Evaluating Fuel, Vegetation, and Disturbance Dynamics Using the Irregular Uneven-Aged Silvicultural System Within Different Forest Structure Stages on the Black Hills EF

Objectives—

Experimental forests and ranges are places designated for long-term and manipulative research of forest and range vegetation (Adams and others 2004), thus they are well suited to evaluate a variety of silvicultural techniques. By using an experimental forest, both the short- and long-term silvicultural, managerial, and ecological effects of treatments can be studied, displayed, and preserved. Black Hills Experimental Forest (BHEF) is located 20 miles northwest of Rapid City, South Dakota, and is 3,500 acres in size, representing the ponderosa pine-cover type near the center of the Black Hills National Forest.

There are several issues concerning forest management in the Black Hills. A large portion of the forests are rated as having medium to high risk of mountain beetle infestation; and are currently experiencing a large-scale infestation. Due to the nature of the growth and development of Black Hills ponderosa pine forests; these areas tend to develop continuous canopy and abundant regeneration that were historically diversified through fire. Because of its high recreation value, much of the Black Hills has substantial amounts of wildland urban interface, requiring continuous fire suppression and limiting the applicability of prescribed fire as a dominant tool for creating diversity in crown and surface fuels. Maintaining wildlife habitat for a variety of species also is a major value placed on the Black Hills. Addressing these issues in an integrated fashion offers both challenges and complexity to forest management. The objective of this study is to develop, implement, and evaluate a variety of management activities designed to integrate these many issues at multiple spatial scales. One such technique that would be tested at BHEF is an approach developed by Graham and Jain (2005) which attempts to balance management objectives and stakeholder values within an ecological context, resulting in the development of the irregular (or free) selection silvicultural system.

Justification and application of R&D results—

The uneven-aged study has two objectives. The first is the development and application of the irregular or free selection silvicultural system in a very productive ponderosa pine forest within different forest structural stages currently in place on BHEF (Graham and Jain 2005). The second is to evaluate a variety of ecological effects of the forest conditions created by these silvicultural systems. For example, this study would document the impact the treatments associated with each silvicultural system have on creating and maintaining forest conditions that are resilient to insect, disease, and wildfire within a changing climate. In addition, because this silvicultural system is fully replicated using a scientific design, future research opportunities exists for wildlife, hydrology, or other research purposes.

27. Landscape-Scale Management Experiments to Test Effectiveness of Riparian Management Practices Based on Historical Range of Natural Variability

Objectives—

- What is the historical range of natural variability (HRV) in the experimental landscapes?
- What are the outcomes of riparian management based on HRV as projected by holistic landscape models?
- What is the effect of HRV-based riparian management on aquatic (instream) habitat as indicated by empirical data?
- What is the effect of HRV-based riparian management on watershed conditions as indicated by empirical data?
- How economically and operationally feasible is the HRV-based riparian management?

Application of R&D results—

Relevance to Washington State Department of Natural Resources (WADNR) management needs: Riparian management in the Olympic Experimental State Forest (OESF) targets habitat complexity as afforded by natural disturbances. There are several major uncertainties related to this management goal including the HRV, the economic and ecological feasibility of management prescriptions based on HRV, and the link between stand-level management prescriptions and landscape level-ecological objectives.

A symposium of scientists, policymakers and land managers examined the scientific basis for riparian forest policy and management in western Washington in 2008. There was consensus among scientists that the latest research has found that high productivity in aquatic and riparian ecosystems depends on maintaining temporally dynamic and spatially heterogeneous conditions. Existing riparian policies and management guidelines that drive these ecosystems toward static and uniform conditions may not be consistent with current science. Recognition of this potential science-policy gap prompted two recommendations: (1) conduct landscape-scale management experiments to test effectiveness of alternative management that is consistent with current science; and (2) analyze current riparian area policies and management guidelines to identify what areas and are not consistent with current science.

Landscape-level management experimentation requires extensive land base and it is difficult to provide adequate replication within a single experimental forest. Replicating the study across EFRs with similar biophysical conditions would greatly improve the inference power of the study.

WADNR contracted the Pacific Northwest Research Station (PNW) to develop scientific synthesis on riparian management. WADNR and PNW are developing a bibliography of information sources on natural disturbance regimes on the western Olympic Peninsula.

28. Testing Different Silvicultural Techniques for Creating and Maintaining Structurally Complex Forests

Objectives—

- What is the effect of different silvicultural prescriptions for creating structurally complex forest? Key hypotheses would be whether we observe accelerated development of old-forest habitat components as a result of lower residual densities, variable residual densities, larger openings, and/or earlier treatment.
- How do empirical data on stand development after thinning differ from the projections of tree growth models like Forest Vegetation Simulator (FVS) and ORGANON?
- How effective are different remote sensing techniques (e.g., LiDAR) in monitoring tree and stand response to thinning across a forest landscape?
- What is the operational and economic feasibility of different silvicultural treatments?

Application of R&D results—

Relevance to Washington State Department of Natural Resources (WADNR) management needs: Considerable part of the forested stands in the Olympic Experimental State Forest (OESF) is in competitive exclusion developmental stage, which provides both low product value and low habitat quality. WADNR is looking for effective silvicultural strategies that restore and maintain older forest conditions while allowing for commodity production. The effectiveness of stand-density management to accelerate the development of structural diversity, understory regeneration, recruitment of snags and coarse woody debris, and large tree development needs to be tested in operational setting.

Many land managers in the Pacific Northwest face the same problem, including the Forest Service, tribes, and environmental organizations managing land for restoration. Replicating the research installations across the EFR network would provide site-specific information relevant to the needs of local land managers.

The use of active management to develop northern spotted owl habitat in moist forests is one of the recommended recovery actions in the recently released Recovery Plan for Northern Spotted Owl. Land managers are advised to "implement silvicultural techniques in plantations, overstocked stands and modified younger stands to accelerate the development of structural complexity and biological diversity that would benefit spotted owl recovery."

Scoping and initial conversations between WADNR and the Pacific Northwest Research Station have taken place for development of a study plan.

29. Accumulation of Heavy Metals in Watershed Soils and Their Subsequent Removal During Postfire Erosion Events Leading to Contamination of Drainage Sediments

Objectives—

The accumulation of heavy metals in watershed soils represents a significant environmental hazard as they are not subjected to biodegradation processes and they bind tightly to clay particles and organic matter in the soil matrix. It is thought that years of fire suppression have allowed further build-up of these metals, especially in areas where forest floor depth has increased. Because they are tightly bound, heavy metals such as mercury, cadmium, lead, and chromium tend to remain in the top 0 to 5 cm of the soil surface or in the humus fraction of organic matter. Following wildfire, soil stability is reduced, making it prone to both dry and water erosion. The topsoil and heavy metals are then transported during subsequent erosion events to a perennial stream or deposited in a dry channel. Sediments entrained in dry drainages are released during the first large storm events following fire. Scientists suspect these sediments exhibit elevated concentrations of mercury, cadmium, lead, and chromium.

Concentrations of heavy metals would vary widely across the forests and rangelands of the United States. Studies have shown that carbon-rich forest soils of the northern United States contain up to 16 times as much mercury as do soils in southern forests. Anthropogenic mercury has accumulated in forests since the industrial revolution (e.g., coal burning power plants). Soils found in areas bordering large metropolitan areas are high in lead. Cadmium is prevalent everywhere as a byproduct of mining and smelting of lead and zinc, electroplating, insecticides, fungicides, and commercial fertilizers. Chromium is present in ultramafic and serpentinite derived soils. Natural processes can oxidize and dissolve chromium contained in sediment leading to hazardous levels of aqueous Cr(VI) in surface waters.

Many regions experience a rise in temperature and also drought due to climate change, both factors resulting in lower fuel moistures which would lead to more wildfires. Impacts would not be similar among regions, but extreme events may become the norm including precipitation and/or flooding. This would only exacerbate postfire erosion and transport of sediments laden with heavy metals.

Application of R&D results—

There has been little research dealing with postfire sediment transport of heavy metals and their subsequent fate. Similarly, sediment accumulation of heavy metals has not been adequately evaluated. A primary objective would be to measure pre- and postfire mercury, cadmium, lead, and chromium concentrations in hillslope soils and drainage sediments at a selected portion of the 80 EFRs located throughout the United States. Using these EFRs, we would hope to find a wide variety of soil, fire, and ecological conditions. Additionally, it would be preferred that the EFRs have experienced fire and are large enough to contain watersheds with established drainages (perennial, intermittent, or ephemeral).

Part 2B—Ideas from National Forest System Personnel for Potential Future Cross-EFR Research and Monitoring (table 8)

30. Develop Guidelines for Eastern Shortleaf Pine Natural and Artificial Regeneration in the Southern Appalachians

Objectives—

Determine appropriate seedling container size, seedling cooler storage time, seedling planting depth, site prep burn, prescribed burn intervals (2 to 3 years), prescribed burn season (growing vs. dormant) and subsequent growth and yield models as the stands mature.

Justification and application of R&D results—

Background: According to recent FIA data (presented at the Shortleaf Pine Conference, September 2011), over 50 percent of shortleaf pine acreage across the nature range has been lost. Losses are due mainly to replanting with loblolly pine on harvested shortleaf sites. Shortleaf pine is more resilient, disease- and pest-resistant, and longer lived than loblolly pine, therefore a more desirable species to plant. National Forest System forest plans are requiring increased shortleaf pine restoration on shortleaf pine sites. Shortleaf pine produces a cone crop only about once every 5 to 7 years, so natural regeneration is infrequent.

Currently the Arkansas and Missouri western shortleaf pine ecosystems are being successfully maintained. Both artificial and natural regeneration techniques are used, along with appropriate prescribed burning. Research has been a key player in the learning curve and subsequent successes. The Southern Appalachians (SAs) present a distinctly different environment, and consequently different challenges. For example: soil type, climate, overstory and understory components, slope, aspect, burn season, and piedmont vs. mountain shortleaf pine planting zones all differ across the length of the SAs, and differ from the western shortleaf pine environments.

Research focused on successful natural and artificial regeneration techniques for eastern shortleaf pine would support restoration as mandated by our forest plans. There is a focus group being formed to address shortleaf pine restoration in the SAs, and research partners would be valuable assets to this growing initiative.

31. Animal Damage Control (ADC) on the Chippewa National Forest

Objectives—

Determine effective ways to minimize browsing of seedlings by deer and hares.

- What (if any) harvest methods and site preparation methods are most conducive to preventing browse by deer and hares during stand establishment?
- What methods of animal damage control (e.g., Plantskydd ™ repellent, budcaps, hot peppers, feeding seedlings garlic via irrigation at the nursery, or other new and un-discovered ideas) are most effective?
- In what stand conditions (e.g., canopy closure, ECS/phase/soil type, species of overstory, etc.) is ADC most effective?

Justification and application of R&D results—

Browsing by deer and hares is having substantial negative impacts on our ability to regenerate stands within 5 years of harvest and meet National Forest Management Act requirements. Browsing kills seedlings, so we need to replant stands (and resite prep in some cases) multiple times, thus the cost of reforestation increases every time we need to retreat stands. Plantskydd and budcaps have been used in the last 10+ years, but are not reliable or effective.

This research would help us gain a better understanding of site conditions, harvest and other cultural treatments, and ADC options to promote a more effective, efficient, fiscally responsible reforestation program.

Browsing is a problem that federal, state, county, and private forest managers have been dealing with for years. Research results would be shared with these local land managers.

32. Ecological Site Development for the Caddo National Grasslands, North-Central Texas

Objectives—

Develop ecological site descriptions for lands at the Caddo National Grasslands in north-central Texas, and for lands nearby that are to be newly acquired by the Forest Service.

Justification and application of R&D results—
The Caddo National Grasslands reside in two major land resource areas (MLRAs) that are small and at the margins of other Texas MLRAs. As such, it has not received attention for ecological site development by the Natural Resources Conservation Service as have other areas. Ecological sites need to be developed to help better plan and communicate management of the land.

Making matters more critical, a new large land acquisition (about 15,000 acres) is about to be made by the Forest Service at the Caddo National Grasslands in soils and topography that are new to us. It is crucial that ecological site descriptions be developed here by the network of experimental forests and ranges so that long-term plans (that are just now being created) would be in the proper frame of reference of the historical and current ecology of the land.

Without ecological site descriptions to guide planning and policymaking for this new land, the Forest Service risks implementing improper land management strategies there—or even pursuing improper desired future conditions. The unfortunate consequences of this would be plant communities and conditions that are cost-prohibitive and infeasible for the Forest Service to correct later.

As a bonus to Forest Service researchers, this effort presents an opportunity for them to enter into the arena of ecological site development, an emerging field with potential long-lasting effects on Forest Service policy.

33. Spruce Reforestation Techniques

Objectives—
Evaluate the best methods for spruce reforestation. Comparable plots would be established using different techniques, including; (1) with and without shelters; (2) microsite planting only; (3) planting with biochar; 4) fall planting versus spring planting. Additional plots would include planting lower elevation spruce along a gradient into higher altitudes to evaluate success in relation to climate change.

Justification and application of R&D results—
This issue is important because the Southwest is experiencing a massive dieoff in spruce resulting from spruce beetle infestations and large high-intensity fires. As the climate changes, foresters are not sure if the old elevation bands are still applicable. The Forest Service has begun pilot projects to grow trees for carbon sequestration. As part of these pilot projects, we need to be able to guarantee that the trees would grow. The more information obtained on establishing successful plantations, the better.

Any techniques that improve survival would be used in future plantings. The results would apply to most spruce reforestation projects, with the caveat that results may be different in different soils or elevations.

Note: Initiatives included in the business plan would be those that require two or more EFRs to cooperate in gathering and analyzing data, in particular to identify the types of questions that can take advantage of a distribution of field sites either regionally or even at a continental scale. This is part of an effort to recognize the potential opportunities that could be realized by making more extensive and strategic use of these R&D assets.

34. Developing Guidelines for Assisted Migration of Populations Within Major Tree Species in the Eastern United States

Objectives—

Determine if it is appropriate to move populations within species in response to, or in anticipation of, changes in climate. If migration is appropriate, develop some guidelines that can be used to determine the most appropriate places to get tree seed in a changing climate.

After guidelines are developed, convert tests to "genetic outposts" that can provides sources of seed for artificial regeneration or introduce pollen adapted to future climate into existing forests.

Justification and Application of R&D results—

The climatic tolerances of populations within tree species tend to be considerably narrower than the climatic tolerances of the species as a whole. In less than 100 years, the shifts in climate would be larger than the differences in climate over the distances we recommend moving tree seed today. Natural migration and evolution are not expected to change local populations of tree species fast enough to compensate for changes in climate. Assisted migration of species is a controversial topic, but assisting the migration of populations within species is likely to be necessary first.

Very little research has been done in the eastern United States, and especially northeastern United States, on how far it is appropriate to move seed of even the most important tree species. This information would be essential for making scientifically defensible movements of populations across the landscape.

A series of test plantations could be established to address this need. The plantations should be established in differing climates and include seed collected in populations that differed in climate. Climate is expected to change continuously for centuries to come. It would not be helpful to establish these tests if all they do is tell us what the best source of seed for a particular site would have been for the last 20 or 30 years. The tests should be designed so they provide generalized guidelines that can be used to predict the best sources of seed for the climate that is predicted for a particular site at some point in the future.

At the end of this test, the plantations could be thinned to provide seed for future operational reforestation or to introduce pollen into the local populations that would make their offspring better suited for future climates. Brad St. Clair of the Pacific Northwest Research Station refers to these as "genetic outposts."

35. Impacts of Herbicide Use on Forest Land to Control Vegetation

Objectives—

How effective are herbicides at controlling vegetation in comparison to mechanical treatments? What are the cost comparisons to mechanical treatments? What are the effects of herbicide use on wildlife and water resources?

Justification and application of R&D results—

Herbicide use is very controversial; some national forests currently are not allowed to use herbicides as a tool to control competing vegetation on reforestation areas. National forests are spending many tens of thousands of dollars annually on mechanical treatments to control vegetation, and are not very successful because of regrowth. If herbicide use were found to be a safe and cost-effective tool to manage vegetation, it could save money, and forest managers would be more successful at meeting vegetation management goals.

Empirical data is needed to demonstrate whether herbicides would be a useful, cost effective, and environmentally safe tool to use in meeting vegetation management goals. Decisions about the use of herbicides are currently influenced strongly by the desire to avoid public conflict.

The application of this research could have impacts on all forms of vegetation management, from rangeland to aquatic habitats to forested land. It could be used to assist reforestation activities, to control nonnative species, and in habitat restoration projects. This could affect all national forests and grasslands.

36. Region 1 and RMRS Draft Adaptive Management Research Framework (AMRF)

Objectives—

Restoration of forest resiliency in the face of an uncertain climatic future would require an adaptive management approach to restoration treatments at various spatial and temporal scales. There are many unknowns as to the long-term results a change in climate may have on disturbance processes, soil moisture deficits, and tree species distribution and regeneration abilities. A resilient forest ecosystem contains the diversity of composition, size, density, and pattern to enable it to cope with disturbance, and to perpetuate itself through periodic regeneration. It is capable of providing various ecosystem services such as wildlife habitat for a variety of species; clean water; recreation; and carbon sequestration, etc., in both the short and long term.

Anticipated climate change exposure and vulnerability of forests and related ecosystem services including wildlife habitat in the northern Rocky Mountains would require assessments and monitoring to evaluate the vulnerability and adaptation of forests to changes in regional climate and the likely increase of various disturbances and ecosystem processes. The combination of these processes including relative changes in temperature and the magnitude and timing of precipitation would likely affect the distribution of species and forest structure across the northern Rocky Mountains. Uncertainty in the direction and magnitude of these changes, and the diversity of water availability across landscape micro sites, requires us to develop a management/research strategy based on an adaptive management research framework. Research could use a multi-scale approach across biophysical settings to quantify changes such as in site water balance deficits, the ability of tree species to adapt to possible increases in disturbance events, and other processes that influence the regeneration, growth, and development of forests.

Results from such studies would be used to develop, test, and evaluate current and alternative management strategies that would favor the appropriate density, structure and distribution of tree species, given social expectations of various ecosystem services. This adaptive management research framework would lead to the development and use of silviculture prescriptions that NFS silviculturists can implement to provide the forest pathways best suited for the forest species that can cope, adapt, and be resilient through the various climate change events to better insure the availability of ecosystem services that society expects from the national forests.

Justification and application of R&D results—
This framework would identify basic and adaptive management monitoring research needs and opportunities that can use ongoing management treatments of various types to function as a field monitoring and research lab. About 20,000 acres of harvest treatments in various forest compositions, 15,000 acres of precommercial thinning, and 20,000 to 40,000 acres of prescribed burning are completed on an annual basis to help restore composition and structure of the forests to create more resilient forest conditions. These annual treatment areas could be selected from for target monitoring and research opportunities as a systematic approach to adaptive management and restoration of resilient forest conditions.

37. Groundwater Survey

Objectives—

The Forest Service has prepared draft national direction for the management of groundwater resources associated with NFS lands. Groundwater is a critical resource on NFS lands, supporting other important resources such as threatened and endangered species and most perennial stream systems. The Forest Service needs to position itself to respond in an informed manner to the increased pressure to access this resource. This draft directive was developed over a nearly 10-year period with the involvement of specialists in all levels of the organization. It received a comprehensive review by regional foresters and Washington Office directors across all three deputy areas in 2005–2006, which resulted in substantial improvements to the original draft document.

Water availability and quality are a concern across the country for ecosystem viability and for human use. NFS lands provide sources of drinking water for about 66 million people. To appropriately manage the watersheds on NFS lands, the Forest Service needs to account for and address all of the water resources on those lands as a single hydrologic system. The Forest Service manages the headwaters and recharge areas of locally and regionally important rivers and aquifers. In most places, streamflow and associated ecosystems are sustained during dry periods by the discharge of groundwater. There is a clear need for the Forest Service, in cooperation with the states, to take an active role in the management of all water resources on NFS lands.

In addition, effective ecosystem management of NFS lands requires taking a comprehensive view of watersheds and water resources on those lands. Cooperative groundwater resource management by the Forest Service and state agencies would benefit the American public with more dependable, higher quality water supplies for human uses as well as protection of aquatic and riparian ecosystems.

Justification and application of R&D results—

The proposed directive would allow the Forest Service to address critical water resources on NFS lands more effectively and comprehensively. By providing for identification and characterization of groundwater and groundwater-dependent resources and existing uses, the proposed directive would allow the Forest Service to monitor and protect those resources and to account for those uses during planning and approval.

Appendix 3: Extracting Value From Experimental Forest and Range Information Assets

This appendix suggests how we can optimize the value of our vast collection of historical records and data that currently exist in paper form, and some other forms of records, that are at risk of loss. Addressing the archiving of this large volume of records that has accumulated as scientists retire or move on to other work is daunting. These records are found in file cabinets and boxes at virtually all of our EFRs or research labs where Forest Service scientists have worked for more than 100 years. We offer a straightforward, albeit laborious, approach to cataloging and extracting the value from these assets and provide a discussion of how investing in EFR data management yields benefits to the rest of Forest Service Research and Development.

Research data—historical: Unlocking the value in the file cabinets is a five-step process.

1. Catalog holdings; includes assembly of basic metadata (data creators, field and lab methods, site descriptions, etc.)
2. Prioritize catalog entries conversion to digital format
3. Convert from paper to digital; includes organizing data into consistent file structures
4. Develop complete metadata compliant with an appropriate standard and EFR/data archive best practices; create supplementary content for understanding the data set
5. Package components and disseminate on the Web via R&D data archive

The "catalog and convert" process was chosen in FY2010 after an eResearch project learned that few EFR scientists had good knowledge of what was in their file cabinets. However, the approach is not unique to Forest Service R&D. For example, the U.S. Fish and Wildlife Service (FWS) recently decided to use this approach to move its historical refuge data into digital format—create catalogs and then prioritize the cataloged data by relevance to refuge management issues. FWS started with two refuges as pilot sites in 2012.

Prioritizing data sets is an important step that can be accomplished using four criteria:

- Scientific importance of the data set—currently or historically important research articles
- Risk of loss (content fragility, impending loss of knowledge owing to staff retirements, etc.)
- Importance to the EFR network projects
- Importance to the public—this can be viewed as an EFR technology transfer activity.

The first two criteria can be managed by each site. For the third criterion, a network-level prioritizing structure to work across sites and within sites would be required. For the fourth criterion, we would post basic metadata documents (generated by the cataloguing activity) on the network website. The website would solicit input from the public (this includes other government agencies, academics, and others interested in our data) about which catalogued data sets they want to have made available. For conversion activities relying on FS R&D allocated resources, it would be important to develop an agreement on how to allocate available resources to the data sets identified by the different prioritization criteria. We can also partner with scientists, nonprofits, or others—they identify data sets of interest based on the Web catalog entry, obtain a copy of the paper data from the relevant EFR, convert the paper data set and provide R&D with a copy in an agreed-upon digital format.

Step 5 implies a number of additional steps by the R&D data archive. After depositing the data product in the public repository, the archive markets dataset availability; manages access as either restricted or unrestricted; tracks scientific use via citations; may package for educational use; and curates the data product over time to maintain value and accessibility. Collectively, these steps facilitate re-use of the data by both the site and the external research community. Both types of re-use contribute to the added value of the research data product. For datasets that are not curated by the archive, a metadata document describing the product is added to the data catalog, which includes information on where to find the actual data.

Research data—modern: Modern data don't require the conversion from paper that historical data do. However, to avoid having the accessibility of modern data degrade over time to the same level as today's historical data, improved data management is necessary. This need increases as a study becomes more complex (time duration, number of researchers, etc.). At a minimum, this involves steps 4 and 5 listed for historical research data. Augmenting the data management plan with direction on how data will be managed during the project (not just after project completion) can forestall many problems. As more projects develop full data management plans, the network can develop and share best practices using its internal website.

Administrative data: Because a significant fraction of administrative data is in the form of paper, the process for extracting its value is as described above—catalog, convert to digital, document, organize, and share with interested parties. Devising and implementing an administrative data system can, as is the case now, be left to each EFR. An improvement would be to develop capabilities addressing common needs across the network; for example, an EFR geographical information system application that allowed each site to track and identify its own current and past studies. A further improvement would be a common network application, accessible to any member of the network, holding information on studies conducted on all EFRs. One can see how this latter capability would be useful for planning multisite research projects by Forest Service or external scientists.

Value can also be found by taking advantage of the new EFR SharePoint site (i.e., internal website) to share information across sites. Taking a step beyond that, asking administrative staff to collaboratively standardize practices and automating those processes, offers an effective way to improve the value of administrative data and broadly improve site administration.

Web presence: EFR staffs have lots of good ideas about ways to enhance their public Web presence. What they lack is time and expertise to implement for their individual site, much less across the network. Strategically, then, the network needs help creating content and deploying new Web technology. Tactically, the network needs two governance mechanisms. One is to approve posting of new or heavily revised content and a second one to decide on allocation of resources to various ideas for enhancing websites. It is also useful to link discoveries across locations—providing a more synthetic view of EFR accomplishments.

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