Chapter 24
Networked Science Among Experimental Forests and Ranges: Past Experience and a Vision for the Future

Douglas F. Ryan and Frederick J. Swanson

Abstract Over its long history, the collection of now more than 80 Forest Service Experimental Forests and Ranges (EFRs) has produced studies involving several EFRs and also participated in other monitoring and research networks. This legacy of networked science involving EFRs has included participation in environmental monitoring networks, cross-site experiments and syntheses, and multiagency research communities, such as National Science Foundation’s Long-Term Ecological Research (LTER) Network. Participation in these networks has produced significant benefits, but has been limited to a small number of EFR sites and Forest Service scientists. A culture of idea and data sharing is a necessary, but not sufficient, ingredient for fostering a highly-functional, well-integrated EFR Network. Additional requirements include sustained leadership and technical, financial, and administrative support for network scientific activities. Some of the EFRs have high quality records of climate, hydrology, vegetation, and biogeochemistry spanning many decades, providing a rare opportunity to examine effects of environmental change on vital ecological services. Several pioneering syntheses on topics such as climate, streamflow, and streamwater chemistry have come from EFR and allied environmental research networks, and demonstrate the potential contributions of these networks for fruitful scientific work of importance to society.

Keywords Research network · Environmental monitoring network · Research syntheses · Cross-site experiments · Data sharing

24.1 Introduction

For most of their century-long history, Forest Service Experimental Forests and Ranges (EFRs) were selected and operated as stand-alone units to represent a broad array of forest and grassland types and conditions. In the first half century of EFRs,
their scientists interacted primarily through informal or scientist-to-scientist ties. More formal linkages among sites developed after 1960. Some EFRs joined environmental monitoring networks; a number of cross-site experiments and science syntheses were conducted; and some sites participated in multiagency groups, such as the National Science Foundation’s (NSF) Long-Term Ecological Research (LTER) Network, founded in 1980, with substantial Forest Service engagement in 6 of the 26 LTER programs. The recognized value of long-term studies and records of observations at EFRs, the emergence of broad-scale science questions related to environmental change, the inception of new research and monitoring networks, and the success of the LTER Network have prompted Forest Service leadership to promote the transition of EFRs from a collection of individual sites to a functional research network. This chapter focuses on the most recent era within EFRs’ long history (see chapter by Shapiro in this volume) in which the Forest Service joined other agencies to push formation of continent-spanning research and monitoring networks (Coleman 2010). In many cases, these new networks have capitalized on the much longer history of EFR work and the EFR system has benefited from the expanded research scope and the new scientific talent that came from participating in networks.

We have examined the experience of EFRs in the constellation of environmental monitoring and science networks that they have participated in over the past several decades, in cross-site science syntheses, and in developing a data-sharing system to find what lessons may be useful for further forming EFRs into a research network. We also examined agency efforts to foster scientific interactions among scientists at multiple sites that would be needed to design and implement science experiments and analyses across EFRs. Finally, drawing on lessons learned from EFRs’ experience doing networked science, we discuss what future directions would move EFRs toward achieving the goal of forming an integrated research network that can contribute to addressing large-scale environmental issues.

24.2 Efforts to Integrate Science Among EFRs

The concept of EFRs as a research network received major impetus in the Forest Service in 2004 when the deputy chief for research and development (R&D) proclaimed the formation of an EFR Network as a national goal for R&D. Several national-level efforts toward that goal followed, including publication of a national summary of EFR sites (Adams et al. 2008), establishment of a national EFR Web site (http://www.fs.fed.us/research/efr/) and business plan, formation of a national-level committee on EFR research, and formulation of an information management plan for EFRs. Important first steps have also been taken toward building a community among EFR scientists, including holding two national meetings for EFR lead scientists, and more frequent monthly meeting of an EFR Working Group with scientist-representatives from each research station to discuss issues that affect large segments of the EFR research community. Other activities, primarily led by
site scientists taking the initiative to work together, have also built a variety of scientific linkages among EFRs (Adams et al. 2010). Many of these bottom-up initiatives predate the current national-level networking activities and have cross-site connections that could make important contributions toward the goal of a functional research network. We review what has been accomplished by existing networking approaches among EFRs to develop a vision of how to make EFRs into a more functional research network that both capitalizes on already existing connections and adds or strengthens needed network components that are currently either weak or do not yet exist.

24.2.1 Why a Network?

The purpose of forming EFRs into a more functional research network is to enhance their collective scientific capacity to address pressing, regional- to continental-scale environmental issues, such as predicting environmental effects on forests and grasslands of widespread influences, such as global climate change, altered atmospheric chemistry, and growth at the urban–wildland interface. Through better coordination and less duplication of efforts, a network could also make better use of the long-term investment in scientific research that the Forest Service has made at these sites. An information-sharing infrastructure to facilitate access to and synthesis of cross-site data is a necessary foundation for a research network.

24.3 Network Approaches and the Ties They Produce Among EFRs

Applying the term “network” to EFRs is complicated, because over time “networks” and activities to form them 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 other EFRs, at universities, and in other agencies, and with land managers and policymakers (Swanson et al. 2010). EFR programs and scientists have participated in other networks; some of them interagency, such as the LTER Network and the National Atmospheric Deposition Program (NADP), and some international, such as UNESCO’s Man and the Biosphere (MAB) Programme (see Table 24.1). 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. We broadly categorized networks in which EFRs have participated to illustrate the kinds of relationships each has created among its members, including participating EFRs.
Table 24.1 A selective list of EFR sites that engage in cross-site activities and some networks in which they participate

<table>
<thead>
<tr>
<th>EFRs</th>
<th>Networks</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LTER(^a)</td>
</tr>
<tr>
<td>H.J. Andrews</td>
<td>x</td>
</tr>
<tr>
<td>Hubbard Brook</td>
<td>x</td>
</tr>
<tr>
<td>Coweeta</td>
<td>x</td>
</tr>
<tr>
<td>Bonanza Creek</td>
<td>x</td>
</tr>
<tr>
<td>Luquillo</td>
<td>x</td>
</tr>
<tr>
<td>Baltimore</td>
<td>x</td>
</tr>
<tr>
<td>Marcell</td>
<td>x</td>
</tr>
<tr>
<td>Fernow</td>
<td>x</td>
</tr>
<tr>
<td>Fraser</td>
<td>x</td>
</tr>
<tr>
<td>San Dimas</td>
<td>x</td>
</tr>
<tr>
<td>Tenderfoot</td>
<td>x</td>
</tr>
<tr>
<td>Santee</td>
<td>x</td>
</tr>
<tr>
<td>Wind River</td>
<td>x</td>
</tr>
<tr>
<td>Olympic Experimental</td>
<td>x</td>
</tr>
<tr>
<td>State Forest</td>
<td>x</td>
</tr>
<tr>
<td>Caspar Creek</td>
<td>x</td>
</tr>
<tr>
<td>Hawai‘i</td>
<td>x</td>
</tr>
<tr>
<td>GLEES</td>
<td>x</td>
</tr>
<tr>
<td>Bartlett</td>
<td>x</td>
</tr>
</tbody>
</table>

\(\text{LTER NFS Long-Term Ecological Research Network, }\text{MAB UNESCO Man and the Biosphere Programme, }\text{NEON NSF National Ecological Observatory Network, }\text{NADP National Atmospheric Deposition Program, }\text{LIDET Long-term Inter-site Decomposition Experiment Team, }\text{Clim/HydroDB Cross-site meteorological and hydrological data-sharing web portal, }\text{LINX Lotic Intersite Nitrogen eXperiment (http://www.faculty.biol.vt.edu/webster/linx/), Stream Chemistry Syntheses}\
\text{science syntheses of long-term stream chemistry monitoring at EFRs, }\text{LTSP Long-Term Soil Productivity study (http://forest.moscowfsl.wsu.edu/smp/ltsp/index.html), Ameriflux network of long-term atmospheric flux monitoring sites}\
\(\text{a Integrated Research Network}\
\(\text{b Network in name}\
\(\text{c Environmental monitoring network}\
\(\text{d Cross-site experimentation network}\
\(\text{e Cross-site data sharing}\
\(\text{f Cross-site science syntheses}\

24.3.1 Networks-in-Name

Networks-in-name provide recognition, but little or no significant network functionality for their members. For example, nine EFRs have been named as sites in the MAB Programme’s World Network of Biosphere Reserves (http://www.unesco.org/new/en/natural-sciences/environment/ecological-sciences/man-and-biosphere-programme/), 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, and has produced occasional scientist-to-scientist contacts. However, MAB’s programmatic and funding support for scientific exchange among its member sites, including participating EFRs, has been very limited.

24.3.2 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 usually follow standard protocols, and data management, analysis, interpretation, dissemination, and publication are usually done by organizations that produce relatively little interaction among the participating sites, including EFRs. Monitoring networks with EFR members address physical parameters, such as the US Geological Survey (USGS) stream gauging system (National Water Information System, NWIS) and NADP, an interagency network measuring wet and dry atmospheric deposition, as well as biological components of ecosystems, such as the National Audubon Society’s Christmas Bird Count and the USA National Phenology Network. In some cases, participation requires dedicated effort on the part of Forest Service personnel (e.g., to maintain and operate an NADP collection site), or little effort, when data are collected by partners (e.g., bird counts or phenology observations). These networks provide data that have been used in inter-EFR studies, but participation in most has not led to cross-site interactions among EFRs. A potential exception may be the NSF’s National Ecological Observatories Network (NEON). Three EFRs have been selected as candidate “core sites” for intensive environmental monitoring that will be highly coordinated. Additional observational sites that may potentially include other EFRs are planned along selected environmental and/or land-use gradients, or as part of multisite, manipulative experiments. The number and strength of linkages that NEON will actually create among EFRs, however, will depend on details of implementation that have not yet been decided (see http://neoninc.org/).
24.3.3 **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, although 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. In the Pacific Northwest, for example, university and Forest Service scientists initiated a three-site experiment examining root decomposition along the environmental gradient from moist-marine to dry-continental climate represented by the Cascade Head—H.J. Andrews—Pringle Falls EFs and a forest canopy gap manipulation experiment replicated at the Wind River and Andrews EFs. Other experiments have had wider participation, such as the extensive Long-Term Inter-site Decomposition Experiment Team (LIDET) study of fine litter decomposition, which spans 28 sites, including 5 EFRs, extending from the North Slope of Alaska to the Caribbean and Central America (see [http://andrewsforest.oregonstate.edu/research/intersite/lidet.htm](http://andrewsforest.oregonstate.edu/research/intersite/lidet.htm)). Such cross-site experiments have engaged scientists in experimental design, data collection, analysis protocols, and interpretation and dissemination of results. Study outcomes can provide important insights into how ecological processes vary over environmental gradients at large geographic scales. However, most have focused on one-time experiments, and made relatively little provision for carryover of data or relationships to future cross-site experiments.

24.3.4 **Integrated, Long-Term Research Networks**

Integrated, long-term research networks 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 science capacity among sites makes it possible to address network-scale questions spanning the extent of the network. Both LTER and EFRs are attempting to reach a high level of research network functionality, even though both were initially set up as a collection of sites rather than as a functioning network. 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.

Interactions among EFRs have been fostered in some cases by their participation in research networks that have originated outside of the Forest Service. Participation of three EFRs in the NSF’s International Biosphere Program (IBP) in the 1970s produced only modest cross-site activity because IBP’s emphasis was primarily on individual sites. Membership of six EFR sites in IBP’s successor, the LTER Network,
which began in 1980, has linked LTER member EFRs to one another as well as to the non-EFR sites within LTER. Beginning in the 1990s, NSF pushed LTER sites to function as a research network. LTER Network activities expanded to include several network-wide synthesis efforts, the beginnings of a network-wide information management system, and development of an LTER Network Office tasked with supporting network activities. The Forest Service EFR sites within LTER have shared leading roles in many LTER networking activities. At H.J. Andrews EF, for example, the Forest Service and its academic partner Oregon State University were especially active in building a dynamic capability to share climate and hydrological information across the LTER Network. Forest Service involvement in the LTER Network has linked the six EFRs that are formal members of LTER, and has in various ways also linked other non-LTER EFRs. The Forest Service–LTER partnership provides several examples of how participation of multiple institutions in a research network can provide mutual benefits.

24.4 EFR Network Accomplishments: Science Syntheses and Information-Sharing Infrastructure

Focusing on areas in which the EFR Network has produced significant accomplishments, we examine examples of cross-site science syntheses and EFR Network information-sharing infrastructure. Both of these activities have been the focus of considerable effort and are related because a primary purpose of information sharing has been to facilitate synthesis work. Although neither of these activities has reached the full potential that we envision could be achieved by an integrated EFR Network, they do illustrate some of the benefits that could be gained by more fully integrating EFRs into a network. Lessons learned in pursuing these activities indicate networking approaches that have worked as well as some remaining obstacles that will need to be overcome to reach the goal of an integrated network.

24.4.1 Cross-Site Science Syntheses

Science syntheses have knitted together existing evidence from multiple EFRs in thought experiments that are analogous, in some ways, to cross-site experiments based on new treatments and observations. Science syntheses draw together the weight of evidence from past studies or directly from analyses of long-term data to seek answers to new science, land management, or policy-related questions. Syntheses among EFRs have a long history (e.g., Lull and Sopper 1966), and some have provided the science basis for major land management and policy decisions (Lugo et al. 2006). For example, the Northwest Forest Plan (USDA/USDI 1994), which set management guidelines for 9.8 million ha (24 million acres) of Federal land in the Pacific Northwest, drew upon syntheses of findings from several EFRs.
Earlier syntheses were usually one-time efforts that did not facilitate follow-up studies. Multisite syntheses were also often meta-analyses of published studies with the drawback that analytical methods and assumptions often varied among studies. Initial attempts to apply common analytical approaches across all sites and data sets required onerous commitments of time and effort to find, assemble, and interpret data that were often managed differently at each EFR. Overcoming these practical issues was a formidable obstacle to analytically rigorous multi-EFR syntheses. However, the demand for science syntheses has increased as the scope and scale of environmental issues have expanded. As a result, more recent synthesis efforts have become better coordinated and have increasingly been supported by information management infrastructure designed to make data more readily available to answer new synthetic questions using the same analytical frame for all participating sites.

For example, a recent synthesis of carbon dynamics under the USDA Global Climate Change Program (Birdsey 2009) combines ground-based measurements of carbon stocks, forest growth, and climate from several EFRs and high-resolution measurements of carbon exchange between terrestrial ecosystems and the atmosphere at AmeriFlux sites (http://public.ornl.gov/ameriflux/) with wide-area land-use information from remote sensing and forest inventory data. Participating investigators at the Bartlett EF in New Hampshire, Marcell EF in Minnesota, Fraser EF in Colorado, and Glacial Lakes Ecosystem Experiments Site (GLEES) in Wyoming are contributing to this effort linking large-scale monitoring to local-scale land management decisions. This project combines environmental monitoring (AmeriFlux and Forest Inventory and Analysis data) with cross-site experimentation (vegetation plots and experimental methods) and synthesizes across sites using models. Information gathered was assembled into a database that will facilitate future syntheses.

Two capabilities will need to be added for EFRs to function as an integrated research network: the ability to seamlessly link long-term research data with associated explanatory documentation (metadata) and the formation of a strong social network among scientists from across EFR sites to facilitate network science. In the following sections, we discuss what progress has been made and what lessons have been learned by recent efforts to create data-sharing infrastructure among EFRs and what work has been done and what remains to be accomplished in developing a viable cross-site scientific community.

## 24.4.2 Cross-Site Data-Sharing Infrastructure

The LTER Network began data sharing among EFRs in the 1990s, when it asked all participating LTER sites, including the EFR members, to make their long-term site meteorological data available on the Web. A cross-site synthesis of these data from all LTER sites was undertaken to examine trends for the period 1980–1990 (Greenland et al. 1997). That initial synthesis encountered several obstacles to gathering and interpreting information, even though the relevant data had been nominally made available on the Web for each individual LTER site. Data were often incompatible across sites for reasons such as nonuniform data formats, units
of measure, or sampling frequency, and/or inconsistencies of metadata, which explain data collection, formatting, analysis protocols, and site characteristics. To address these shortcomings, information managers at the H.J. Andrews EF, with NSF funding, led the design of a Web-based, cross-site, data-sharing system named “ClimDB” to assemble long-term site climate data using an approach called “Web harvesting” (Henshaw et al. 1998). Content and format were guided by consensus developed at meetings of lead scientists and information managers from across the LTER Network. This group agreed that local control of data was essential while still providing both a cross-site repository of consistent data and metadata and a single portal that serves users by making the data easily accessible with search, display, and download capabilities. Participation in ClimDB was open to any long-term study site, including EFRs, regardless of whether they were an LTER member.

Forest Service R&D was interested in building a cross-site data-sharing capacity for long-term EFR streamflow data based on the Web harvesting approach used in ClimDB. An initial effort to synthesize streamflow data from six EFR sites (Post and Jones 2001) had encountered difficulties locating and interpreting data from multiple sites similar to those encountered in the initial LTER climate synthesis. Gathering streamflow data from six EFRs took almost 3 years to complete, although these archived data were nominally publicly available. To address these shortcomings, in 2000 the Forest Service funded “HydroDB”, a Web harvester to make EFR cross-site hydrologic data and metadata available on the web. Modeled after ClimDB, the content and format of HydroDB were designed by consensus among lead scientists and information managers from several interested EFRs. To get broad participation, Forest Service R&D provided funds to individual EFRs to offset costs to enter data and metadata in HydroDB, and NSF’s LTER program funded similar efforts at LTER sites to encourage them to join. Subsequently, HydroDB was merged with ClimDB to form a unified web portal at the H.J. Andrews EF named “ClimHydroDB” and operation of the combined central Web harvester and data warehouse was migrated to the LTER Network Office in 2010. As of this writing, ClimHydroDB participation has expanded to include a total of 45 sites that share long-term data including EFRs, LTERs, International LTER (ILTER), and other sites (see http://www.fsl.orst.edu/climhy/hydrodb/).

The Web harvester was an early approach within a whole class of possible future solutions that can and will facilitate data discovery and integration in the EFR Network. Although that larger class of solutions is appropriate when looking to information sharing for the future, a number of accomplishments of the Web harvester approach and lessons learned from its implementation give some indications of the potential benefits and obstacles for future information-sharing efforts for the EFR Network.

24.4.2.1 Accomplishments of the Web Harvester

**Practical Benefits of the Web Harvester** Individual EFRs have realized a number of “value added” benefits from participating in the Web harvester. EFRs’ long-term data are more likely to be included in cross-site syntheses, providing opportunities
for sites to demonstrate that their data are being used to address important, large-scale scientific or natural resource questions. For example, a new member of the EFR Network, the Olympic Experimental State Forest (OESF), was able to participate in a national-scale synthesis on climate change (Jones et al. 2012) in only its 3rd year as an EFR Network member because ClimHydroDB had made it possible for OESF to share its long-term site data. As a result, in a remarkably short time, Washington Department of Natural Resources, which administers OESF, was able to show significant progress toward one of its goals for joining the EFR Network: participation of OESF in cross-network science. Prior to joining the Web harvester, many EFRs did not provide convenient access to local long-term environmental data. The Web harvester offers templates for organizing long-term data and assembling appropriate metadata, as well as means to update and perform quality control checks on the data. Additionally, the Web harvester includes a tool kit that allowed scientists to easily search, download, and graphically compare both local and cross-site data. ClimHydroDB benefited participating sites by giving them a persistent Web presence from which site scientists and the public could access daily, monthly, and annual aggregations of site data. Leaders of several EFRs that joined the Web harvester commented that they had planned to eventually build local capabilities analogous to the Web harvester, but were spared the effort by joining. Federal agencies participating in ClimHydroDB were also complying with the E-Government Act of 2002 (http://www.archives.gov/about/laws/egov-act-section-207.html) that directs them to make federally funded data freely available to the public.

Dr. Robert Waide has used the Web harvester to teach a graduate/undergraduate course at University of New Mexico called “Ecosystem Dynamics.” “We used Clim/Hydro DB in a lab exercise in which we asked students to obtain data on precipitation for a given period from any three LTER sites and graph the data together,” said Waide. “What seems to be a straightforward task is more complicated than they realize, and few if any of them complete the task after an hour of work. We then tell them to try ClimHydroDB to complete the same task, and most are able to do so in a few minutes. It’s a very good example of the value of this kind of data tool. I would think that this lesson could be applied in many educational settings.”

24.4.2.2 Benefits to the EFR Network of ClimHydroDB

The large number and variety of intensive study sites that participate in ClimHydroDB provides a rich diversity of ecosystems from which to draw data for synthesis studies. Most participating research sites are locations of multiple ecological investigations, so their value for examining ecosystem processes and environmental trends is much greater than if only a small number of environmental variables were measured. As sites and data themes are added to the Web harvester, the number
of relationships among environmental variables and locations that are potentially available for analysis expands geometrically.

The long-term data and metadata stored on ClimHydroDB are tapped by several groups of users. On average, 30 users per day are served by this publicly accessible site. Users have self-identified their purposes as 40% for research, 35% for education, and 25% for exploring or participant testing (Suzanne Remillard, Oregon State University, pers. comm. 2010).

Although education was not the primary purpose for developing ClimHydroDB, the site has received substantial educational use. Among the 35% of users who self-identified their use as educational, 90% were students. For example, students in the NSF’s Research Experience for Undergraduates (REU) program at the H.J. Andrews EF have used ClimHydroDB in their individual research projects (Don Henshaw, USDA Forest Service, pers. comm. 2010), and university faculty have drawn on ClimHydroDB for content in undergraduate/graduate courses (see Text Box).

ClimHydroDB has formed or strengthened linkages among EFRs and with other environmental networks. Participation of 20 EFR sites in ClimHydroDB has expanded interactions of EFRs with the LTER Network considerably beyond the 6 EFRs that are formally LTER members. The Consortium of Universities for the Advancement of Hydrologic Science, Inc. (CUAHSI) is a research network that is planning to link ClimHydroDB to its Hydrologic Information System (CUAHSI-HIS), a Web-based research library of hydrologic data sources to facilitate large-scale syntheses on water resources (see http://www.cuahsi.org/).

Joint operation of ClimHydroDB with LTER sites has also brought new technical capabilities that give EFRs access to additional environmental networks. For example, the information manager at Georgia Coastal Ecosystems (GCE) LTER developed a computer application that provides data mining of the USGS NWIS real-time and historical streamflow data and transmission of these data into ClimHydroDB. Twelve participating sites, with a total of 65 USGS real-time gauges, have adopted the GCE application to automatically include their streamflow data in ClimHydroDB. When USGS recently changed the data format for NWIS, GCE adapted the application to the new format, which restored operations for all sites with little duplication of effort or disruption of data flow. Recently, GCE extended these capabilities to include weather data from the National Oceanic and Atmosphere Administration’s National Climate Data Center sites.

Synthesis efforts that used data and metadata from ClimHydroDB have contributed to scientific advance. A comparative analysis of streamflow at six EFRs representing different roles of snow and mixes of deciduous versus evergreen forest cover revealed varying types and strengths of vegetation control on streamflow (Post et al. 1998), and led to the development of a new research field called ecohydrology. ClimHydroDB was identified in subsequent studies (e.g., Jones and Post 2004; Jones et al. 2012) as a tool that made possible development of this new cross-disciplinary research field by greatly expanding and facilitating access to long-term hydrology and climate data for synthetic analyses.
The Web harvester has also stimulated support from Forest Service R&D to incorporate an additional theme of long-term stream chemistry data from EFRs to address new, policy-relevant synthesis questions. Ten EFRs are contributing water quality data to answer a series of questions about how stream nutrients respond to forest harvest and other disturbances across North America (Johnson et al. 2009). Data and metadata being assembled are incorporated into an information-sharing Web portal called “StreamChemDB” that is currently being developed http://web.fsl.orst.edu/streamchem/. The forest products industry has supported this effort, which has the potential to provide critical data needed by state and federal agencies formulating water quality standards for forestry operations. A critical next step is to develop a “VegDB” for vegetation data for small, experimental watersheds where long-term climate, streamflow, and biogeochemistry data exist. This would make possible analysis of a suite of questions concerning effects of changing climate, atmospheric chemistry, and vegetation growth on ecological services, such as water quantity and quality, carbon sequestration, wood production, and biodiversity.

24.4.2.3 Elements Contributing to the Success of the Web harvester

Successful development and use of ClimHydroDB is the result of a combination of technical capacity, the needs of the science community, and the existence of incipient EFR and LTER Networks that could rally several dozen sites to participate (Henshaw et al. 2006). Given below are the critical factors in this development.

Scientific and Practical Interest A key point for persuading Forest Service and LTER leadership to support developing ClimHydroDB was the selection of themes with demonstrated utility for answering important synthesis questions of value to basic scientists, to land managers, and to policy makers.

Scientific Leadership Site-level science leaders gave their time and effort freely to the development of a consensus for the design of the Web harvester and made individual site personnel, time, data, and resources available to support site participation. Leadership by research administrators in both the Forest Service and the NSF was crucial in securing funding.

Technical Leadership Information managers from several sites, led by H.J. Andrews EF, brought computing and electronic networking capability to the project that could achieve user-friendly connectivity and search capabilities that were required by its scientific goals.

Incentives for Site Participation Incentives have encouraged voluntary participation of EFRs and LTER sites in ClimHydroDB. The Forest Service provided small grants for EFR site participation. Grants to individual sites to initially join HydroDB totaled about US$ 200,000 (approximately US$ 10,000 per site), which exceeded the initial software development cost of the central Web harvester of about
US$ 100,000. The LTER program likewise offered modest financial incentives to LTER sites to participate in ClimDB and later in HydroDB. These small grants to individual sites were an effective way to quickly expand voluntary participation.

**Bottom-Up and Top-Down Development Approaches** Both the Forest Service and LTER combined bottom-up and top-down approaches to developing ClimHydroDB. The scientific content and technical design were largely the result of bottom-up initiatives that drew upon the personal and professional interests of scientists and information managers from across EFR and LTER sites. Site personnel willingly worked together, developing consensus on the formats and content to which all sites conform to participate in the Web harvester. The Web harvester has benefited from the collective creativity of cross-site cooperation. Top-down leadership primarily consisted of concurrence on overall direction and provision of financial support. Experience developing ClimHydroDB illustrated that an appropriate mixture of both bottom-up and top-down leadership could achieve a collaborative network among a heterogeneous group of independent study sites. A contributing factor in achieving multiparty cooperation was the long experience of most partners working together toward a common goal of sustaining long-term ecological studies.

**Interagency Cooperation** NSF/LTER and the Forest Service took leadership of different phases and functions in ClimHydroDB development. For example, NSF/LTER funded initial development of ClimDB and the cost of LTER sites to join, while the Forest Service funded the initial development of HydroDB and the cost of EFRs to join. More recently, the Forest Service has funded initial development of StreamChemDB, while the LTER Network Office has assumed the operation of the central Web harvester function of ClimHydroDB. Contributions of both agencies have been largely complementary. Together they brought participants, funding, and technical capabilities to the enterprise more easily than either could have assembled on its own.

### 24.5 Discussion

Each of the various network approaches contains ingredients that could contribute toward the goal of an integrated EFR network (Fig. 24.1). Networks in name provide visibility and recognition. Environmental monitoring networks collect standardized observational data that can be used in cross-site analyses. Cross-site experimentation fosters cooperation among scientists from multiple sites and creates new observations and manipulations designed to address scientific questions at large scales. Integrated research networks have the potential to facilitate a richer suite of interactions and information sharing among scientists that crosses site boundaries. These networking approaches are not mutually exclusive and could be linked synergistically; for example, scientific cooperation within an integrated research network could encourage more active cross-site experimentation, cross-site syntheses, and other cross-site collaboration.
However, for achieving an integrated EFR Network with limited resources, the key question is what network approaches will most effectively address the factors that limit the capability of an EFR Network to respond to emerging, large-scale environmental issues? EFRs already have considerable experience and capability in achieving public recognition, participating in environmental monitoring, and performing cross-site experimentation. Advances in these areas might add increments to an EFR Network’s capabilities, for example, if future NEON development increased environmental monitoring capacity of a subset of EFRs. However, efforts in these areas, as they have been done in the past, have created linkages among only the limited subset of EFRs that participate. An integrated EFR Network that can respond to emerging large-scale environmental issues requires more wide-ranging cooperation and communication among EFRs on scientific matters than these approaches have provided in the past.

Interactions among EFRs within networks centered outside the Forest Service have clearly benefited the EFR Network by developing models of how to integrate across research sites, and, in cases such as LTER, by working as partners facilitating integrated research among EFRs that are LTER members. However, it would be unrealistic to expect networks centered outside the Forest Service, even integrated research networks, to contribute more than peripherally to the goal of
integrating EFRs into a functioning research network. Forest Service R&D is the only organization likely to have a strong enough stake in integrating EFRs into a functioning research network to provide the sustained leadership and support that will be needed.

Forming EFRs into an integrated research network requires more than just data sharing. Probably the greatest challenge will be developing a viable community of EFR scientists to foster sharing of ideas and cooperation in designing and carrying out multiple long- and short-term cross-EFR research projects. Despite some recent activities building cross-site cooperation, enthusiasm and participation of EFRs in Network activities has been highly variable. Building a culture of cross-site sharing among scientists within a Network will take persistence, practice, and leadership to overcome attitudes and habits developed in the past when sites were quite independent.

Scientists working at EFRs must play a central role in developing cross-site science, but these network-wide social and scientific interactions are likely to grow only if the tasks required are rewarding for EFR scientists. Recognition of scientists’ achievements in the EFR Network and funding for cross-site experimentation, synthetic analysis, and publications will be critical to motivate and enable scientists to reach this goal. In addition, Network scientific activities would also be encouraged and enhanced if a support staff were dedicated to facilitating and coordinating Network interactions among EFR scientists. The LTER Network Office provides an example of the kinds of support that network staff can provide (see http://lno.lter). Although the specifics of support that would suit the EFR Network would likely differ from the LTER Network Office, the general kinds of support functions an EFR Network would need are probably analogous to the LTER Network. For example, the LTER Network Office provides communications among network member sites, including a network-wide, online newsletter, and arranges venues for cross-site interactions among scientists and technical personnel, including facilitating cross-site working groups on several topics, holding all-scientists’ meetings every 3 years, and coordinating and operating the Network’s data-sharing infrastructure. The LTER Network Office is a work in progress that has evolved over time to serve the LTER Network’s needs. An EFR support staff would likewise adapt as needs of the EFR Network develop and mature, and could probably benefit from the experience of the LTER Network Office.

A compelling research agenda could mobilize EFRs as a research network, and the EFR system has a unique opportunity to set such as an agenda with its long-term record of climate, streamflow, vegetation, and biogeochemistry observations from several dozen experimental watershed sites across the Nation. These records could be used to frame and explore a suite of questions concerning effects of changing climate, atmospheric chemistry, and vegetation on ecosystem services, such as water quantity and quality, carbon sequestration, wood production, and biodiversity. Research questions would include, for example, distinguishing changes in ecosystem services (e.g., streamflows) that can be attributed to changing climate from those with other causes, for example, from vegetative succession related to
land use and natural disturbances. Jones et al. (2012) suggested an example of such a new approach to EFRs, when they proposed that rather than only viewing traditional experimental watersheds as decades-long study sites of forest hydrology and forest management effects, these installations should be reconceptualized as “headwater ecosystem” research sites with high potential for addressing emerging issues such as global climate change and ecosystem services. This work would be greatly facilitiated through use of information-sharing infrastructure for access to data about streamflow (HydroDB), climate records (ClimDB), biogeochemistry (StreamChemDB), and changing vegetation (VegDB). In such a project, it would be important to present data in terms that are relevant to a suite of ecosystem services. Site vegetation data, for example, would need to include characteristics such as leaf area to be relevant to ecosystem services such as carbon stocks and sequestration rates, and streamflows. Simply building information infrastructure, however, will not be enough: Achieving an integrated research network will require funds to sustain activities such as ongoing entry of site monitoring data into these data bases, for the continued operation, maintenance, and upgrades of these information-sharing systems and for active use of data they contain in cross-site synthetic analyses.

The experience developing ClimHydroDB showed that technology was not the limiting factor in making data and metadata widely accessible. Rather, it was bringing groups of scientists and information managers from across multiple sites to consensus on how to design and implement an approach. That lesson applies to other parts of building an integrated research network as well. Engaging groups of scientists from multiple sites to focus and agree on common solutions to priority research questions takes leadership, negotiation, and, above all, time. Forming EFRs into a research network that can respond in timely ways to pressing issues requires developing agreement in advance and at a broad enough scope to be ready to respond quickly and effectively to emerging issues and funding opportunities. A research network that starts from scratch on each new issue will have great difficulty responding to pressing issues expeditiously. Developing a network and a culture that is prepared to address emerging issues requires support and organization to engage scientists from across sites in network design and implementation. Although social networking technologies, Web meetings, and video conferences may reduce the logistics of consensus building, gaining agreements among diverse individuals will probably continue to require hard work. Support staff could facilitate this necessary work but cannot be expected to provide the foresight and leadership to anticipate national-scale issues.

National-level leadership has an important strategic role to play in forging a research network. National R&D leaders need to make building an EFR research network a high priority, for example, by providing rewards and incentives, and also by guiding development of network capabilities to ensure that the EFR Network can anticipate national-scale issues. Another role of national R&D leaders will be to mobilize the EFR Network by providing the resources required to perform research that will address large-scale environmental issues as they arise.
24.6 A Vision for the Future

A fully functional and integrated EFR Network will have the capability to effectively address scientific questions concerning the implications that are relevant to the policy and management of emerging, large-scale environmental issues on the nation’s forest and grassland ecosystems. The Network will accomplish this goal by building working relationships among scientists doing research within and across sites throughout the EFR Network. The foundation of the Network will be a culture of cooperation that encourages, facilitates, and rewards EFR scientists working together. EFR scientists will have a strong community that fosters mutual trust and facilitates interactions among EFR sites and their programs of research. For example, the EFR Network will enhance cross-site interactions by sponsoring network-wide events similar to those of the LTER Network. The EFR Network will hold EFR all-scientists meetings every 3 years to build community by serving as a forum for collaboration on topics of major interest to scientists, providing a seedbed for multisite research projects. Gatherings of EFR scientists would 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 will 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; so subsets of sites will have developed the capacity to address critical questions, so that together they can address national-scale questions related to vegetation dynamics, biogeochemistry, or hydrology, even though not all sites will have all of these capabilities.

The Network will provide selected services that enhance science at all sites and their science programs throughout the Network. Common protocols will be established for environmental data collection and documentation. Information-sharing capacity will be developed that enables scientists to build upon science done across the entire network and is readily shared with the larger scientific community and the public. EFRs will participate in research networks managed by other institutions, such as LTER, NEON, and NADP, that can extend the reach and inferences of findings from EFRs and share lessons learned about networking processes. Dedicated administration and leadership will be in place to support network science with an appropriate mix of top-down and bottom-up approaches. Funding and resources for network science will 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 grasslands.

References

USDA/USDI (US Department of Agriculture, US Department of Interior) (1994) Record of decision for amendments to Forest Service and Bureau of Land Management planning documents within the range of the northern spotted owl (place of publication unknown), 74 p