Chapter 2
Forest Service Experimental Forests and Long-term Data Sets: Stories of Their Meaning to Station Directors

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Abstract As Forest Service Research and Development worked to prepare this book reporting important results from long-term research conducted on U.S. Department of Agriculture Forest Service Experimental Forests and Ranges, the station directors added a chapter to highlight additional accounts of long-term research, its benefits to land managers and policy makers, and lessons learned from the first century of research on Experimental Forests and Ranges. The Northern Research Station described research on tree care and the opening it created to urban natural resource research. The Pacific Southwest Research Station described a series of studies on the relationships among logging, landslides, and water quality that began in 1963 and continues through the present. The International Institute of Tropical Forestry described pioneering work in measuring tree growth in tropical forests. The Pacific Northwest Research Station showed how conclusions vary with the length of an environmental record, and the ways in which their research has contributed to

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understanding old-growth forests. The Southern Research Station highlighted the contributions of the Coweeta EFR to the science of forest ecosystem hydrology. The Rocky Mountain Research Station showed how data from even a single plot measured over many decades can enhance our understanding of forests and environmental change. Lessons learned include the importance of data quality, sampling intensity and consistency, scale, scientific creativity, and manipulative research. These stories also show us that sites on which long-term data have been collected can serve as settings for important conversations about important social and management questions.

Keywords Long-term research · Urban forestry · Landslides · Tropical forestry · Hydrological research · Old-growth forests · Forest change · Research policy

2.1 Introduction

The network of Experimental Forests and Ranges (EFRs) is a crown jewel of the Forest Service. There is no other country in the world with such treasures as the 80 individual EFRs. This is certainly evident by the number of scientists and students who visit from other countries and conduct research on a number of our EFRs. Since their establishment in 1908, the wealth and breadth of scientific knowledge gained from EFR research has provided both public and private land managers invaluable information on how to manage their forestland and has added to the very structure of natural resource science. In addition, seminal research on watershed issues has contributed to enhancing the quality and quantity of our nation's water resources. Research on EFRs ranges from development of new methods to study forests and ranges through studies whose longevity allows them to answer, in profound ways, questions not foreseen at the time the studies were initiated. Each chapter in this book tells a story that reflects these contributions and shows how EFR research enables Forest Service Research and Development to provide the science that managers and policy makers need to sustain forests, grasslands, and associated waters.

The research and development (R&D) branch of the U.S. Department of Agriculture (USDA) Forest Service is organized regionally. The seven research stations (Fig. 2.1) help the agency bridge the range of research needs—from questions specific to the ecological and social context of a local site through those appropriate to a single region to questions of national and international scale. In this chapter, the directors of each station highlight questions answered by research on the EFRs within their station. Each example illustrates the special contribution of EFR data sets to the mission of the Forest Service: "to sustain the health, diversity, and productivity of the Nation's forests and grasslands to meet the needs of present and future generations." Each research station is represented by at least one chapter elsewhere in this volume, but here, the directors place one or a few data sets or programs in the historical context of their respective parts of the country and highlight how the long-term focus has not only facilitated achieving the mission of the agency but also allowed Forest Service R&D programs to remain vibrant and relevant to the needs of society, even with the passage of time and changing research priorities.

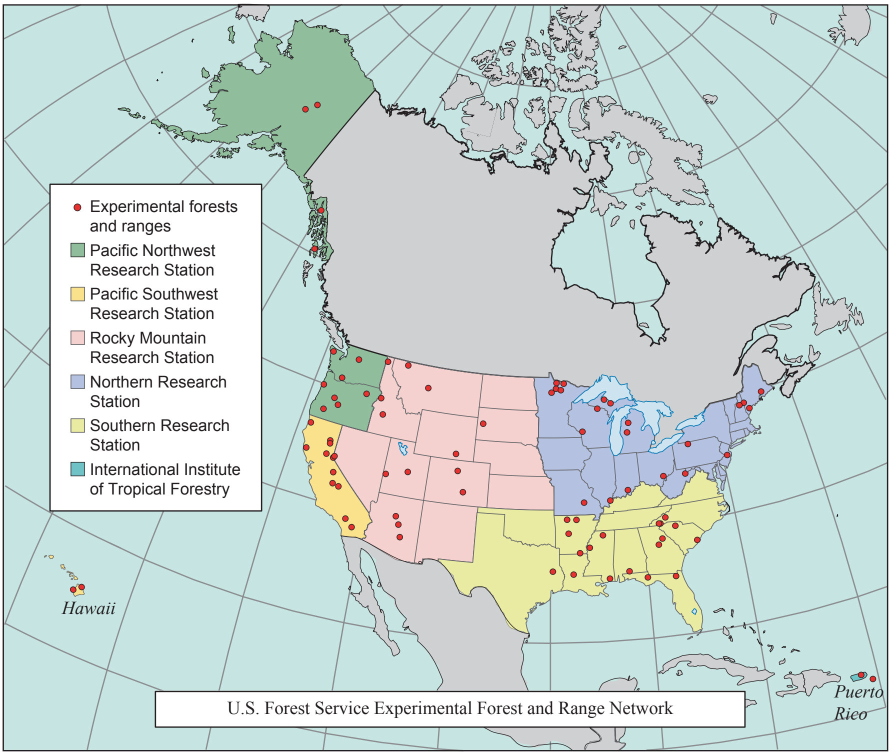

Fig. 2.1 The seven regional research stations of the USDA Forest Service, with locations of the 80 Experimental Forests and Ranges

The accounts span almost the full life of Forest Service R&D, from one of our most recent long-term ecological research sites in Baltimore to one of our very first experimental forests in northern Idaho.

The directors' questions range from how society values older forests through how the effects of forest management accumulate across space and time to how research in rural forests is shaping the environmental policies of cities today. The studies they report range from single plots, in Idaho and Puerto Rico, through watersheds in California and North Carolina to a city that is breaking the ground of urban EFRs. These examples demonstrate that the Forest Service's long-term approach to research gives the agency flexibility to address changing natural resource conservation questions and advance forest science methods while maintaining stable field research programs in the nation's premier experimental forest network, the EFRs of the USDA Forest Service (Lugo et al. 2006). In conclusion, the directors summarize the characteristics of this research approach that make it particularly powerful to address questions of sustainable management and global climate and environmental change.

2.2 Experimental Forests in the Northern Research Station: Lessons From the Heart of the Forest to the Heart of the City

Michael Rains

What difference does an experimental forest (EF) make, especially to those living far from the distant forests and woodlots? EFs are touching lives in the midst of the city. Modern tree trimming standards, better street tree placement, and drinking water protection methods are all lessons learned in rural settings that benefit urban dwellers.

The health of our towns and cities are inextricably linked with the health of our forests. Healthy forests yield water to drink and lumber to use; they shelter wildlife and wildflowers and offer a respite from urban crowds. Across the USA, an expanding population is spreading beyond city limits, blurring the lines between town and country. Our forests face ever-greater demands for the services they provide.

The network of EFRs maintained by the USDA Forest Service is one way we can help cope with those demands. From these remote locations, we have learned fundamentals of how trees grow and how water flows and what that tells us about how our cities work.

These lessons are possible because of a long-term commitment—a commitment to patient, repetitious, continuous measurement of the flow of water, the acidity of soil, and the growth of trees. In most cases, researchers did not know what they would learn but knew what information was needed in order to learn. And the slow and steady accumulation of data yields knowledge that could not be gained in any other way. Long-term data let us mark the changes occurring around us over the decades and help us anticipate what conditions we face in the future. The lessons we have learned so far surprise, excite, and encourage us.

As the baby boom was just underway in this country, a plant physiologist from Pennsylvania named Alex Shigo was wondering how trees lived and how they died. How does a tree make new wood? What keeps a branch growing? Why can an injury kill a tree?

He began exploring these questions through studies on EFRs in New England and around the Great Lakes. At first, his focus was economic, understanding the factors that degrade wood quality or kill the trees remaining after a harvest. Earlier researchers expected that wood products deteriorate in the same way that cut logs would. But Shigo's studies revolutionized how foresters and biologists thought about trees. They came to understand that, instead of being passive organisms acted upon by fungi, trees were living systems actively responding to injury, insect, drought, and changing soil conditions.

That knowledge changed the way we treat trees, especially those subject to the hazards of an urban environment, and launched modern arboriculture, the science and practice of tree care. Shigo's studies led the tree care industry to stop using tar to seal tree wounds, because trees naturally seal off an injury to resist the spread of infection. He shaped how utility crews and homeowners prune trees, based on a better understanding of how trees grow and how branches attach to trunks. Other research

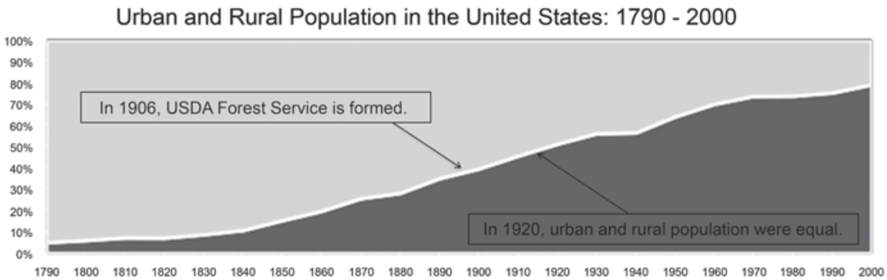

Fig. 2.2 Percentage of the US population that is urban (*dark area*) or rural (*clear area*) between 1790 and 2000. At 50 %, the rural and urban population was equal

helped plant nurseries understand that soil organisms are vital to the health of trees, refocusing their industry from the biology of plants to the biology of the landscape.

Shigo succeeded in his work because he had access to much more data about trees and decay than he could have accumulated in his lifetime. By building on the long-term data from EFs, his base of knowledge could approach that of the lifespan of a tree rather than just the life of a single scientist.

EFs were also critical to his success because his research involved deliberately wounding trees and observing the results. Few forest managers willingly create damage to their resources. So a place for manipulative research was essential to fostering the health of trees elsewhere.

Shigo's work illustrates the importance of a place dedicated to understanding the linkage of forests and cities. As the significance of that linkage has grown, the Forest Service started a new set of EFs in urban settings: Urban Long Term Research Areas (ULTRAs). These fledging sites represent the next frontier of the EF legacy. Their importance is underscored by the predominance of urban population over rural population in the USA (Fig. 2.2) and the world. It is also a real tribute to the Shigo legacy that arboriculturists in Italy are creating an Alex Shigo Modern Arboriculture Park in Barasso, Italy.

The oldest of these urban sites, the Baltimore Ecosystem Study (BES), was launched just a decade ago on the shores of the Chesapeake Bay. Part of the National Science Foundation's Long-term Ecological Research Network, the BES explores a new field of knowledge, urban ecology, which looks at how organisms and environments in and around cities are affected by the buildings and paved surfaces, the things that people do (Fig. 2.3), and the new environments that cities create.

In many ways, the approach proven at older, rural EFs applies at the BES. Researchers here mirror the long-term watershed approach established at EFs such as Hubbard Brook, Coweeta, H.J. Andrews, and Luquillo. The demonstrated value of interdisciplinary research brings ecologists, soil scientists, hydrologists, and social scientists together to apply their traditional expertise to a nontraditional setting. Field trips and demonstrations are an important tool for sharing lessons learned.

But a unique focus of the BES is engagement of the community beyond the scientific circle. BES engages decision makers, from local communities to multistate policy makers, in the formation of questions, collection, and analysis of data,

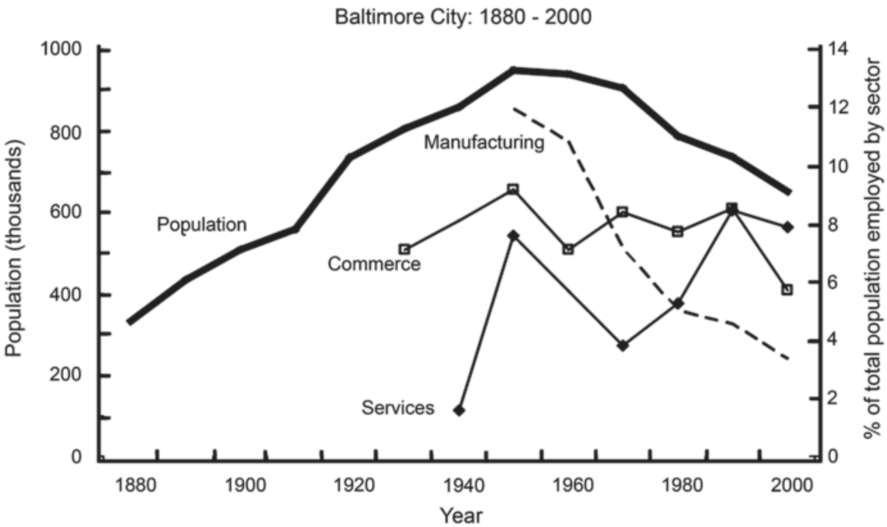

Fig. 2.3 The population of Baltimore between 1880 and 2000 and the proportion of the population involved in three economic activities

and the dissemination of findings. A core team of educators and researchers meets bimonthly to help others learn and teach about Baltimore's urban ecosystem. As a result of this engagement, the work here is already changing the face of Baltimore.

As a result of BES findings, regional planners at the Chesapeake Bay Program shifted their policy from planting trees in urban riparian buffers to increasing overall tree canopy in urban areas. In turn, the City of Baltimore established a goal of increasing its tree canopy from 20 to 40 % by 2037. When achieved, that increase will mean a cooler city with less air and water pollution, increased property values, and a more pleasant and healthy setting for urban residents. And the circle of lessons widens. Following on Baltimore's success, New York City, Boston, and other metropolitan areas conducted similar analyses and have adopted urban tree canopy goals.

The legacy of EFs, new and old, is improvement of human communities from urban to rural settings. By maintaining this vital network for long-term research, we ensure that the learning continues. The more we learn about trees and forests, the more we understand how our health and that of our cities depends on them. From the heart of the forest to the heart of the city, EFs link us to those important lessons from the natural world.

2.3 EFs of the Pacific Southwest Research Station: Long-Term Research at the Caspar Creek Experimental Watersheds

Leslie M. Reid, Larry Rabin, and Deanna J. Stouder

Why study the same site for decades? Wouldn't more information be gained by studying many sites for short periods? The answers to these questions are at the

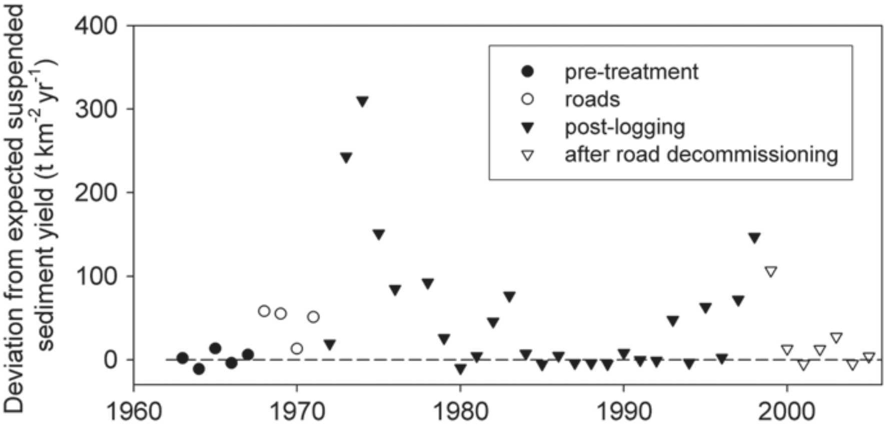

Fig. 2.4 Deviation of annual suspended sediment production in the South Fork Caspar Creek watershed from that expected for unlogged conditions. Roads were constructed in 1967, and the watershed was selectively logged between 1971 and 1973

same time simple and complex, like science itself. Consider the story of the Caspar Creek Experimental Watersheds, located in the forests of California's north coast. A century and a half ago, the North and South Fork watersheds supported an old-growth forest of towering coastal redwoods, some with diameters of 3 meters or more. But California's growing population required building materials, and by 1905 Caspar Creek's old growth had been replaced by young second-growth stands.

Over the next half century, an important fishing industry developed along the north coast, lowland communities grew, and logging continued at other sites. Conflicts between resource users raised new questions: Did logging reduce salmon populations by damaging spawning streams? Did it degrade the water supply by adding sediment? Did it aggravate the episodes of flooding and landsliding that the region had experienced in the 1950s? By the late 1950s, it was becoming clear that policy makers would need some solid information about the environmental impacts of logging if regulations were to be designed to reduce conflicts. In 1960, the USDA Forest Service and the California Department of Forestry and Fire Protection joined forces to address these issues by designating the North and South Forks of Caspar Creek as a site for studying the effects of logging on streamflow, sedimentation, and fish habitat in a rain-dominated forest.

The first study—the South Fork experiment—was developed to be a watershed-scale experiment quantifying the effects of tractor-yarded selective logging on streamflow and sediment yield. Construction of a small dam enabled monitoring at each watershed mouth, and measurements began in late 1962. After 5 years of pretreatment monitoring to define the baseline conditions at both forks, scientists left the 473-ha North Fork undisturbed as a control and roads were constructed in the 424-ha South Fork watershed. Logging then began on the South Fork in 1971, 4 years after road construction.

Data from the roading phase of the study showed that sediment inputs increased dramatically from road construction alone (Fig. 2.4). These preliminary results became evident just as a rising level of environmental concern was leading to passage of legislation at both federal and state levels. In 1973, the California legislature passed the Z'berg-Nejedly Forestry Practice Act, which authorized the California Board of Forestry to "…adopt rules for control of timber operations which will result or threaten to result in unreasonable effects on the beneficial uses of the waters of the state." The early Caspar Creek results underscored the need to develop methods for controlling road-related sediment, and later results quantified increases in runoff and sediment yield from tractor logging. Thus, Caspar Creek analyses and results contributed to the body of information that eventually resulted in restrictions on the use of tractor yarding on steep slopes in California.

By 1985, flow and sediment loads had returned to near pretreatment levels in the South Fork, and scientists initiated a new experiment in the North Fork watershed. By this time, controversy had begun to focus on the issue of the "cumulative impact," the "…impact on the environment which results from the incremental impact of the action when added to other past, present, and reasonably foreseeable future actions…" (40 CFR § 1508.7). Forest management plans governed by either Federal or California rules were required to assess cumulative impacts, but controversies—and litigation—persisted over what level of assessment was adequate and over what actually constituted the cumulative impact.

The North Fork experiment was designed to identify trends in the hydrologic and sediment response to clearcut logging along a downstream sequence of gauging stations. Comparison of proportional changes in flow and sediment as watershed size increased from 10 to 473 ha would reveal whether the cumulative downstream effects were additive, synergistic, or dampened with increasing scale. The design called for clearcutting five gauged tributary watersheds while leaving three unlogged watersheds as controls, allowing the direct effects of clearcutting to be evaluated. In addition, the overall changes at the downstream gauging weir could be compared with those observed during the previous long-term experiment to assess the relative effects of old and new logging practices. Information provided by the South Fork experiment allowed design of a North Fork sampling strategy that would provide the level of precision necessary to detect likely effects.

Monitoring for the experiment began with gauge installation in 1985, and 39 % of the North Fork watershed was logged between 1989 and 1992. Results of monitoring through 1995 showed that runoff, low flows, peak flows, and sediment loads increased in most of the logged watersheds (Ziemer 1998). Hydrologic changes were additive over the range of watershed scales present, but sediment changes displayed no uniform downstream trend—other factors must be influencing the response. Additional information became necessary to explain the results.

That information became available because other kinds of research were also taking place during the North Fork experiment. Surveys of woody debris showed that riparian blowdown increased along the margins of clearcuts, and monitoring of channel cross sections revealed that this new wood trapped sediment. Further, data from a study of tributary channels showed that channels enlarged downstream of clearcut catchments, suggesting that the logging-related flow increases generated off-site erosion.

As results of the North Fork experiment were becoming available in the mid-1990s, a new issue emerged about 160 km north of Caspar Creek. Residents of several lowland communities in Humboldt County reported increased flood frequencies after intensive logging of upstream watersheds. Like studies elsewhere, the North Fork experiment had shown that logging greatly increased the small peak flows that occurred early in the wet season, when decreased transpiration after logging led to increased soil moisture and thus reduced the capacity for further water storage on hillslopes. But North Fork results also showed that the larger, midwinter peaks increased, and this result ran counter to expectations. Common wisdom had assumed that midwinter peaks are immune from increases because soils are near saturation in both logged and unlogged sites. Therefore, a rainstorm falling on saturated forest soils should affect stream flows in exactly the same way as it would falling on saturated logged soils.

But it did not. Clearly, changes in transpiration were not the only mechanism for hydrologic change after logging. Researchers conducted a brief study at Caspar Creek to determine whether the observed peak flow changes could be explained by differences in how much rain is trapped by foliage before and after logging. Comparison of rainfall under forest stands with that in adjacent clearcuts showed that the redwood forest canopy trapped and evaporated about 20 % of even the largest rainstorms. When logging removed the canopy, more of a storm's rainfall hit the ground; so more runoff reached streams to increase peak flows. With the mechanism for change now explained, personnel from the California Department of Forestry used a flow model based on Caspar Creek results to calculate desired logging intensities for the Humboldt County watersheds.

Meanwhile, routine long-term monitoring continued at the South Fork weir. After 1985, flow and sediment loads remained at near pretreatment levels until the early 1990s, but then the sediment loads began to rise once again. Field surveys showed that culverts were rusting out along the main haul road, so the road was decommissioned in 1998 to deactivate potential future sediment sources. Even after decommissioning, sediment loads remained higher than prelogging levels, and the total excess sediment produced after 1993 rivals that contributed during the first 12 years after logging.

Research at the Caspar Creek experimental watersheds is nearing its 50th year. Work there has led to more than 100 publications describing research results, and hundreds of other publications have cited Caspar Creek results, demonstrating their relevance to research elsewhere. Caspar Creek studies have been cited in planning documents ranging in scale from environmental assessments for individual projects to the Northwest Forest Plan, which guides forest planning for multiple Federal agencies in the Pacific Northwest.

Today, new controversies are emerging in America's forestlands. Along the west coast, second- and third-growth forests are now being logged, this time using today's state-of-the-art practices. But concerns have been raised that the new practices are being superimposed on a landscape that still reflects effects from earlier logging, thus potentially generating a multi-cycle cumulative impact. We do not yet have the information needed to predict the outcome of multi-cycle logging, but that information awaits us in the South Fork watershed. South Fork now reflects the third-growth conditions present through much of the redwood region and is ready to be reentered. Here, the effects of earlier second-growth logging practices are known, and the nearby North Fork experiment quantified the effects of more modern practices. Because of the nearly 50 years of records that now exist, it will be possible to very quickly assess the short-term effects of multi-cycle logging. Baseline monitoring for the third watershed-scale experiment began in 2001.

So why study the same site for decades? First, long-term studies are essential for defining the full trajectories of impact and recovery. Had monitoring ended when the South Fork study formally ended in 1985, the portion of the management-related sediment that has been produced since 1990 would have gone unnoticed. In the North Fork, management treatment did not end with logging, and peak flow magnitudes and sediment yield continue to show the effects of pre-commercial thinning carried out in 2001. Only long-term monitoring will reveal when recovery has been achieved. Until that information is available, we will not know the extent to which impacts from sequential logging entries will be superimposed, thus contributing to cumulative impacts at the watershed scale.

Second, experimental responses are often subtle for watersheds, and variations in conditions through time may introduce "noise" that hinders detection of the response. A long period of pretreatment data helps researchers differentiate between signal and noise. At South Fork, 13 years had elapsed between initiation of monitoring and completion of the experimental treatment—only then did monitoring of experimental results begin. If multiple studies are conducted at a long-term research site, each new study can use some of the same baseline data, allowing new experiments to progress with shorter calibration periods.

Third, long-term study sites often allow quick response times when a new need for information becomes apparent. When logging-related flooding became controversial, preliminary results from Caspar Creek were already available to help address the issue. And when an additional study was needed to explain the observed changes, the necessary background work had already been completed at Caspar Creek, allowing the rainfall interception study to progress quickly.

Fourth, long-established research sites prove invaluable in attracting researchers across a range of disciplines, all of who can make use of the long-term data sets while themselves contributing to a more holistic understanding of process interactions and conditions at the site. Had the North Fork wood and channel morphology studies been carried out elsewhere, their relevance to the sediment load would have been less evident. Long-term research sites also provide the data needed to test hypotheses derived elsewhere, and can provide a long-term context for short-term measurements at other sites. Researchers from elsewhere often use Caspar Creek data to help determine how broadly their own results might be generalized.

And finally, long-term research is essential for understanding natural and managed systems that are continuously changing. For example, a 100-year-old redwood stand is changing in character as it continues to mature. Without data to define long-term trends, we would be unable to distinguish the effects of differences in experimental treatment from those of differences in initial condition. Recent human-caused climate change produces a similar challenge, increasing the need to identify causal factors that affect patterns observed in monitoring data. Long-term data sets allow us to describe a system's responses to a wide range of weather patterns, thus making it possible to distinguish the effects of current and future climate change from those of other influences.

A research watershed is an outdoor laboratory that provides the infrastructure to support many kinds of research, allows careful control of experimental conditions, and permits experimental treatments to be designed to most efficiently address particular problems. The product of the laboratory is knowledge. We rarely know beforehand how basic knowledge will be used, but each time a critical emerging problem demands an immediate response, the pool of existing research results provides the basis for the response. Knowledge gained from nearly 50 years of research at the Caspar Creek Experimental Watersheds is part of the edifice of understanding that guides science-based management of rain-dominated, temperate forests in the USA and elsewhere.

2.4 The EF in the International Institute for Tropical Forestry: Pioneering Tree Growth Measurements in the Tropics

Ariel E. Lugo

How to measure and document the effect of weather, management, and other disturbances on tropical forests where tree rings do not represent historical record in the same way that they do in temperate forests? When the USDA Forest Service began research in temperate and boreal forests, the record of growth found in tree rings gave scientists a leg up in understanding the forces that determine forest growth. In tropical forests, seasonality is less predictable and growth more constant year-round, challenging the ability of scientists to discern these patterns.

Before there was a USDA Forest Service, employees from the Division of Forestry of the USDA visited Puerto Rico and the Luquillo Mountains to assess the forestry situation and make land management recommendations (Hill 1899; Gifford 1905). The forest condition in Puerto Rico was dire. Only about 20 % of the original forest cover remained and the situation was non-sustainable because “every year the people of Porto Rico consume over three times as much as the forests of the entire island produce” (Murphy 1916, p. 1).

Crown lands in the Luquillo Mountains were transferred to the USA after the Hispanic American War and the Luquillo National Forest (then named the Luquillo Forest Reserve) was established in 1903, 2 years before the USDA Forest Service was organized (the forest has undergone numerous name changes and is now the El Yunque National Forest). From the outset, forest managers faced many challenges, some unique to the tropical nature of the new National Forest. For example, the climate was different from familiar temperate and boreal climates. Rainfall and air temperatures remained high year-round and there was no frost. The vegetation was lush and diverse. The National Forest was later found to have 207 tree species in 133 genera and 55 plant families, all in the relatively small area of about 10,000 ha (Little 1970). Between 1913 and the 1940s, Puerto Rico and the National Forest were visited by prominent scientists under the leadership of Nathaniel Britton, who led a scientific expedition sponsored cooperatively by the New York Academy of Sciences, the University of Puerto Rico, and the Puerto Rico Legislature (Baatz 1996). Among the dozens of scientists who participated in the expedition was the prominent American ecologist H. A. Gleason, who with M. Cook described the vegetation of Puerto Rico (Gleason and Cook 1926) and had just published a paper that would revolutionize the field of ecological succession (Gleason 1926).

Efforts to manage the forest stands of the Luquillo National Forest became bogged down because familiar temperate forestry techniques led to failures, particularly the problem of land restoration and dealing with a high number of tree species for which silvicultural information was scant at best (Wadsworth 1995). By 1956, a tropical research station had been established in Puerto Rico (authorized by Congress in 1928 and operational since 1939) and the National Forest was designated the Luquillo Experimental Forest. Contrary to convention in the mainland, the entire National Forest was proclaimed an EF in recognition of the need for a close partnership between research and forest management. This close partnership was anticipatory of the model that would come to predominate in the Forest Service decades later.

Forest Service research solved the problems of reforestation in Puerto Rico through decades of research activity (see, Wadsworth 1995). But I will highlight the approach taken to address the challenges of assessing tree growth in tropical forests. I view this research as one of the most notable contributions by the Institute toward the understanding of the functioning of tropical forests.

In temperate and boreal forests, it is possible to assess the age and growth rate of trees by counting and measuring the width of the growth rings. Each tree carries its own history of growth in the width and number of radial rings of its woody parts. If a treatment is administered to a stand, the forester can assess its success by examining tree rings to determine the growth response of trees to the treatment compared to untreated trees. Tree ring analysis relies on a winter season (cold temperatures of near below or below freezing) with insignificant tree growth and a growing season (warm temperatures) where larger cells form. Combined, these define an annual cycle of growth. The width of the annual ring reflects the rate of growth during that year. In the tropics, tree ring analysis is not as simple.

Trees in the dry tropics experience a growing season that coincides with the rainy season, and they then grow more slowly during the dry season. However, the periodicity of the seasons and their length are not as neatly defined as they are in the temperate and boreal regions. The events that define tree growth in the tropics are not annual. Instead, the rainy season may or may not occur in a particular year or more than one rainy period may occur, which makes it very difficult to assign an age to the number of rings. In the moist and wet tropics, the situation is even more complicated because the growing season is year-round and trees may or may not produce rings, and for those that do, it is difficult to relate individual growth rings to particular time intervals.

Pioneer tropical foresters had no practical methods for determining age structure of stands, nor rates of tree growth. Forest Service research provided the solution and, in so doing, advanced the understanding of long-term processes in tropical forests.

The scientist involved was Frank H. Wadsworth, who in the early 1940s decided to assess tree growth in the Luquillo Mountains. His only alternative was to measure, mark, and remeasure trees over and over until rates of growth could be established by the differences in dimension between two known intervals of measurement. This approach is straightforward but it is time consuming, requires accurate record keeping, consistent measurements, long-term data management, and long-term institutional commitment. Dr. Wadsworth grouped his trees in plots, established plots in the major forest types of the Luquillo Mountains, and conducted experiments with basal area reductions to assess growth responses to change in spacing and tree sizes. The plots he established in the 1940s are the oldest known in the Neotropics. They continue to be studied today and were instrumental in the development of long-term ecological research in the Luquillo Mountains.

One of these plots is in the *Dacryodes excelsa* (tabonuco) forest, the tallest forest in the Luquillo Mountains. Known as El Verde 3, data for this plot extend from 1943 to 2005 and the 62-year record of the plot was just published by Drew et al. (2009). From that publication, I estimated rates of change to illustrate four short stories embodied in the long-term data set.

Before presenting the stories, it is important to keep in mind some of the events that characterize the 62-year record of tree measurements at El Verde 3. The first one happened in 1932, before the El Verde 3 plot was established. It was the passage of hurricane San Ciprián, one of the strongest hurricanes to pass over the Luquillo Mountains. Using data from El Verde 3, Crow (1980) attributed the behavior of the stand to that event, which thinned the forest and caused a growth pulse that was measurable up to 1951. This report by Crow, a USDA Forest Service scientist stationed at the Institute, was one of the first documentations of the long-term hurricane effects on Neotropical forests. After this event, the plot experienced a long period of uninterrupted development without any major interruptions by hurricanes. In 1989, Hurricane Hugo affected the Luquillo Mountains, including El Verde 3, and in 1998, Hurricane Georges passed south of the Luquillo Mountains and had some effects on the El Verde 3 plot. What do the El Verde 3 long-term data tell us about how these disturbances shaped the forest, and what do they tell us about today's management questions?

2.5 Hurricanes Cause Pulses of Tree Recruitment and Growth

After Hurricane Hugo in 1989, tree basal area growth (Fig. 2.5, closed circles) peaked sharply with the highest rate in the long-term record. At the same time, there was a peak in stem recruitment (Fig. 2.5, open circles). The highest rate of increase in stem density occurred at the beginning of the record, probably a residual effect from the 1932 hurricane. However, until the 1989 hurricane, stem density

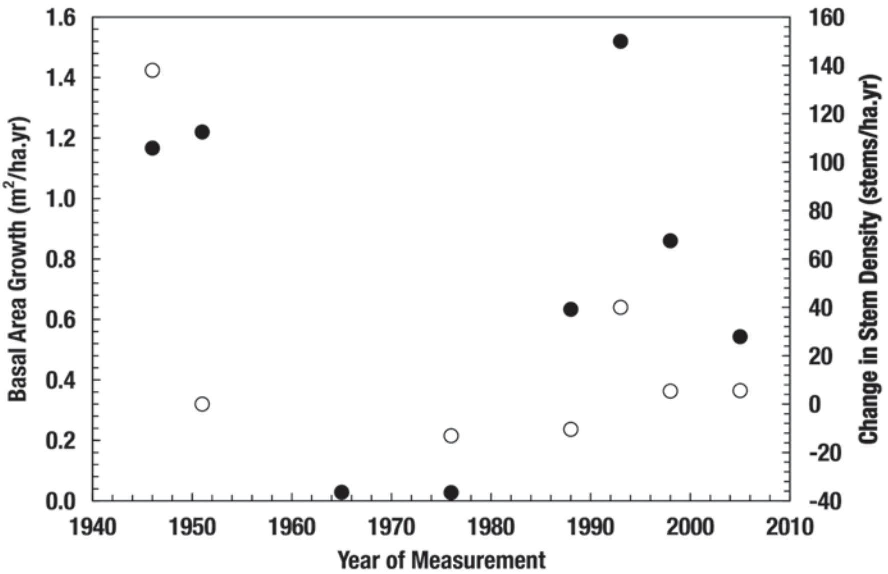

Fig. 2.5 Basal area growth rate (*solid circles*) and change in stem density (*open circles*) of a tabonuco forest stand (El Verde 3) in the Luquillo Experimental Forest. These rates were derived from data in Drew et al. (2009). The data points are plotted at the end of each interval of measurement, and the record extends from 1943 to 2005. (F. H. Wadsworth established the plot)

steadily declined, which provided more space for surviving trees. The basal area increment was low during the period of forest thinning and then increased significantly just before Hurricane Hugo passed over the forest. Again, the hurricane induced a peak in basal area growth and stem density was followed by reduced but positive rates.

2.5.1 The Bulletwood tree thrives after hurricanes

Manilkara bidentata, ausubo, or the bulletwood tree, is "one of the strongest and most attractive commercial woods in Puerto Rico" (Little and Wadsworth 1964, p. 444). It is also a primary forest species, with slow rates of growth and seedlings that remain on the forest floor for periods as long as 40 years before releasing in rapid bursts of growth toward canopy dominance (You and Petty 1991). Bulletwood growth benefits from the passage of hurricanes (Fig. 2.6). Bulletwood had peak recruitment and basal area increments after hurricane passages in 1932, 1989, and 1998 (Fig. 2.6). Bulletwood canopy trees benefited from the additional space allowed by stand thinning between the 1932 and 1989 hurricanes (1976 data point). However, the peaks in basal area accumulation after the hurricanes were higher than the 1976 basal area growth.

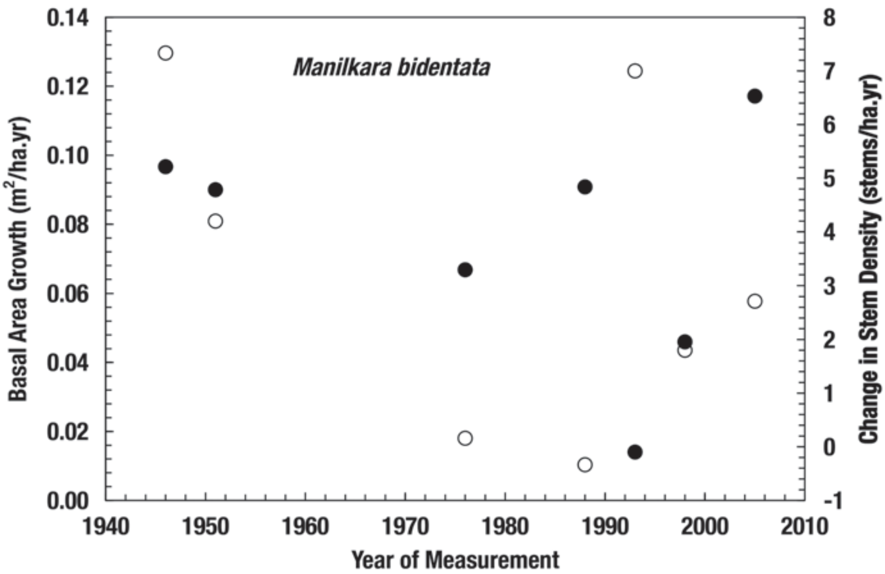

Fig. 2.6 Basal area growth rate (*solid circles*) and change in stem density (*open circles*) of *Manilkara bidentata* trees in a tabonuco forest stand (El Verde 3) in the Luquillo Experimental Forest. These rates were derived from data in Drew et al. (2009). The data points are plotted at the end of each interval of measurement, and the record extends from 1943 to 2005. (F.H. Wadsworth established the plot)

2.5.2 The Forest is a Carbon Sink

A steady accumulation of aboveground biomass occurred at El Verde 3 (Fig. 2.7). Accumulation rates were faster in the 1940s and 1950s than they were after 1976, but they were all positive with the exception of the period between 1951 and 1976. Others have interpreted short-term reductions in rates of biomass accumulation in tropical forests as a response to climate change (Phillips et al. 2005). However, our long-term record shows that the reduction is associated with forest maturation, i.e., as the forest approaches maximum biomass, its rate of biomass accumulation diminishes and this is compounded by increased tree mortality. Also of interest in this record is the continuing accumulation of biomass (a carbon sink) in spite of the passage of Hurricanes Hugo and Georges indicating rapid forest recovery following large-scale disturbance. The El Verde 3 plot reflects patterns documented elsewhere in the EF (Lugo 2008).

The 62-year record of tree growth at the El Verde 3 plot illustrates the complexity of tropical forest dynamics. Some species benefit from disturbance, while others fail to do so, and these responses seem to vary by site. Lacking tree ring data, the task of collecting, processing, and interpreting data is challenging and the results always seem far from conclusive. Each set of measurements initiates more questions given the variability of conditions and responses by so many species. Nevertheless,

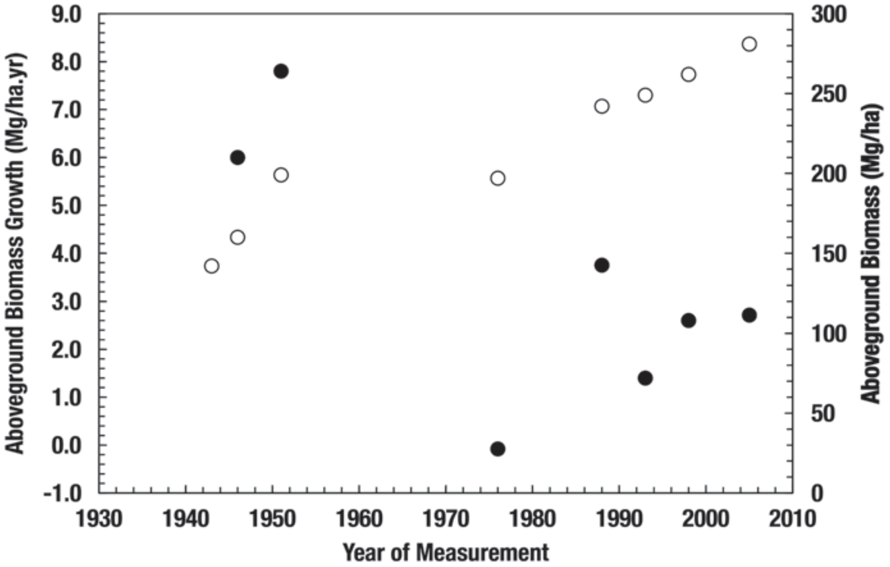

Fig. 2.7 Aboveground biomass growth rate (*solid circles*) and aboveground biomass (*open circles*) of a tabonuco forest stand (El Verde 3) in the Luquillo Experimental Forest. These rates were derived from data in Drew et al. (2009). The data points are plotted at the end of each interval of measurement, and the record extends from 1943 to 2005. (F. H. Wadsworth established the plot)

it behooves us to maintain and expand these plots as only through them will we be able to infer the long-term adjustments of tropical forests to climate and environmental change.

2.6 EFRs of the Pacific Northwest Research Station: From Water Yields to Old-Growth Forests

Bov Eav and Frederick J. Swanson

Are there patterns in the data from long-term records? Can we use them to inform our research program? Our experience with the EFRs of the Pacific Northwest Research Station provides examples of positive answers to both these questions. PNWS EFRs represent the programmatic and geographic diversity of Forest Service EFRs well. Sites range from several EFs on remote islands in southeast Alaska to the Wind River EF, a short drive from Portland, Oregon. On the Starkey Experimental Range, the presence of elk and cattle across the entire landscape integrates research that spans topics from grazing to forestry. Several studies use multiple EFs arrayed along environmental gradients or generally distributed across the region to assess broad-scale variation in peak streamflow in response to forest cutting and regrowth (Jones 2000), characteristics of forest communities (Acker et al. 1998), and ecological processes, such as wood decomposition (Chen et al. 2001). The historical

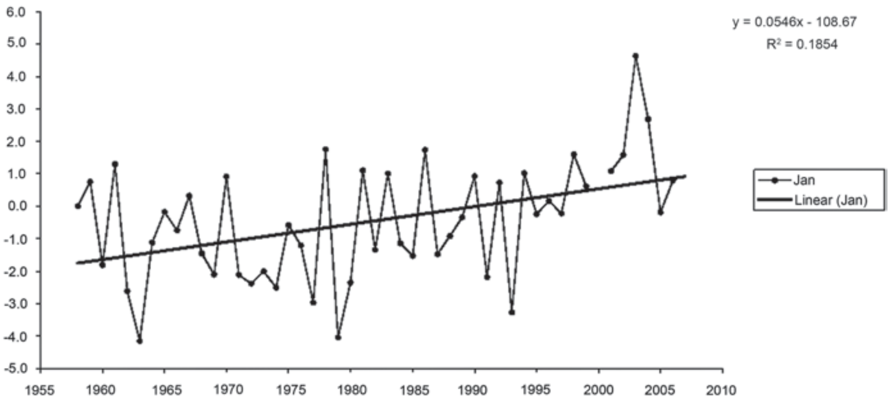

Fig. 2.8 Mean daily minimum air temperatures (°C) in January at the CS2 meteorological station in the H.J. Andrews Experimental Forest, 1958–2007. January is the month showing greatest warming at this meteorological station. January minimum air temperature has increased by 2.7 °C (36.86 °F) over the period 1958–2007. Monthly minimum air temperature is significantly correlated with the Pacific Decadal Oscillation (PDO), a measure of sea surface temperatures in the northern Pacific Ocean ($r^2=0.19$, 0.13, and 0.31 for January, March, April). When the effect of PDO is removed, January minimum air temperature has increased significantly by 2.0 °C (35.60 °F) from 1958 to 2007

scope of this work at several Pacific Northwest EFRs is captured in recent books (Luoma 2006, Geier 2007, Herring and Greene 2007, Joslin 2007).

2.6.1 Long-Term Records

Long-term records from EFRs have become exceptionally valuable scientific resources and common ground for intensive collaboration between the research and natural resource management communities. Some of the most valuable records have documented straightforward phenomena, such as air temperature and streamflow. Records initiated for one reason have gained unexpected value as science questions, research tools, and societal issues have moved in new directions over the years.

Records of air temperature and streamflow spanning about 55 years for the H.J. Andrew EF in the Cascade Range of Oregon offer excellent examples (Figs. 2.8 and 2.9), and the same could be said of many other EFRs. At the national level, EFRs have been the anchor points for these types of records. While the National Weather Service and U.S. Geological Survey sustain weather and gauging stations around the country, the EFRs are distinctive in combining these records with others, such as the chemistry of precipitation and streamflow and long-term vegetation change, and do so in mountain terrain and on small watersheds where other agencies seldom sample. This broad portfolio of ecosystem components sampled provides wonderful opportunities for interdisciplinary synergies and learning.

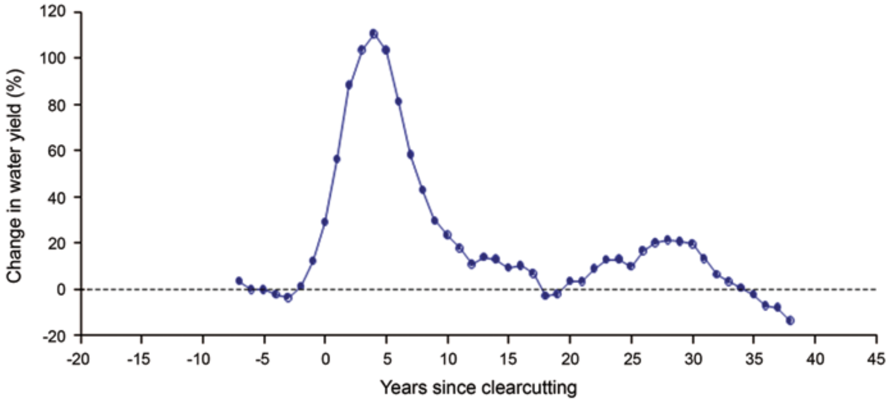

Fig. 2.9 Five-year running mean of percent changes in water yield relative to the pretreatment period in clearcut versus control watersheds at the H.J Andrews Experimental Forest for the water year (October–September). Maximum increases in annual water yield occurred in the first 5 years after clearcutting concluded in 1966, and were 110 % at the Andrews (460-year-old evergreen conifer forest). Maximum decreases in annual water yield occurred in the most recent record, 30–40 years after clearcutting, when annual yields were 86 % of pretreatment yields. (Adapted from Jones and Post 2004)

Uses of long-term environmental data have changed over time. Initially, data sets were used to characterize the environment of newly established EFRs. Record keeping commonly commenced with climate observations in support of studies in other fields, such as hydrology and forest growth. Initially, we thought that climate and streamflow were variable, but we did not expect them to exhibit long-term trends. However, as we now realize that climate change is underway, scientists return to the data sets with new questions; and interesting discoveries are emerging. For example, warming appears to be taking place in the H.J. Andrews EF, but the signal varies across the landscape and over the seasons of the year (most strongly in January—Fig. 2.8), which may have implications for biota and biological and geophysical processes. A part of the story now under investigation is the possibility that cold air drainage in this mountain landscape is ameliorating warming in valley floors during some seasons.

A focus of long-term streamflow studies is assessing annual water yield from clearcut watersheds blanketed with regrowing, young forest relative in comparison with runoff from unmanaged, control watersheds (Fig. 2.9). In the longest running experimental watershed study in H.J. Andrews EF, we observed greater runoff from the clearcut watershed for a period lasting more than 15 years. This is generally consistent with findings from similar studies in other sites.

Recently, we have made a surprising observation concerning streamflow from “control” watersheds (i.e., watersheds with no management actions). These have been exhibiting declining water yield for several decades. We do not yet have a clear explanation for this observation. Perhaps warmer air temperature is increasing evapotranspiration. Or perhaps vegetation succession over a period of several decades in the 150- and 500-year-old forests may be changing water use by vegetation. These observations are leading to new lines of research and fresh discussions of management implications.

Long-term environmental data have also become an important meeting ground for Forest Service researchers, land managers, and academic colleagues, thus fostering partnership efforts. Passions can run high on issues of public land management and policy, and long-term records ground discussions of these issues in objective measurements. Forest Service research has distinctive roles in the research–management partnerships involving these organizations collaborating at EFRs—maintaining long-term environmental records, guiding applied research projects, and helping bridge between research and land manager cultures. The partnerships extend well beyond the confines of the EFRs as scientists located elsewhere use long-term data for science and management purposes—in some cases never having to visit the field site.

An example of this role is found in the contributions that EFRs have made to our understanding and discussions of old-growth forests. Old-growth forests of the Pacific Northwest have meant many things to many people. In the 1930s, they were termed "large sawtimber"; in the 1960s, they were referred to as "decadent and overmature"; by the 1990s, those working for the preservation of these forests dubbed them "ancient" (Spies and Duncan 2009). Work at EFs brought important science into the picture. Highly interdisciplinary work in the International Biological Program at the H.J. Andrews EF during the 1970s revealed the great complexity of plant, animal, and fungal life of old forests and associated streams (Franklin et al. 1981). Further studies at Wind River, Cascade Head, and Pringle Falls EFs contributed to the picture of geographic variation in characteristics of old-growth forests. Findings from these studies have been used in conservation and restoration of old forests and also management of young plantations.

Over the 40 years history of public attention to old-growth forests, the EFs of the region have been a continuing source of new information from science, and also a meeting ground for public discussions of the future of the forest. This blending of the scientific work and public discourse is well represented in the recent book edited by Spies and Duncan (2009).

2.7 EFs of the Southern Research Station: Coweeta Hydrologic Laboratory: Long-Term Watershed Research in the Southern Appalachians

Jim Reaves, Katherine J. Elliott, and James M. Vose

How does our specific place within a larger landscape affect the way rain moves through forests and into soils and streams? How do changes in forest composition and structure affect these processes? How does our landscape affect the way we experience global weather patterns? The Coweeta Hydrologic Laboratory, located in the southern Appalachian mountains of western North Carolina, is one of 19

EFs across the southern USA within the Southern Research Station. Building on long-term climate, water quantity and quality, and vegetation data, the Coweeta Hydrologic Laboratory has advanced an interdisciplinary approach to understanding how watershed ecosystems respond to natural and human-caused disturbances. The basic philosophy is that if we understand how the watershed ecosystem works—the interconnections between climate, vegetation, soils, and water—then we can develop management practices to deal with the consequences of disturbances such as climate change, insects and disease, and extreme storm events. This approach requires integrating many scientific disciplines to understand the complex nature of both natural and managed forest ecosystems. Long-term data and experiments at Coweeta have been critical for separating treatment responses from natural variation; for testing hypotheses about vegetation, soil, and climatic controls on ecosystem processes; and for developing, testing, and validating predictive models.

2.7.1 Climate

Much of what is known today about mountain climatology and hydrology was determined from the extensive long-term climate network at Coweeta. For example, at the basin scale, precipitation consisted of frequent, small, low-intensity rains with occasional large storms at longer return intervals. In general, precipitation increases with elevation (about 5 % per 100 m) along the east–west axis of the Coweeta valley but changes little with elevation over north–south-facing side slopes (Swift et al. 1988). On an annual basis, precipitation exceeds evapotranspiration demand and streams flow perennially. Soil depth decreases and slope steepness increases with elevation. Both factors reduce the ability of the watershed to retain precipitation and thus increase the percentage that appears as streamflow. Upper elevation watersheds have lower precipitation minus runoff (P−RO) factors because they have less soil moisture storage capacity, a relatively higher percentage of precipitation as quickflow, and less evapotranspiration demand to create soil moisture storage opportunity before a rain (Swift et al. 1988). In addition to understanding rainfall–runoff relationships in managed and reference watersheds, accurate long-term climate measurements are critical for detecting variation in local climate. For example, climate trends at Coweeta reflect more extreme events in annual precipitation (Fig. 2.10) in the past two decades and an increasing temperature (Fig. 2.11) since the mid-1970s.

2.7.2 Water Quantity

Coweeta has been a leader in developing highly accurate measurement and data analysis procedures for gauged watersheds since 1934. Coweeta's 15 gauged watersheds provide some of the longest and best quality streamflow data in the world. The paired watershed approach—where one watershed is treated and one serves as a

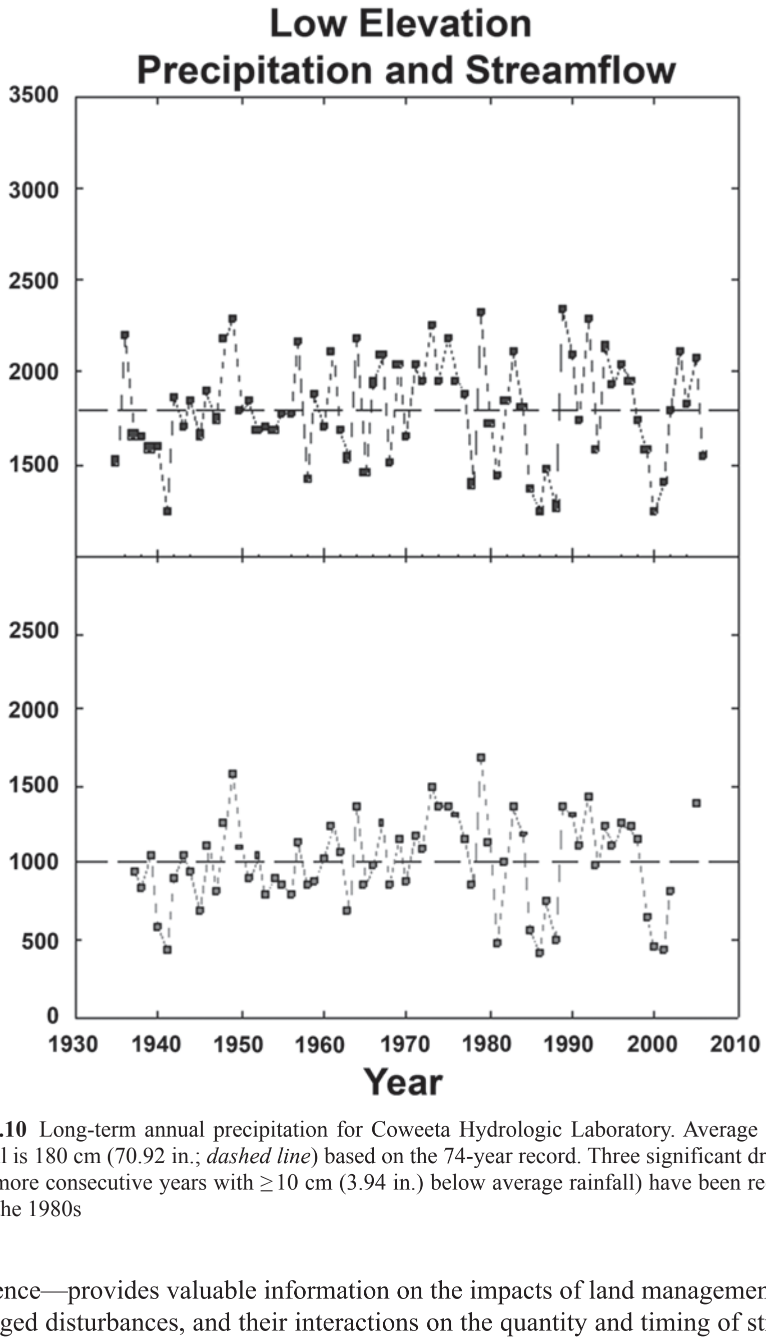

Fig. 2.10 Long-term annual precipitation for Coweeta Hydrologic Laboratory. Average annual rainfall is 180 cm (70.92 in.; *dashed line*) based on the 74-year record. Three significant droughts (2 or more consecutive years with ≥10 cm (3.94 in.) below average rainfall) have been recorded since the 1980s

reference—provides valuable information on the impacts of land management, unmanaged disturbances, and their interactions on the quantity and timing of streamflow from forested watersheds. The long-term data are also extremely valuable for developing and validating hydrologic models. Watershed-scale experiments include high-elevation (WS37) and low-elevation (WS7) clearcuts, pasture (WS6), white

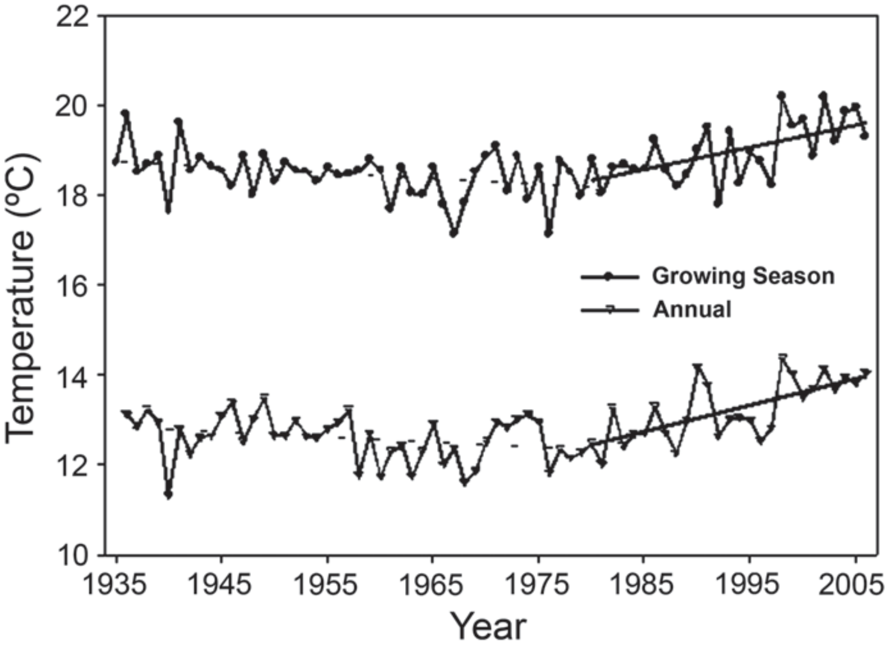

Fig. 2.11 Mean annual and growing season temperature for Coweeta Hydrologic Laboratory. Since 1976, a small but continuous increase in temperature has been recorded

pine (WS1 and WS17, Fig. 2.12), evergreen understory removal (WS19), 50% basal area removal (WS22), and multiple use (WS28). In addition to examining fundamental relationships among management, natural disturbance, and hydrologic processes, these long-term studies are being used to address important societal concerns both in the USA and internationally. For example, watershed experiments at Coweeta are being used to answer questions such as: (1) Does forest cutting increase flood risk? (2) Can forest cutting be used to augment streamflow to meet future water needs? (3) What are the hydrologic consequences of varying land cover types? (4) How does management interact with other stressors, such as extreme climatic events and native and nonnative invasive insects and diseases?

2.7.3 Water Quality

In the early days of Coweeta research, water quality research focused on sediment production as a result of land-use demonstration experiments (WS10 and WS3). In the 1970s, water quality research expanded to include water chemistry and nutrient transport, moving Coweeta into the area of ecosystem and nutrient cycling research (see Vose et al., Chap. 17). Coweeta now has a 36-year record of atmospheric deposition inputs and stream chemistry outputs. Coweeta scientists have used these

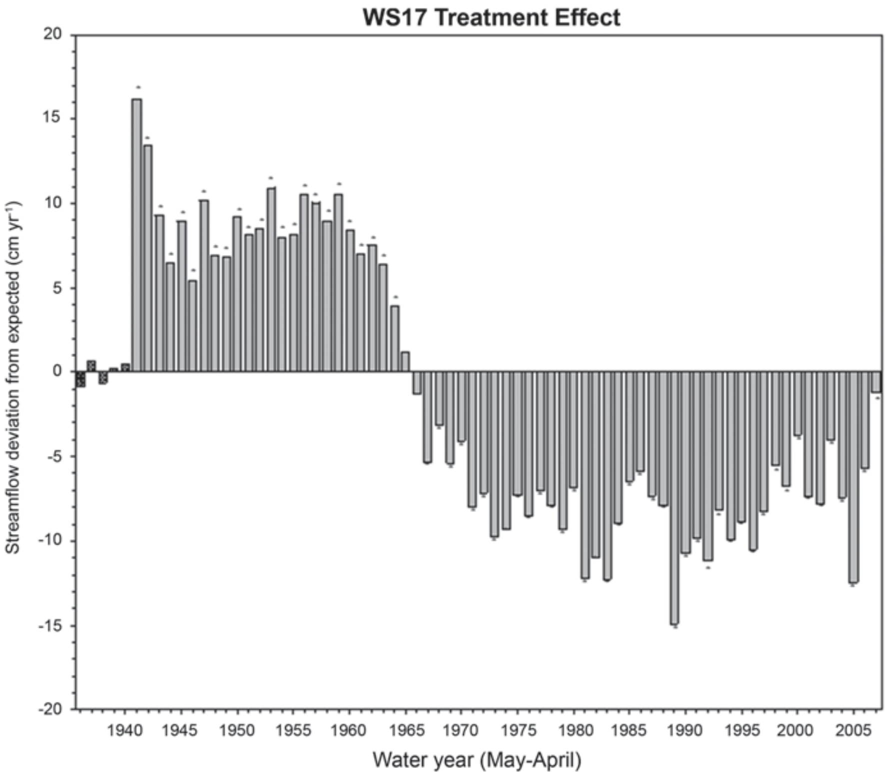

Fig. 2.12 Streamflow deviation from expected value for watershed 17, a deciduous forest that was converted to a white pine (*Pinusstrobus*) plantation in 1967. Reduced streamflow on the pine stand is attributable to greater interception and transpiration in the fall, winter, and spring

data to examine long-term changes in nutrient cycling patterns on reference watersheds (WS18 and WS27), effects of commercial clearcutting (Fig. 2.13, WS7), effects of prescribed burning, and effects of SO_4 deposition on class I wilderness areas. Knowledge gained from the long-term research program has had broad application. For example: Southern Appalachian forest watersheds retain nutrients—stream water has very low nutrient concentrations. Rapid vegetation recovery after disturbance retains nutrients on site. Long-term chronic acidic deposition may alter stream chemistry, particularly at high elevations. Losses of total site nitrogen after prescribed fire results from mass loss due to combustion not export via streams.

In addition to serving as signatures of ecosystem response to management and natural disturbances, stream chemistry studies provide guidance for forest management and streamside management and restoration. These long-term data are critical for understanding the relationships among disturbance, management, and water quality—and for developing the guidance to keep forests healthy and productive and water protected by the riparian zones that keep nutrients bound up in soils and vegetation. Further, these data have been important for validating computer-

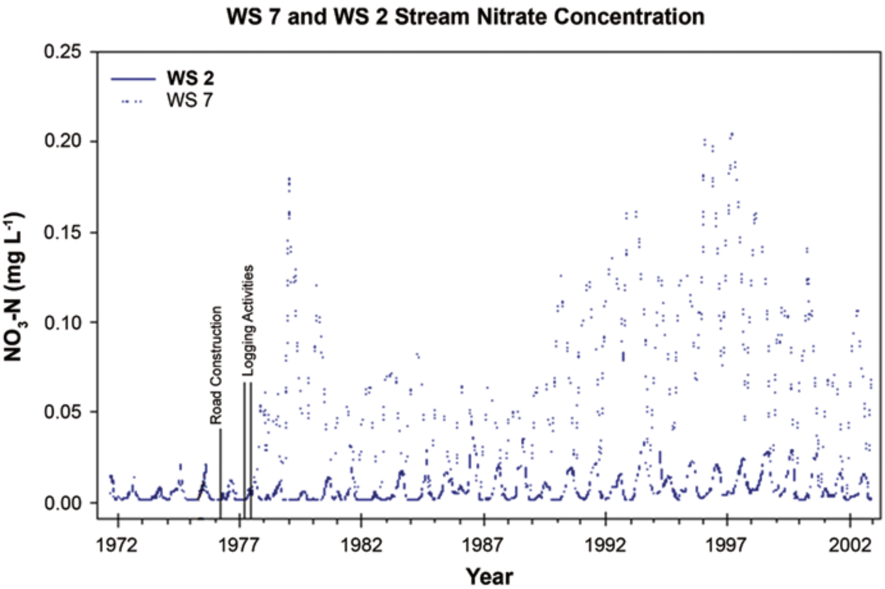

Fig. 2.13 Long-term changes (20 years) in water yield, the storm hydrograph, stream inorganic chemistry, and sediment yield were analyzed for a 59-ha (145.73 acres) mixed hardwood-covered catchment (Watershed 7; Swank et al. 2001). Stream chemistry has been measured on both WS7 (clearcut in 1977) and WS2 (reference) since late 1971. Nitrate (NO_3–N) concentrations began to increase on WS7 in early fall 1977, about 9 months after the initiation of logging and at the conclusion of site preparation cutting. Concentration increases remained low (0.02 mg L^{-1}) through the following summer and then peaked (0.18 mg L^{-1}) during the winter of 1978. A second peak also occurred the next summer. With forest regrowth, NO_3–N concentrations declined; peak summer values during the next 9 years were 0.07 to 0.12 mg L^{-1}. However, beginning in the summer of 1989, NO_3–N concentrations began to increase again, with peak values near 0.22 mg L^{-1}. In fact, in the summers of 1992 and 1995, stream water NO_3–N concentrations equaled or exceeded values observed in the first several years after clearcutting. Studies are currently being conducted to examine causal factors for the observed variation in stream NO_3 on WS7

based models that predict how Southern Appalachian watersheds might respond to changes in climate and air pollution.

2.7.4 Vegetation

A network of more than 900 permanent vegetation plots was first measured in 1934 and a subset has been remeasured in 1969–1972 and 1988–1993 (Elliot et al. 1999). Long-term vegetation plot surveys have allowed Coweeta scientists to evaluate the changes in forest structure, composition, and diversity from numerous disturbances, such as logging, drought, hurricanes, and invasive insects and pathogens. For example, American chestnut (*Castanea dentata*) was eliminated from the southern Appalachians and the eastern USA (Ellison et al. 2005) by the chestnut blight fungus

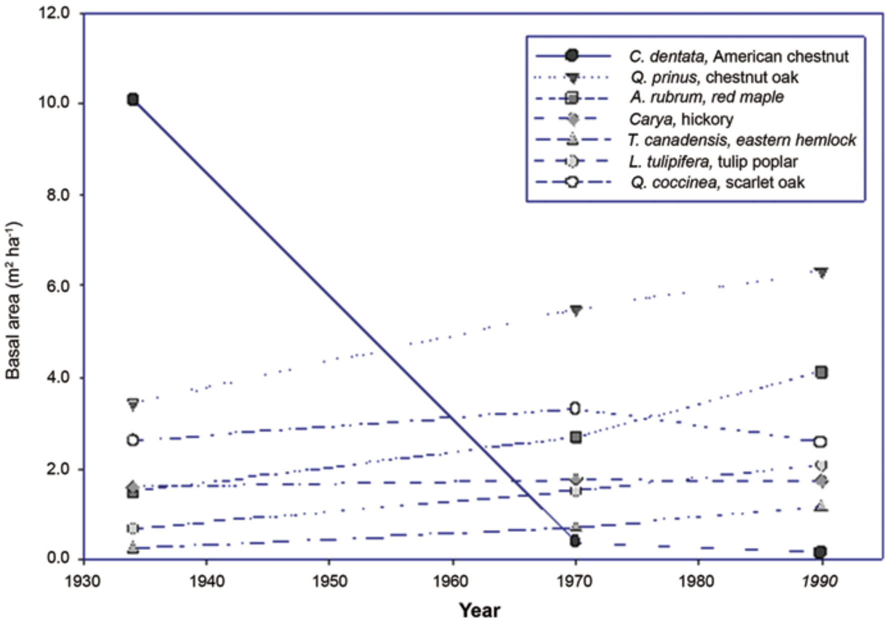

Fig. 2.14 Long-term changes in select tree species in the Coweeta Basin from inventories of permanent plots in 1934–1935, 1969–1972, and 1988–1993. American chestnut was the most abundant species in 1934, then it declined dramatically due to the chestnut blight fungus (*Endothiaparasitica*). Eastern hemlock increased in abundance and distribution, especially near streams across elevations. Tulip poplar replaced American chestnut in moist coves. Chestnut oak and red maple are ubiquitous, much like American chestnut before the chestnut blight, becoming dominant or codominant species across all environmental conditions. Red maple is now the second most abundant species in the Coweeta Basin. (Elliott and Swank 2008)

(*Endothiaparasitica*). In the 1934 survey, American chestnut was the most abundant species in the Coweeta Basin (Fig. 2.14). With the loss of American chestnut as the dominant species, other tree species replaced it in the forest canopy. Red maple (*Acer rubrum*) and chestnut oak (*Quercus prinus*) became the dominant species and tulip poplar (*Liriodendron tulipifera*) and eastern hemlock (*Tsuga canadensis*) were more abundant in coves and along riparian corridors (Elliott and Swank 2008). Hemlock, a species that increased following the loss of American chestnut, is threatened by another invasive species, hemlock woolly adelgid (HWA; *Adelgestsugae*; Ford et al. 2007; Nuckolls et al. 2009).

Long-term vegetation measurements at Coweeta have been used to understand the linkages between vegetation composition, structure, and watershed ecosystem processes. For example, ecosystem processes have changed with the demise of American chestnut and subsequent replacement of that species by others with different growth rates, litter qualities, and decomposition and nutrient cycling rates. Coweeta scientists are currently investigating the effects of the potential demise of eastern hemlock on ecosystem processes such as water (Ford and Vose 2007; Ford et al. 2007), carbon (Nuckolls et al. 2009), and nutrient cycling in riparian areas.

2.8 EFRs in the Rocky Mountain Research Station: Understanding Patterns of Forest Growth, Weather, and Disturbance

G. Sam Foster, Todd Mowrer, Russell Graham and Theresa B. Jain

How does forest growth integrate weather, insect and disease attach, management actions, and natural disturbance? Which of these has the most impact on forest growth, composition, structure, and change? These questions have animated the activities of scientists of the Rocky Mountain Research Station (RMRS) since its earliest days, and continue to animate our research today. RMRS is home to some of the first EFRs established in the Forest Service system: (1) Fort Valley Experiment Station was established in 1908 near Flagstaff, Arizona; (2) Fremont EF was established in 1909 on the Fremont and Pike National Forest near Wagon Wheel Gap Experimental Watershed (established 1911) and west of Colorado Springs, Colorado; (3) Priest River Experiment Station was established in 1911 at Priest River EF near Priest River, Idaho; and (4) Utah Experiment Station (now Great Basin Experimental Range) was established in 1912 near Ephraim, Utah. Perusal of the scientific and forest resource management literature, especially in the early to mid-twentieth century, reveals many examples of the research being conducted at least partially on EFRs (Daubenmire 1957; Davis 1942; Gisborne 1922). At one time, the current area of the RMRS contained at least 27 EFRs; the current number is 14.

The Priest River EF contains a long-term study that is representative of the ways we have answered the question about these interacting forces. The Priest River EF was established in the fall of 1911 and its northern Idaho location was selected because it contained the major forest types occurring in the northern Rocky Mountains and inland northwestern USA. The early researchers at Priest River EF recognized the value and importance of quantifying the response of forests to management actions (silviculture), disturbances, and weather. Within days of arriving at the forest, these scientists located a weather station in the compound at Priest River EF, at which temperature and precipitation have been continuously recorded since 1911 (see, Climate of the Priest River Experimental Forest 1983). After installing the weather station, they began establishing experiments on the forest to investigate how stands responded to silvicultural activities (cleanings, weedings, thinnings, and regeneration methods) and compared these results to how forests developed naturally. The resulting combination of vegetative growth data and weather data provides invaluable insights into patterns of forest change in managed and unmanaged stands, one example of which we provide here.

In 1914, a series of eight 0.2-ha plots were established adjacent to the weather station at Priest River EF to follow the development of both thinned and unthinned mixed conifer stands. These plots typified where western white pine (*Pinusmonticola* Douglas ex D.Don) forests grow as they receive at least 635 mm of precipitation a year and have a minimum of 25.4 cm of ash-capped soils underlying them (Haig et al. 1941; Jain et al. 2004). Western white pine and western larch (*Larixoccidentalis* Nutt.) were the dominant species with all other moist forest species present.

Initially, the plots were measured every 5 years; however, in 1954, the remeasurement cycle was extended to every 10 years. Each tree on the plots was tagged and heights and diameters were measured each time the plots were visited. As trees regenerated, they were added to the plot and the cause of death was noted for dead trees. Fire was excluded from the plots but weather (e.g., wind, snow ice), insects, and diseases impacted how the stands developed and the effects and evidence of these agents were recorded for each tree.

When established, the untreated plot contained a mix of naturally regenerated conifers about 30 years of age. The plot contained about 2,471 trees per hectare and 35.8 m^2/ha of basal area.

At Priest River EF, as in most of the western USA, the late 1920s and early 1930s was a period of low precipitation (Fig. 2.15c). Although this was the driest period in the history of Priest River EF, the reduced precipitation only minimally impacted tree growth as illustrated in Fig. 2.1 by the slight change in the slope of the basal area curve for the years 1933–1936. In addition, from 1921 through 1925 some low average minimum temperatures (Fig. 2.15b) occurred at Priest River EF. Growth of native forests on the Priest River EF was not impacted by this cold; however, the low temperatures killed a family of ponderosa pine trees of California origin growing at the forest. From 1940 through 1947, the average warmest high temperature ever recorded at the forest occurred and there was also a spike in the average minimum temperature observed (Fig. 2.15a and 2.15b). Again these climate fluctuations were not noticed in the growth of the native forests, as basal area exceeded 57.9 m^2/ha in 1948.

In 1985, the basal area occurring on the untreated plot peaked at 65 m^2/ha. A peak or culmination of volume and basal area around age 120 years is the norm as a western white pine forest ages or the stand becomes fully occupied (Haig 1932), not much different from the 110 years of age found on this plot. However, the decline exhibited in basal area in this undisturbed stand was the result of the mortality caused by disease in both western white pine and western larch. An introduced disease, white pine blister rust (*Cronartium ribicola*) killed the majority of the western white pines and red ring rot (Phellinuspini) significantly reduced the number of western larch. These tree species are being succeeded by grand fir (*Abiesgrandis* (Douglas ex D. Don) Lindl.), western red cedar (*Thujaplicata* Donn ex D. Don), and western hemlock (*Tsugaheterophylla* (Raf.) Sarg.); all shade-tolerant or late successional species, which in 2004 dominated the plot. This example showed that disease could be a major driver of forest development, while, at least in this case, the forests were very resilient to weather variation.

What we have illustrated here is only one of the hundreds of plots (replicated and non-replicated) for all types of vegetation, wildlife, insects, diseases and various other uses that have been established on the EFRs of the RMRS. This resource encompasses all of the vegetation types of the Rocky Mountains, desert and plains, and when combined with weather information the analytical and modeling possibilities are numerous. For example, data from these plots and many others located on RMRS EFRs are uniquely useful for validating models of forest growth, such as the Forest Vegetation Simulator (FVS; Dixon 2002). This forest growth model is used throughout North America and has utility at all levels of local to national forest management. Prediction of tree mortality, especially that induced by stresses and diseases, is greatly strengthened when data are available concerning trees and their growing conditions

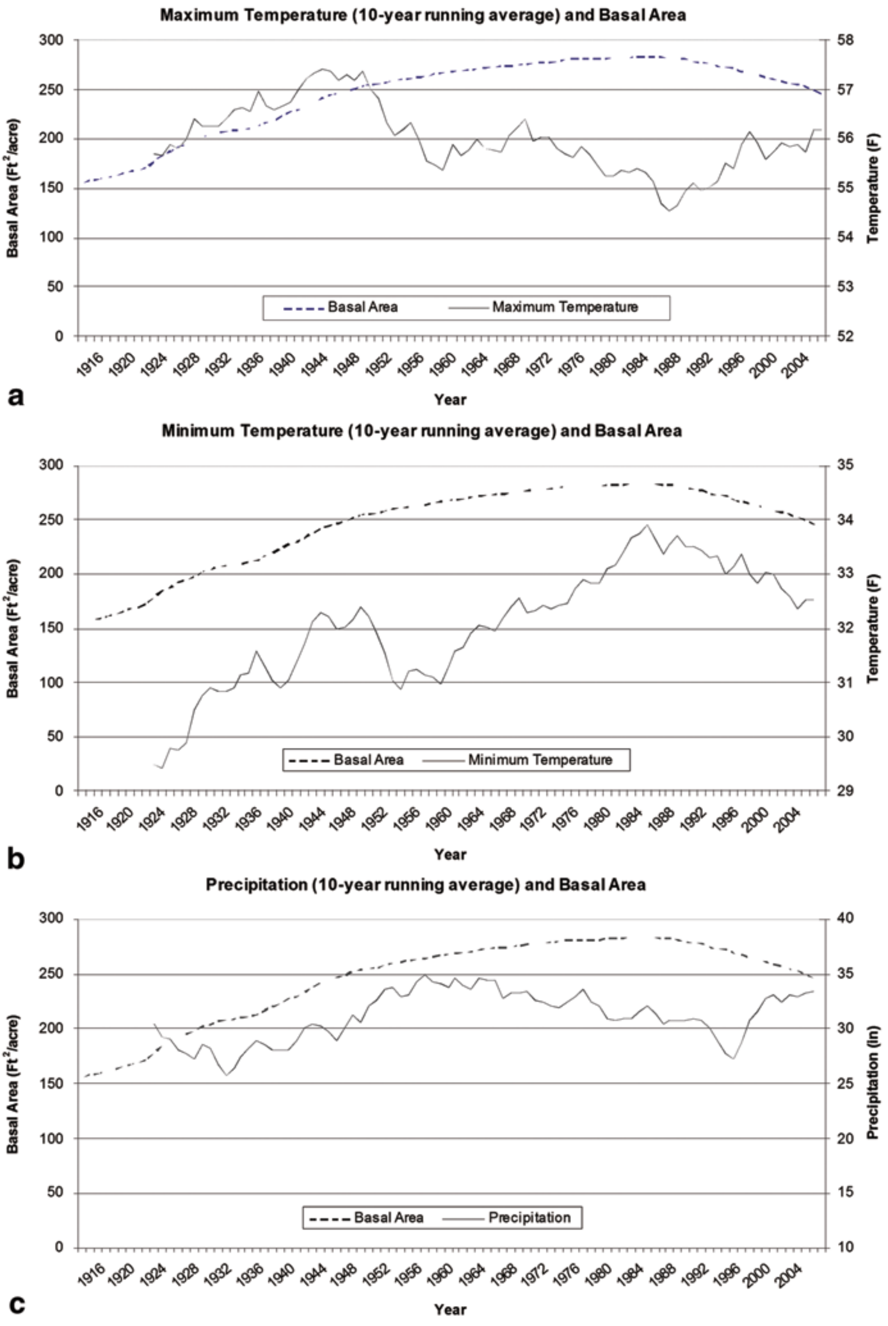

Fig. 2.15 The basal area growth of a natural mixed conifer stand located on the Priest River Experimental Forest in northern Idaho was minimally impacted by climate variations from 1914 through 2004. (**a**) Temperatures and precipitation (**b**) are displayed as 10-year running averages and basal area was estimated (**c**) from 5- and 10-year remeasurements of a fixed 0.2-ha (one-half acre) plot

over time. Permanent plots and associated long-term weather records such as those we have at Priest River EF are well suited to fulfilling this need, and will become more important as climate changes accelerate through the next century.

2.9 Conclusions

As directors of the seven regional research stations, each of us has found the long-term research conducted on EFRs a powerful tool for understanding patterns and processes of forests and forested watersheds at the deepest level. Scientists in Forest Service R&D have used—and continue to use—these data to answer critical societal questions, such as the cumulative effects of forest harvesting activities over time and space or how climate is changing. They have used EFRs to develop and test new methods of conducting natural resource science, from biogeochemistry to measurement of growth in tropical forests. What lessons emerge from our experience with these very valuable long-term data sets and studies on EFRs?

Data quality matters and reflects commitment throughout the R&D organization. The human dimension of long-term environmental research is as critical and challenging as the science itself. Long-term record keeping, even for seemingly simple measures of the environment, requires dedicated team effort. Field technicians and professionals maintain and calibrate instruments and collect the data over the years, punctuated by icy days with frozen fingers and sweaty days in the heat of late summer. Data managers carefully comb the data for glitches, store it, and make the hard-won data available to others for analysis. Scientists use the data in many ways—some planned, some serendipitous. A key to keeping the work moving forward is to balance persistence in record collecting with attention to the issue of the day to show the value of the records. Inattention either to the long-term persistence in record keeping or to addressing its relevance to current issues puts the enterprise at risk. All this takes a great deal of dedication of the entire workforce, which is motivated in part by respect for the forest and streams.

Data consistency matters. When measurements are skipped in one data series, our ability to capture the relationship among different elements of the system is compromised. Surprising patterns documented at the Caspar Creek EF, or in the long-term water yields from unmanaged watersheds on the H.J. Andrews EF, would be more difficult to detect if background stream measurements were suspended between formal studies. The comparison of insect and disease with weather on forest growth and development on the Priest River EF and the observations about species composition over time on the Luquillo EF are only possible because detailed measurements have been sustained through decades.

Scale and sampling intensity matter. Scientists at the Coweeta Hydrologic Laboratory are able to draw conclusions about the variability in hydrologic processes at different elevations and along different axes of the EF only because their sampling grid represents these differences adequately. Scientists at the Luquillo EF have gained better understanding of the site relationships of the hundreds of species in their forests because the network of plots across that forest encompasses a wide variety of sites.

Fig. 2.16 Scientists confer in an old-growth forest in the H.J. Andrews Experimental Forest. (Photographer: Michael Furniss, U.S. Forest Service)

Scientist creativity matters. Our public discourse often treats climate change in a fairly simplistic way, but scientists at the HJ Andrews have noticed seasonal differences in the pattern of warming, leading them to hypothesize and study patterns of the effects of cold air drainage on valley floor climate. Shigo, working with timber quality research data from northern EFRs, identified applications in urban and suburban tree care.

The ability to manipulate trees and forests matters. Shigo's research on tree quality and recovery from wounds depended upon the ability to damage trees, and Caspar Creek's ability to assess cumulative effects depended on the ability to superimpose disturbances on sites with long-term data records.

Sites with long-term data records are places in which important conversations can occur. Across the wide range of public opinion about sustaining forests and their values and benefits, passion for the forest itself is a common denominator. While EFRs are in no sense a panacea for the deep divisions in public opinion, their value for demonstrations and conversations cannot be overstated.

Data such as those acquired from permanent plots and long-term weather stations provide a more compelling and richer record than that acquired by sampling forest vegetation at a single point in time or from chronosequences of plots established in forests of different ages. Such sampling does not capture fine-scale disturbances, their interactions, and how they influence forest succession. In addition to the specific benefits illustrated by these examples from each station director, these data are valuable for addressing such issues as changes in wildlife habitat, vegetative responses to climate change, vegetative successional pathways, water use, sense of place, and timber production. Additionally, permanent plots provide great demonstrations of how forests develop and the treated plots readily show what different structures and compositions can be created and maintained through silvicultural treatments. Such demonstrations are invaluable to managers when making informed natural resource decisions and equally invaluable for communicating to policy makers, scientists, and the public.

The work at EFRs can lead to unexpected discoveries as well as findings based on careful hypothesis testing. Even rather simple observations can have great impact, if data are gathered for long periods of time, maintained well, and shared. The EFRs have a central role in sustaining observations at individual sites, and collectively the EFRs form a backbone of continental-scale sentinels for observing environmental change in the context of twenty-first century issues. But above all, the EFRs are meeting grounds (Fig. 2.16) for scientists, land managers, the public, and many others to discuss what we know about forests, rangelands, and watersheds, what else we need to know, and how to engage with these ecosystems in the future.

Much of what we currently know about forest and range ecosystems and their management has its roots in R&D conducted at least partially on EFRs.

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