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.

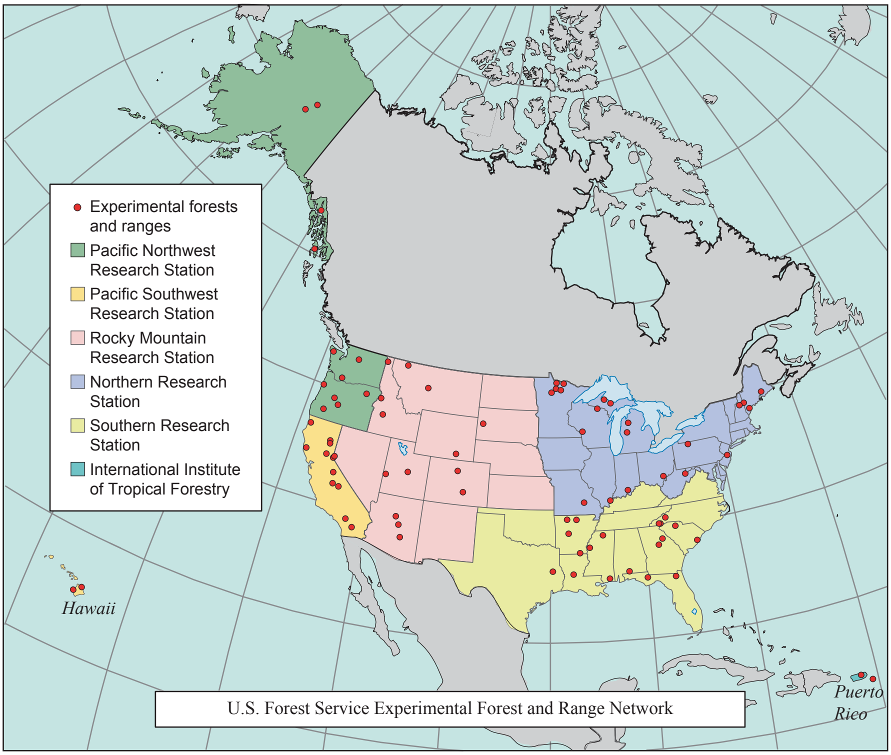

Fig. 2.1 The seven regional research stations of the USDA Forest Service, with locations of the 80 Experimental Forests and Ranges

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

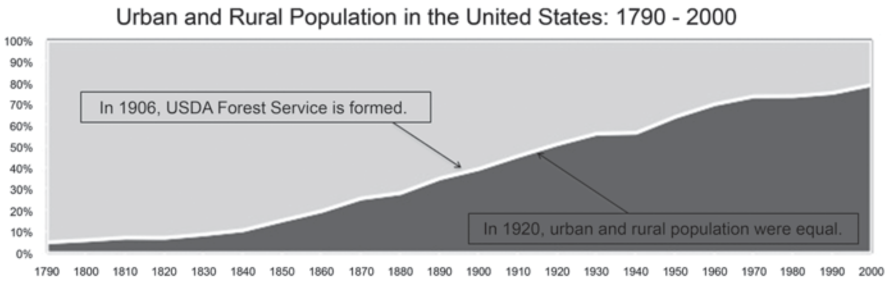

Fig. 2.2 Percentage of the US population that is urban (*dark area*) or rural (*clear area*) between 1790 and 2000. At 50 %, the rural and urban population was equal

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,

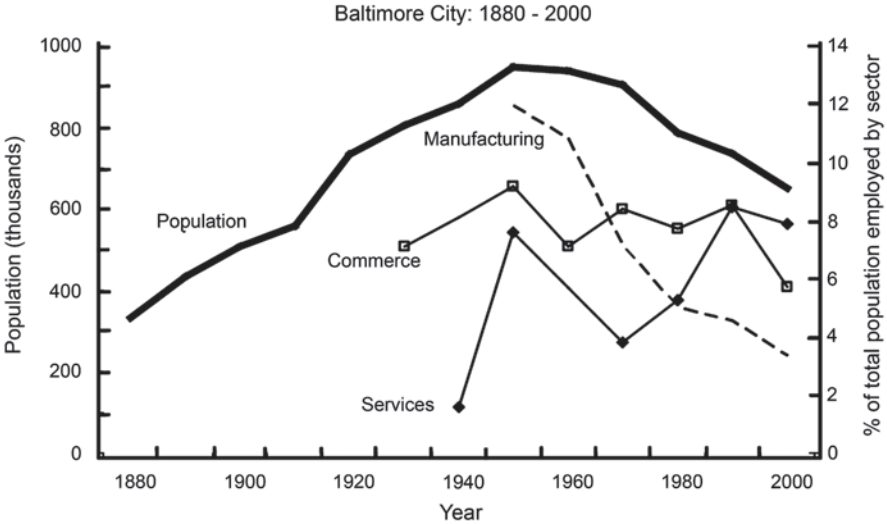

Fig. 2.3 The population of Baltimore between 1880 and 2000 and the proportion of the population involved in three economic activities

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

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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

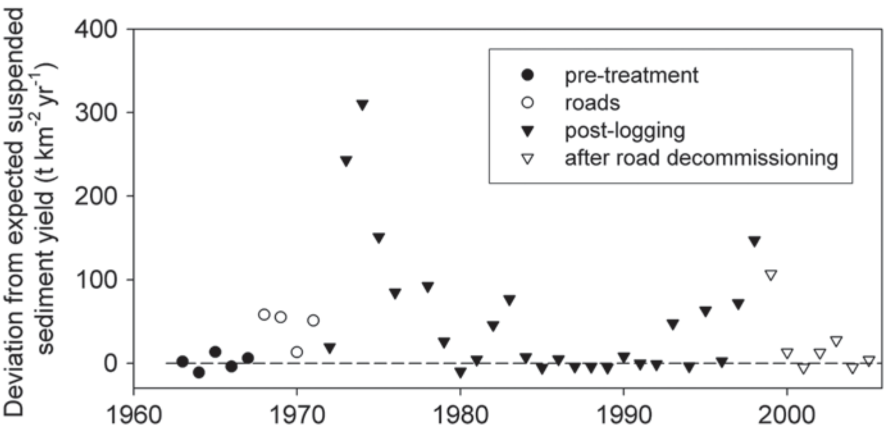

Fig. 2.4 Deviation of annual suspended sediment production in the South Fork Caspar Creek watershed from that expected for unlogged conditions. Roads were constructed in 1967, and the watershed was selectively logged between 1971 and 1973

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

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