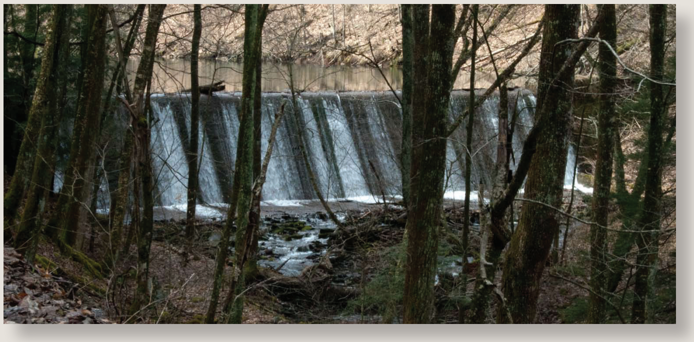
Fernow Experimental Forest: Research History and Opportunities



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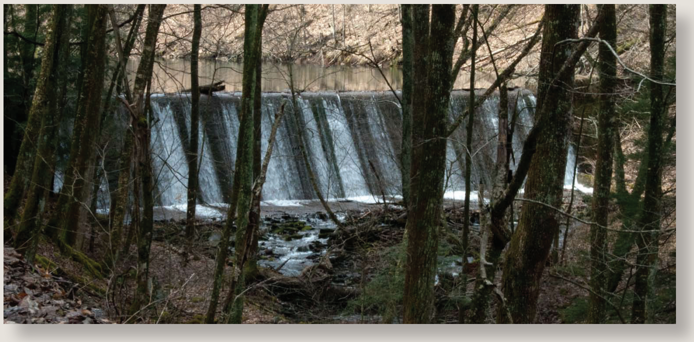

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Introduction

The Fernow Experimental Forest (39.03° N, 79.67° W) is located in north-central West Virginia near the community of Parsons, in the Allegheny Mountain section of the mixed mesophytic forest (Braun 1950). Named after Bernhard Fernow, an early forestry research pioneer, the Fernow Experimental Forest (Fernow) was established in 1934 from land originally purchased as the first tract for the Monongahela National Forest (Monongahela). The Fernow was set aside to "make permanently available for forest research and the demonstration of its results a carefully selected area representing forest conditions that are important in Northeastern West Virginia." The Fernow Establishment Order, dated March 28, 1934, and on file at the Timber and Watershed Laboratory, Parsons, WV, was signed by Arthur A. Wood, supervisor of the Monongahela, and E.H. Frothingham, director of the Appalachian Forest Experiment Station, who, in the order, described the forest at the time and detailed working relationships between the Monongahela and the Appalachian Forest Experiment Station.

Early research on the Fernow focused on silviculture. Put on hold during World War II because of manpower limitations, research began again in earnest when the Northeastern Forest Experiment Station established a branch unit on the Fernow in 1948 (Trimble 1977). Early post-war work on the Fernow involved collecting inventory data, establishing study compartments, and constructing weirs on small watersheds (Trimble 1977). In 1964, headquarters were established at Parsons and named the Timber and Watershed Laboratory.

The Fernow is managed by the Northern Research Station's Research Work Unit NRS01, Ecological and Economic Sustainability of the Appalachian Forest in an Era of Globalization. The mission is to *develop timely, relevant knowledge and provide management guidelines to sustain and enhance the ecological and economic function and value of Appalachian forests in the context of changing environments and human values.* The Fernow serves as an outdoor laboratory where scientists from the Timber and Watershed Laboratory and cooperating institutions focus their work on two goals.

1. To provide useful management information critical for sustaining and enhancing Appalachian forests, we must *understand forest ecosystem processes and properties and their responses to natural disturbances and management actions at multiple scales.*

2. To support the sustainability and health of forest communities and forest-based industries in a changing world, we must *discover and disseminate knowledge of forest management, silviculture, forest product economies and markets, and efficient resource utilization. Further, we must deliver tools and recommendations to help our partners and customers better sustain forests for a variety of outcomes, products, and uses.*

General Description of the Research Area, Including Historical Perspective

The early history of the area that is now the Fernow Experimental Forest is well described by Trimble (1977) and Kochenderfer (2006). Most of the Elklick Run watershed, which was originally a land grant to Frances and William Deakin from the State of Virginia in 1783, is now part of the Fernow. A Deakin heir sold the 1,673-hectare (ha) Big Spring tract to Jonathan Arnold for $4,000 in 1856 (Fansler 1962). In 1915, the U.S. Department of Agriculture (USDA), Forest Service purchased 2,888 ha of land, which included the Big Spring tract, for about $40,000. The Forest Service established the Fernow on March 28, 1934. The original boundary of the Fernow contained 1,473 ha, encompassing almost the entire watershed of Elklick Run (fig. 1), a fourth order tributary of the Black Fork of the Cheat River, and was expanded to 1,902 ha in 1974. In the 1930s, the Civilian Conservation Corps (CCC) constructed many of the main access roads on the Fernow. Like the early railroads, many of these roads were located close to Elklick Run.

The first permanent settlement near the Fernow was established in 1776 (Fansler 1962), but most of the settlement and some land clearing occurred later, in the 19th century. As late as 1880, less than 1 percent of the area surrounding the Fernow had been cleared, at least partly because the mountainous terrain was not well suited for agriculture (Maxwell 1884). The arrival of the railroad in 1890 to Parsons (Fansler 1962) stimulated timber harvesting and the rapid development of forest-based industries in the area that is now the Fernow. The largest sawmill near the Fernow, the Otter Creek Boom and Lumber Company, began operating in 1897 (Fansler 1962). Two tanneries that used hemlock and chestnut oak bark and a large pulp mill were also located nearby. The Elklick Lumber Co. established a single-band sawmill near the mouth of Elklick Run in 1902; this mill sawed the timber that was harvested from what is now the Fernow.

Current Land Use

The Fernow is dedicated to research and demonstration, according to the original Establishment Order and the Monongahela's Revised Forest Plan (2007, Section 8.5). Research is the primary land use, although the Fernow also is popular for wildlife viewing and recreational activities. The Fernow shares its eastern boundary with the Otter Creek Wilderness, and two trailheads into the Wilderness are located on the Fernow. Camping and fires are not permitted on the Fernow, but hunting, which is an important local pastime, is allowed. Collecting firewood is controlled through a permit system, but it is not allowed in many places on the Fernow. Collecting medicinal herbs or other vegetation is not allowed, because it could interfere with ongoing vegetation research. Approximately 1,000 visitors per year visit the Fernow to learn about the research being conducted and about forest management and ecosystems. Groups of visitors range from school children to college students, to professional foresters and visiting scientists from around the world.

Climate

The growing season on the Fernow extends from May through October, and the average length of the frost-free season is 149 days (unpublished data, Fernow Experimental Forest; on file at the Timber and Watershed Laboratory, Parsons, WV). Leaves begin emerging in late April, are fully developed by early June to mid-June, and begin to fall in late August or early September. Snowfall commonly occurs from December through March but can also occur intermittently in October, November, April, and May. Snowpacks typically are short lived; most of the snow accumulations generally melt within a few weeks at all but the highest elevations (elevations range from 533 to 1,112 meters (m)) and coolest aspects (east and north aspects).

Annual precipitation has averaged 145.8 cm over the past 30 years and is relatively evenly distributed between growing and dormant seasons. The months of highest average precipitation are May (14.5 cm), June (13.9 cm), and July (16.1 cm), and the months of lowest average precipitation are February (10.1 cm), September (10.6 cm), and October (9.2 cm). Precipitation during the growing season commonly occurs as convectional thunderstorms, and periods of high precipitation intensity are often associated with these storms. Although precipitation originating from regional frontal systems also occurs during the growing season, regional frontal systems are most common during the dormant season. These regional frontal systems can result in storms that span 2 or more days. Throughout the year, precipitation events occur, on average, about every 3 days (Patric and Studenmund 1975).

Mean annual air temperature on the Fernow over a 30-year period is 9.3 °C, with a minimum of 7.3 °C occurring in 2003 and a maximum of 10.9 °C in 1991 (unpublished data, Fernow Experimental Forest, based on the years 1978–2007, available at the Timber and Watershed Laboratory, Parsons, WV). Mean monthly temperatures range from -2.8 °C in January to 20.4 °C in July. Potential evapotranspiration was estimated to be 56 cm per year (Patric and Goswami 1968).

Disturbances

Prior to settlement, forests were shaped by a variety of natural and human-caused disturbances, including wind, fire, and agricultural practices (Maxwell 1910), resulting in "a diverse mosaic of forest stands whose age, tree species, and wildlife varied widely…" (MacCleery 1992). The Fernow was logged from 1903 to1911 using the conventional technologies of the day. A railroad was constructed along Elklick Run, and Climax and Shay steam engines transported logs to the company sawmill near the mouth of Elklick Run. Horses and, in some cases, log slides were used to move logs from the woods to the railroad. Logging was heaviest near railroads, and trees that were inaccessible or of low value were not felled (Kochenderfer 2006).

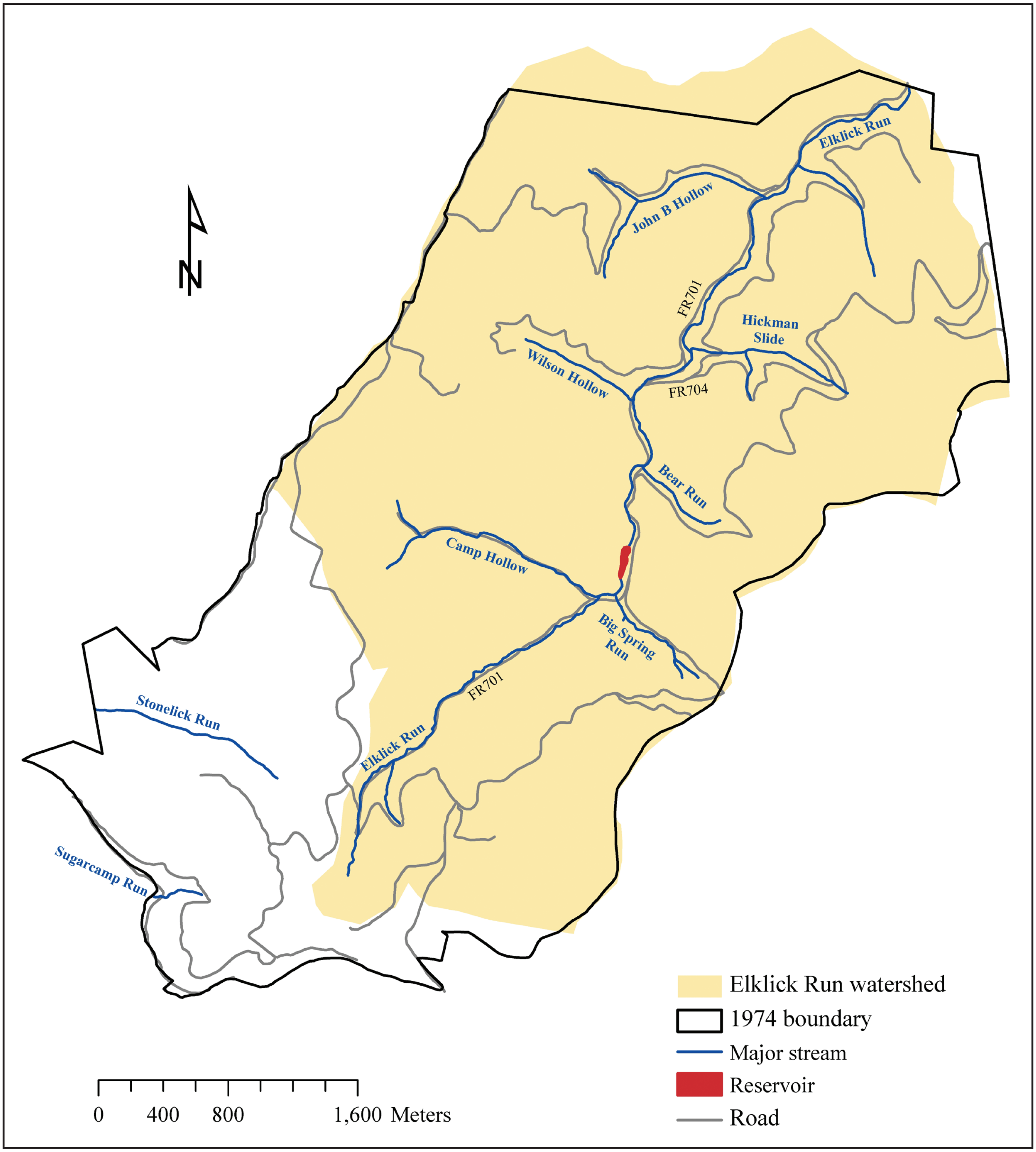

Figure 1. The Fernow Experimental Forest.

Woody regeneration was abundant, and a 1932 cover type map indicated that the entire tract was forested, except for about 50 hectares of pasture and fields.

After this initial logging of the Fernow, the next major disturbance was the widespread death of American chestnut (*Castanea dentata* [Marsh.] Borkh.) due to the chestnut blight (*Cryphonectria parasitica*). Weitzman (1949) estimated that 25 percent of the timber volume on the Fernow was composed of American chestnut before the blight. Using old land surveys and early timber cruises from the area, Schuler and Gillespie (2000) estimated American chestnut importance values as 8.3 percent in the 1856 old-growth forest, 15.1 percent in 1915 after the first logging, 5.5 percent in 1922 after the onset of the blight, and completely absent from the overstory by 1948. Because of its rot-resistant wood, American chestnut coarse woody debris is still a major constituent in some watersheds (Adams et al. 2003).

More recently, several insects and diseases (Kuhlman 1978, USDA Forest Service 2003), most of them nonnative, have severely affected Appalachian forests. Those of potential or existing threat to the Fernow include butternut canker *(Sirococcus clavigignenti-juglandacearum*), dogwood anthracnose *(Discula destructiva*), hemlock woolly adelgid *(Adelges tsugae*), Asian gypsy moth *(Lymantria dispar*), beech bark disease *(Nectria coccinea* var. *faginata*), Dutch elm disease *(Ophiostoma ulmi*), emerald ash borer (*Agrilus planipennis* Fairmaire), and chestnut blight.

Air pollution is another chronic disturbance to which the Fernow has been exposed. In the 1980s, deposition of sulfate and nitrate in this region was among the highest in the United States. Since the enactment of the Clean Air Act amendments, wet deposition of sulfate and nitrate has decreased significantly (fig. 2a); nonetheless, these levels still represent some of the highest in the Northeast. Tropospheric ozone concentrations remain a concern (fig. 2b) (Adams et al. 2006, Edwards et al. 2004).

Natural gas exploration and development are recent disturbances that must be added to the list. When the land was purchased in 1915, the subsurface mineral rights were not conveyed along with the surface rights, resulting in privately held mineral rights underneath the original Tract No. 1 (the Fernow and the northern quarter of the current Otter Creek Wilderness). In 2008, a gas well was drilled in a research compartment on the southeastern side of the Fernow, and, upon discovery of natural gas, a buried pipeline connecting the gas well to a delivery pipeline was installed across the western part of the Fernow (Adams et al., 2011). Although the effects are generally localized, additional open space was created and will be maintained. In addition, other possible disturbances resulting from the gas well and pipeline must be considered and remain to be evaluated.

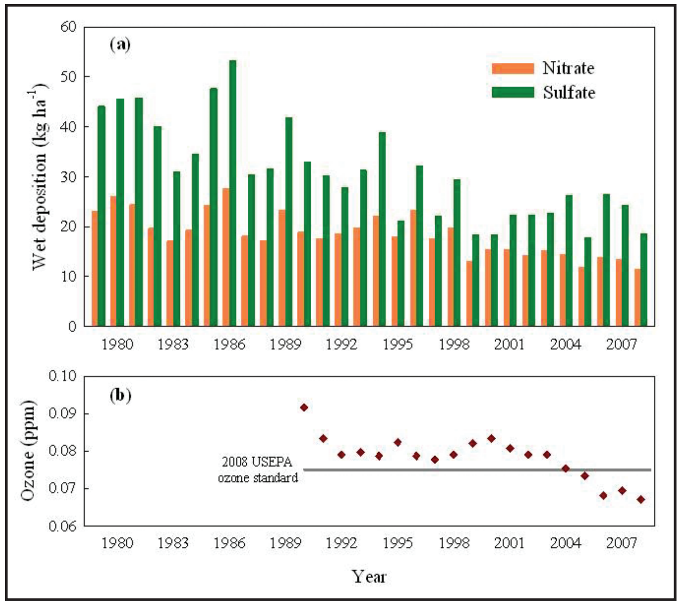

Figure 2. (a) Mean annual nitrate and sulfate wet deposition measured at the Timber and Watershed Lab National Acid Deposition Program site and (b) 3-year mean 4th highest 8-hour annual ozone concentration measured at the Timber and Watershed Lab Clean Air Status and Trends Network site.

Hydrology

Streams dominate surface water hydrology on the Fernow, although one small, spring-fed pond, which was constructed in the late 1980s, is located near the ridgetop on Fork Mountain. A reservoir that was used as the city of Parsons' primary water source from 1936 to the mid-1990s also is present on Elklick Run (fig. 1).

The watersheds on the Fernow tend to be bowl shaped. Streams in the Fernow generally begin as ephemeral reaches in the upper headwaters of watersheds and become intermittent and then perennial channels farther downstream. Some of the watersheds, however, have intermittently flowing springs that initiate tributaries, so the upper reaches of those channels may be intermittent. Most streams are ephemeral and intermittent channels.

Different segments of these ephemeral channels vary in their hydrologic responsiveness. Some segments may have surface flow during most storms and snowmelt events, while others, especially those farther upstream, may flow much less frequently, during only a few of the larger or more intense storms each year. Because of differences in flow frequencies, the ephemeral channels may have different physical characteristics along their lengths. Some segments are distinguishable only by scouring on the litter layer and perhaps the soil surface. Other ephemeral streams, or segments of those streams, are much more well defined and physically discernable as channels. The streambed consists of a combination of gravel and cobble.

Intermittent reaches flow in response to the presence of underlying local or seasonal water tables; thus, the upper extent of these channels varies over time. In general, they achieve their greatest longitudinal extent into the headwaters during spring when local water tables are fully recharged. As the growing season progresses, the upper reaches of the intermittent channels dry up and surface flow exists only farther downstream where the local water table continues to intersect the bottom of the streambed. Typically, the entire length of the intermittent channels dries up from about late August or early September through early November when evapotranspiration is high and precipitation is low. If precipitation events recharge local water tables during these periods, however, surface flow can return, at least temporarily. Streamflow in intermittent channels usually restarts more or less continuously in late fall or early winter; however, if winter conditions are sufficiently cold, snowmelt may be delayed, resulting in intermittent streams remaining dry during much of the winter. This situation is generally rare because rain-on-snow events or incoming warm fronts are common during most winters. Because of their propensity to have streamflow during the wettest portions of the year, intermittent channels are well defined.

Perennial channels also are well defined; they typically are wider and deeper than even the largest intermittent channels. Streams with perennial sections that flow into Elklick Run are John B. Hollow, Wilson Hollow, Camp Hollow, Big Spring Run, Bear Run, Hickman Slide, and an unnamed stream (fig. 1). Stonelick Run and Sugarcamp Run also have perennial sections on the Fernow (fig. 1). Long reaches of Elklick Run are eroded down to bedrock, particularly downstream from where Forest Service Road (FR) 704 crosses Elklick Run (fig. 1). Some reaches of Elklick Run above the intersection with FR 704 also have bedrock streambeds, but these reaches are much shorter (typically less than 3-5 m in length) than the downstream reaches. Overall, in the reaches not dominated by bedrock, the streambed of Elklick Run has moderate to relatively high amounts of materials less than 8 mm in diameter. Levels of fine sediment, less than or equal to 4 mm, are highest in portions of Elklick Run upstream of the reservoir (unpublished data; Fernow Experimental Forest; available at the Timber and Watershed Laboratory, Parsons, WV; fig. 1).

Baseflow dominates stream discharge in the Fernow as it does throughout the central Appalachian Mountains. Stormflow discharge is considered to be fairly flashy; that is, the storm hydrograph responds relatively rapidly to precipitation inputs and then returns quickly to baseflow conditions. Typically, stormflow discharge occurs less than 15 percent of the time.

The hydrologic, or water, year on the Fernow extends from May 1 through April 30. This water year is used because soil saturation is consistent and dependable in spring. Based on data for water years 1978–2007 from watersheds 1 through 13 (15 to 50 ha), streamflow averages are about 71 cm per year. This is approximately 48 percent of precipitation inputs. On watershed 14 (130 ha), streamflow has averaged 73 cm per year since gauging began in 1993. This larger catchment returns about 50 percent of precipitation as streamflow. In both instances, most discharge (averaging 73 percent) occurs in the dormant season.

Geology and Soils

Today's Appalachian Mountains are remnants of a much higher mountain system that was uplifted during the Appalachian Orogeny, which began about 250 million years ago (Cardwell 1975). Practically all exposed rocks in West Virginia are sedimentary, originating during the Paleozoic Era (Core 1966). Late in the Cenozoic Era, less than 100,000 years ago, glaciers crossed the North American continent but did not extend into West Virginia (Cardwell 1975); therefore there are no glacial features in the vicinity of the Fernow.

The geologic formations underneath the Fernow and the soils derived from them are closely related to elevation. The Upper Devonian Hampshire formation (Canon Hill Member) occurs on Fork Mountain between about 762 m and 854 m in elevation (fig. 3). This formation is typically associated with the Dekalb soil series (loamy-skeletal, mixed mesic Typic Dystrudept). The Upper Devonian Hampshire formation (Rowlesberg Member) occurs near the mouth of Elklick Run and extends to about 823 m above sea level on Fork Mountain (fig. 3). The most common soil on the Fernow, Calvin channery silt loam (loamy-skeletal, mixed, active, mesic Typic Dystrudept), derives from this formation. The Lower Mississippian Price formation (Pocono Member) occurs at about the same elevation on the southeastern side of Elklick Run (fig. 3). The Dekalb soil series is associated with this formation on benches in the headwaters of Elklick Run. In general, these geologic members are largely composed of sandstones and acid shales that weather into soil with low supplies of base cations. The most productive soils on the Fernow are derived from the Middle Mississippian Greenbrier Limestone formation that occurs above the Pocono formation at about 793 m elevation. Belmont silt loam (fine loamy, mixed, active, mesic Typic Hapludalf) is the most common soil associated with this formation on the Fernow. Early settlers of the region recognized the natural fertility of limestone-derived soils, often selecting them for agricultural use. The CCC also established a quarry on a limestone outcrop in this formation near Big Springs Gap in the 1930s to obtain stone for the Fernow road system.

The Mauch Chunk group occurs above the Greenbrier Limestone at around 854 m (fig. 3). The predominant soil associated with this group is the Cateache series, another highly productive soil (fine-loamy, mixed, active, mesic Ultic Hapludalf). Soils derived from the Greenbrier Limestone and Mauch Chunk groups occur in the upper reaches of Elklick Run and on the eastern side of the Fernow, while soils on the

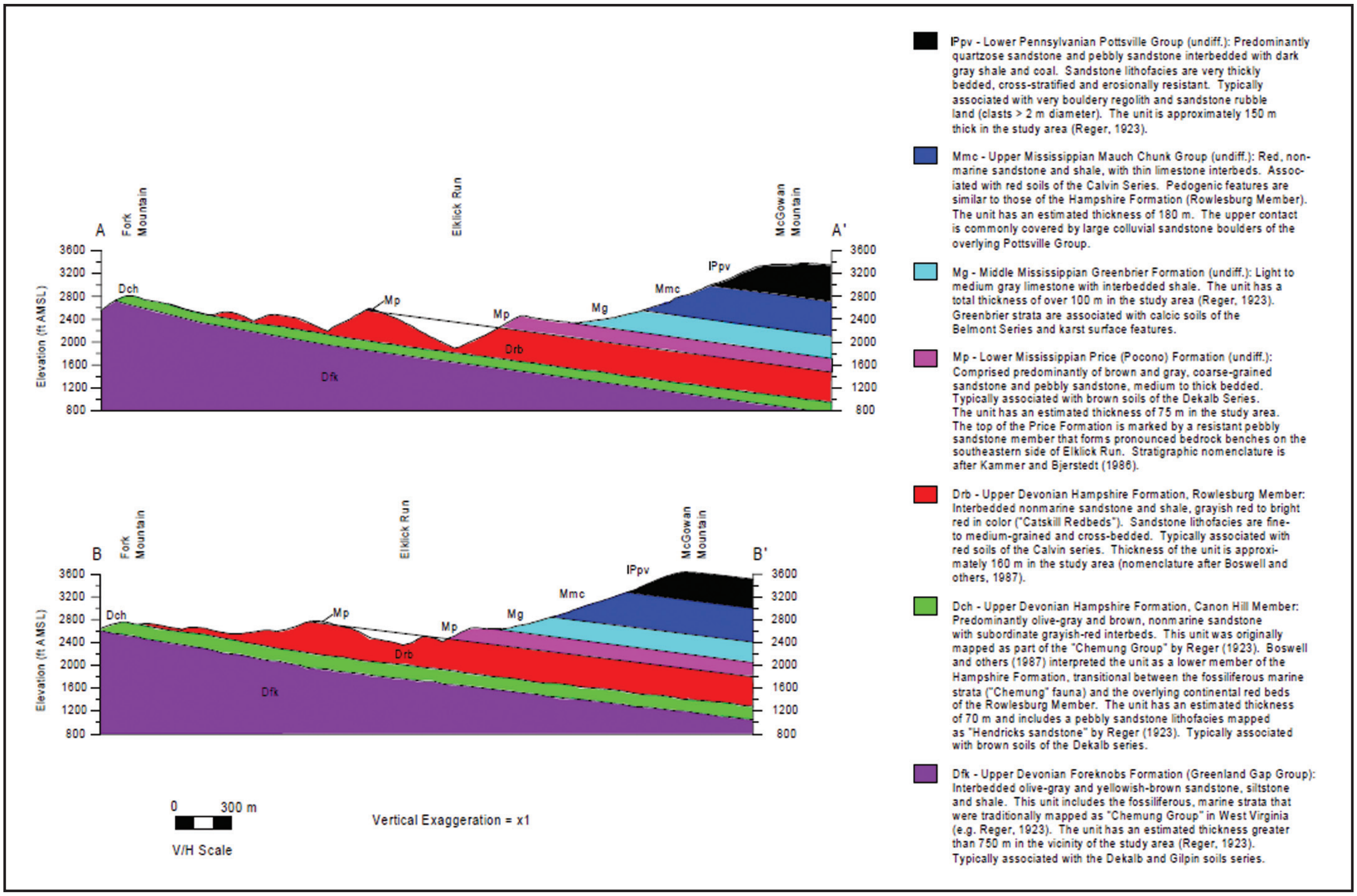

Figure 3. Northern view of the geologic cross-section of the Fernow Experimental Forest (after Taylor 1999).

western half of the Fernow are predominantly derived from the acidic sandstone and shale of the Hampshire formation. Early researchers established the experimental watersheds on the western side of the Fernow, away from the porous karst topography, so they could conduct water balance studies. The Lower Pennsylvanian Pottsville group occurs above 915 m on McGowan Mountain. The Dekalb soil series formed in the material weathered from sandstone is usually associated with this geologic group.

Vegetation

The Fernow lies within the area classified as Allegheny Mountain Section of the Central Appalachian Broadleaf Forest (M221B) (McNab and Avers 1994) and can be described as a mixed mesophytic forest (Braun 1950). The Fernow is primarily a hardwood forest with a canopy of northern red oak (*Quercus rubra* L.), yellow-poplar (*Liriodendron tulipifera* L.), black cherry (*Prunus serotina* Ehrh.), sugar maple (*Acer saccharum* Marsh.), American beech (*Fagus grandifolia* Ehrh.), black birch (*Betula lenta* L.), red maple (*A. rubrum* L.), basswood (*Tilia americana* L.), white ash (*Fraxinus americana* L.), chestnut oak (*Q. prinus* L.), sassafras (*Sassafras albidum* [Nutt.] Nees), blackgum (*Nyssa sylvatica* Marsh.), and bitternut hickory (*Carya cordiformis* [Wangenh.] K. Koch). American chestnut was a major component of the Fernow before the chestnut blight. Eastern hemlock (*Tsuga canadensis* [L.] Carr) and scattered red spruce (*Picea rubens* Sarg.) provide a natural conifer component, although hemlock is threatened by the hemlock woolly adelgid. One area on the Fernow (watershed 6, 22.3 ha) has been converted from a hardwood forest to a Norway spruce (*Picea abies* [L.] Karst.) stand to study the effects of forest-cover type on streamflow.

Understories often include striped maple (*Acer pensylvanicum* L.), sugar maple, American beech, and great laurel (*Rhododendron maximum* L.). Herbaceous plants on higher quality sites often include stinging nettle (*Laportea canadensis* L.), black snakeroot (*Cimicifuga racemosa* (L.) Nutt.), blue cohosh (*Caulophyllum thalictroides* Michx.), violets (*Viola* spp.), white snakeroot (*Eupatorium rugosom* Houtt.), and Christmas fern (*Polystichum acrostrichoides* (Michx.) Schott). A profusion of spring wildflowers also occurs on these good sites. Common understory woody plants on the more xeric sites include blueberry (*Vaccinium* spp.), greenbrier (*Smilax rotundifolia* L.), serviceberry (*Amelanchier arborea* (Michx f.) Fern.), red maple, and mountain laurel (*Kalmia latifolia* L.). A partial list of species found on the Fernow includes more than 500 species of vascular flora (Madarish et al. 2002). Running buffalo clover (*Trifolium stoloniferum* Muhl. Ex. A. Eaton), a federally endangered species, occurs on areas that are periodically disturbed, such as logging roads (Madarish and Schuler 2002), primarily on limestone-derived soils on the eastern portion of the Fernow.

Fauna

At the advent of European settlement, the Allegheny Mountain region supported several faunal species that have since been extirpated because of habitat change, largely from landscape conversion to agriculture and unregulated hunting. Surviving longer here than anywhere else in the Eastern United States, the largest herbivores, bison (*Bison bison*) and elk (*Cervus elaphus*), were extirpated from the eastern mountain region in the early 1830s (Fansler 1962) and in the 1870s (Shoemaker 1939), respectively. The gray wolf (*Canis lupus*) was gone by the late 1800s, as were river otter (*Lutra canadensis*), fisher (*Martes pennanti*), and beaver (*Castor canadensis*). Eastern cougars (*Puma concolor*) likely were extirpated during the same time period; however, persistent, albeit unreliable, sightings of cougars persist to this day (Trani and Chapman 2007). White-tailed deer (*Odocoileus virginianus*), scarce in West Virginia by the 1890s (DeGarmo and Gill 1958), were believed absent from the Fernow during the 1903-to-1911 logging era (Pennington 1975). In addition, populations of black bear (*Ursus americanus*) and wild turkey (*Meleagris gallopavo*) were still present but greatly reduced. Their populations, which depended on hard mast, suffered because of the loss of the American chestnut. Fairly common on the Fernow, ruffed grouse (*Bonasa umbellus*) populations have declined as the second- and third-growth forests have matured and the percentage of early successional forests have declined (Dobony 2000) in the region. The West Virginia Division of Natural Resources successfully reintroduced beaver in 1930, fisher in 1968, and river otter in 1985 near the Fernow; all three species currently are considered present (West Virginia Division of Natural Resources, unpublished data). Following establishment of harvest restrictions and improvements in habitat condition and availability over the past five decades, white-tailed deer are now considered overabundant (Campbell et al. 2006) and black bear and wild turkey are very common on the Fernow and the surrounding Monongahela. Over the same period, coyotes (*Canis latrans*) expanded their distribution to include much of the Eastern United States and are now present on the Fernow. Overall, the Fernow is home to a high diversity of mammals (48 species) and birds (92 species), including many neotropical migratory songbirds, but lesser numbers of reptiles (8) and amphibians (18) (Madarish et al. 2002). Of the nongame species present on the Fernow, the most notable are the approximately 300 endangered Indiana bats (*Myotis sodalis*) that hibernate in Blowing Springs Cave during the winter, as well as those individuals that day-roost locally during the spring, summer, and fall months (Ford et al. 2002a). This Indiana bat hibernaculum is the largest on public land in West Virginia. White nose syndrome, associated with the fungus *Geomyces destructans*, was first observed on bats in this cave in the winter of 2010/2011.

Research Program

Through the years, researchers at the Fernow Experimental Forest have investigated a variety of disciplines related to natural resource management (silviculture, watershed hydrology, wildlife, air pollution) in addition to addressing basic research topics related to ecosystem processes, structure, and function. The research trajectories for major areas of research are described below.

Silviculture

The earliest silvicultural research, which started in the 1930s, focused on thinning and crop tree release efforts to facilitate recovery of the vast landscape in the central Appalachians that was greatly altered by the turn-of-the-century logging and the associated fires. The site conditions and species mixtures of the Fernow were diverse and reflected most of the conditions that were found regionally. Although some of the early research was published, research operations were put on hold in 1941 with the United States' entry into World War II (Trimble 1977).

In 1948, after the war, a research plan in silviculture and watershed management was initiated as part of an interdisciplinary approach to solving forest management problems—a hallmark of research on the Fernow that continues to the present day. The silvicultural research was designed to be applicable to both private landowners and public agencies. Research compartments were established ranging in size up to 60 ha that allowed manipulative studies on a scale that would be appropriate to evaluate costs and returns in a typical operational sense within the region (Weitzman 1949). The road system was designed to accommodate the research compartments, most of which are still in use today, although some new roads and research compartments have been added over time. Parts of the road system were experimental and were used to better understand the relationship between road design, location, and drainage and the subsequent water and sediment movement. Although the emphasis and study objectives have shifted somewhat through the decades, many of the original treatments assigned to the individual compartments have continued as part of long-term studies and have enabled analyses pertaining to forest productivity, species composition, and log quality after many decades of repeated treatments.

One of the first studies established on the Fernow after World War II was designed to demonstrate the effects of different levels of management. Other experimental forests in the Eastern United States shared this initiative. These demonstration areas often are referred to as Cutting Practice Levels (CPL) or Management Intensity Demonstrations (MID). A CPL study was established on the Fernow in 1948 and has continued without interruption for six decades. This study includes diameter-limit cutting, commercial clearcutting, two forms of single-tree selection, and an unmanaged reference area (Lamson and Smith 1991, Schuler and Gillespie 2000). In the autumn of 2008, the seventh decadal single-tree selection harvest, with detailed residual stand guidelines, was completed as part of the Fernow CPL study. This study represents one of the longest examples of uneven-aged management in the Eastern United States. Recently, efforts have been initiated to compare the results of numerous CPL studies from throughout the Northern Research Station and include the Bartlett (NH), Dukes (MI), Fernow (WV), Kane (PA), Penobscot (ME), and Vinton Furnace (OH) Experimental Forests. This network of CPL installations represents a unique opportunity to synthesize silvicultural findings across forest types and ecoregions. Today, some of the early ideas regarding sustainability of different cutting practices and commonalities in treatment response across forest types are being explored in depth (fig. 4). Because the combined CPLs provide a data record of unparalleled length and spatial extent, this regionwide analysis will provide new perspectives on forest management that will address not only silvicultural issues but also regional questions of forest productivity and sustainability that span an era of global climate change, air pollution, invasive species, and exotic pathogens (Kenefic and Schuler 2008).

Early Fernow silviculture research also recognized the importance of small private landowners and farm woodlot forestry operations. Small farms that derived both revenue and raw materials from forest products were common in the central Appalachians in the 1950s and still remain an important part of the regional ownership pattern today. After World War II, these lands often were in poor condition due to the common practice of repeated burning, grazing, and unregulated harvesting. Early researchers noted that fire had partially eliminated valuable sugar maple and other shade-tolerant trees. Grazing also damaged much of the regeneration in farm woodlots, and

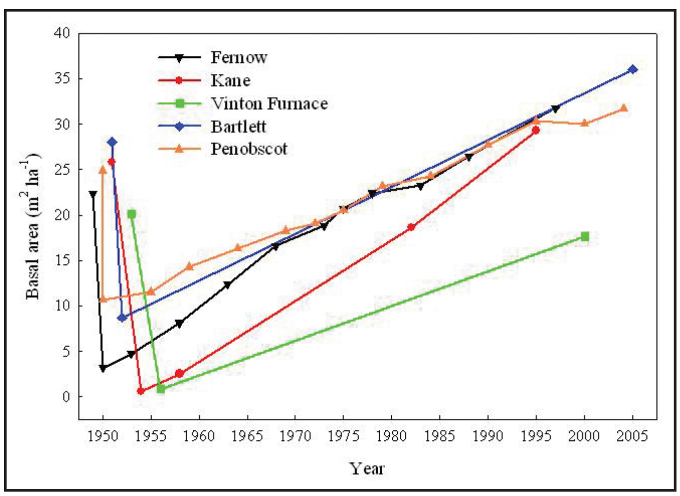

Figure 4. Basal area of trees greater or equal to 12.7-cm d.b.h. before and after commercial clearcutting in conjunction with the Cutting Practice Level or Management Intensity Demonstration (CPL/MID) studies from five Experimental Forests in the Northern Research Station. See text for details of these studies.

demand for mine timbers provided an ever-present market for forest products. Although significant decreases in fire and grazing were achieved rather quickly, many questions remained about the impacts of these practices, or lack thereof, on the forest, and there was a need for economically desirable and ecologically sustainable silvicultural practices for small, private landowners (Holcomb and Weitzman 1950). The farm woodlot demonstration areas on the Fernow were designed to be easily accessible and were managed for five decades to provide demonstrations of techniques useful to small, nonindustrial landowners. Through the years, these so-called "farm woodlots" also provided an opportunity to demonstrate new techniques being evaluated in larger, replicated studies elsewhere on the Fernow (McGill and Schuler 2003). These and other easily accessible demonstration areas have been an important part of educational outreach for the past 60 years on the Fernow; approximately 1,000 visitors per year view these demonstrations and see the effects of a range of forest management practices on the forest.

Overall, during the past 60 years, silvicultural research on the Fernow has been broad in scope and has reflected many important topics of the time. Silvicultural research has included crop tree release and other intermediate thinning options, economics of forest practices, even- and uneven-age management, natural and artificial regeneration, provenance testing, grapevine control, growth and yield predictions, silvicultural herbicide use, logging methods, and design and construction of forest roads. The body of this work has contributed significantly to the regional silviculture guidelines as is evident by the significant number of citations credited to researchers working on the Fernow (e.g., Barrett 1995).

Because of research conducted on the Fernow and elsewhere, crop tree release has been widely accepted in the region as an efficient means of releasing desired stems and shaping species composition in young stands (Lamson et al. 1990, Schuler 2006). Crop tree release has proven to be more useful than areawide thinning because of the wide range of values that exist among individual trees and species even within a relatively small operational area. Forest practice economics were also evaluated to determine where and when treatments were justified (Miller 1991, 1993) and when trees reach financial maturity (Schuler and McGill 2007, Trimble et al. 1974). Guidelines for combining economic and silvicultural selection have been tested and are still being studied on the Fernow in several research compartments that span four decades.

The advantages and disadvantages of uneven-age management versus clearcutting or other forms of even-aged management have been the focus of much research on the Fernow, which has led to the development of a new silvicultural system known as deferment harvesting (or two-age management) that incorporates some of the benefits of each system (Miller et al. 1997, Thomas-Van Gundy and Schuler 2008). In part, this system was an outgrowth of the clearcutting controversy of the 1970s, which arose from widespread clearcutting on several national forests, including the Monongahela. Deferment harvesting has been used extensively during the past two decades in the central Appalachians on both industrial and public ownerships sensitive to the aesthetic effects of clearcutting and has been one of the most widely adopted new practices pioneered on the Fernow.

Although natural regeneration dominates in the central Appalachians, the Fernow staff have conducted significant work on artificial regeneration and related issues. Artificial regeneration research has focused most recently on the use of planted or natural seedlings and sprouts protected by tree shelters or wire cages to mitigate deer browsing effects on desirable species (Kochenderfer and Ford 2008, Schuler and Miller 1996). The species composition of even-aged stands approaching 20 years of age has been enhanced using this technique, and many tours of the Fernow include stops to view the results. This research has been recognized internationally and used by private landowners and public agencies alike. Also, for about three decades, the Fernow was part of regional provenance testing of white ash, black walnut, sugar maple, and white pine (Schuler 1994, Wendel 1980). Although these studies are no longer active, the outplantings have been protected, and recently, there has been renewed interest in them as scientists seek to understand how climate change may affect the relative competitive ability of seed sources from different latitudes.

Foresters grapple with many issues during the regeneration phase of stand development, among which grapevine control is a critical issue on some sites. Grapevines exacerbate winter storm damage and can indefinitely delay canopy closure that can result in poorly stocked stands with low-quality stems. Although grapevine control studies have ended on the Fernow, the resulting management guidelines are still used throughout the region (Smith 1984, Smith and Lamson 1986).

Growth and yield predictions, which were developed for many tree species and forest types in the latter part of the 20th century, are the foundation for numerous models often used in forest management. Fernow researchers developed predictive equations for a number of hardwood species by site class, and these local volume tables are still in use (Miller and Sullivan 1993, Yandle et al. 1988). Fernow researchers programmed the first version of the Northeast Decision Model Stand Inventory Processor and assembled long-term permanent plot data to measure the performance of numerous growth and yield models being used from Ohio to Maine (Schuler et al. 1993). This work was a research station-wide effort that eventually evolved into a family of expert decision models referred to as the Northeast Decision Model. These models incorporate research results into everyday decisionmaking and are an excellent technology transfer tool.

Controlling species composition is a major challenge for all natural regeneration methods, and the use of herbicides has been shown to be an effective silvicultural tool in some cases. Much of the research focus on the Fernow has been on using stem-injected herbicides in valuable cherry-maple stands and using cut-stump treatments to control aggressive sprouting and vegetative reproduction of American beech (Kochenderfer et al. 2004, Kochenderfer et al. 2006). Stem-injected herbicides offer many advantages over other control methods, including minimal effects on nontarget resources and greater ease of use, safety, and effectiveness. This research was the foundation for guidelines that have been readily adopted by small landowners and public agencies.

Logging techniques and related costs were the subjects of Fernow research for several decades. From its beginning in 1948, the research plan for the Fernow included a three-person logging crew that would test new techniques and maintain records of equipment use so researchers could evaluate efficiencies of both silvicultural practices and different logging methods (Weitzman 1952, Wendel et al. 1974). The Fernow logging crew used one of the first two-person chain saws for tree felling and has been involved in subsequent trials of novel logging equipment. The logging crew remains an integral part of the research operations on the Fernow because of its inherent ability to harvest smaller research compartments within limited timeframes. The Fernow logging crew is the only Forest Service logging crew in the Nation. It has an outstanding safety record, and the crew's conscientious efforts are essential for continuing long-term studies that require periodic harvests within strictly defined operational windows.

More recently, new silvicultural research topics have emerged, including the use of prescribed fire for mixed-oak forest sustainability and the ecology and management of high-elevation montane forests. Oak regeneration failure is a widely recognized forest management problem of serious magnitude throughout the hardwood regions of the Eastern and Central United States. Both managed and unmanaged forest stands exhibit declining oak abundance as overstory oaks experience natural mortality or are harvested (Schuler 2004). Sustaining oak forests that have been present for thousands of years is critical to both economic and ecological objectives in the eastern and central hardwood regions. Researchers are evaluating fire as a restoration tool to reduce interfering vegetation and alter forest structure to favor numerous oak species (Brose et al. 2001, Schuler and McClain 2003). They are also evaluating the effects of fire on other ecosystem attributes, including acorn pests, woodland salamanders, soil water chemistry, herbaceous layer vegetation, and the seed bank (Ford et al. 2002b, McCann et al. 2006). Researchers from other Northern Research Station units and cooperating universities have been actively involved in fire research on the Fernow. Landscape level analyses have been completed to model locations where fire can be most effectively used to restore oak competitiveness (Thomas-Van Gundy et al. 2007).

High-elevation spruce-fir forests, dominated by red spruce in the central and southern Appalachians, have been identified as one of the most highly endangered forest types in the United States. The red spruce forests in this region were exploited a century ago, and cutover stands suffered from high-intensity wildfires and subsequent wind and water erosion. The red spruce forests that exist today are a small fraction of what existed before the exploitative logging era. Research to facilitate the recovery of this forest type is critical to improving the status of numerous endangered or sensitive species that rely on or are endemic to this ecosystem and for buffering anticipated effects associated with global climate change. Scientists on the Fernow led the way for advocating the need for increased research emphasis on this forest type and are now actively involved in studying the ecology and management of this critical landscape component (Adams and Eagar 1992, Rentch et al. 2007). They have also contributed significant information about the habitat and extent of the West Virginia northern flying squirrel (*Glaucomys sabrinus fuscus*), an endemic of this forest type (Ford et al. 2004), leading to removal of this species from the endangered species list between 2008 and 2010, with the final decision pending conclusion of litigation. Although most of the Fernow is lower in elevation than that where red spruce is dominant, Fernow scientists are actively involved in research on other State and Federal ownerships to facilitate the recovery of this critical landscape component.

Hydrology and Watershed Management

Of the 10 gauged watersheds on the Fernow (fig. 5), 5 (watersheds 1 through 5) have been gauged since 1951 (table 1). About that same time, scientists also established a network of precipitation monitoring sites (consisting of standard rain gauges and recording rain gauges) (fig. 5). They later installed stream-gauging stations on an additional five watersheds (table 1). The largest gauged watershed on the Fernow (watershed 14), which

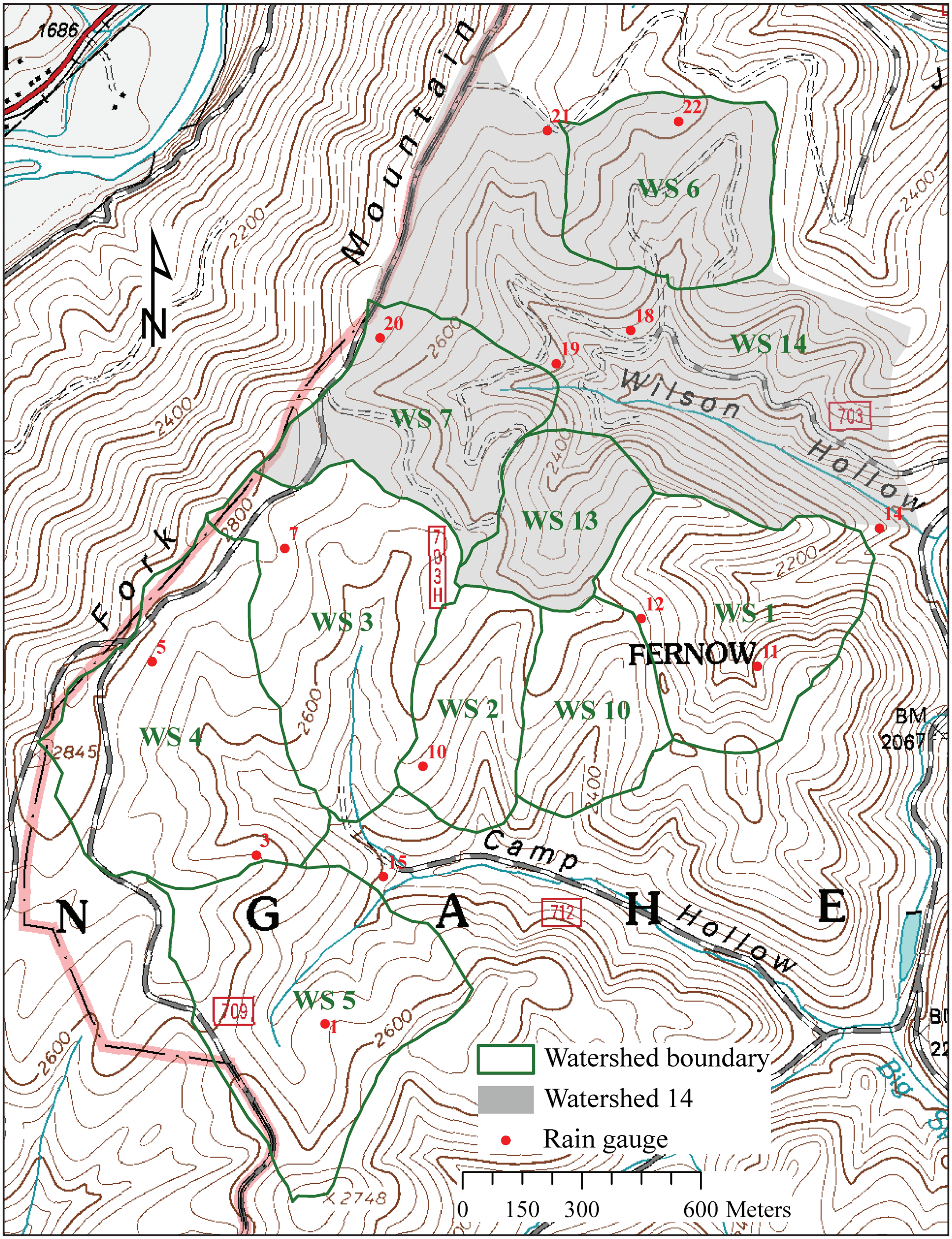

Figure 5. Gauged watersheds and rain gauge network on the Fernow Experimental Forest. Dots indicate rain gauge locations.

includes three gauged subwatersheds in its headwaters, was the most recently instrumented. To accommodate needs of various studies, scientists added weather- and air-quality-monitoring stations over time and implemented studies quantifying basic physical conditions. These include studies on solar radiation measurements (Hornbeck 1970), soil moisture (Patric 1973), evapotranspiration (Patric and Goswami 1968, Tajchman et al. 1997), and dendroclimatology (Pan et al. 1997, Schuler and Fajvan 1999).

In 1957, scientists chose watershed 4 to serve as the primary control watershed on the Fernow. That same year, after 6 years of calibration, they initiated the first watershed management studies on the Fernow on watersheds 1, 2, 3, and 5 (table 1). They harvested these watersheds using different silvicultural treatments and varying degrees of environmental protection during forest operations (Hornbeck and Reinhart 1964, Reinhart et al. 1963). Watershed 1 was commercially clearcut without

Table 1. Watershed characteristics and treatments.

Watershed	Established	Size (ha)	Treatment	Treatment date
1	1951	30.1	Clearcut to 15.2-cm d.b.h. except culls, no soil or water resource protection	May 1957–June 1958
2	1951	15.5	43.2-cm diameter limit cut	June 1958-Aug. 1958
			Repeat treatment on 10.8 ha	Aug. 1972
			Repeat treatment on 4.7 ha	Jan. 1978
			Repeat treatment on 10.8 ha	May–July 1988
			Repeat treatment on 4.7 ha	Feb.–Apr. 1997
			Repeat treatment on 10.8 ha	Jan.–Mar. 2004
3	1951	34.3	Intensive selection harvest in trees >12.7-cm d.b.h.	Oct. 1958–Feb. 1959
			Repeat treatment	Sept.–Oct. 1963
			Patch clearcuts on 2.3 ha	July–Oct. 1968
			Clearcut to 2.5-cm d.b.h.	July 1969–May 1970
			Acidification by ammonium sulfate fertilizer applied 3 times per year	Jan. 1989–present
4	1951	38.7	Control	
5	1951	36.4	Extensive selection harvest in trees >27.9-cm d.b.h.	Aug.–Dec 1958
			Repeat treatment	Feb.–May 1968
			Repeat treatment on 31.6 ha	Jan.–June 1978
			Repeat treatment on 4.8 ha	Feb.–Mar. 1983
			Repeat treatment on 31.6 ha	Feb.–May 1988
			Repeat treatment on 4.8 ha	Oct.–Nov. 1998
			Repeat treatment on 31.6 ha	Jan.–Apr. 2007
6	1956	22.3	Clearcut lower half (11.2 ha)	Mar.–Oct. 1964
			Lower half herbicided	May 1965–Oct. 1969
			Clearcut upper half (11.1 ha)	Oct. 1967–Feb. 1968
			Entire watershed herbicided	May 1968–Oct. 1969
			Planted Norway spruce	Spring 1973
7	1956	24.2	Clearcut upper half (12.1 ha)	Nov. 1963–Mar. 1964
			Upper half herbicided	May 1964–Oct. 1969
			Clearcut lower half (12.1 ha)	Oct. 1966–Mar. 1967
			Entire watershed herbicided	May 1967–Oct. 1969
10	1984	15.2	Control	
13	1988	14.2	Control	
14	1993	131.5	Includes watersheds 6, 7, and 13, and 2 silviculture compartments	

d.b.h. = diameter at breast height.

regard for protecting soil and water resources, or in more modern terms, without the use of best management practices (BMPs). Watersheds 2, 3, and 5 were selectively harvested under different intensities. Effects of the harvesting treatments on streamflow were determined primarily by using the traditional paired watershed approach (Reinhart 1958).

The first four harvesting treatments demonstrated that at least 25 percent of the basal area of a watershed must be harvested before a significant increase in annual streamflow is measurable, annual streamflow increases proportionally to the basal area removed, most of the annual streamflow increases occur during the growing season because of decreasing evapotranspiration after harvesting, and even the most extreme streamflow increases are generally short lived because of rapid regrowth of vegetation (Hornbeck et al. 1993). In addition, the lack of resource protection during clearcutting on watershed 1 showed that very large increases in sediment losses can result from poor road location, lack of water control on the roads, and disturbance of the streambed and streambanks during skidding (Reinhart et al. 1963). Although elevated sediment in streamflow also was short lived, returning to predisturbance levels in 2 to 3 years (Reinhart et al. 1963), the legacy effects of poor road location and lack of BMPs remain today. Portions of the stream are still deeply incised and appear to be unstable and eroding; active headcutting has extended the head of the channel to near the ridge top of the watershed. None of the other three watersheds appear to have been so severely affected by the initial harvesting treatments or by any other more recent treatments.

In the early 1960s, an extended, severe drought in the Eastern United States created concerns about water availability in several major cities. Because forested watersheds are important sources of drinking water, scientists conducted research to determine if they could use forest management to increase water yields. Previous findings on the original four watersheds showed that traditional forest harvesting would result in only short-term increases in streamflow, so they initiated research into more intensive watershed treatments on watersheds 6 and 7. They applied harvesting, in combination with repeated annual herbicide applications to maintain the watersheds free of most vegetation, to determine if these treatments could increase streamflow even more. Indeed, stream discharge increases were about double those from clearcutting in terms of maximum annual amounts (Kochenderfer et al. 1990, Patric and Reinhart 1971) and duration (Edwards and Troendle, in press; Kochenderfer et al. 1990). Despite the positive outcomes, the interest in augmenting streamflow for water supplies passed quickly because the eastern drought ended and concerns about the effects of herbicides on drinking water quality developed. Interest in streamflow augmentation has recently been rekindled, linked to concerns about climate change and water availability.

After terminating herbicide applications, scientists used watershed 6 to investigate the effects of species conversion on stream discharge; this study was a companion to another species conversion study performed at the Coweeta Hydrologic Laboratory in North Carolina. In 1973, scientists planted watershed 6 with Norway spruce and, 30 years later, spruce cover had progressed to 65 percent of the watershed (Adams and Kochenderfer 2004). Streamflow began decreasing about 10 years after the spruce was planted and, by year 15, streamflow declined below that of the original deciduous forest because of year-round increased interception and evapotranspiration (Edwards and Troendle, in press). Streamflow continued to decline until around 2003 (fig. 6). The greatest deficits in water yield occurred during the dormant season.

Streamflow reductions over the past 15 years on watershed 6 have resulted in a substantial change in stream channel morphology. The active channel has decreased in width and depth to a fraction of what it had been as a hardwood watershed due to filling with mosses and streambed aggradation (Edwards and Watson 2002). In less than two decades, the channel has changed from a typical Rosgen A type channel to an E4 channel.

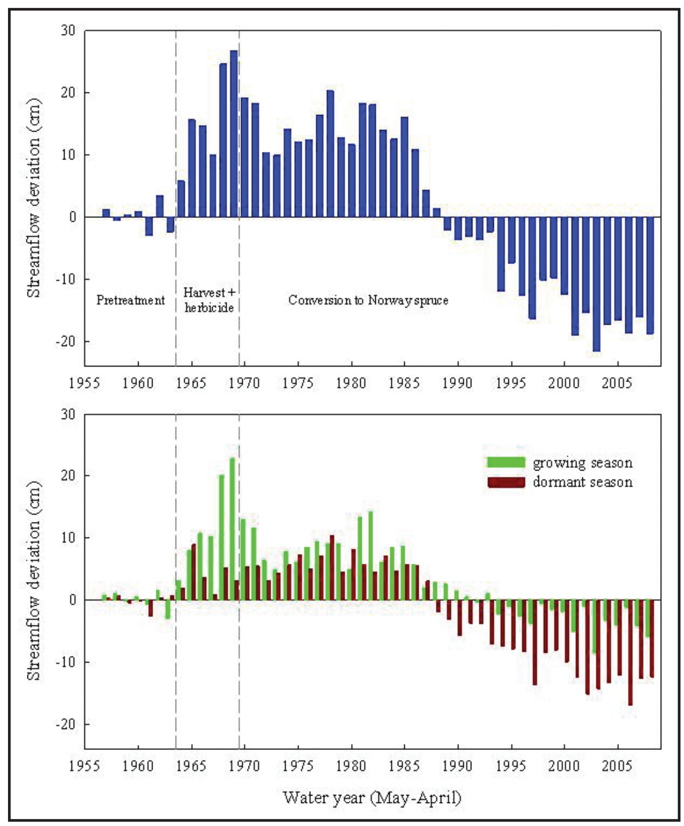

Figure 6. Watershed 6 streamflow deviations from amount predicted, over time.

Over the past several decades, Fernow scientists have remained interested in erosion and sedimentation caused by forest management activities. Results from the first harvesting experiment on watershed 1, in which no attention was paid to soil and water resource protection, were compared to those from watershed 3, where soil losses were much lower because care was taken during harvesting and road layout and construction. Research on the Fernow, and at other experimental forests, was used to develop methods of road planning and construction that could reduce erosion and sedimentation (Kochenderfer 1970, Kochenderfer and Helvey 1984, Kochenderfer and Helvey 1987) and to transferring that information in user-friendly forms to forest managers and the public (e.g., "Building Roads" and "Water in the Forest" from *Managing Your Woodlot,* a nine-part video series that Fernow scientists developed cooperatively with the West Virginia University Extension Service). In large part, scientists working on the Fernow developed or recommended many of the West Virginia forestry BMPs. Currently, Fernow researchers are helping to develop protocols for evaluating BMP implementation and effectiveness regionally and nationally (Ryder and Edwards 2005, 2006).

Studies involving water chemistry became a more integral part of the Fernow's research in the 1970s as more sophisticated analytical techniques became available and the Fernow water-quality laboratory was formally established. Chemistry-based studies became an even more important part of the Fernow's research portfolio around 1980 when the laboratory became more automated. Since then, scientists have conducted analyses of major cations and anions and various metrics of alkalinity or acidity on water samples from the Fernow. Studies involve examining data sets from long-term monitoring of precipitation, streamwater, and soil water chemistry and focusing on specific chemical relationships and responses to treatments.

Among the first studies able to exploit the capabilities of the water-quality laboratory were fertilizer studies, which were designed to examine the effects of typical forest application rates on streamwater quality. Initial studies evaluated applications of urea or ammonium nitrate plus triple superphosphate fertilizers. Regardless of the type of nitrate fertilizer applied, about 20 percent of that applied was exported during the first 2 to 3 years (Aubertin et al. 1973, Edwards et al. 1991, Patric and Smith 1978). Changes in streamwater concentrations of nitrogen and cations from the urea applications were small, and nitrate concentrations did not exceed drinking water standards (Aubertin et al. 1973). Streamwater nitrogen concentrations resulting from the ammonium nitrate application remained elevated for 3 years, however, and exports of nitrogen increased by more than 18 times the prefertilization rates. These elevated nitrogen concentrations also exceeded drinking-water standards for 3 weeks (Helvey et al. 1989). Phosphate concentrations did not increase in response to the fertilization because Fernow soils are generally low in available phosphorus (Edwards et al. 1991).

Streamwater and precipitation chemistry from weekly samples collected since the startup of the water chemistry laboratory also provided opportunities to study biogeochemical cycling on the Fernow. Helvey and Kunkle (1986) constructed the first input-output nutrient budget for the Fernow—for watershed 4. The most important findings of this research were that sulfate inputs exceeded outputs and that they provided the first descriptions of possible future scenarios of accelerated base cation leaching and subsequent watershed acidification. Building on this work, DeWalle et al. (1988) developed a more intensive biogeochemical budget for the control watershed, which showed that parent materials played an important role in controlling soil and streamwater acidification. Later analyses of streamwater chemistry from watershed 4 showed that nitrate concentrations in streamwater had increased over time (Edwards and Helvey 1991) in relation to increasing nitrogen deposition. This response had been hypothesized in the literature under conditions of increasing nitrogen deposition, but it was not widely accepted at that time because forests traditionally have been considered nitrogen limited.

These findings, linked with results from air pollution research that began in the 1980s on the Fernow and other locations, suggested that the central Appalachian Mountains were among the ecosystems most at risk for acidic deposition effects (Herlihy et al. 1993). This finding of risk was part of the impetus for the initiation of the Fernow whole-watershed acidification study that began in 1989. As one of only two whole-watershed acidification studies in the United States aimed at examining biogeochemical responses to soil acidification, it was originally funded by the U.S. Environmental Protection Agency and then was entirely funded by the Forest Service for many more years. Currently, the study is a partnership between Forest Service Work Unit NRS01, West Virginia University, and the Long-Term Research in Environmental Biology Program (Grant DEB-0417678) at the National Science Foundation. Results have been published and widely presented, and the major findings from the first 15 years of watershed acidification are described in Adams et al. (2006).

The Fernow and the Timber and Watershed Lab also participate in numerous nationwide research and monitoring efforts in soil, water, and air quality research. The Timber and Watershed Lab was the site of the first installation of the National Atmospheric Deposition Program in July 1978. It also participates in the Clean Air Status and Trends Network; the Interagency

Monitoring of Protected Visual Environments Network; the Long Term Soil Productivity Network, the HydroDB and ClimDB (http://www.fsl.orst.edu/climhy/); and international networks, such as the Global Terrestrial Observing System/ Terrestrial Ecosystem Monitoring Sites Network (http://www.fao.org/gtos/tems/index.jsp) and the EcoTrends Project (http://www.ecotrends.info). Recently, the Fernow also became part of the Experimental Forest and Range Synthesis Network. Established in 2007, the network is a group of scientists affiliated with Forest Service experimental forests and ranges who have joined forces to address transcontinental questions concerning effects of environmental change on ecosystem function and services. Networking the Fernow with other long-term research sites expands the statistical inference of the work conducted in these forests to regional, national, and global scales.

Wildlife Ecology and Management

Although to a lesser extent than forestry research or hydrologic research, wildlife investigations have been part of the research program on the Fernow for nearly 40 years. Depending on the taxa studied, complete wildlife-oriented research projects have been contained on the Fernow. In other instances, research requiring large areas or multiple treatments used the Fernow as a replicate in the matrix of a larger overall project (Keyser and Ford 2005). The first documented wildlife study on the Fernow examined the production of white-tailed deer browse across a variety of cutting practices (Cromer and Smith 1968) at a time when similar research was being conducted in the southern Appalachians (Della-Bianca and Johnson 1965). From a wildlife research perspective, ongoing and varied forest manipulation has provided excellent templates for forest-habitat relationship studies. Gehring (1997) used forest management compartments on the Fernow to assess wildlife habitat-quality rankings for numerous species in the central Appalachians. Research on nongame and threatened, endangered, or sensitive species has predominated, focusing mainly on herpetofauna, avifauna, and bats.

Research on woodland salamanders (Plethodontidae) has dominated herpetological investigations on the Fernow. Kees (1994), Marcum (1994), and Ordiway (1994) examined various facets of salamander natural history, including reproduction, growth, and niche separation dynamics among species in the genera *Plethodon* and *Desmognathus*. Little et al. (1990) and Barrett (1996) examined woodland salamander response across a variety of successional series following timber harvest, whereas Pauley et al. (1990) took advantage of drought conditions to examine the interactions of abiotic factors and forest recovery on salamander detection and aboveground activity patterns. In general, woodland salamander abundances were correlated with time since harvest and forest age. Rowan (2004) assessed the effect of spring burning for oak restoration purposes on woodland salamanders on the Fernow and found little or no measurable change in extant salamander communities after a single fire. The gauged watersheds on the Fernow have provided an excellent template for more rigorous experimental work with salamanders. Using an information-theoretic, model-building approach, Moseley et al. (2008) observed a subtle but negative long-term effect of timber harvest and roads on aquatic salamander abundance in surveyed timber compartments and gauged watersheds on the Fernow that was congruent with the aforementioned descriptive studies. Both Pauley (1995) and Moseley (2008) observed little biological effect on woodland salamanders immediately and several years after the application of diflubenzuron for gypsy moth control. Pauley et al. (2006) and then Moseley (2008) also assessed the effect of experimental acidification treatments in watershed 3 on salamanders; both authors found little or no meaningful response in terms of either salamander community assemblage or relative abundance in either the short or long term (more than 15 years), respectively. These findings collectively suggest that terrestrial and aquatic woodland salamanders in the central Appalachians are moderately tolerant of disturbance as is observed in the southern Appalachians and elsewhere in the East (Russell et al. 2004), in contrast with other research (Petranka et al. 1994).

Research on avifauna, in many cases, has mirrored that of herpetofauna on the Fernow. Most work has concentrated on understanding songbird assemblages and ecological response to changes in forest condition after harvest or other disturbance or among various forest types and structures, beginning with the work of McArthur (1980) and Mauer and Whitmore (1980). McArthur (1980) was among the earliest in the central Appalachians to show that forest structure rather than forest age per se is an important determinant in the residing bird community at the stand level. Moreover, many years before the concepts of adaptive and ecosystem management were applied to national forest lands, he observed that active forest management could be used to manage for early-successional shrub-scrub guilds, whereas passive forest management would favor interior forest songbird assemblages. DeMeo (1999) used point-count methodologies across the Monongahela, including the Fernow, to better define patterns of songbird association with defined forest types, such as mixed mesophytic forests, northern hardwood forests, and xeric oak-dominated forests, and to compare upland and riparian areas within forest types. In addition, he examined the influence of edge and forest fragmentation on interior species, finding discernable edge effects only to about 25 m into the forest. DeMeo (1999) also observed virtually no difference in composition or abundance of songbirds between smaller, less contiguous forest patches and large, unfragmented patches within this largely forested landscape of the central Appalachians. Williams (2002) used the Fernow and adjacent portions of the Otter Creek Wilderness to examine nesting ecology and reproductive success of wood thrush (*Hylcocihia mustelina*) at various landscape- and stand-level scales. Building on the associations of forest type and stand structure observed by McArthur (1980) and DeMeo (1999), Williams (2002) found that wood thrush production was negatively correlated with increasing amounts of open area at the landscape scale.

With the exception of Rowan et al. (2005), who studied home-range size response of eastern chipmunks (*Tamias striatus*) and found little difference in home range or core area among burned and unburned forest stands, mammal research on the Fernow in the 21st century has been heavily skewed toward bats. Acoustical sampling techniques have been widely used to better understand bat movements and habitat (fig. 7). Using these acoustical sampling methodologies, Owen et al. (2004) compared bat activity in older, second-growth stands on the Fernow's reference areas with clearcut, leave-tree, and diameter-limit harvested stands on the MeadWestvaco Wildlife and Ecosystem Research Forest and in riparian zones in both areas. Owen et al. (2004) documented distinct bat species use associated with varying stand structures, as has also been documented elsewhere for songbirds. For example, the big brown bat (*Eptesicus fuscus*), a large bat with a high wing loading, lower frequency echolocation, and feeding preferences for flying Coleopterans, was recorded more often in leave-tree harvests than in the more structurally cluttered intact forests. The reverse was true for bats in the genus *Myotis*—presumably mostly the northern bat (*Myotis septentrionalis*)—that have low wing loading, higher frequency echolocation, and gleaning feeding preferences. Activity of all bat species was highest along forested riparian habitats relative to any other type or stand condition. Also using acoustical methodologies, Ford et al. (2005) conducted species-specific, fine-scale habitat modeling for bats on the Fernow, linking metrics such as canopy gap width, canopy height, and stream order to bat activity. This work was notable for showing the preference of endangered Indiana bats for second- and third-order stream corridors over first-order corridors or surrounding upland forests.

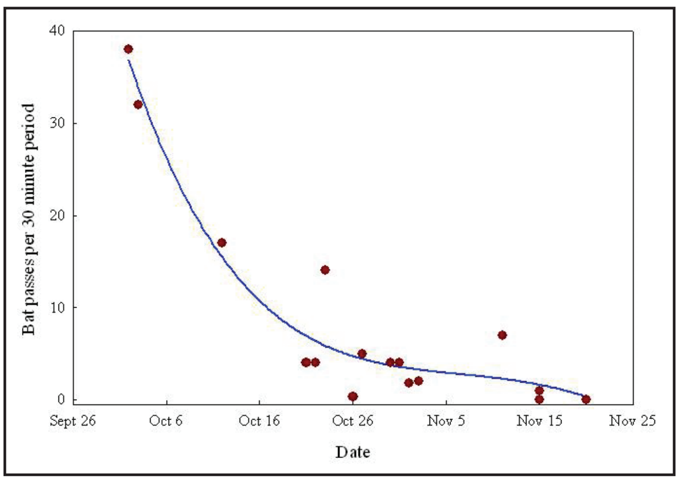

Figure 7. Fall acoustical activity of Myotid bats (northern bat, little brown bat, Indiana bat) at Blowing Springs Cave, Fernow Experimental Forest, 2000–05.

The fact that most bats on the Fernow day roost in trees and snags during the growing season has prompted a need to understand possible effects of forest harvesting on bats. Consequently, the Fernow has hosted three completed day-roost studies: two on male Indiana bats (Ford et al. 2002a, unpublished data; C. Stihler, West Virginia Division of Natural Resources) and one on male northern bats (Ford et al. 2006). Male Indiana bats tended to select tree species with sloughing bark characteristics, such as shagbark hickory (*Carya ovata* (Mill.) K. Koch) or sugar maple, although species selection, tree size, and tree position were highly variable. Male northern bats almost exclusively selected large, sawtimber-size black locust (*Robinia pseudoacacia* L.), similar to females in terms of species preference, but not in size, on the nearby MeadWestvaco Wildlife and Ecosystem Research Forest (Menzel et al. 2002).

Long-Term Data Sets

Silviculture

Timber management research data collection began in 1949 with stand structure measurements on the CPL and farm woodlot compartments (fig. 8). For these long-term stand structure measurements, all stems greater than 12.7-cm diameter at breast height (d.b.h.) were tallied by species, 5-cm d.b.h. class, and condition: merchantable, cull, or dead – these measurements have continued until the present. Data for additional compartments were collected as studies were initiated. Data typically are classified as pretreatment, volume treated, and post-treatment with multiple iterations for compartments

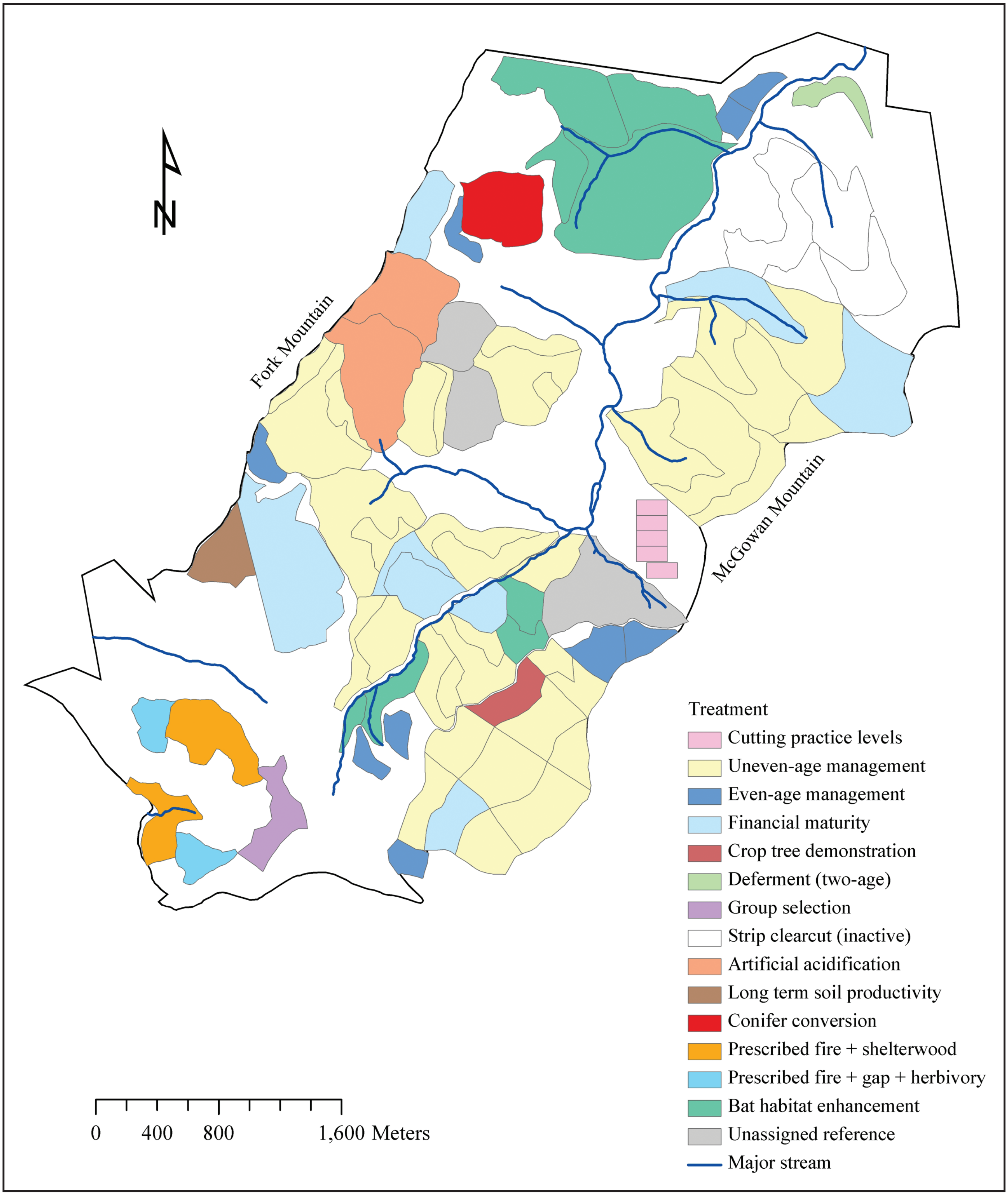

Figure 8. Research compartments and watersheds on the Fernow Experimental Forest grouped by experimental treatment.

receiving repeated harvest treatments. Log grade data were collected with the first harvest treatments in 1949. Reproduction data collection began in 1950. Seedling- and sapling-sized stems generally are tabulated by species, size, condition, and origin. The first permanent growth plots were established on the Fernow in 1979. All trees either larger than 2.5-cm d.b.h. or larger than 12.7-cm d.b.h. are tagged and their species, d.b.h., crown class, and condition recorded. Today, approximately 400 permanent growth plots are being measured on either 5- or 10-year cycles on the Fernow. Data collection on the effects of tree shelter use began in 1989 and continues on several areas on the Fernow. Size and condition of the sheltered tree as well as distance to and size of its nearest neighbor are collected annually or biannually.

Watershed Management

Long-term streamflow records are available for 10 gauged watersheds on the Fernow. Data have been collected almost continuously on the five original watersheds (watersheds 1 through 5) (fig. 5) and five watersheds that were instrumented later (table 1). Data gaps exist on watershed 2 (water years 1980–1987) and watershed 5 (water years 1973–1990). Weekly maximum and minimum stream temperature data were collected on several Fernow watersheds from 1959 to 2002. Continuous hourly stream temperature data have been collected since 2002 on watersheds 2, 4, 6, and 10. Stream chemistry data collection began in 1951 on watersheds 1 through 5 with the intermittent measurement of pH, conductivity, and alkalinity; weekly or biweekly sampling began in 1958 and was expanded to the other watersheds, typically as they were instrumented for streamflow measurement. Anion and cation analyses were added in 1971, but data collected before 1981, when the laboratory acquired an ion chromatograph and an atomic absorption spectrophotometer, are considered less reliable. Additional water-quality data include suspended sediment and turbidity measured for watershed 4 from 1978 to1999.

A network of standard and recording rain gauges has collected precipitation data since 1951. Daily watershed-weighted precipitation amounts were calculated by the Theissen method (Brakensiek et al. 1979) for all watersheds except watershed 14 for the same periods as for streamflow but without the watershed 2 and 5 gaps. Air temperature and relative humidity data collection began in 1951, first as daily maximum and minimum values, then in 1959 as hourly data. Continuous hourly data collection continued in 1997 with the installation of digital data loggers. In 1996, when a weather station was installed on Fork Mountain, the meteorological data set was expanded to include wind direction and speed and quantum and solar radiation. Precipitation chemistry sampling began in 1983 at two sites on the Fernow. Weekly samples are analyzed for pH, conductivity, acidity, anions, and cations when precipitation amounts are sufficient.

Many of these hydrologic and climatic data are available from the HydroDB and ClimDB Web server (http://www.fsl.orst.edu/climhy/). Other data are available on the Fernow Web page (http://www.nrs.fs.fed.us/ef/locations/wv/fernow/). A full-time data manager ensures the quality, security, and timeliness of the data sets.

Research Opportunities

Abundant opportunities for collaborative research exist on the Fernow. Collecting additional measurements from ongoing, long-term research plots is welcome, as are using existing data sets in a collaborative manner and proposing new research. Because of the close proximity of the Timber and Watershed Lab to the Fernow, it is possible to make frequent and repeated measurements as necessary. Submitting a proposal to the project leader of Work Unit NRS01 is a good way to initiate the conversation about collaborative research.

Education and Outreach

The Fernow provides show-me trips and educational field tours for groups ranging from school children to college students to visiting scientists. One of the Fernow scientists usually leads the tours, which can accommodate small- to medium-sized groups (around 30 to 50 people). Each tour is tailored to the specific needs of the visitors. In addition, visitors may choose a driving tour of the Fernow, which follows well-marked signs posted to indicate the research activities in particular compartments of the forest.

Facilities

Solar panels or batteries run the facilities on the Fernow because no electrical lines have been run into the forest. The only buildings on the Fernow proper are weir houses and storage buildings. Facilities available at the Nursery Bottom (15 minutes away) include a small historic bunkhouse, quarters for up to six people, dirty labs, a water-quality laboratory, office and meeting space, and a small greenhouse.

Conclusion

Collaborative, interdisciplinary research on the Fernow is a longstanding tradition and one that is deeply embedded in the culture of Forest Service personnel who work there. Decades of research on the Fernow have strongly influenced development of forest management guides and recommendations and, thereby, have affected management of public and private forest lands in the central Appalachians. The importance of research findings related to forest management, watershed management, wildlife management, and basic ecosystem science speaks to the rich future of research opportunities on the Fernow. The opportunities are outstanding, thanks to the invaluable legacy of past Forest Service scientists, technicians, the Fernow logging crew, and support staff.

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