Continuing Fire Regimes in Remote Forests of Grand Canyon National Park

Peter Z. Fulé
Thomas A. Heinlein
W. Wallace Covington
Margaret M. Moore

Abstract—Ponderosa pine forests in which frequent fire regimes continue up to the present would be invaluable points of reference for assessing natural ecological attributes. A few remote forests on the North Rim of Grand Canyon National Park come close to this ideal: never-harvested, distant from human communities and fire suppression resources, and with several low-intensity fires in the past century—a highly unusual recent fire regime in the Southwest. Recent fires appear to have played a crucial role in preventing the increases in forest density that characterize most southwestern pine forests. The study sites are not unaffected by the ecological changes associated with settlement, but they do present an important reference resource for study and management of ponderosa pine ecosystems.

Ponderosa pine forests in which historically frequent fire regimes continue up to the present would be invaluable points of reference for assessing natural attributes of ecological structure and function. Grand Canyon National Park contains one of the largest old-growth forests in the Southwest, where tree harvesting has not occurred and grazing has been eliminated for over 60 years. Although most fire disturbance regimes in the park have been disrupted since European settlement, a few remote sites may retain near-natural conditions. The majority of the forested area lies on the North Rim, part of the Kaibab Plateau, which supports ponderosa pine, mixed conifer and spruce-fir forests at elevations ranging from 7,500 to 9,165 feet on well-drained limestone soils.

The North Rim is remote from modern human communities, but Altshul and Fairley (1989) document the long human history of the region. The lower elevations of the rim were densely populated by Native Americans prior to 1250-1300 A.D. Six tribes—the Paiute, Hopi, Havasupai, Hualapai, Navajo, and Zuni—have ancestral and current connections to the canyon and rim habitat. An expedition led by the Spaniards Dominguez and Escalante in 1776 marked the first European presence on the Arizona Strip, the land north of the Colorado River that includes the Kaibab Plateau. It took another 78 years before the first European settlement was begun by Mormon explorers and pioneers in 1854. Fighting with Utes and Navajos kept settlers out of the Arizona Strip until 1869. With the establishment of peace, there was a rapid expansion of livestock grazing, logging and mining activity.

Frequent fire regimes were disrupted in forested highlands of the Arizona Strip as early as 1870 in the Mt Trumbull area (Fulé and others, unpublished data). As elsewhere in the Southwest, early livestock grazing was excessive (Altshul and Fairley 1989) and removed fine herbaceous fuels, stopping fire spread. The establishment of the Grand Canyon Forest Reserve in 1893 and creation of Grand Canyon National Park (GCNP) in 1919 brought organized fire detection and suppression crews. On the North Rim, Wolf and Mast (1998) found complete fire exclusion by about 1920 in ponderosa pine and mixed conifer forests. Even in the high-elevation spruce-fir forests, with historically longer fire-return intervals and more severe fires, protracted fire exclusion has led to the development of increasingly dense, homogeneous stands (White and Vankat 1993). Park management policy has changed in recent decades to favor restoration of natural ecological processes, including fire (GCNP 1992), but the presently dense forests and heavy fuel loads hinder effective reintroduction of fire on much of the North Rim. Fuel problems are not only an ecological concern: the difficulty of fire management on the North Rim has been cited by Pyne (1989) as a major factor impeding the Park's plan for wilderness designation of the area (Morehouse 1996).

Among the challenges faced by managers are: 1) lack of knowledge about natural ecological conditions as a point of reference for restorative management (Moore and others 1999), 2) uncertainty about the appropriate mix of prescribed fire and tree thinning for treating accumulated fuels (Nichols and others 1994), and 3) a host of off-site issues including air quality, developing management procedures suitable for wilderness areas and working in a highly charged political environment.

Our study focuses on the first of these questions: characterizing fire regimes on several sites that may be among the least impacted by recent fire exclusion in the Southwest. The northwestern points and plateaus of the North Rim have the most frequent lightning ignitions in the Park (GCNP fire records). As part of a broader study on fire and forest structure in the Park, we selected three representative sites: Powell Plateau, a mesa separated from the Kaibab Plateau "mainland," Fire Point, the westernmost extension of the rim, and Rainbow Plateau, a peninsula to

In: Cole, David N.; McCool, Stephen F.; Borrie, William T.; O'Loughlin, Jennifer, comps. 2000. Wilderness science in a time of change conference—Volume 5: Wilderness ecosystems, threats, and management; 1999 May 23–27; Missoula, MT. Proceedings RMRS-P-15-VOL-5. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Peter Z. Fulé is Assistant Research Professor, Thomas A. Heinlein is Research Specialist, W. Wallace Covington is Regents' Professor, and Margaret M. Moore is Professor, School of Forestry, Northern Arizona Universiy, Flagstaff, AZ 86011 U.S.A.

the southeast (fig. 1). The forests are dominated by old trees, with lush understory vegetation and substantial evidence of recent fires. The sites are not without recent human impact: these areas were grazed prior to construction of the North Rim boundary fence in 1938 (Schroeder, personal commnication) and fire suppression was practiced here through much of the 20th century (Pyne 1989). However, we anticipated that the limited water for livestock and difficult access for firefighters might have minimized disruption of the fire regime. Our goals were to quantify the fire regime, describe any post-settlement changes and assess management implications.

Methods

The study sites totaled nearly 1,700 acres. The Powell Plateau site covered 780 acres, ranging from 7,400 to 7,660 feet in elevation. The Fire Point site was 333 acres, 7,570 to 7,770 feet in elevation. The Rainbow Plateau site was 550 acres, 7,550 to 7,658 feet in elevation. Soils have not been mapped in detail for these sites, but North Rim soils in general are predominantly of the Soldier series, derived from Kaibab limestone. Average annual precipitation on the North Rim is 23 inches, with an average annual snowfall of 129 inches. Temperatures are cooler than on the South Rim, ranging from an average July maximum of 79° F to an average January minimum of 30° F (GCNP1992; White and Vankat 1993). Vegetation includes ponderosa pine (*Pinus ponderosa*), Gambel oak (*Quercus gambelli*), and New Mexican locust (*Robinia neomexicana*) trees, with an understory of forbs and perennial grasses (Bennett 1974).

Fire-scarred tree sampling was done in June-July, 1998. Partial cross-sections were cut from scarred "catfaces" on trees, logs, and stumps of conifers that appeared to represent the oldest and/or most extensive fire records. Samples were mapped when collected and were well-distributed throughout the study areas. In the lab, samples were mounted, surfaced with progressively finer sandpaper and crossdated (Stokes and Smiley 1968) using characteristic patterns of narrow marker years: 1722, 29, 35, 48, 52, 72, 82 (false ring), 1810, 13, 20, 22, 45, 47, 73, 79, 96, 99, 1902, 04, 51, 63, 77, 96. All dates were independently confirmed by another dendrochronologist. The season of fire occurrence (Baisan and Swetnam 1990) was estimated from the relative position of each fire lesion within the annual ring.

Fire history data were analyzed with the FHX2 software (Grissino-Mayer 1995). Analysis at each site began with the first year with an adequate sample depth (Grissino-Mayer and others 1994). Fire return intervals were analyzed statistically in different categories related to the size and/or intensity of past fires. The fire data were filtered to look at progressively greater proportional scarring as a proxy for

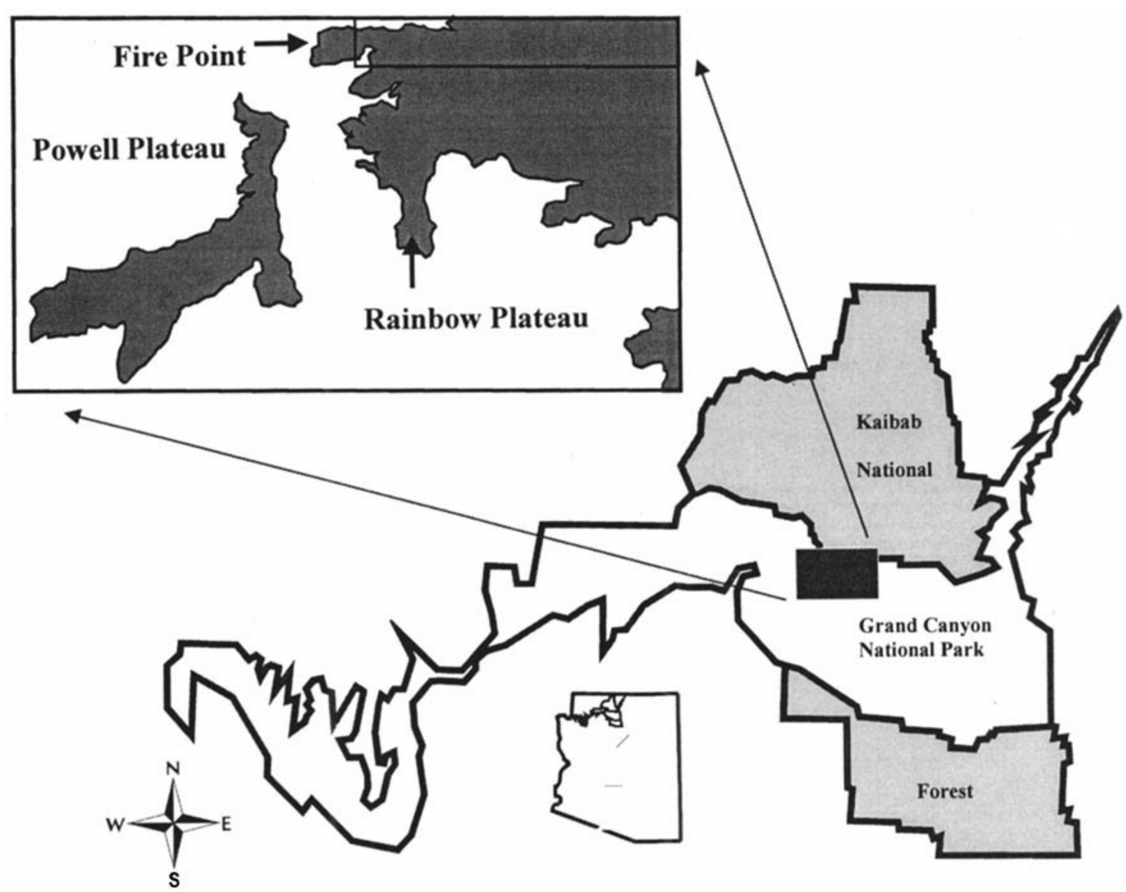

Figure 1—Study sites on the North Rim of Grand Canyon National Park.

fire size (Swetnam and Baisan 1996). First, all fire years, even those represented by a single scar, were considered. Then, we included only those fire years in which 10% or more, and 25% or more, of the recording samples were scarred. The statistical analysis of fire return intervals includes several measures of central tendency: the mean fire interval (MFI, average number of years between fires), the median and the Weibull median probability interval (WMPI).

The relationship between climatic fluctuations and fire occurrence was compared by superposed epoch analysis (SEA), using software developed by Grissino-Mayer (1995). A locally developed, ponderosa pine tree-ring chronology served as a proxy for climate. The SEA superimposes fire years and summarizes the climate variable (tree-ring width) for fire years, as well as preceding and succeeding years. The output of the SEA was a comprehensive comparison of the climate, as represented by tree-ring width, for five years before fire years, the fire years themselves, and two years after fire years. The degree to which the climate variable in each analysis year differed from the average climate was assessed with 90%, 95%, and 99% confidence intervals, developed using bootstrapping methods, with 1,000 simulations based on random windows with the actual fire events (Grissino-Mayer 1995).

Accuracy of the fire scar record could be tested because a relatively high number of fires occurred on the study sites in the 20th century, due both to the isolation of the sites and to recent fire management policies. Across western North America, we usually find sites with good records but no fires (USA—Swetnam and Baisan 1996) or many fires but limited records (Mexico—Fulé and Covington 1997, 1999). The Grand Canyon sites in the present study have both recent fires and written historical data: fire records maintained at GCNP since 1924 provide an unusual opportunity for a quantitative test of the utility of fire scars in reconstructing the temporal and spatial pattern of past fires.

The fire record data were used with caution. The database was patchy in the early years. Many recorded fire sizes and geographic locations were considered approximate, and some evident errors were observed, such as coordinates that placed fires well outside the Park's boundaries. Nonetheless, the database was a valuable independent source of fire history information. After completing the fire scar analysis without reference to the database, we selected records of fires occurring in and around (within 1 km) the study sites for comparison with the fire scar data.

Results and Discussion

Fire Regimes

Composite fire history graphs for all fires on all three sites show that fires were frequent through 1879 and fires continued to occur sporadically up through the present (fig. 2). Prior to 1879, the Weibull Median Probability Interval

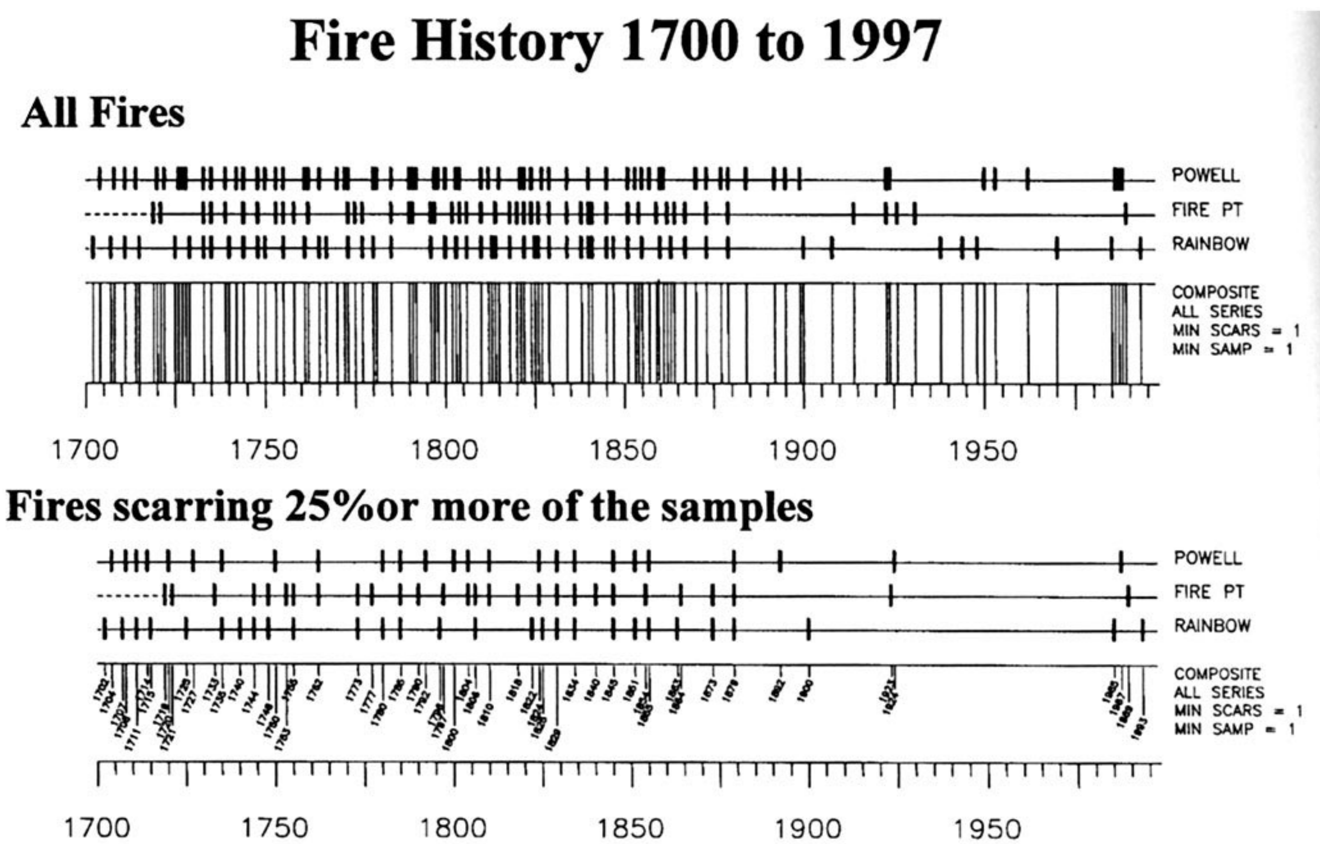

Figure 2—Fire history results are summarized in these graphs, with each horizontal line representing the composite of all sampled trees on a site and the short vertical lines noting the year of fire occurrence. Fire regimes are compared in two categories: all fires, including even those which scarred only a single sample tree (top graph); and fires scarring 25% or more of the sample trees (bottom graph).

(WMPI) at Powell Plateau was less than three years, rising to about 3.9 years on Rainbow Plateau (table 1). Considering only the 25%-scarred fires, the WMPI values were about two to three times higher, suggesting that small fires were more common than larger ones. The fire return intervals fall within the range of values reported at other southwestern sites (Swetnam and Baisan 1996), close to the high frequency end of the distribution. These sites might have been expected to have relatively infrequent fires, as did isolated smaller mesas in Zion National Park, Utah (Madany and West 1982), because the study sites are isolated high-elevation landmasses at the western edge of the canyon rim. The prevailing southwestern winds tend to carry fire out of the sites, while the likelihood of importing fire from lower-elevation lands to the west seems low, due to the reduced chance of low-elevation lightning strikes and discontinuous fuels (although there is a chaparral belt extending for about 1,000 feet below the rim). The fact that high fire frequencies were observed suggests that lightning densities are high on the study sites. Ignitions by Native Americans may have played a role as well (Schroeder, personal communication). The many synchronous fire dates in fig. 2 suggest that presettlement fires spread between the study sites in many years, or that sites were ignited separately in the same years.

Fires occurred primarily in dry years following wet years (fig. 3), assuming that tree-ring widths in the local chronology adequately reflect moisture varability. Similar patterns were observed across the Southwest by Swetnam and Betancourt (1990), who suggested that increased herbaceous production in moist years led to high fuel loading and continuity in subsequent years.

Clearly, fewer fires burned after 1879, especially using the 25%-scarred criterion that filters out the presumably smaller fires that scarred fewer samples (fig. 2). The question is, how much disruption of the fire regime results in ecologically significant changes? Each site has had either two or three large fires since settlement. These post-settlement fires contrast with fire exclusion in the majority of forests in the Southwest (Swetnam and Baisan 1996). Fires were excluded in most of the only other large unharvested southwestern ponderosa pine forest, New Mexico's Gila/Aldo Leopold Wilderness Areas (Swetnam and Dieterich 1985), although some portions of the Wildernesses have had repeated 20th century fires (Rollins and others, in press).

The timing of postsettlement fires may also be important. Regeneration flushes in the early 20th century, especially 1919, were important in forming dense forests in northern Arizona (Savage and others 1996; Mast and others 1999). Large fires on Powell Plateau in 1892 and 1924, Fire Point in 1923 and Rainbow Plateau in 1900 may have been instrumental in thinning seedlings. The other post-settlement fires were all post-1980, reflecting the change in park policy toward prescribed natural fire. In light of the fire regime data, we will evaluate forest structural information from the same study sites to assess changes from reference conditions.

Comparison to Fire Records

Fire scars were highly accurate in identifying historic fires: every fire on the study sites recorded since 1924 and larger than 20 acres was identified from fire scars. The largest fire from written records missed in the fire-scar reconstruction was a 20-acre prescribed natural fire on the Rainbow Plateau in 1987. Many smaller fires, suppressed at one acre or less in size, did not show up in the fire scar record. The proportion of scarred trees was generally related to fire size. The greatest discrepancy between fire size and scarring proportion occurred with the 1931 Fire Point fire, which burned 160 acres but was recorded only on a single scarred sample. In the case of this fire event, reliance on the 25%-scarred criterion would underestimate fire size.

Mapped fire perimeters from the Emerald prescribed natural fire in 1993 matched well with fire scar data (fig. 4). The fire was recorded on only half of the 12 fire-scarred samples collected from within its boundary, but the six samples were well-distributed. Taking these six samples and applying a reasonable spatial buffer of 1,000 feet around them would fairly closely approximate the geographic boundary and size of the Emerald fire.

The close correspondence between the fire scar data and the Park's fire records builds confidence in the interpretation of presettlement fire regime characteristics. While fire scar methods do have limitations (Johnson and Gutsell 1994), our results suggest that the rationale described by Swetnam and Baisan (1996) for proper use of fire scar data,

Table 1—Fire return intervals at the study sites, in two categories: (1) all fire years, including even those represented by a single scarred sample, and (2) fire years in which 25% or more of the recording trees were scarred.

Site	Mean fire interval (MFI)	Minimum	Maximum	Weibull Median Probability Interval (WMPI)
Powell – All	3.24	1	9	2.97
Powell – 25%	9.45	3	24	8.56
Fire Pt. – All	3.65	1	11	3.42
Fire Pt. – 25%	6.35	2	11	6.25
Rainbow – All	4.00	1	11	3.86
Rainbow – 25%	7.81	3	18	7.53

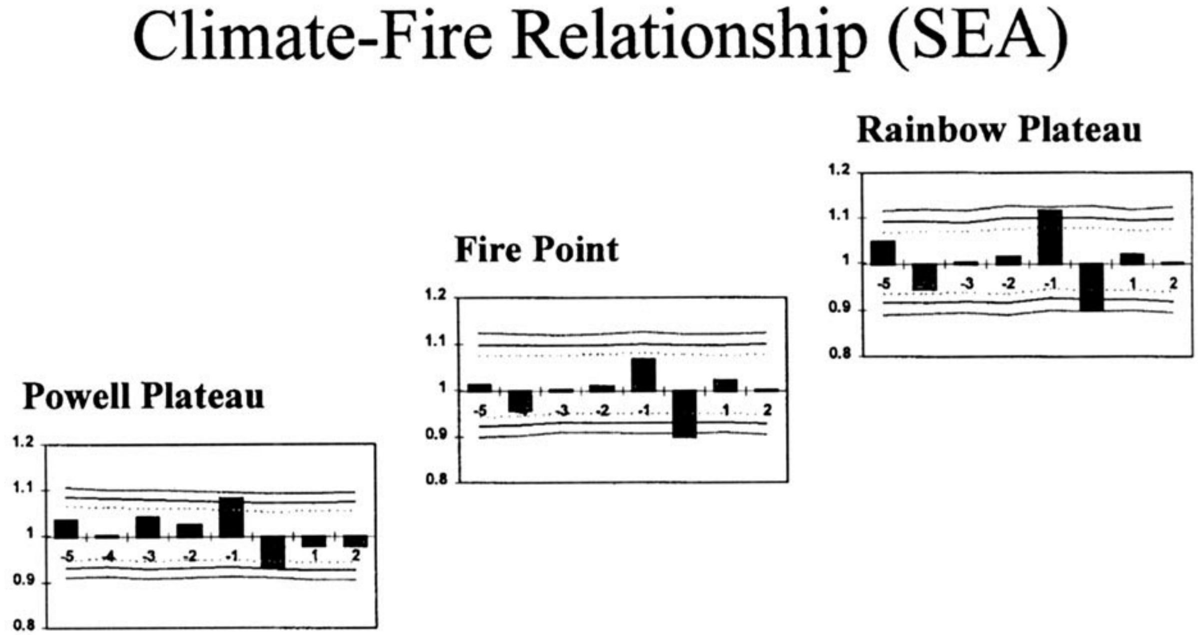

Figure 3—Relationship between local climate (tree-ring width index) and fire occurrence determined by superposed epoch analysis (SEA). The average climate value is scaled to one. Bootstrapping procedures were used to assess the statistical significance of climate departures above the mean ("wet years") and below the mean ("dry years") in the fire years (year 0), the five years preceding fires (-5 through –1), and the two year after fires (1-2). The three lines above and below the x-axis in each graph represent confidence intervals of 90%, 95%, and 99%.

filtering data according to the proportion of scarred samples, is sound.

Management Implications

Presettlement fire regime data serve as a point of reference for ecosystem management, particularly in Park Service wildlands managed primarily for their natural qualities. One logical course of action would be to permit natural ignitions to burn without impediment, using the reference fire regime data as a standard against which to judge the effectiveness of fire restoration.

But if a natural fire policy were to be fully adopted, the Park would have to accept the occurrence of large fires spreading over thousands of acres, dropping below the rim and burning during the summer fire season. The biggest fires, reaching well into the higher elevations of the Kaibab Plateau, would most likely occur during the driest years. When these fires encountered the dense mixed conifer forests above 8,000 feet elevation, intense fire behavior and severe fire effects would occur, in contrast to the effects of the frequent surface fires that prevailed prior to settlement (Wolf and Mast 1998). In the past decade, the two driest years in northern Arizona have been 1989 and 1996. The 1989 Muav wildfire, ignited by lightning, was perceived as a threat of such magnitude that the use of bulldozers was authorized in the Park to construct fireline. The 1996 fire season was the worst on record in the Southwest, with the 50,000 acre Bridger Complex fire burning just north of the Park boundary. Neither in 1989 nor in 1996 would park managers have been able to authorize natural fires to burn, even though it is in precisely such years that large presettlement fires occurred.

Current management policy is directed toward beneficial use of wildland fire for resource benefits, primarily applied in ponderosa pine forests, where burning is less risky. In 1998, for example, a small lightning-ignited fire was intentionally expanded with aerial ignition over the Rainbow Plateau. When fire use involves management ignitions, park managers are faced with different questions. The fire behavior may be less hazardous, but the fire timing and spread will be controlled more by management than by fuel and weather patterns. Fire use is unlikely to be permitted during dry fire seasons, so fire timing and size would probably remain outside the range of natural variability. Fire use may also pose conflicts with the Park's wilderness proposal, because fire managers rely on helicopters, vehicles, and other equipment to carry out burns.

Smoke remains a significant management challenge at Grand Canyon because of the Class I airshed designation, the importance of scenic vistas for park visitors, and the active role taken by the Park in opposing other off-site pollution sources, such as power plants.

Despite the difficulties in restoring fire to the Park, there is no alternative: fuels will burn eventually. The question is how best to intervene. An ecological restoration experiment that tests thinning of small trees, as well as prescribed burning (Covington and others 1997; Heinlein and others, in press), may offer management alternatives for some areas of the Park.

The resilience of forest ecosystems will be key to the eventual restoration of natural processes. Although presettlement fire

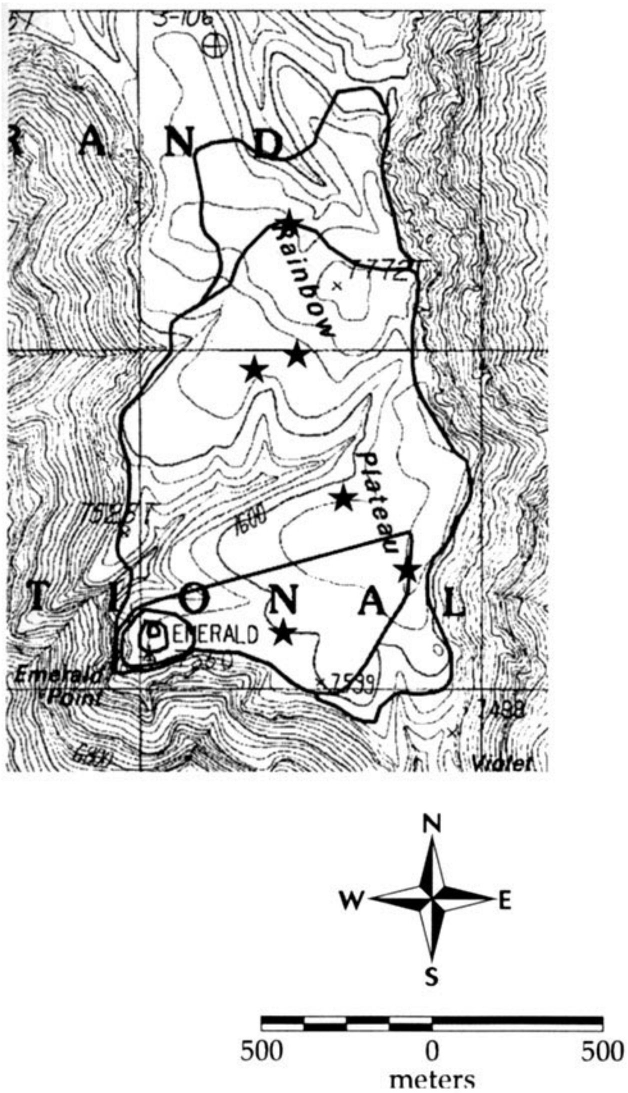

Figure 4—Map of the Emerald prescribed natural fire, which burned from 8/10/93 to 8/24/93, reaching a size of approximately 342 acres. Fire perimeters are shown at approximately 2-day intervals. The stars indicate the locations of six fire-scarred samples that recorded the fire; another six samples within the fire perimeter did not scar in this burn.

frequency was much higher than the post-1879 fire occurrence, and post-settlement fire-free intervals have been substantially greater than the presettlement maximums, the study sites on the northwestern points and plateaus may still be the best existing representatives of natural ponderosa pine forest landscapes in the Southwest. If a few widely spaced fires can have ecological effects reasonably similar to those of the natural fire regime, managers may be able to manipulate modern fire regimes to accommodate constraints without significant damage to ecosystems.

Acknowledgments

We thank the Grand Canyon National Park staff assisting with this research, especially R. Winfree, K. Kerr, D. Oltrogge, D. Spotskey, M. Schroeder, J. Schroeder, K. Crumbo, N. Bryan, J. Balsam, R.V. Ward, A. Horn-Wilson and D. Bertolette. Northern Arizona University's Ecological Restoration Program students and staff, especially J.P. Roccaforte, supported data collection and sample preparation. This work was funded by a grant from the U.S. Department of the Interior.

References

Altschul, J.H., and H.C. Fairley. 1989. Man, models, and management: An overview of the archaeology of the Arizona Strip and the management of its cultural resources. USDA Forest Service and USDI Bureau of Land Management Report contract # 53-8371-6-0054), submitted by Dames & Moore, Inc.

Baisan, C.H., and T.W. Swetnam. 1990. Fire history on a desert mountain range: Rincon Mountain Wilderness, Arizona, USA. Canadian Journal of Forest Research 20:1559-1569.

Bennett, P.S. 1974. The fire ecology of the ponderosa pine ecosystem of the North Rim forests, Grand Canyon National Park. Report on file at Grand Canyon National Park, AZ.

Covington, W.W., M.M. Moore, P.Z. Fulé, and H.B. Smith. 1997. Grand Canyon Forest Ecosystem Restoration. Proposal for Adaptive Ecosystem Research and Management to the U.S.D.I. Interior Fire Coordinating Committee.

Fulé, P.Z., Assistant Research Professor, Northern Arizona University, and others: unpublished fire history data from Mt. Trumbull area, AZ.

Fulé, P.Z., and W.W. Covington. 1999. Fire regime changes in La Michilía Biosphere Reserve, Durango, Mexico. Conservation Biology 13(3):640-652.

Fulé, P.Z., and W.W. Covington. 1997. Fire regimes and forest structure in the Sierra Madre Occidental, Durango, Mexico. Acta Botanica Mexicana 41:43-79.

Grand Canyon National Park. 1992. Fire management plan. On file at Grand Canyon National Park, AZ.

Grissino-Mayer, H.D. 1995. Tree-ring reconstructions of climate and fire history at El Malpais National Monument, New Mexico. Ph.D. Dissertation, University of Arizona, Tucson.

Grissino-Mayer, H.D., C.H. Baisan, and T.W. Swetnam. 1994. Fire history and age structure analyses in the mixed conifer and spruce-fir forests of Mount Graham. Final Report, Mount Graham Red Squirrel Study Committee, US Fish and Wildlife Service, Phoenix, AZ.

Heinlein, T.A., W.W. Covington, P.Z. Fulé, and M.M. Moore. In press. Restoration of fire-adapted forest ecosystems at Grand Canyon National Park. In: Cole, David N.; McCool, Stephen F. 2000. Proceedings: Wilderness Science in a Time of Change. Proc. RMRS-P-000. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Johnson, E.A., and S.L. Gutsell. 1994. Fire frequency models, methods, and interpretations. Advances in Ecological Research 25:239-287.

Madany, M.H., and N.E. West. 1983. Livestock grazing—fire regime interactions within montane forests of Zion National Park, Utah. Ecology 64(4):661-667.

Mast, J.N., P.Z. Fulé, M.M. Moore, W.W. Covington, and A. Waltz. 1999. Restoration of presettlement age structure of an Arizona ponderosa pine forest. *Ecological Applications* 9(1):228-239.

Moore, M.M., W.W. Covington, and P.Z. Fulé. In press. Evolutionary environment, reference conditions, and ecological restoration: a southwestern ponderosa pine perspective. *Ecological Applications*.

Morehouse, B.J. 1996. A Place Called Grand Canyon: Contested Geographies. The University of Arizona Press, Tucson.

Nichols, T., B. Callenberger and G. Kleindienst. 1994. Report of the task force review of the hazard fuel situation on the North Rim of the Grand Canyon. Report on file at Division of Resource Management, Grand Canyon National Park.

Pyne, S.J. 1989. Fire on the Rim. Weidenfeld & Nicolson, New York.

Rollins, M., T. Swetnam, and P. Morgan. In press. Twentieth-century fire patterns in the Selway-Bitterroot Wilderness, Idaho/Montana, and the Gila/Aldo Leopold Winderness Areas, New

Mexico. In: Cole, David N.; McCool, Stephen F. 2000. Proceedings: Wilderness Science in a Time of Change. Proc. RMRS-P-000. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Savage, M, P.M. Brown, and J. Feddema. 1996. The role of climate in a pine forest regeneration pulse in the southwestern United States. Ecoscience 3(3):310-318.

Schroeder, M. Archeologist, Grand Canyon National Park. Personal communication, 1999.

Stokes, M.A., and T.L. Smiley. 1968. An introduction to tree-ring dating. University of Chicago Press, Chicago.

Swetnam, T.W., and C.H. Baisan. 1996. Historical fire regime patterns in the southwestern United States since AD 1700. Pages 11-32 in Allen, C.D. (ed.), Proceedings of the 2nd La Mesa Fire Symposium. USDA Forest Service General Technical Report RM-GTR-286, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO.

Swetnam, T.W., and J.L. Betancourt. 1990. Fire—Southern Oscillation relations in the southwestern United States. Science 249:1017-1020.

Swetnam, T.W., and J.H. Dieterich. 1985. Fire history of ponderosa pine forests in the Gila Wilderness, New Mexico. Pages 390-397 in Lotan, J.E., B.M. Kilgore, W.C. Fischer, and R.W. Mutch (tech. coords.), Proceedings—Symposium and Workshop on Wilderness Fire. USDA Forest Service General Technical Report INT-182, Intermountain Forest and Range Experiment Station, Ogden, UT.

Wolf, J.J., and J.N. Mast. 1998. Fire history of mixed-conifer forests on the North Rim, Grand Canyon National Park, Arizona. Physical Geography 19(1):1-14.

White, M.A., and J.L. Vankat. 1993. Middle and high elevation coniferous forest communities of the North Rim region of Grand Canyon National Park, Arizona, USA. Vegetatio 109:161-174.