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A Sky Island Fire Ecology Primer, with a Focus on Chiricahua National Monument: A Reference Document for the National Park Service

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Horseshoe Two Fire in 2011, Chiricahua National Monument in the foreground (photo by Walt Anderson).

Introduction

Fire is a keystone ecological process in the vegetation of the Sky Islands of Arizona and beyond, affecting every aspect of these ecosystems, including soils, forest structure, species composition, carbon storage, wildlife populations, and much more. For thousands of years, wildfires have been, not a disruptive external force, but an intrinsic part of these natural communities, as integral as water, sunlight, soil, and air. Times have changed. Human-induced fire suppression and climate change have dramatically altered fire regimes across the region, and the fires of the 21st century are a serious problem. Not only are uncharacteristically large and intense fires disrupting ecosystems that historically experienced more frequent, low-intensity wildfire, they are also threatening human communities in the rapidly-growing wildland-urban interface. A key recommendation of the 2007 Statewide Strategy for Restoring Arizona's Forests was that "The Arizona State Legislature, county and local governments, tribal governments, and state agencies should develop land use policies and practices that support forest restoration, community protection, and fire management efforts." (Recommendation 2.2, p.9).

The goal of this essay is to discuss the landscape role of fire in the Sky Islands of southern Arizona, and in particular Chiricahua National Monument. We will describe fire and vegetation conditions before Euro-American settlement, changes in fire regime and ecosystems wrought over the past 150 years, the accompanying shifts in plant communities, and projections for the future. We will marshal our recent field research, tying our results to specific places in the park, but we will also summarize general principles developed from many decades of ecological research across the Southwest. Our mission is to provide essential fire ecology background for park staff, who enlighten park visitors about the ecologically-rich and regionally-important environments of Chiricahua National Monument (CHIR).

The Eco-Geography of Vegetation and Fire in Arizona

Vegetation and fire regime vary naturally in relation to climate, topography, and soils. Arizona is blessed with great variety in these factors and thus impressive diversity of natural communities (Figure 1). In terms of landforms and ecology, the state can be divided roughly into three parts. To the north is the high Colorado Plateau, forested over large areas but also dissected by deep arid canyons, such as the Grand Canyon. A vast desert landscape covers the southwestern part of the state. In southeastern Arizona, is a sea of low desert scrub and grassland punctuated by alternating "island" mountain ranges, some of which rise as high as 10,000 feet—often referred to as the "Sky Islands" or "Madrean Archipelago".

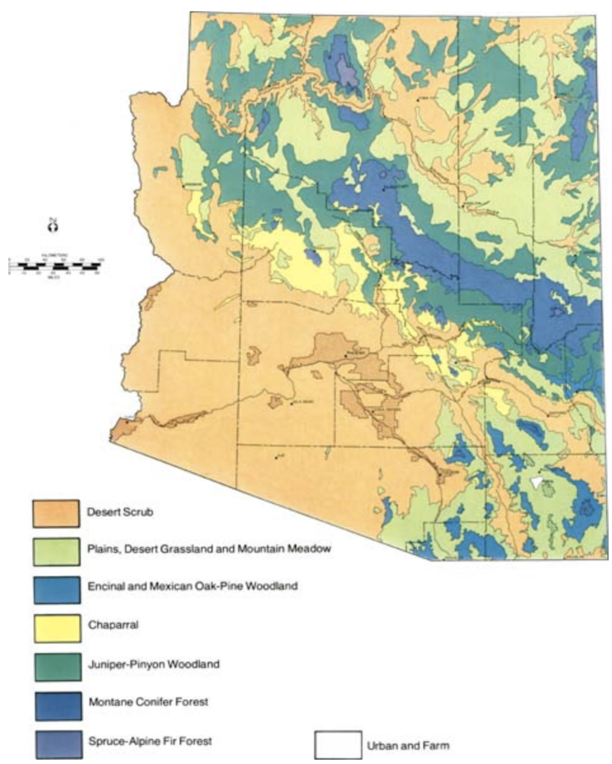

Figure 1. Vegetation map of Arizona (from Brown 1973).

The Sky Islands of the American Southwest and northern Mexico comprise an ecological convergence zone among the Rocky and Sierra Madre Mountain ranges and the Chihuahuan and

Sonoran deserts, promoting a remarkable diversity of species and communities, making them, along with the Sierra Madre proper, a regional *biodiversity hotspot*. Steep elevational gradients and highly-dissected terrain engender complex vegetation patterns, which can be summarized according to the following elevational zonation: lowland Chihuahuan and Sonoran desert scrub and desert grassland; mid-elevation piñon pine-oak-juniper woodland, chaparral, Madrean pine-oak forest, and Arizona pine forest; and high-elevation ponderosa pine forest, montane mixed conifer forest, and subalpine spruce-fir forest. The more mesic (cooler, moister) higher elevations support species mainly from the Rocky Mountains, whereas species from the Sierra Madre are prevalent in the lower to mid-elevation, arid zones.

On the ground, Sky Island sites such as Chiricahua National Monument more closely resemble a mosaic rather than a staircase of zones. One can walk, for example, with little change in elevation and still pass through multiple types of natural communities, as in Echo Park or the Natural Bridge Trail. Nevertheless, this vegetation mosaic shifts as one rises in elevation, leaving more arid, open communities behind and encountering more mesic, closed communities. Hike up the Mushroom Rock Trail to Inspiration Point for a good example of this phenomenon. It's helpful to divide up natural communities in the park into the following:

- *desert grasslands and savanna*, along the park's southern and western borders,
- *riparian forest (*Arizona sycamore*,* Arizona cypress, Velvet ash), along streambeds,
- *chaparral* (low shrubs, sometimes forming dense stands), on steep slopes and exposed sites,
- *piñon-juniper-oak woodland*, outside canyons throughout the park,
- *lower pine-oak forest* (Chihuahua and Apache pines; Arizona white and Emory oak), in lower canyons, and
- *upper pine-oak forest* (Arizona pine, Douglas-fir, silverleaf oak), in upper canyons and higher elevations.

This primer will focus on chaparral, woodlands, and forests, the most common vegetation types in the park. Scientific names of species can be found in Appendix 1.

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Vegetation pattern across CHIR is influenced by both topography and fire, which also varies naturally across the landscape. Wildfire has three requirements: a spark, sufficiently dry conditions, and continuous fuel. In the Sky Islands, sparks are provided by the lightning that occurs at the beginning of the monsoon season, when conditions are still relatively dry. Ridgetops and lowland grasslands are thought to have been common ignition points, from where fire would then spread up or down canyons. Apache-set fires may have contributed to increased fire frequency in some places before and during Euro-American settlement, but most fires were apparently lightning-caused. Today, many wildfires are caused by humans, most through carelessness, a few on purpose, but lightning continues to play a key role in sparking wildfires.

The other two requirements for fire—dry conditions and continuous fuel—vary with climate and vegetation. Fires are rare in deserts, which are sufficiently dry but lack continuous fuel. In somewhat moister low- and mid-elevation grasslands, woodlands, and forests of the Sky Islands, fuels are more continuous and conditions still sufficiently dry enough for fires to occur frequently, which, under natural conditions, limits fuel accumulation and fosters low-intensity, surface burns. Madrean pine-oak and Arizona pine forests are good examples of these types of ecosystems. In the mixed coniferous forests at the highest elevations, fire regimes are more complex. On north-facing slopes, where spruce and fir predominate, moist conditions limit fires to unusually hot/dry years. These long intervals lead to fuel build-up and high-intensity fire, often causing stand replacement. On drier south-facing slopes, which favor ponderosa pine and Douglas-fir, fires range widely from low to high-severity, depending on weather conditions.

Changing Fire Regimes: Three Eras

Our description of the fire regimes of the Sky Islands thus far has been historical in nature, that is, we have characterized fires in pre-Euro-American times. These are not the fire regimes of today. In fact, for the dry woodlands and forests of the Southwest, such as those in Chiricahua National Monument, we can divide the history of fire regimes into three distinct eras: (1) naturally frequent fires before Euro-American settlement, which maintained largely open vegetation; (2) a 20th century period with few fires as a consequence of livestock grazing and active fire suppression that led to landscape-scale surges in tree density and fuel; and (3) a contemporary era of large, intensified wildfires. The ecosystems viewed by visitors to parks such as Chiricahua National Monument are a product of these three fire eras. The massive Horseshoe Two Fire of 2011, discussed below, is the dominant force shaping the current appearance of the vegetation throughout the park.

Natural Fire Regime Before Euro-American Settlement (up to 1870). Chiricahua National Monument was one of the early sites to attract researchers seeking to characterize fire regimes in the Southwest. Tom Swetnam, Chris Baisan, and their colleagues at the Laboratory of Tree-ring Research at the University of Arizona started research in Rhyolite Canyon in the 1980s. How did they figure out the fire regime of this area from centuries ago? Many fire-adapted tree species possess bark that is sufficiently thick that surface fires injure but don't kill them. Such "fire-recorder" trees are readily apparent, as they bear large triangular wounds, usually with black char, on their lower trunk surface—so-called *cat faces* (see Figure 2). Several common tree species in the monument—Chihuahua, Apache, and Arizona pines, for example—readily form these.

Figure 2. "Cat face" on an Apache pine damaged by fire (photo: Andrew Barton).

When a fire damages the trunk, it also leaves a clear mark on the wood inside the trunk, directly on the annual tree-ring of that year. Because of a lack of bark on the cat face, the next fire readily damages the tree, leaving its signature once again on the annual ring for that year. Once injured, trees can continue to accrue fire scars for as long as they live. To get at the wood bearing these scars, researchers can take an increment core, but more often they will excise a small horizontal section from the tree. These wood sections are then sanded and polished, exposing the tree-rings and fire scars, the rings are cross-dated with other dated trees to ensure a correct ring chronology, and the exact years of past fires are recorded. Figure 3 shows a section of wood from a sequoia in California, revealing multiple fire years. When multiple fire-scarred trees are analyzed for fire scar dates, a history revealing the key fire regime patterns can be developed for the area.

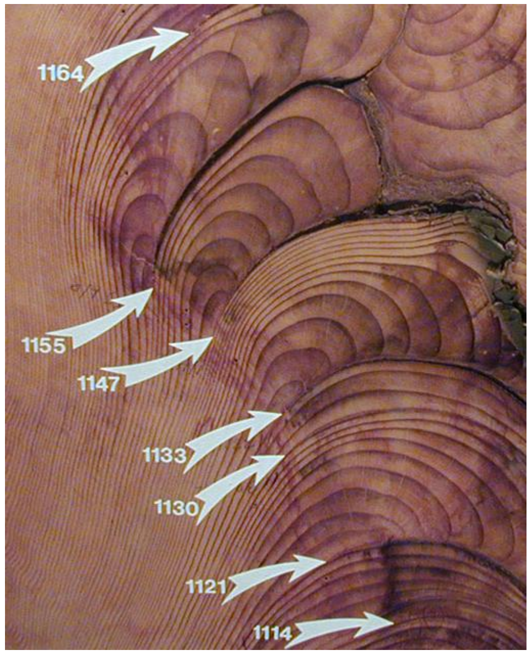

Figure 3. Fire scars on a giant sequoia (*Sequoia giganteum*) (photo: Tom Swetnam).

Let's take a look at the fire history for Madrean pine-oak forest in Rhyolite Canyon (Figure 4). Each horizontal line is for an individual tree; each vertical tick marks a fire year for that tree; the trees are divided into three elevational groups. Several key patterns are apparent for the pre-settlement era (1600s to the 1860s). First, fires naturally occurred very frequently, with any given tree recording a fire about every 4-8 years. Second, given that trees survived for centuries, we know that these fires were low-intensity, surface fires, which spared most mature trees and probably killed off smaller trees, shrubs, grasses, and herbs. Finally, fires were synchronized, that is, when a fire left its mark on one tree, it often burned many of the others during that same year as well (i.e. the vertical lines indicating a fire on one individual in one year are recorded by multiple individuals, or multiple horizontal lines in Figure 4). What is responsible for that final pattern? Fires tended to occur in drier years following a moist period. Dry conditions promoted fire spread, and moist conditions fostered fine fuel buildup from grasses and herbaceous plants that would later carry fires across the landscape in later hot/dry years. The fires recorded in Rhyolite Canyon also exhibit synchrony with other sites in the Chiricahua Mountains, other Sky Islands, and the entire Southwest, suggesting that region-wide climate patterns play an important role in controlling wildfire. These major climate patterns are, in turn, controlled to some degree by the hemispheric-scale Pacific Ocean cycles of El Niño-La Niña.

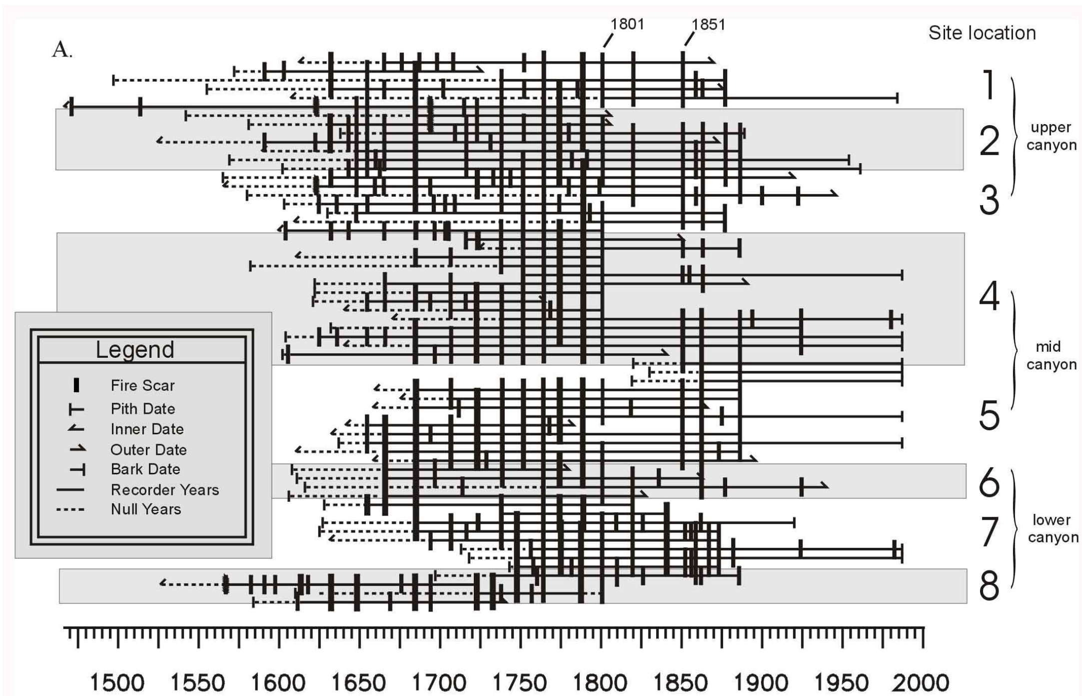

Figure 4. Fire chronology in Madrea pine-oak forest in Rhyolite Canyon, Chiricahua National Monument, Arizona (Swetnam and Basian 2001).

We know much less about natural fire regimes in piñon-juniper-oak and chaparral vegetation, which occur on drier, more exposed sites within the park. These species are not fire-resistant, are generally killed by surface fires, and thus do not record fire history. This very fact, as well as research from piñon-juniper vegetation across the West, suggests a natural mixed-severity fire regime for these communities where some places burn cool and kill only some vegetation and others burn hotter and kill most plants. This landscape, which covers large portion of Chiricahua National Monument, is highly-dissected and heterogeneous, which probably engendered considerable variability in fire behavior from place to place. It's important to keep in mind both this heterogeneity and the differences between pine-oak forests, common in the canyons, and woodland and chaparral vegetation on more exposed sites.

Fire-suppression Era (1880-1994). The second fire regime era—which was characterized by a decline in fire frequency—can be readily seen in the fire chronology as well. Starting in the 1880s, fires largely ceased in Rhyolite Canyon, a pattern found throughout the Southwest. This shift coincides with the onset of fire exclusion through the introduction of livestock, which drastically reduced grass cover (fine fuels) and created fire breaks from cattle trails. By the early 1900s, active fire suppression with people directly putting out fires, began in earnest, ensuring the diminution of fire as a dominant influence on plant community structure across most ecosystems of the Southwest. What seemed like a good idea at the time—saving natural resources from the disruptive effects of fire—turned out to a be a misguided policy, the consequences of which continue to bedevil us. Photographs in Appendix 2 reveal the dramatic increase in forest cover in Chiricahua National Monument resulting from fire suppression.

Fire Intensification Era (1994-). At least for the Chiricahua Mountains, the third fire regime era—intensification—started in 1994 with two major events. That year was the first in a long and continuing series of drought years (Figure 5). Combined with more than a century of fuel buildup, those conditions generated the Rattlesnake Fire, which burned nearly 25,000 acres on the east side of the mountains, with about 1/3 of the fire at moderate- and high-severity (severity meaning the impact on vegetation), largely in areas that would have burned at low-severity in pre-settlement times. The Monument, however, escaped the effects the Rattlesnake Fire, as it burned only on the surrounding Forest Service land.

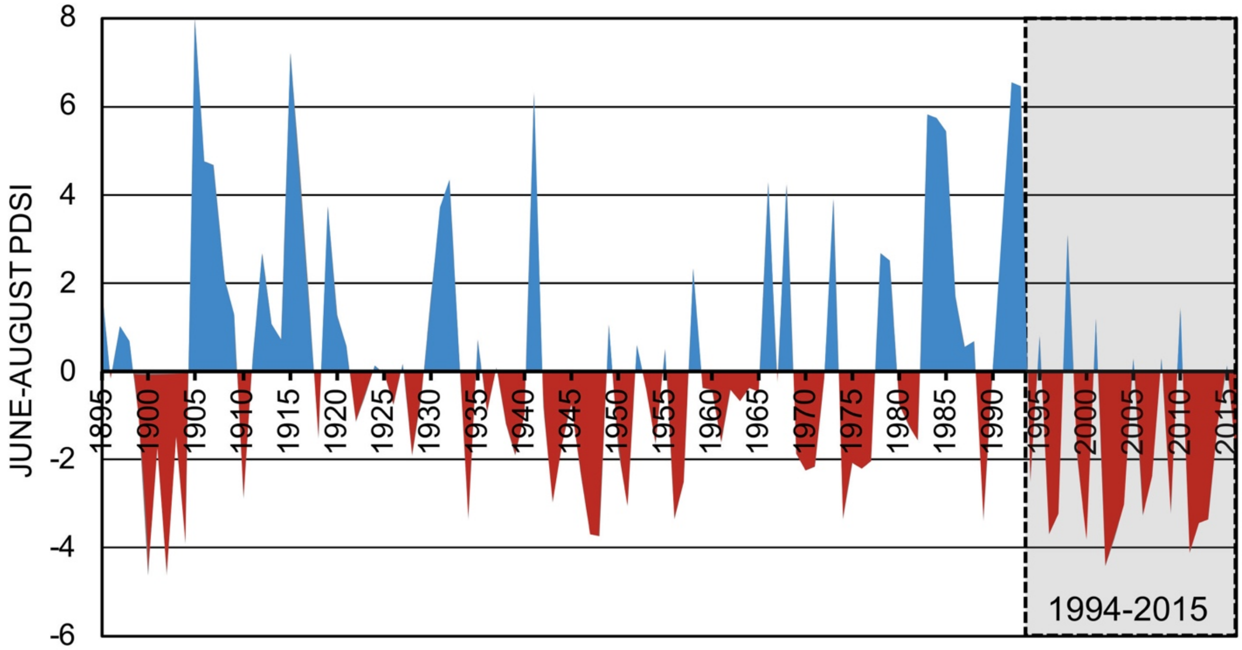

Figure 5. Palmer Drought Severity Index for 1895-2015 in southeastern Arizona (Barton and Poulos 2018)

Then, in 2011, the Horseshoe Two Fire burned 225,000 acres, about 75% of the mountain range including CHIR, and more than 40% of the fire burned at moderate- and high-severity (Figure 6). The effects were profound, killing trees across entire mountainsides, gouging deep erosion channels, contributing to severe monsoonal flooding, and more. In Chiricahua National Monument, the impacts are evident along every mile of road and trail and from every viewpoint in the park. One of the driest years on record (see Figure 5), 2011 brought massive fires throughout the Southwest, burning over one million acres in Arizona alone, including the 538,049-acre Wallow Fire, the largest in state history. Driven by a powerful combination of fuel buildup and climate change, the contemporary fire intensification era in the Southwest continues through the present, and is causing economic hardship, human tragedy, and ecosystem disruption.

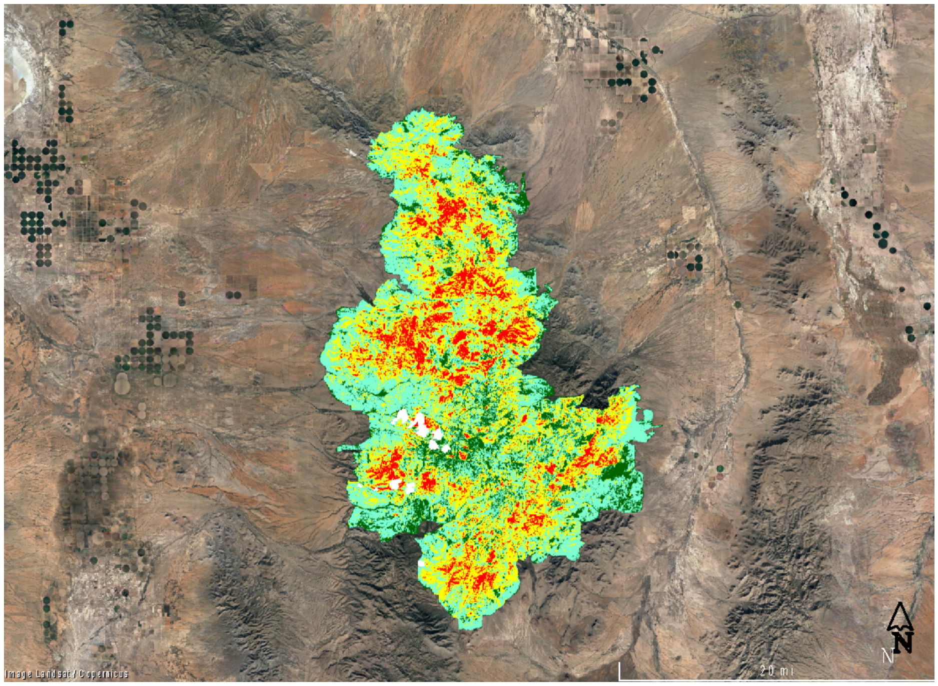

Figure 6. The Horseshoe Two Fire in the Chiricahua Mountains, AZ. High severity: red, Moderate severity: yellow, Low Severity: blue-green, Unburned to Low Severity: dark green (Miller and Thode, 2007).

Effects of Changing Fire Regime on Natural Communities

How have these dramatic shifts in fire regime altered the vegetation of Chiricahua National Monument. Ecologists divide up vegetation characteristics into three categories: *physical structure*, *process*, and *species composition*. *Structure* refers to the sizes and density of trees, the height of the canopy, the layers of the forest, the amount of dead wood (snags, logs, branches, etc.). The term *process* captures the chemical and biological flows (e.g. photosynthesis), cycles (e.g. nitrogen), and events (e.g., droughts) that connect organisms to their environment and each other. *Composition* means the mixture of species supported on a site, including the diversity and types of species (e.g., conifers).

Structural changes in forests of CHIR are the most obvious and easily-detectable impacts of changing fire regimes on vegetation. During the pre-settlement era, fire maintained open vegetation, with multiple layers of trees, shrubs, and grasses, and low amounts of dead wood on the forest floor. Fire suppression created denser, shadier communities, with higher levels of dead organic matter. The

Horseshoe Two Fire dramatically reversed this trend, which resulted in widespread loss of forest cover and conversion of sites formerly in closed forests to open shrubby chaparral. Figure 7 clearly reveals this, with a startling loss of closed forest and increase in open chaparral in response to the fire. At least for the short run, extensive plant mortality also increased the amount of standing and dead and downed wood, possibly amplifying the chance of more fire in the future.

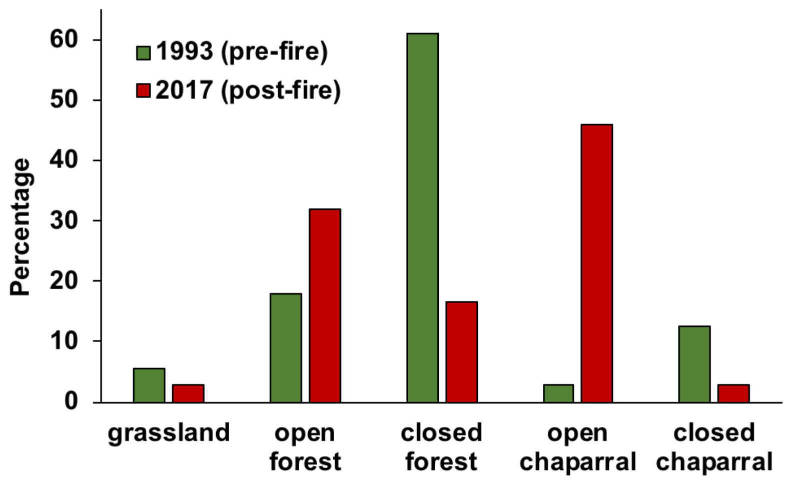

Figure 7. Percentage of cover types (72 plots) in Chiricahua National Monument in before vs. after the Horseshoe Two Fire. "Open forest" is also known as "woodland."

Although we know less about the impacts of changing fire regime on *process*, several alterations in response to recent wildfires are clear in the Chiricahua Mountains. The loss of plant cover destabilized soils, leading to widespread erosion, massive debris flows, gully formation, and soil loading into streams. High-intensity fire reduced the amount of soil nitrogen (an important soil nutrient for plant growth) and perhaps other nutrients as well. Little is known about the impacts of the fire soil micronutrient concentrations or on the microbial community that maintains healthy soil conditions, but these were likely also disrupted. Finally, a large amount of the carbon stored in these ecosystems—in live trees, dead wood, and soils— was volatilized into the atmosphere when it burned, shifting these forests from carbon sinks to sources (i.e. releasing rather than storing carbon).

Changing fire regimes also transformed plant species composition in Chiricahua National Monument significantly, mainly by favoring certain fire tolerance strategies over others. Woody plants have evolved myriad adaptations for living in fire-prone environments, which can be grouped into three fundamental strategies: *fire resistance*, *resprouting*, and *fire seeding*. *Fire resistant* species, like Apache and Arizona pines possess thick bark and branch-free lower trunks that enable mature individuals to survive all but high-intensity fire (Figure 8). Other plants, such as oaks and trembling aspen, are readily top-killed by fire, but *resprout* prolifically from the stump, roots, or damaged trunks that survive even high-intensity fire (Figure 8). *Fire seeders* invest little in fire resistance or resprouting, but instead produce seeds that germinate readily after wildfire. Fire-sensitive Arizona cypress, for example, are killed by fire, but have cones that open and release seeds in fires—a term called *serotiny*. Their seeds enjoy mineral soil (i.e. no litter) and high light levels in the post-fire environment and have the capacity to quickly replace the former stand. Cherries take a different approach to the seeder strategy: their readily-dispersed seeds (by animals) lie dormant in the soil until stimulated to germinate by the open conditions created by fire.

Figure 8. Fire-resistant Arizona pine, with thick bark and no lower branches (left) and fire-sensitive silverleaf oak resprouting after top-kill (right) (photos: Andrew Barton).

Not all species occur at the extremes of these strategies. For example, very large Arizona white oak can survive low-severity fires, but resprout when they are top-killed. Chihuahua pine is a jack-of-all-trades, with thick bark, modest resprouting (unlike other pines in the Monument), and semi-serotinous cones. Where do shrubs fit into this classification? Surviving fire is generally not a viable option for a shrub, so shrubs usually follow either the resprout or seeder strategy. For example, the seeds of point-leaf manzanita are actually stimulated to germinate by fire, whereas Wright's silktassel is a common sprouter in the park. Appendix 1 provides a list of common woody plants in Chiricahua National Monument categorized by fire tolerance strategy (or lack thereof).

The presettlement surface fire regime in Madrean pine-oak forests maintained a balance of fire-resistant pines (Apache, Chihuahua, and Arizona), which readily survive fires, and oaks, which would have been tamped down by fire but recovered quickly through resprouting. Highly-variable fire regimes, ranging from no fire to high-intensity fire, in open piñon-juniper-oak woodlands and chaparral would have promoted co-existence of a diverse mix of sprouters (such as oaks and junipers), seeders (such as manzanita), and fire-sensitive species (such as piñons).

The Horseshoe Two Fire drastically changed these patterns, especially in sites subject to high-intensity fire. In Madrean pine-oak forests, fire resistance failed as a strategy in such conditions, where crowns alight and all stems were killed. Compounding this problem, post-fire establishment of pines has been extremely low, probably due both to the exposed conditions created by intense fire and the continuing region-wide drought. Although they died above ground, oaks and shrubs readily sprouted after fire, regardless of intensity, and have quickly captured precious growing space in recovering ecosystems (Figures 8 and 9). In woodlands and chaparral, fire killed all trees across vast mountain-sides. Resprouts (especially oaks), seeder species (especially manzanita), and grasses have taken over these sites—clearly revealed by the striking increase in percentage of open chaparral in Figure 7. In contrast, fire-sensitive border piñon, previously one of the most abundant trees on these sites, shows little evidence of regeneration and has largely disappeared (Figure 10).

Vegetation changes resulting from the Horseshoe Two Fire are dramatic, and they can be boiled down to (1) loss of cover, (2) transition of some forests and woodlands to chaparral, (3) loss of pines, and (4) replacement of fire-resistant and fire-sensitive species (pines) by fire-responsive sprouters, seeders, and grasses. These patterns can be viewed throughout the park. A hike up the Natural Bridge trail is revelatory. At the first height of land are entire hillsides where nearly all piñon pines, oaks, and junipers were killed above-ground, and all but the pines have readily regenerated by resprouting (Figure 11). Farther along in an open canyon, only remnants remain of a previously-extensive pine-oak forest (Figure 9). Contrast this with the intact pine-oak forest along the Lower Rhyolite Canyon Trail, where the Horseshoe Two Fire burned at low severity (Figure 9). The slopes around Inspiration Point are also striking, with large dead remnants of Arizona pines and Douglas-fir and a rapidly-coalescing shrub layer of silverleaf oak sprouts and point-leaf manzanita (Figure 10).

Figure 9. Madrean pine-oak forest burned at low severity (left) and high severity (right) (photos: Andrew Barton).

Figure 10. Arizona pine-silverleaf oak-Douglas-fir stand unburned (left) and burned at high severity with top-kill (right). The two conifers have not regenerated. Oak regenerated throughout resprouting. Manzanita established prolifically from a dormant seed bank (photos: Andrew Barton).

Figure 11. Piñon-oak-juniper woodlands burned at low severity (left) and high severity (right). Oaks and junipers resprouted; piñons exhibit almost no regeneration (photos: Andrew Barton).

The Future

Fifteen thousand years ago, during a cooler, moister time, the valleys between the Sky Islands were filled with piñon-juniper-oak forests where desert scrub exists today. Nature is intrinsically dynamic, and we should not expect the natural communities of Chiricahua National Monument to remain static. On the other hand, the rate of change at the hands of humans is unprecedented. A century of fire suppression drastically changed the structure of woodlands and forests, and, without a doubt, the Horseshoe Two Fire is the most profound environmental event in the history of the park, perhaps since the arrival of desert elements thousands of years ago.

What are likely scenarios for the future? Seven years since the Horseshoe Two Fire is a relatively short period for long-lived plants, such as the conifers in Chiricahua National Monument. Favorable regeneration conditions are certainly possible in the future, allowing recolonization of communities that are now dominated by oaks and small shrubs such as manzanita. On the other hand, intensification of drought and wildfire is projected for the American Southwest. Unless actual future conditions depart from these projections, we would expect more not less conversion of vegetation away from pines and slow recovery of already-affected stands. Given their capacity to readily regenerate after high-severity fire, the shrubby vegetation that has taken hold in parts of the park that burned at high-intensity and in other recent wildfires elsewhere in the Southwest may well be more resilient to contemporary and future climate and fire regimes than are pines and Douglas-fir.

These projections raise important questions for land managers in the Sky Islands. Is precautionary protection of existing pine communities warranted? For example, combined targeted thinning and prescribed fire could potentially reduce the risk of future wildfires, a well-established management intervention elsewhere in the Southwest. Should land managers consider restoration pilots for conifers? Manipulative field experiments focused on pine establishment, for example, could elucidate the mechanisms responsible for recent failure of these species, both in terms of environmental stresses and the stages of establishment that act as bottlenecks. These experiments could also serve as trials for actual pine restoration, enabling assessment of effective interventions and feasibility, as well as establishing initial nuclei for future stands. These issues beg the larger philosophical question: what is the appropriate role of land managers trying to heal the past damage wrought by human civilization on natural ecosystems of the American Southwest?

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Appendix 1. Adaptations and responses to fire of common trees and shrubs in Chiricahua National Monument (Sources: USDA Fire Effects Information System; Barton 1999, 2002; Gebow 2005; Barton and Poulos 2018; Barton and Poulos, unpublished data.)

PLANT SPECIES	Adaptations & Reponses to Fire
TREES	
Arziona Madrone *(Arbutus arizonica)*	Variable trunk damage Can survive extensive bark and cambium damage Root crown and epicormic sprouting
Arizona Cypress *(Hesperocyparis arizonica)*	Fire-sensitive trunk Serotinous cones
Alligator-bark Juniper *(Juniperus deppeana)*	Large individuals can survive low-intensity fire Sprouting from root crown, trunk, and branches
Arizona Pine *(Pinus arizonica)*	Can survive low- and moderate-intensity fire
Border Piñon *(Pinus discolor)*	Fire sensitive Seeds germinate from seeds cached by amimals Nurse plants facilitate establishment in the open
Rocky Mountain Piñon *(Pinus edulis)*	Fire-sensitive trunk Seeds germinate from seeds cached by amimals
Apache Pine *(Pinus englemannii)*	Can survive low- and moderate-intensity fire
Chihuahua Pine *(Pinus leiophylla)*	Can survive low- and moderate-intensity fire Modest sprouting, mainly in small stems Semi-serotinous cones
Douglas-fir *(Pseudotsuga menziesii)*	Can survive low-intensity fire; moderate intensity in large trees Susceptible to fire crowning due to low branches
Arizona White Oak *(Quercus arizonica)*	Large individuals can survive low-intensity fire Sprouting after top-kill
Emory Oak *(Quercus emoryi)*	Fire-sensitive trunk Sprouting after top-kill
Gambel Oak *(Quercus gambelii)*	Sprouting after top-kill from root crown and roots Large individuals can survive low-intensity fire
Silverleaf Oak *(Quercus hypoleucoides)*	Fire-sensitive trunk, but Large individuals can survive low-intensity fire Sprouting after top-kill
Southwestern Black Cherry *(Prunus serotina* var. virens*)*	Fire-sensitive trunk Dormant seed banks stimulated by fire-created openings
White fir (*Abies concolor*)	Fire-sensitive trunk
SHRUBS	*Shrubs exhibit low shoot survival of fire*
Netleaf Oak *(Quercus rugosa)*	Sprouting after top-kill from root crown
Toumey Oak *(Quercus toumeyi)*	Sprouting after top-kill from root crown
Pointleaf Manzanita	Obligate seeder

(Arctostaphylos pungens)	Dormant seed banks stimulated by fire Rooting of low branches observed
Wright's Silktassel *(Garrya wrightii)*	Sprouting from root crown
Catclaw *(Acacia greggii)*	Sprouting from root crown
California Buckthorn *(Frangula californica)*	Sprouting from root crown
Skunkbush and *(Rhus trilobata)*	Sprouting Possible dormant seed bank
Littleleaf Sumac *(Rhus microphylla)*	Sprouting Possible dormant seed bank
Mesquite *(Prosopis glandulosa)*	Sprouting after top-kill from underground stem
Fendler's Ceanothus *(Ceanothus fendleri)*	Sprouting after top-kill from root crown Extensive seedling establishment after fire
Mountain-mahogany *(Cercocarpus montanus)*	Sprouting after top-kill from root crown
Schott's Yucca *(Yucca schottii)*	Sprouting after top-kill from roots

Appendix 2. The effects of fire suppression (before and after) on forest structure in the Chiricahua Mountains.

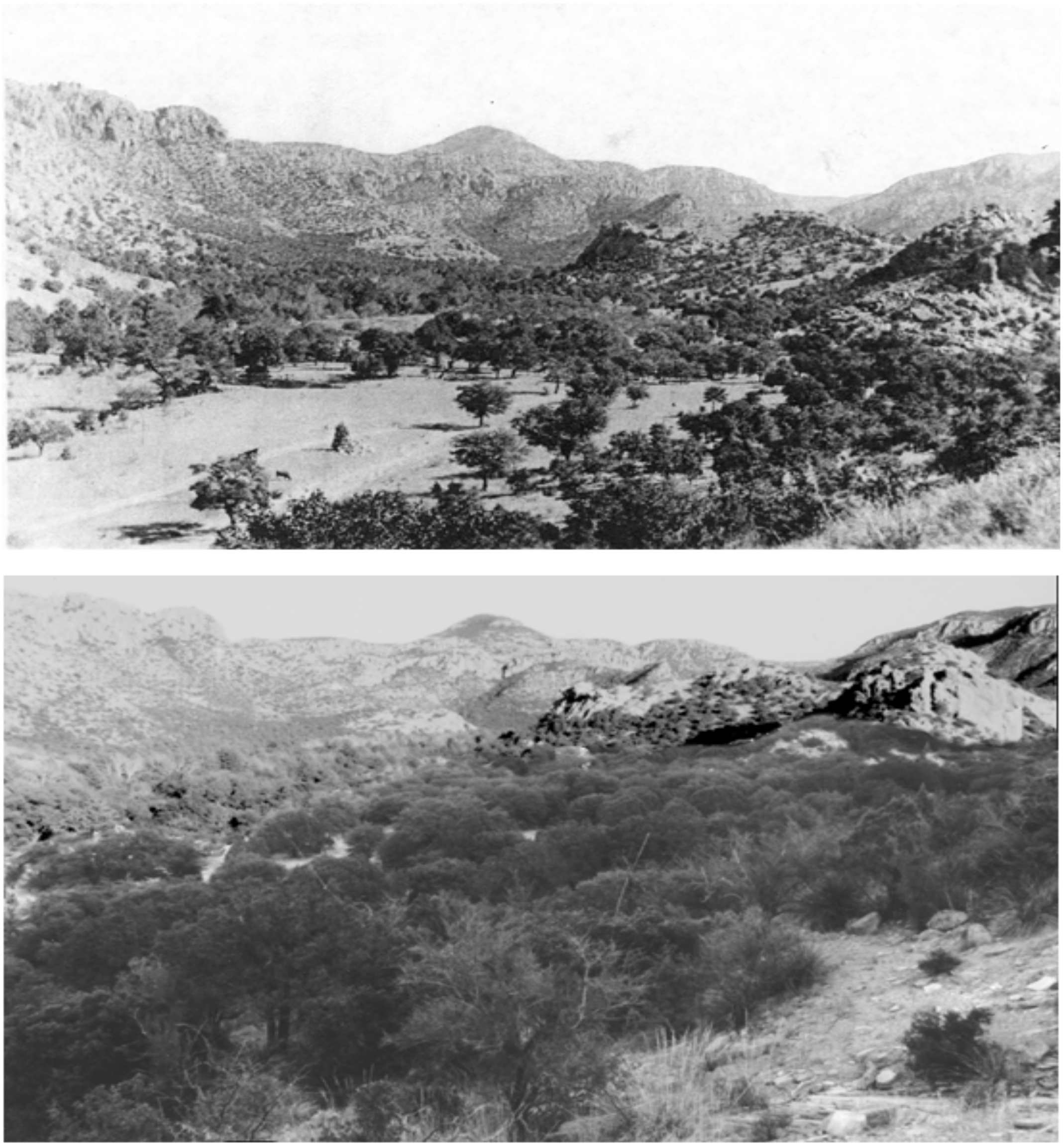

Figure A. Looking up Bonita Canyon from near the CHIR entrance (up a hill). The top is from about 1920, the bottom 2000. (Photos: archival and Jennifer Kluber)

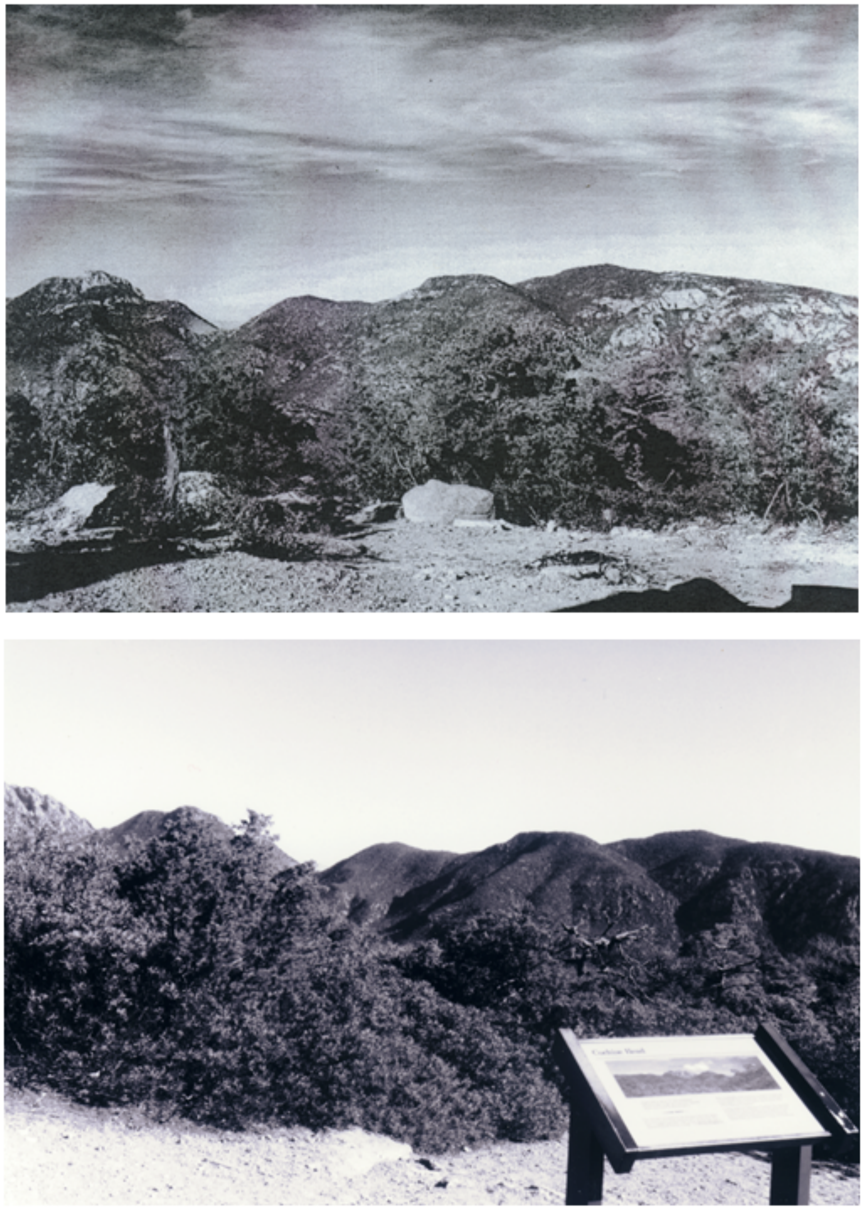

Figure B. View northeast over Case #4 Massai Point. Top is from 1940, bottom 2000 (Dodge, Fish, Alberts 917.3 Chir and Jennifer Kluber).

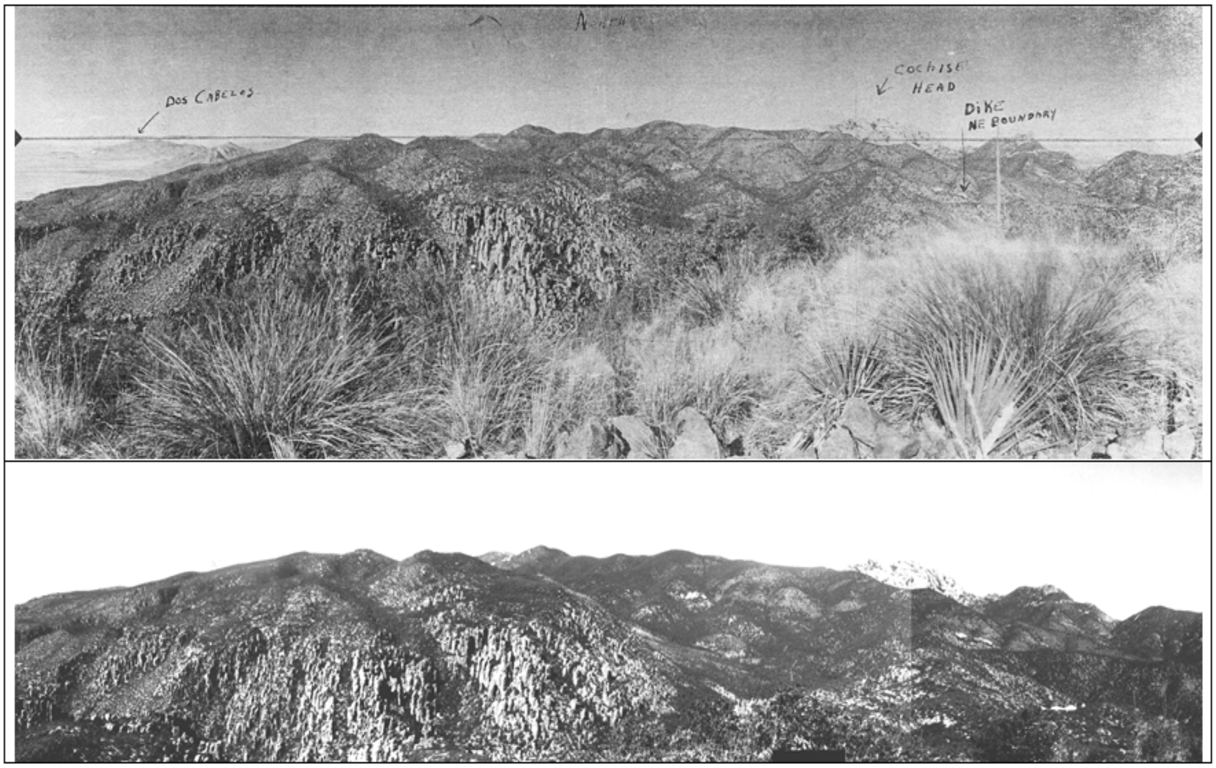

Figure C. View from Sugarloaf Mountain. Top is from 1934, bottom 2000. (Photos: archival and Jennifer Kluber)