The Forests of Southwestern Colorado and Northwestern New Mexico: How the Past and Present Inform our Choices for the Future

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Introduction

The South Central Highlands Section is a major forested region centered on the San Juan Mountains of southwestern Colorado and northwestern New Mexico (Figure 1). It includes the Uncompahgre Plateau and La Garita Mountains to the north of the San Juan Range and the Tusas and Jemez Mountains to the south. Three major rivers flow from this region: the San Juan, the Gunnison, and the Rio Grande. This rugged mountainous landscape supports extensive forest cover, with some of the most spectacular scenery in western North America. Until recently it was a sparsely settled region with an economy founded on agriculture, forestry, mining, and tourism. The human population in the San Juan region now is growing rapidly and the economy is shifting away from traditional industries toward an emphasis on amenities, recreation, and fossil energy production, similar to other scenic mountainous areas in the American West. In some portions of the region, rapid change now threatens to overwhelm the cultural heritage and ecological integrity of this unique and beautiful place.

Land managers are striving to maintain the outstanding natural features and ecosystem services of the South Central Highlands Section, while accommodating the new demands and expectations being placed on the area's resources. These goals require an understanding of the basic ecology of these landscapes, including historical processes that shaped these dynamic ecosystems over years, decades, and centuries. This report briefly summarizes the ecological context of the region in three sections: (i) historical range of variability, i.e., the ecological history and natural processes that have shaped the landscape, (ii) human impacts and current ecological conditions, and (iii) some promising opportunities for effective ecosystem management. This report is an abbreviated version of a longer report, available from the Colorado Forest Restoration Institute at Colorado State University (http://welcome.warnercnr.colostate.edu/cfri-home/index.php).

Historical Range of Variability in the South Central Highlands Landscape

For thousands of years, the topography and biotic communities of the San Juan Mountains region have been shaped by natural geological, climatic, and ecological processes. Understanding these natural processes provides the critical basis for seeing how they are still operating today, and how humans have manipulated and altered the forests ever since we first arrived in the region some 10,000 years ago. Three important natural influences account for the basic makeup of the San Juan Mountain country: (i) the local geography and geology, (ii) periodic disturbance by fire and other natural agents, and (iii) long-term regional climate variability.

<u>Local Geography and Geology</u>: The climate of the South Central Highlands region is characterized by extremes in temperature and precipitation, because of its northerly latitude and interior continental location far from the moderating influences of the ocean. Winters typically are cold, summers are hot; spring and early summer typically are dry, late summer and mid-winter are wet. Add in the huge range in elevation from the warm basins to the cool tops of the mountains, plus the variety of topographic settings from relatively cool and moist north-facing slopes to warm and dry south-facing slopes, and the result is a remarkable diversity of micro-climates throughout the South Central Highlands Section. This climatic variability, combined with a diversity of geological substrates ranging from fine-textured wind deposits to coarse-textured glacial debris and from ancient volcanic rocks to recent stream sediments, results in a huge diversity of local environments (Figure 2). This natural environmental diversity allows the region to support an amazing diversity of thousands of native plant and animal species, including such novelties the Mesa Verde cactus that grows nowhere else in the world but in dry, heavy clay soils in the southwest corner of the region, and the Uncompahgre fritillary butterfly that lives only among the willows above timberline in the San Juan Mountains.

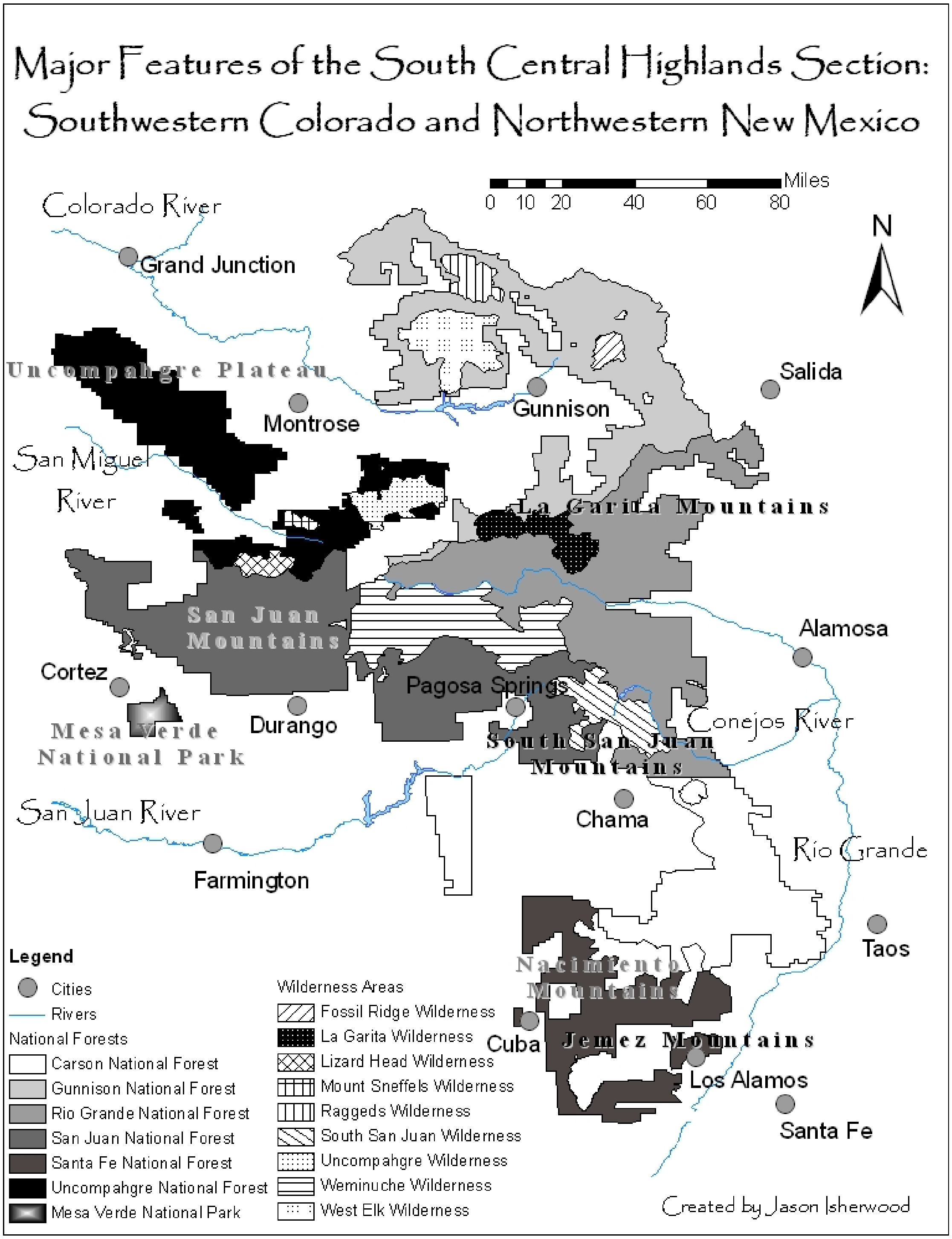

Figure I-1. Major features of the South Central Highlands Section in southwestern Colorado and northwestern New Mexico.

The broad variety of vegetation types shows some clear patterns with elevation and topography, as summarized in Table 1. The effects of local geography, geology, and micro-climate continue to shape the region today; Euro-American alterations of these basic landscape patterns have been generally minor or local.

Effects of Natural Disturbances: If every year in the forest was "business as usual," with no droughts or fires or windstorms, then the distribution of plants and animals would reflect simply the species best adapted to the local environmental conditions at each particular place. The total number of species would be less than what we actually see in the landscape, because less competitive species would be crowded out by the more competitive species. For example, a dense forest would be dominated by a small suite of shade-tolerant plants; sun-loving species would not be able to survive in the perpetually shady environment. The flora of the region does include many shade-intolerant species, because natural disturbances occasionally interrupt the potential dominance of shade-lovers. A host of species adapted to open conditions persists and thrives in the temporary but ever-replenished environments created by natural disturbances. To see some of these disturbance specialists, one must be on the scene quite promptly. Wild tobacco, for instance, typically germinates within the first year after a fire in piñon-juniper woodlands, flowers and sets seed during the second year, and then persists solely as dormant seed stored in the soil until the next fire. This little plant requires plenty of light and nutrients (both available right after fire) but cannot tolerate competition with other plants, so it grows only when potential competitors have been knocked back by fire. Other sun-loving species, such as aspen, also increase in abundance after a disturbance like fire, but then can persist for many years without further disturbance. Nevertheless, where shade-tolerant conifers are also present, aspen forests slowly become conifer forests during long decades without disturbance.

Figure 2. Contrasting habitats and vegetation in the South Central Highlands region. *Above*: subalpine spruce-fir forest and Thurber fescue meadow below Chama Peak in the South San Juan Mountains, an environment of moderate summer temperatures, high precipitation, and relatively fertile, igneous-derived soils. *Below*: a sparse cover of low-growing, drought-tolerant saltbush shrubs on "adobe badlands" near Delta, Colorado, where summer temperatures are high, precipitation is low, and the soils contain salts that accentuate plant water stress.

Fire is perhaps the most important natural disturbance in the South Central Highlands area. "Fire regimes" characterize the number of fires commonly expected in a century, as well as the varying ecological effects of fire. Prior to arrival of Euro-Americans in the late 1800s, fire regimes varied tremendously from one vegetation type to another (Table 2). Fires occurred most frequently in ponderosa pine forests, because these ecosystems receive the moisture needed to grow enough plant material to fuel spreading surface fires, yet weather

Table 1. Major vegetation types in the South Central Highlands Section. Environmental data provided by Jeffery S. Redders, San Juan National Forest.

Vegetation Type	Environment	Dominant Species
Piñon -juniper woodlands and mountain shrublands	lower elevations (1500-2600 m), warm, dry	Colorado piñon, Utah juniper, Rocky Mountain juniper, Gambel oak, Utah serviceberry, bitterbrush, muttongrass
Ponderosa pine forests	lower elevations (2100-2600 m), warm (90-110 frost-free days/yr), dry (50-65 cm/yr)	Ponderosa pine, Gambel oak, snowberry, Arizona fescue, muttongrass, elksedge
Mixed conifer forests	middle elevations (2400-2900 m), cool (75-90 frost-free days/yr), moist (60-75 cm/yr)	Ponderosa pine, Douglas-fir, white fir, blue spruce, southwestern white pine, trembling aspen, Gambel oak, snowberry, elksedge
Aspen forests	middle elevations (2400-3400 m), cool (55-90 frost-free days/yr), moist (60-90 cm/yr)	Trembling aspen, snowberry, Douglas-fir, white fir, subalpine fir, blue spruce, Engelmann spruce, snowberry, geranium, heartleaf arnica, meadow-rue
Spruce-fir forests	high elevations (2700-3600 m), cold (45-75 frost-free days/yr), wet (75-100 cm/yr)	Engelmann spruce, subalpine fir, whortleberry, geranium, strawberry, heartleaf arnica, daisy
Grasslands & meadows	all elevations and climatic zones; may be on drier sites than nearby forest vegetation	Big sagebrush, Arizona fescue, Thurber fescue, mountain muhly, Parry's oatgrass, other grasses & forbs
Riparian vegetation	permanently moist sites in all elevation and climatic zones	Cottonwoods, willows, thin-leaf alder, sedges

conditions are dry enough for fire to occur in most years. All that is needed for frequent fires under these conditions is an ignition source, commonly provided by lightning or humans. Because fires recurred at relatively short intervals (one or a few decades) in ponderosa pine forests, fuel levels remained low and fires often burned with low intensity, killing predominantly small trees and shrubs. Most herb and shrub species in these forests re-sprout after fire. Thus, fire maintained much of the ponderosa pine forest type as open stands of widely spaced clumps of large trees, mixed with small meadows of shrubs, herbs, and grasses.

In contrast to ponderosa pine forests, spruce-fir forests and other moist, higher-elevation ecosystems support plenty of potentially flammable biomass, but the weather is rarely dry enough to permit fires to spread over large areas even if ignited. Extensive fires with major ecological impacts in spruce-fir forests occur only in rare years of extreme drought. Moving to the dry end of the spectrum, lower-elevation piñon -juniper woodlands generally lack the continuous plant cover (fuel) necessary to carry a fire beyond an ignition point; even though lightning is frequent in these dry vegetation types, fires rarely burn more than a single tree. But just like the spruce-fir forests, rare weather conditions that combine drought and high winds can allow flames to blow from tree to tree. Because fires in both spruce-fir and piñon-juniper tend to occur only under severe fire weather conditions, these fires typically burn at high intensity, killing most of the trees over large areas. However, pockets of undamaged trees often are seen within the perimeter of a large burn because of a wind shift or other chance event that caused the fire to bypass a local area. The forests gradually grow back after intense fires, sometimes taking more than a century. For example, young spruce-fir forests on Molas Pass are developing after a large fire in 1879, with charred remains of the burned forest still very much in evidence today. At higher elevations, aspen trees come back quickly after fire, and many aspen forests in the region today owe their origin to severe forest fires that occurred in the middle and late nineteenth century—a time of extensive burning throughout the Southwest (Figure 3).

Table 2. Historical fire regimes in the major vegetation types of the South Central Highlands Section. "Fire interval" refers to the average number of years between successive fires occurring within a 100-ha stand during the several centuries prior to Euro-American settlement in the mid to late 1800s. Note that "fire interval" is an ambiguous concept because greater numbers of fires occur within larger land areas, e.g., a fire is more likely to occur in any given year within a 100,000-ha watershed than in a 100-ha stand; hence the number computed for "average fire interval" reflects both the inherent frequency of fire in an ecosystem and the size of the area chosen for analysis. Moreover, the larger the land area, the less likely it is that any given fire will burn the entire area. Thus, average fire interval is useful primarily for comparing fire regimes among different kinds of ecosystems.

Vegetation Type	Fire Interval	Predominant Effects of Fire and Responses of the Vegetation
Piñon -juniper woodland and mountain shrublands	ca. 100-400+ years	Death of nearly all trees and top-kill of shrubs & herbs within the fire perimeter … rapid re-sprouting of many shrub & herb species; rapid establishment of post-fire colonizing species (e.g., wild tobacco); very slow re-establishment by seed of trees and of some shrub & herb species
Ponderosa pine forests	ca. 10-100 years	Death of most small trees and top-kill of shrubs & herbs, but survival of most large canopy trees … rapid re-sprouting of most shrub and herb species
Mixed conifer forests	ca. 30-300 yr	Death of small trees but survival of large trees in some patches; death of all trees in other patches; top-kill of most shrubs & herbs … rapid re-sprouting of aspen and most shrubs and herbs; slow re-establishment by seed of conifer trees
Aspen forests	ca. 40-400 yr	Death of almost all large and small aspen trees and top-kill of shrubs & herbs … rapid re-sprouting of aspen, shrubs, and herbs
Spruce-fir forests	ca. 100-400+ yr	Death of nearly all trees and top-kill of shrubs & herbs within the fire perimeter … rapid re-sprouting of shrubs & herbs; rapid establishment of post-fire colonizing species (e.g., fireweed); slow re-establishment by seed of trees
Grasslands & meadows	not known[1]	Death of some shrub species (e.g., sagebrush); top-kill of most others; top-kill of grasses & forbs … rapid re-sprouting of most grasses & forbs
Riparian vegetation	not known[1]	Death or top-kill of most trees, shrubs, & herbs … rapid re-sprouting of some (e.g., willows); slow re-establishment by seed of others (e.g., cottonwoods)

[1] Probably similar to intervals in surrounding forest vegetation

Figure 3. Aspen forests near Molas Pass that developed after a large fire in 1879. Most conifers were killed by the fire, but the aspen re-sprouted promptly from surviving roots. Conifers are gradually becoming re-established, and some of the aspen forests eventually may develop into spruce-fir forests before the next big fire occurs.

Euro-American settlers profoundly changed the fire regimes of this region beginning in the late 1800s. Ponderosa pine forests were affected most strongly, with lesser impacts in spruce-fir forests and piñon-juniper woodlands; these changes and their consequences are examined later in this report.

Long-Term Regional Climatic Variability: In contrast to the fine-scale variability in micro-climate controlled by local elevation and topography, as described above, the broad regional-scale patterns of temperature and precipitation in the South Central Highlands Section are influenced by atmospheric processes occurring far away, in the Pacific and Atlantic Oceans. For example, fluctuations in water temperatures of the tropical Pacific Ocean produce the El Niño – Southern Oscillation (ENSO) phenomenon, which brings above-average precipitation to the southwestern U.S. during the El Niño phase and drought during the la Niña phase. Throughout most of the western U.S., a gradual warming trend began in the mid to late 1800s, and has accelerated during the most recent two decades. The early twentieth century was unusually wet, as was the period from the mid 1970s through early 1990s, but the first years of the twenty-first century brought severe drought. Reconstructions of long-term climate patterns, based on tree rings, reveal that this kind of climatic variability is not unusual; equally severe (or greater) droughts occurred, for example, in the late 1200s (coinciding with abandonment of Mesa Verde pueblos) and in the late 1500s.

Recognition of long-term climatic variability is important to our understanding of the ecology of this region for at least two reasons. First, the historical data demonstrate that periodic severe drought is a fact of life. All of the native species have biological adaptations for surviving the dry spells that have recurred throughout their evolutionary past. Some of these adaptations are quite fascinating; e.g., spadefoot toads can remain dormant in the soil for months or even years, emerging only after the rain finally returns, to feed and reproduce quickly in temporary ponds. The second reason why we need to understand long-term climatic variability is because climate drives the natural disturbance processes described above. Dry years (often associated with la Niña) can bring extensive fires, especially when the dry year follows unusually wet years. The wet years allow growth of abundant grass and herbs, which provide fuel in the subsequent dry year. Widespread fires occurred in this area in 1748, 1851, and 1879; these all were very dry years preceded by wet years.

Long periods of drought and warm temperatures also can trigger outbreaks of tree-killing insects. Native bark beetles periodically kill large numbers of conifers and open up forest stands in a manner similar the effects of fire. The trees and beetles have co-existed for thousands of years, and each beetle species is associated with one or more tree species. Human settlement of the region has not altered the ups-and-downs of climate variation. Nevertheless, the effects of the global human population on the earth's climate have important implications for the future of this region, as discussed below.

Human Impacts and Current Ecological Conditions in the South Central Highlands Landscape

The most extensive, profound, and probably long-lasting ecological changes in the region since the end of the last Ice Age, some 12,000 years ago, were ushered in by Euro-American settlers beginning generally in the mid to late 1800s (somewhat earlier in parts of northern New Mexico). We can better understand our current ecological challenges and opportunities by understanding some of the important ways in which the natural ecological processes have been altered during the past century and a half. This section emphasizes changes wrought by Euro-American settlement, though it is important to remember that the settlers' activities took place within a context of ongoing climatic and ecological variability, and that all of these processes and influences were interconnected. It is also important to remember that the magnitude and ecological significance of Euro-American impacts has varied greatly among the region's different ecosystems, as explained below.

Current ecological conditions in the South Central Highlands Section reflect primarily (i) the continuing and largely unchanged influences of the region's geography and geology, as described above; (ii) legacies of early Euro-American settlement, notably mining, logging, grazing, and fire exclusion; (iii) recent human impacts including road-building, exurban development, recreation, and water diversion; and (iv) the unique climatic patterns of the past century and a half.

<u>Legacies of Early Euro-American Settlement</u>: Miners entered the South Central Highlands region in substantial numbers as early as the 1860s, and mining for gold, silver, and other metals has continued off and on to the present day. This kind of mining can cause major environmental damage, especially to streams affected by acidic water draining out of mines that penetrate acid-rich rocks, but the impacts are usually somewhat localized. Early logging also was largely restricted to easily accessible forests located near settlements.

The early settlers' indirect effects on the area's natural fire regimes were more subtle and far-reaching than the direct effects of mining and logging. The initial changes were brought about by intensive, unregulated grazing of tens of thousands of cattle and sheep, beginning in most areas in the 1870s (earlier in parts of northern New Mexico). Many of the region's grasslands still have not recovered some of the grazing-sensitive plant species that were removed by early livestock operations. For example, Thurber fescue was a major meadow grass on the Uncompahgre Plateau, but now botanists are pleased when they can find even a few surviving plants. In the forests, the animals consumed the grass and other herbaceous plants that formerly had carried low-intensity surface fires. Lightning and humans continued to ignite fires, but the fires could not spread over large areas as had occurred before grazing. The frequent, low-intensity fires which previously had maintained an open forest structure in many ponderosa pine forests essentially ended between 1880 and 1900. Grazing began to be regulated in the 1930s, but by that time land management agencies had implemented policies of fire exclusion, and fire suppression capabilities continued to increase through the twentieth century. Many ponderosa pine forests that used to burn every decade or so now have gone for a century without fire. A unique convergence of historic events—disruption of the thinning effect of periodic fire, removal of most large merchantable trees through selective logging in the late 1800s and early 1900s, and moist climatic conditions favorable to tree establishment and growth during the early 1900s—combined to produce dramatic changes in many of the ponderosa pine forests of the region. Low-density forests dominated by large, old trees interspersed with small meadows were converted to high-density forests of small, young trees. These changes have created fuel conditions that support high-intensity fires that kill all of the trees, unlike the former low-intensity fires that maintained open forest conditions.

The disruption of natural fire regimes was not uniform throughout the region. The greatest disruption occurred in vegetation types where fire was formerly frequent, notably ponderosa pine and lower-elevation mixed conifer forests. However, in other vegetation types where fire had never been frequent, either because of moist climatic conditions or inherently unfavorable fuel structure for fire (see Table 2), grazing and fire suppression altered fire regimes to a far lesser degree than in ponderosa pine forests. It is true that relatively few large fires occurred in high-elevation forests during the twentieth century, but it is unlikely that this was primarily due to human fire suppression because even with modern fire-fighting technology we cannot put out fires burning under severe fire weather conditions--which are the only conditions in which large fires occur in these kinds of forests. Large high-elevation fires probably were infrequent primarily because climatic conditions were not often conducive to extensive burning during the twentieth century. We may have a somewhat greater extent of old forests today than would exist without past fire suppression, but within a given patch of high-elevation forest, fire continues to play pretty much the same ecological role as it did before 1880.

<u>Recent Human Impacts</u>: Logging began in the late 1800s in many low-elevation forests (e.g., ponderosa pine), but not until the mid 1900s in many high-elevation areas. Logging often was less profitable in the high country because of steep slopes and long haul distances to markets. Nevertheless, by the end of the twentieth century most of the commercially suitable timber base within the spruce-fir zone of the San Juan National Forest had been partially logged at least once. An extensive network of roads was constructed to support the logging activity (Table 3). These roads may have greater long-term ecological impacts than the logging itself, because roads are among the most un-natural of landscape elements, with impacts very different from natural disturbance processes. Roads fragment natural habitats, serve as conduits for invasion of non-native species, facilitate disturbance of wildlife, and can cause erosion and sedimentation of waterways (Figure 4).

Table 3. Road densities in the four major forest types of the San Juan National Forest. Forest Service staff estimate that 20 - 30 % of the roads that actually exist on the ground are not included in data base; thus, the road densities in this table are under-estimates of actual road densities on the ground.

Forest Type	**Miles of Road per Square Mile: Entire San Juan National Forest *Including* Wilderness Areas (Total Number of Square Miles in Parentheses)**	**Miles of Road per Square Mile: San Juan NF *Excluding* Wilderness Areas (Total Number of Square Miles in Parentheses)**
Ponderosa Pine	2.6 miles/square mile (472 square miles)	2.6 miles/square mile[1] (470 square miles)
Aspen	1.1 miles/square mile (481 square miles)	1.2 miles/square mile (444 square miles)
Douglas-Fir & White Fir	0.9 miles/square mile (381 square miles)	1.0 miles/square mile (340 square miles)
Spruce-Fir	1.1 miles/square mile (876 square miles)	1.8 miles/square mile (537 square miles)

[1] Wilderness Areas on the San Juan National Forest are mostly at high elevations and include almost no ponderosa pine forest.

Road-building and habitat fragmentation also have become increasingly important ecological processes associated with rapidly expanding exurban development of private lands located in scenic areas, often adjacent to public lands. Rural subdivisions and widely dispersed homes on large lots require miles of road access. These developments often have unintended effects of promoting invasion of non-native plant species into native vegetation and displacing native wildlife species that require large tracts of wild country. Moreover, many homes have been constructed in vegetation types that are highly vulnerable to wildfire (e.g., ponderosa pine forests), thus complicating managers' efforts to manage fire as a natural ecological process and to allow some beneficial fires to burn. Even in many remote areas far from homes, a strong human presence exists in the form of outdoor recreation, both motorized and non-motorized. Although long viewed as environmentally benign, outdoor recreation displaces sensitive wildlife and is a leading cause of species endangerment at a national level.

Other important impacts of recent and ongoing human activity in portions of the South Central Highlands Section are related to fossil energy production, notably oil and gas development in the basins adjacent to the mountains. Oil and gas development requires extensive roads and produces waste material that can pollute water supplies. Water also is diverted from many of the streams to supply urban, industrial, and agricultural needs. Only a handful of the region's major rivers continue to exhibit a natural flow regime; most now have dams and diversions that alter both the total quantity of water in the channels and the timing of high and low flows. Disruption of the natural rhythms of high and low stream flow impairs regeneration of native cottonwood and willow, and facilitates invasion by non-native plant species such as tamarix and Russian-olive.

In spite of the many impacts of human activities in the region, the South Central Highlands Section still retains large expanses of wild country with scant evidence of human presence. Some of these areas lie within officially

Figure 4. Canada thistle growing along a roadside in the San Juan Mountains. Non-native invasive species like this one can expand from road corridors into adjacent burned or harvested areas, where they may displace native species and alter ecological processes.

designated Wilderness Areas (e.g., Weminuche and South San Juan), but much is de facto wilderness with no formal protection. The type and magnitude of human-caused change varies greatly among the vegetation types that make up the region, as summarized in Table 4.

<u>Climatic Influences in the Twentieth and Twenty-First Centuries</u>: Broad-scale climatic trends have continued to influence the ecosystems of the South Central Highlands Section during the period of Euro-American impacts. It is important to recognize that early grazing, logging, and fire exclusion took place against a backdrop of climate change, as many parts of the world moved out of the "Little Ice Age" of the eighteenth and early nineteenth centuries and into the warmer climate that has prevailed since the mid-1800s. The pulse of widespread tree establishment in the early twentieth century and the impressive effectiveness of fire suppression in the mid-twentieth century both were due in part to the generally moist climate of those periods. Unfortunately, key legal decisions about regional allocation of western water were made during the unusually wet portion of the early twentieth century, and more water was allocated than actually is available in most years. The period from the mid-1970s through mid-1990s was another very wet period in the region—one of the wettest in the last thousand years—and

another pulse of tree establishment occurred during this time, notably in piñon-juniper woodlands, which in some areas expanded into adjacent shrublands. This moist period also saw an increase in the building of homes in fire-prone settings, encouraged in part by land managers' success in controlling wildfires.

An upsurge in large fires developed in the past decade throughout the West, including the Cerro Grande fire in northern New Mexico (2000) and the Missionary Ridge fire in southwestern Colorado (2002). This increase in uncontrollable wildfire reflects the legacies of past land use (e.g., fuel accumulation in ponderosa pine forests because of fire exclusion) and a climate-driven trend of warmer temperatures, longer fire seasons, and drought. In addition to fires, outbreaks of several species of bark beetles have killed millions of trees across the West, including the South Central Highlands Section (see below).

Looking to the Future: Challenges and Opportunities

Although the South Central Highlands Section retains much of the exceptional ecological diversity and aesthetic beauty for which the region is famous, current conditions and recent trends indicate that we face some significant challenges in the future—but also some significant opportunities. The most serious challenges are related to the direct and indirect effects of anticipated climate change, continuing habitat degradation by road-building and development, invasion by non-native plant and animal species that displace native species and alter key natural ecological processes, and social problems of polarization and gridlock in natural resource management. Major opportunities include restoration of disrupted natural ecological processes, notably fire, emulation of natural disturbance processes in conducting timber and grazing activities, and collaborative community conservation programs.

Major Challenges: Projections of twenty-first century climate indicate that the South Central Highlands Section can anticipate a continuation of the trend that began in the mid-1980s of warmer temperatures and earlier spring snowmelt. It is uncertain whether total precipitation will increase, decrease, or remain the same. These direct climate effects may be accompanied by indirect effects, including more frequent large fires and insect outbreaks. The fires and insect outbreaks that we have seen in the past two decades may be harbingers of things to come: more area has burned in Mesa Verde National Park since 1985 than burned in the previous two centuries; and millions of piñon trees throughout the Four Corners region were killed by bark beetles during the first few years of the twenty-first century when trees' natural defenses were weakened by moisture stress and beetle growth and survival were enhanced by unusually warm temperatures. (This recent widespread death of piñon trees has been followed by the establishment of millions of seedlings, so the long-term significance of this event for piñon-juniper woodlands remains unclear.) In the past decade aspen trees have been dying in numerous places, especially on drier sites at lower elevations; the cause is uncertain, but could be another consequence of recent drought. Despite these hints of potentially major ecological changes coming our way, it is important to emphasize that the magnitude and direction of future climate change in this region, and of associated ecological impacts, are poorly understood. Managers and the public can expect that change is almost certain, but that the kind and magnitude of change is most uncertain.

What would be the consequences of an increase in fire and insect activity in coming decades? Many trees would die, but tree death is a natural process in forests. Ponderosa pine is well adapted to low-intensity fires, and aspen thrives after high-intensity fires that remove competing conifers. Both trees persisted for millennia prior to Euro-American settlement with even more fire than is projected for the future. Therefore, increased burning may not be a serious threat to these species. However, the kind and intensity of fire, and the climatic conditions during and after the fire or insect outbreak, are also critically important: the wrong sort of high-intensity fire in ponderosa pine forests, or fire in aspen forests during a deep drought, might threaten the long-term viability of both ponderosa pine and aspen forests.

Another serious threat to ecological integrity in the wake of future fires is invasion by non-native plant species that can take over a burned site more rapidly than the native species. Recent burns in piñon-juniper woodlands are increasingly being dominated by non-native muskthistle, cheatgrass, and other weeds (Figure 5). Two broad categories of invasive species are of particular concern: those that co-opt local resources and displace native plants (e.g., muskthistle), and those that alter fundamental ecological processes (e.g., cheatgrass). Cheatgrass is an annual grass that was accidentally imported from Eurasia in the late nineteenth century and is now widespread across the American West. When cheatgrass dies it creates a continuous, highly flammable fuel bed which can carry fire over expansive areas. Cheatgrass was formerly rare and localized in piñon-juniper woodlands of Mesa Verde, but in the past decade it has expanded into most of the Park. Large fires were infrequent in Mesa Verde prior to 1985; however, with cheatgrass invasion comes the potential for dramatically more frequent burning, to which the native biota would be poorly adapted. The consequence could be loss of native plant species, as well as the animals and soil organisms that depend on the plants, and replacement by suites of aggressive non-native species that would not provide the aesthetic or ecological benefits of the displaced natives.

Figure 5. Cheatgrass expanding from a roadside into a recently burned area in Mesa Verde National Park.

Some Exciting Opportunities: Despite the very real threats of climate change, invasive species, and continuing habitat degradation by roads and development, some very encouraging approaches to ecosystem management are taking shape that promise to restore and maintain the aesthetic and ecological characteristics that make this area special. Whereas the nineteenth and twentieth centuries were predominantly times of expansion and resource exploitation throughout the American West, one of the major land management activities of the twenty-first century likely will be restoration of damaged landscapes and disrupted ecological processes. An example of this new emphasis is management agencies turning away from earlier policies of total fire exclusion toward a goal of restoring fire as a key ecological process in ponderosa pine forests and other fire-adapted vegetation types. Before simply allowing wildfires to burn, it often is necessary to mechanically restore the lower tree densities and fuel loads that characterized these forests prior to 1900. This kind of forest structure is essential to facilitate the low-intensity burning that formerly helped maintain the basic character of these ecosystems. Without this pre-treatment, modern fires could be more intense and kill more trees than typically occurred in prehistoric fires, and could threaten fire-sensitive buildings and infrastructure located within the forest environment. Sometimes the trees that are harvested to reduce stand density can be marketed to support local economies. Unfortunately, there often is little profit to be made because the larger trees generally are the ones that need to be left in place and the less merchantable smaller trees removed to restore a forest structure in which low-intensity fires can burn safely and effectively. The San Juan National Forest and Montezuma County, Colorado, initiated a forest restoration program of this kind in the 1990s, and similar programs are being conducted elsewhere in the region (Table 5, Figure 6).

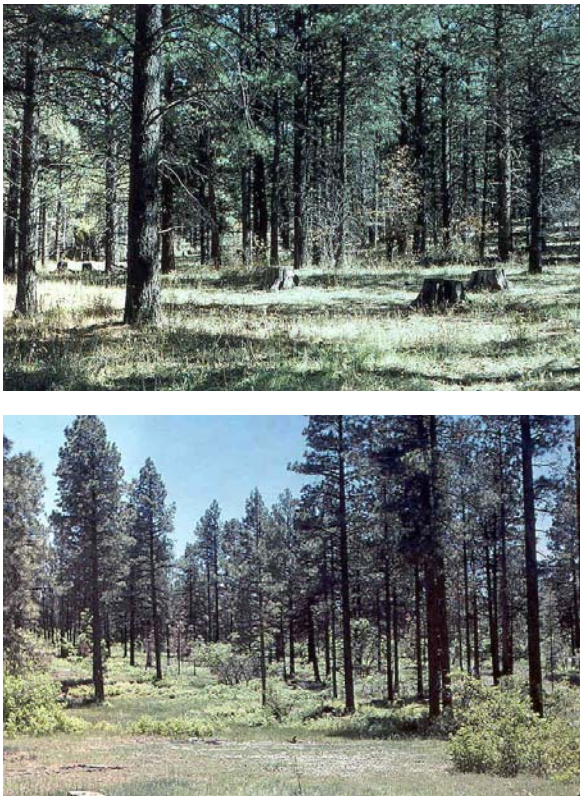

Figure 6. Ecological restoration of ponderosa pine forests. *Above*: An untreated dense stand in the background, in which the living trees all germinated after 1900, while the stumps reveal the size and dispersion of pre-1900 trees. *Below*: A ponderosa pine stand after thinning and burning to restore clumps of variably-sized trees interspersed with small meadows.

The economic importance of logging and grazing in this region has diminished in recent decades, but these activities remain important for other reasons. Summer grazing on public lands is essential to the economic viability of many ranchers, whose private lands (often homesteaded a century ago and located in prime wildlife habitat) typically are converted to real estate developments if the ranching enterprise fails. When logging and grazing are conducted within a framework of ecosystem management they can contribute positively to broader goals of sustainable land stewardship. For example, selective logging is often a precursor to restoration of natural fire regimes in ponderosa pine forests as described above. In all forest types, logging can be carried out in ways that mimic the kinds of natural disturbances to which the native biota are adapted. By emulating natural disturbance processes in our forest management practices, we avoid subjecting native plants and animals to stresses that exceed what they experienced in their evolutionary history and to which they are biologically adapted, thereby minimizing the risk of pushing the native biota beyond their tolerance limits. In aspen forests, for instance, prehistoric fires usually were more intense and killed more trees than in ponderosa pine forests, and aspen readily responds to intense disturbance by re-sprouting prolifically from surviving root systems. Thus, commercial aspen harvests can be more intense as well, cutting trees in patches that resemble the sizes and shapes of patches that are created naturally by stand-replacing fires—all the while retaining large patches of uncut forest for species and ecological processes that require old-growth conditions.

Because so much of the South Central Highlands Section is public land, it is essential that any program of ecological restoration or emulation of natural disturbance processes be conducted with the understanding and support of the public. One of the disturbing trends of recent decades has been polarization of the many groups who have a stake in the management of the public lands. The land management agencies are caught in the middle of this conflict, and the result often is gridlock and inability to implement any policy or program. However, new efforts in collaborative community land management are underway with encouraging results. For example, the Uncompahgre Plateau Project and the Public Lands Partnership are groups of governmental and private foresters, loggers, ranchers, and environmentalists who have come together to chart a new course in stewardship of forest resources in southwestern Colorado (http://www.upproject.org/). Their progress has been slow but steady, with numerous public meetings and field trips, as all participants have the opportunity to provide input in an open and transparent process.

Table 5. Summary of major changes in ponderosa pine forest ecosystems of the South Central Highlands Section, and opportunities and challenges for restoration of desired ecological components and processes that have been lost.

Component or Process	Reference Conditions	Current Conditions	Restoration Opportunities	Pitfalls & Cautions
Predominant canopy structure	- low density, diversity of tree size and age classes in most stands	- high density, little diversity of size and age classes, few large trees in most stands	- restore diversity of tree sizes by thinning, removing mostly small trees and retaining larger trees	- not all stands had open structure during reference period; need to retain some dense stands
Ground layer vegetation	- diverse herb stratum co-dominant with shrubs & tree saplings	- depauperate herb layer; some species (e.g., Arizona fescue, mountain muhly) greatly reduced or locally extirpated	- stimulate herbaceous growth and diversity through canopy thinning, grazing control, and prescribed fire	- risk of invasive non-native species increasing or invading treated areas
Fire regime	- frequent, low-intensity surface fire, causing little canopy mortality	- infrequent, high-intensity crown fire, destroying the canopy	- restore low-intensity fire regime through prescribed fire coupled with thinning and fuel reduction	- fire mortality of remaining old-growth trees - potential nutrient loss & reduced site productivity
Organic litter layer on the forest floor and overall fuel loads	- patchy and generally low fuel loads in most areas, due to frequent fire	- continuous and moderate to high fuel loads in most areas, due to lack of fire	- reduce litter layers and fuels with prescribed fire coupled with thinning	- a single prescribed burn unlikely to be adequate
Vertebrate communities, and soil organisms	- apparently diverse, but poorly documented	- probably lower abundance of species needing large trees, snags, & logs	- restore large trees and snags through thinning of smaller trees & prescribed fire	- some species (e.g., deer, elk, turkey) thrive in current stand conditions

The Quivira Coalition in northern New Mexico is re-envisioning livestock grazing on public and private lands in the same spirit of broad community engagement in ecosystem management. Similar groups are developing throughout the region, their efforts facilitated in part by governmental organizations such as the Center for Collaborative Conservation (http://welcome.warnercnr.colostate.edu/ccc-home/index.php) and the Colorado Forest Restoration Institute at Colorado State University (http://welcome.warnercnr.colostate.edu/cfri-home/index.php).

Despite many unfortunate legacies of poor land management that we have inherited from the past, new visions and programs of the kind described above hold a promise of ecological and social progress in the South Central Highlands Section as the twenty-first century unfolds.

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