

Pinyon-Juniper Woodlands

Introduction

Pinyon-juniper woodland (fig 1) is the most common forest type in the American Southwest, covering over 40 million hectares (100 million acres) in ten states, and extending south into Mexico, and north into Idaho, Oregon, and Wyoming (Romme et al. 2008). Defined by the presence of one or more species of pinyon pine (*Pinus spp.*) and juniper (*Juniperus spp.*), this forest type is associated with a range of different vegetation. The majority of pinyon-juniper woodlands are found in regions subject to temperature extremes and limited moisture availability. Covering as much as 15% of the land area in 5 states—Arizona, Colorado, Nevada, New Mexico, and Utah (fig 2)—pinyon-juniper woodlands provide a wealth of resources and ecosystem services, from wildlife habitat and vegetative cover for watershed protection, to pinyon nuts and fuelwood (Gottfried et al. 1995). Although they cover millions of acres, pinyon-juniper woodlands are among the least-studied North American forest types.

Distribution

Studies of packrat middens, dry caves, pollen cores, lake sediments, and archaeological sites provide important information about the distribution of pinyon juniper woodlands since the last major advance of continental glaciers in North America. During the “Wisconsinan” glaciation, which ended roughly 10,000 to 15,000 years ago, pinyon-juniper woodlands occurred in areas that today are the Chihuahuan, Mojave, and Sonoran desert lowlands (Betancourt et al. 1993). Warming temperatures and decreasing precipitation caused the range of pinyon-juniper woodlands to shift northward and to areas of higher elevation, roughly 13,000 years ago (Betancourt et al. 1993, Gori and Bate 2007). Predictably, pinyon-juniper woodlands extended to lower-elevation, more xeric communities during periods of higher moisture availability, and receded to higher elevations again as climatic conditions became warmer and drier.

Elevation and climate

Today, pinyon-juniper woodlands generally occur between 1,370 and 2,290 meters (4,500 to 7,500 feet) in elevation, transitioning from grasslands or shrublands at lower elevations, and to ponderosa pine (*Pinus ponderosa*) or other montane forest associations at higher elevations (Daubenmire

OVERVIEW



PHOTO: NPS/SCPN

Figure 1. Pinyon-juniper woodland in Mesa Verde National Park

1943, Gori and Bate 2007). With a few exceptions, juniper is more abundant than pinyon at lower elevations, while pinyon predominates at higher elevations (Gottfried et al. 1995). Mean annual temperatures in pinyon-juniper woodlands range from 40° to 61° F (4.4° to 16.1° C), and mean annual precipitation ranges from 7 to 25 inches (18 to 63 cm) (Ronco 1990, Gori and Bate 2007).

Range, species composition, structure, and many stand characteristics of pinyon-juniper woodlands are greatly influenced by moisture availability and season of precipitation (Gottfried et al. 1995). Some types occur in regions where the majority of precipitation falls as winter snow. Other types are found in regions where summer monsoon rains predominate, and still others occur in regions of bi-modal annual precipitation (occurring in summer and winter).

Soils

The soils of pinyon-juniper woodlands vary in texture from gravelly, sandy loam to compacted clay. Substrates vary in depth, parent material, and moisture availability. Although pinyon-juniper woodland soils are often alkaline, well-drained, shallow, and rocky with low fertility, some sites with deeper, more mesic (moderately moist) soils support higher productivity, and higher density of trees and understory shrubs and grasses (Ronco 1990, Gori and Bate 2007). Pinyon and juniper trees make use of what are generally moisture- and nutrient-limited environments

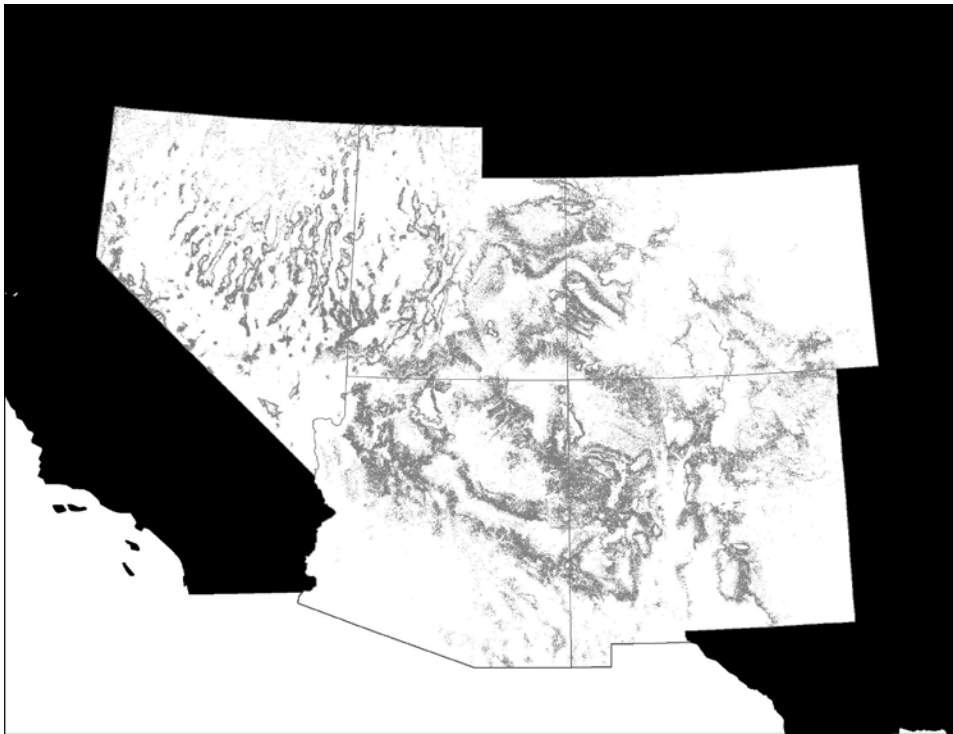


Figure 2. Distribution of pinyon and/or juniper dominated woodland/savanna in Nevada, Utah, Colorado, Arizona, and New Mexico

by concentrating soil, soil moisture, organic material, and nutrients beneath their canopies over time, creating “islands” of higher fertility (Barth 1980).

Species composition and stand structure

Pinyon-juniper woodlands exhibit a wide variety of stand structures and compositions, which are influenced by local climate, topography, growing conditions and disturbance regimes. Five common species of juniper occur across the American Southwest: redberry juniper (*Juniperus coahuilensis*), alligator juniper (*J. deppeana*), one-seed juniper (*J. monosperma*), Utah juniper (*J. osteosperma*), and Rocky Mountain juniper (*J. scopulorum*). Redberry juniper is considered a hybrid of alligator and one-seed juniper. Rocky Mountain juniper will hybridize with alligator, one-seed, and Utah junipers, among other species.

These species of juniper are associated with four species of pinyon pine: two-needle, or common pinyon (*Pinus edulis*), and singleleaf pinyon (*P. monophylla*), which are the most widespread; and Mexican pinyon (*Pinus cembroides*) and border pinyon (*P. discolor*), which occur at lower elevations in Arizona, New Mexico, Texas, and Mexico. Some taxonomists consider border pinyon and Mexican pinyon to be similar enough in characteristics, such as flowering time and needle number, that they are treated as one species

(Pavek 1994). Two-needle pinyon, which has needles occurring in bundles (fascicles) of two, and singleleaf pinyon, with needles occurring singly, hybridize where their ranges overlap, creating populations of trees with one- and two-needled fascicles on the same tree. Two-needle pinyon is also known to hybridize with Mexican pinyon.

The extensive networks of lateral roots and deep taproots in mature pinyon and juniper trees are highly effective at extracting moisture from the soil, thereby reducing the amount of moisture available to understory vegetation. As a result, understory vegetation has been reported to decrease with increasing pinyon and juniper density, and to rebound dramatically after removal of the trees by burning, thinning, or some other form of disturbance (Davenport et al. 1998).

PHOTO: USCS NATIONAL GAP ANALYSIS PROGRAM, SOUTHWEST REGAP, 2004

Classification of pinyon-juniper woodlands

Pinyon-juniper woodlands have been classified in a number of ways, using variables such as climate zones, understory composition, overstory species dominance, soils, climate, and elevation. Romme et al. (2008) identified 3 major types, based on historical stand structure, disturbance regimes, and landscape dynamics: (1) pinyon-juniper savanna, (2) pinyon-



Figure 3. Pinyon-juniper savanna at El Morro National Monument

PHOTO: NPS/SCPN

Table 1. Pinyon-Juniper Woodland types

	Savanna	Wooded Shrubland	Persistent Woodland
Precipitation	Receives mainly summer precipitation. Bi-modal precipitation in some areas.	Most often occurring (but not restricted to) areas of winter precipitation.	Receives mainly winter precipitation.
Soils	Deeper, fine-textured soils support a range of vegetation types.	Wide variety of substrates.	Shallow, often rocky soils do not support continuous vegetative cover.
Terrain	Gentle terrain- valleys, basins, and foothills.	Wide variety of topography- plains, valleys, and lower montane.	Rugged upland sites and steep, rocky terrain.
Stand Structure	Open savanna-like stand structure, supports low density of trees and shrubs, and dense herbaceous growth: grasses, forbs, and annuals.	Areas of woodland expansion and contraction. Shifts from herbaceous, to shrub, to tree dominance over time, in the absence of fire. Often shrub-dominated, with trees colonizing when growing conditions are favorable.	Multi-aged stand structure. Range of tree densities and canopy cover, depending on site conditions.
Historic Fire Regime	Frequent, lower-intensity surface fires maintain grasses and open stand structure. Few barriers to fire spread.	Infrequent, high-severity fires and patchy, mixed-severity fires.	Infrequent high-severity fire. Significant barriers to fire spread: cliffs, canyons, exposed rock, topographic isolation.
Impacts: Livestock & Fire Suppression	Increased density of younger trees, reduced ground cover, and higher-severity fires when they occur.	Increased tree density, cover, and canopy closure, decreased shrub density, and larger higher-severity fires when they occur.	Little impact to fire frequency and severity. Understory species composition altered by livestock grazing.

juniper wooded shrubland, and (3) pinyon-juniper persistent woodland (Table 1).

Pinyon-juniper savanna

Pinyon-juniper savanna is characterized by an open savanna-like stand structure, with low densities of trees and shrubs, and a dense herbaceous groundcover of grasses and forbs (Figure 3). It extends onto portions of the southern Colorado Plateau and is commonly found in basins and foothills of southern and central Arizona and New Mexico, where deep, fine-textured soils support a range of vegetation types. The majority of precipitation in pinyon-juniper savanna takes the form of monsoon rains, which occur during the summer growing season and tend to favor the growth of warm-season grasses. Common warm season grass species found in pinyon-juniper savanna include blue grama (*Bouteloua gracilis*) and other species of grama grass (*B. curtipendula*, *B. hirsuta*, *B. eriopoda*), New Mexico muhly (*Muhlenbergia pauciflora*), curlyleaf muhly (*Muhlenbergia setifolia*), and needle and thread grass (*Hesperostipa* spp.). It is hypothesized that a regime of frequent, low-intensity surface fires is responsible for maintaining the open stand structure and dense herbaceous growth of pinyon-juniper savanna.

Pinyon-juniper wooded shrubland

Pinyon-juniper wooded shrubland is often found in, but is

not restricted to, areas where winter precipitation predominates, including portions of northern Arizona and New Mexico (Figure 4). It can occur on a wide variety of substrates and terrain, from plains and valleys to lower montane areas. Pinyon-juniper wooded shrublands are areas of woodland expansion and contraction, which often border other forest types or vegetation communities. In the absence of fire, pinyon-juniper wooded shrublands shift from grass and forb-dominated, to shrub-dominated, and to tree-dominated communities over time. Stand structure and vegetation composition are influenced by growing conditions, infrequent stand-replacing fires, and occasional mixed-severity fires. Due to discontinuous fine fuels, low-intensity surface fires have historically had a limited influence on stand structure and dynamics (Romme et al. 2008). Typical shrub species associated with pinyon-juniper wooded shrubland include big sage (*Artemisia tridentata*) and other *Artemisia* species, antelope bitterbrush (*Purshia tridentata*), rabbitbrush (*Chrysothamnus* spp. and *Ericameria* spp.), mountain mahogany (*Cercocarpus* spp.), and snakeweed (*Gutierrezia* spp.)

Pinyon-juniper persistent woodland

The third type of pinyon-juniper woodland—persistent woodland—occurs throughout the southwestern United States, usually in areas where winter precipitation predominates, or where precipitation is bi-modal. In many cases,



Figure 4. Pinyon-juniper wooded shrubland at Mesa Verde National Park

persistent woodland sites are unproductive, with thin soils and sparse herbaceous and shrub cover. A range of tree densities and canopy cover occur, influenced by site conditions and history of disturbance. Persistent woodlands often exhibit a multi-aged stand structure that includes some very old trees (Figure 5). They often occur on rocky terrain and rugged upland sites where topographic features such as cliffs, canyons, and large areas of exposed rock create significant barriers to fire spread.

Repeat aerial photography, examination of tree rings, and permanent study plots reveal an increase in tree densities and canopy closure (infill) in many persistent woodlands over the past century. The factors driving this increase are not fully understood, but are more likely to include past livestock grazing or favorable climatic conditions, than fire exclusion (Romme et al. 2008).

Ecosystem drivers and disturbance processes

Climate and drought

Moisture availability and temperature are important factors influencing the expansion and decline of pinyon-juniper woodlands. Surges of pinyon pine and juniper seedling recruitment and growth generally correspond with periods of wet climatic conditions, creating higher-density stands with greater fuel continuity. Subsequent periods of drought create conditions conducive to large, stand-replacing fires. One of the most severe droughts of the 20th century occurred between 1950 and 1956 in the southwestern United States and Mexico, causing massive die-off of many types of drought-adapted vegetation, including



Figure 5. Persistent pinyon-juniper woodlands at Mesa Verde National Park

conifers, grasses, and cacti (Betancourt et al. 1996). Two decades of higher precipitation, followed by drought, and combined with high winds have fueled six large fires in Mesa Verde National Park since 1996 (Floyd et al. 2004).

Periods of extreme drought intensify a number of other disturbance processes and ecological effects. Shaw et al. (2005) attribute a recent increase in pinyon mortality across portions of the Southwest to “a complex of drought, insects, and disease”—the cumulative effects of multiple mortality agents working in concert.

Endemic insects and disease

Pinyon pines that are affected by moisture stress are more susceptible to outbreaks of disease, parasitism by pinyon dwarf mistletoe (*Arceuthobium divaricatum*), and damage from endemic insects which feed on cones, needles, shoots, roots, and conductive tissue. Bark beetle and other insect outbreaks are closely tied to drought-induced moisture stress (Allen and Breshears 1998). Populations of pinyon tip moth (*Dioryctria albovitella*), pinyon cone moth (*Eucosma bobana*), pinyon Ips (*Ips confusus*), pinyon twig beetles (*Pityophthorus* spp. and *Pityogenes* spp.), pinyon needle scale (*Matsucoccus acalyptus*), and pinyon needle miner (*Coleotechnites edulicola*), normally present in pinyon-juniper woodlands at low levels, can increase dramatically during periods of drought, causing large-scale defoliation, reduced growth and reproduction, tree mortality, and a myriad of other effects. Although pinyon Ips beetles usually attack only trees which are already weakened by other agents, they are responsible for the majority of pinyon mortality in the drought-stricken western U.S. Juniper is similarly affected by insects and pathogens, including twig beetles (*Phloeosinus* spp.), twig

pruners (*Stylox bicolor*), western cedar borer (*Trachykele blondeli*), and branch-girdling rusts (*Gymnosporangium* spp.). Juniper is also parasitized by its own species of mistletoe, the juniper mistletoe (*Phoradendron juniperinum*).

Fire

Wildfire has played an important role in structuring pinyon-juniper woodlands, with different fire regimes historically present in the three pinyon-juniper woodland types described above and in Table 1. Fires are described in terms of their severity, which is determined by the fire's effect on vegetation, and is usually defined in terms of survival of dominant trees. Three major types of wildfire influence the range, age class, species composition, structure, and density of pinyon-juniper woodlands: (1) low-severity surface fires, (2) high-severity fires, and (3) mixed-severity fires. Low-severity surface fires are fueled primarily by dense herbaceous biomass, leaving most overstory trees alive. High-severity stand-replacing fires can burn over the surface, or up in the tree crowns (crown fire), killing most trees, and initiating stand replacement. Finally, mixed-severity fires are a combination of low-severity surface fires in some areas, and high-severity fire in other areas, leaving a patchwork of surviving trees interspersed with patches of tree mortality where shrubs and herbaceous ground cover regenerate first. According to Baker and Shinneman (2004), no observations have been made of modern mixed-severity fire in pinyon-juniper woodlands. Rather, mixed-severity fires are assumed to occur because they have been documented in other types of woodlands, and because patchworks of surviving trees and tree mortality have been observed in pinyon-juniper stands.

Succession

Seed production and establishment

Pinyon pine reproduces only by seed, and not vegetatively. Heavy crops of pinyon pine cones (called mast crops) vary by species, and are produced every two to six years, followed by multiple years of low cone production (Betancourt et al. 1993). On average, mast crops in pinyon pines will occur in one to three out of every ten years (Gori and Bate 2007). The cycle of flowering, fruiting, and seed maturation takes three years, with seedlings becoming established four growing seasons after cone initiation (Betancourt et al. 1993). Pinyon seedlings are shade-tolerant, and have the best chance of establishment and survival under the protected micro-climates of "nurse plants".

Juniper exhibits a similar seed-production cycle, where heavy (mast) crops of juniper berries/seed are produced

every two to five years, interspersed with intervals of low seed production (Gori and Bate 2007). Young alligator juniper trees are able to sprout prolifically after the death of the main trunk, but the ability to re-sprout declines with age (Gottfried et al. 1995, Tirmenstein 1999). One-seed, redberry, Utah, Rocky Mountain, and mature alligator juniper must rely on seed production and dispersal for re-establishment.

For both pinyon and juniper, levels of germination and establishment are highest when a mast seed crop is followed by a period of increased precipitation and the absence of fire (Gori and Bate 2007).

Herbivory and seed dispersal

Birds and small mammals, including chipmunks, raccoons, and squirrels feed on and cache juniper berries and pinyon nuts. Birds are considered to be the primary dispersal agents for juniper (Gottfried et al. 1995). Seeds that have passed through their digestive tracts germinate faster than uneaten seeds (Johnsen 1962). Bird species responsible for dispersing pinyon seeds include scrub jays (*Aphelocoma californica*), pinyon jays (*Gymnorhinus cyanocephalus*), Steller's jays (*Cyanocitta stelleri*), and Clark's nutcrackers (*Nucifraga columbiana*). Seeds deposited or cached under the protective microclimate of nurse plants or other debris are more likely to germinate and become established than those deposited or cached in the open. One potential advantage of seed masting is that surplus seeds remain after seed predators have consumed a portion of that year's crop.

Succession after fire

Generally, after a stand-replacing fire, succession begins with the establishment of annual grasses and forbs for several years, followed by perennial grasses and forbs. Shrubs are the next cover type to become established, utilizing the increased humidity and buffering from the sun and wind provided by perennial vegetation. In the absence of fire, juniper and pinyon will become the climax species, but they may take several decades or longer to become established. As canopy cover increases, shrubs and herbaceous cover tend to decrease in density and abundance. Shrubs may remain a component of pinyon-juniper woodland indefinitely, or may eventually be suppressed by the slow-growing overstory, which takes hundreds of years to reach the "open" old-growth stage.

After a low-severity surface fire, surviving shrubs may regenerate quickly by re-sprouting. Frequent low-severity fires can eliminate pinyon and juniper seedlings, and maintain shrub-dominated plant communities.

Anthropogenic use and post-settlement stressors

Native American use of pinyon-juniper woodlands

Wood and bark artifacts, such as digging sticks, cradle-boards, arrow shafts, weaving tools, and bundles of juniper bark, provide evidence that, as long as 10,000 years ago, Paleo-Indian peoples were using the plants of pinyon-juniper woodlands for clothing, tools, house-building material, food, and medicine, and as fuel for heating, cooking, and firing pottery (Flint-Lacey 2003; Cartledge and Propper 1993). These ancient peoples relied heavily on pinyon pine nuts, which had significant nutritional value and contained proteins, carbohydrates, fats, and two amino acids that are present only at low levels in other regional indigenous plant foods (Litzinger 2003). Pinyon, juniper, and associated species of vegetation continue to be harvested and utilized by modern peoples today.

By A.D. 1300, after over 1,000 years of occupation, the ancient Puebloan peoples had abandoned the region of Mesa Verde, Colorado (Flint-Lacey 2003). Some evidence indicates that they may have depleted the pinyon-juniper resources near their settlements, and that deforestation may have been one of the factors that contributed to the abandonment of settlements in this area (Flint-Lacey 2003, Litzinger 2003). A dramatic decline in pinyon remains found at late Ancestral Pueblo archaeological sites suggests an intensive, widespread forest clear-cutting near the end of this period of occupation (Litzinger 2003). Archaeological surveys at Bandelier National Monument, southeast of Mesa Verde, revealed significant impacts to pinyon-juniper woodland resources during a period of peak occupation, from A.D. 1200 to 1500 (Gottfried et al. 1995). Flint-Lacey (2003) and Litzinger (2003) suggest that only small, remnant pinyon-juniper stands remained in the Mesa Verde region by A.D. 1300.

Post-settlement stressors

A host of anthropogenic disturbance factors have affected pinyon-juniper woodlands since Euro-American settlement in the late 1800s. Post-settlement anthropogenic stressors included timber harvest, livestock grazing, landscape fragmentation, the introduction of invasive exotic organisms, and altered fire regimes. Post-settlement changes observed in pinyon-juniper woodlands included a loss of herbaceous groundcover in some regions, a shift from pinyon to juniper-dominance in others, increased tree density, and soil erosion. It is difficult to attribute these changes to any one

stressor or disturbance factor. Rather, we should consider that pinyon-juniper woodlands are continually influenced by the complex interplay of multiple natural disturbances and anthropogenic stressors.

Timber harvest

Pinyon-juniper woodlands have long been an important source of fuel for domestic heating, cooking, and building material, in both pre- and post-settlement times. Pinyon and juniper wood were also major sources for fuel for mining operations in the 1800s, and continue to be widely used for domestic heating and cooking today. Historically, impacts of unsustainable timber harvest were most likely concentrated around population centers.

Livestock grazing

A marked increase in pinyon-juniper tree density and extent over the past century has been attributed by many researchers to a combination of livestock grazing and the disruption of historic wildfire regimes (Gori and Bate 2007, Gottfried et al. 1995). Some have hypothesized that livestock grazing has aided the spread of juniper into grasslands by reducing the density of grasses and palatable shrubs that compete with juniper seedlings for soil moisture, nutrients, and other limiting factors (Johnsen 1962). Livestock overgrazing has modified fire regimes and erosion processes across multiple spatial scales by altering the density and spatial patterning of groundcover (Allen 2007). More trees survive in the absence of fire, further reducing vegetative groundcover by outcompeting grasses and forbs for limited soil moisture. Livestock can also transport non-native, invasive weed seed from weed-infested rangelands into more pristine areas, where they, too, can outcompete native grasses and forbs.

Erosion

Pinyon-juniper woodland systems in the southwestern United States are particularly susceptible to erosion. When fire, livestock grazing, or drought reduces the amount of vegetative ground cover and organic litter, rates of soil erosion during and after precipitation events can increase dramatically. Where appropriate grazing management systems are not implemented, livestock grazing contributes to soil erosion by compacting the soil. Soil compaction reduces the amount of water that filters down through the soil (infiltration) and increases surface water runoff. As a result, topsoil is lost and large quantities of sediment are deposited by surface runoff into rivers and streams, negatively impacting water quality and aquatic habitat.

Furthermore, livestock, off-road vehicles, hikers, and other

types of mechanical disturbance damage biological soil crusts (communities of bacteria, cyanobacteria, lichens, mosses, algae, and/or fungi on the soil surface). These crusts reduce erosion from wind and water, hold nutrients and moisture, enrich the soil via atmospheric nitrogen fixation, and initiate primary succession by re-colonizing disturbed areas (Gottfried et al. 1995). Biological soil crusts play an important role in reducing surface runoff and erosion, but they are fragile and can be slow to recover after disturbance (Belnap and Eldridge 2001).

Fragmentation

Many woodland ecosystem properties are a function of forest patch size and pattern (Allen and Breshears 1998). Patches of tree mortality within a stand can be caused by insect outbreaks, mixed-severity fire, drought, and climate-driven shifts in the transition zones between vegetation community types (ecotones). Levels of surface water runoff and erosion are affected when vegetation structure is disturbed. Wilcox et al. (2003) measured levels of runoff and erosion in semi-arid pinyon-juniper woodlands in northern New Mexico. Following precipitation events, levels of runoff and erosion were found to be higher in individual patches of vegetation than in large areas of uninterrupted vegetation. Furthermore, the cumulative impacts of erosion were more likely to persist on steep-slope sites, whereas low-slope gradient sites were more resilient and better able to return to pre-disturbance levels of runoff and erosion over time.

Exotic invasive plants

Natural and anthropogenic disturbances, such as drought, fire, timber harvest, livestock grazing, road construction, and erosion create conditions that allow non-native invasive species to become established. Invasive species can be introduced into pinyon-juniper woodlands through many pathways (vectors). Weed seeds, or material harboring exotic insects, or plant pathogens may travel on recreationists' gear or road building equipment. Weed seeds may be present as a contaminant in broadcast seed mixes used for revegetation or erosion control. Seeds of exotic plants are also transported in the digestive tracts of livestock, and moved from infested to uninfested areas. Once established, many non-native invasive plants can out-compete native vegetation for space, moisture, nutrients, and other limiting factors. They spread aggressively and are difficult to control, as they have few natural enemies in their new environment. Some exotic plants that cause concern in pinyon-juniper woodlands include cheat-grass (*Bromus tectorum*), knapweeds (*Centaurea* spp.), thistles (*Cirsium* spp., *Carduus* spp., and *Onopordum* spp.), mustards (*Sisymbrium* spp. and *Brassica* spp.), and Dalma-

tian toadflax (*Linaria dalmatica*).

Altered fire regimes

Natural (historic) fire regimes for each of the three types of pinyon-juniper woodlands are briefly described in Table 1. Limited information is available on pre-European settlement fire disturbance history and successional dynamics in these forests. Land managers seeking to understand how natural disturbance events have been influenced by anthropogenic factors in post-settlement times are challenged by a lack of research focused on pinyon-juniper systems and a lack of evidence of past fires on the landscapes. Neither pinyon nor juniper reliably forms fire scars like ponderosa pine and other conifer species. Both pinyon pines and junipers, with thin bark and low crowns, are easily killed by wildfire. With the exception of young alligator juniper, pinyon and juniper species do not re-sprout after fire as do associated species of shrubs and oaks, but take several decades to become re-established by seed. Although dead juniper snags can be persistent on the landscape, they are difficult for researchers to age.

The introduction and expansion of livestock grazing throughout much of the Southwest removed the fine herbaceous fuels that create a continuous layer of combustible material over the surface of the landscape. Combined with fire detection and suppression efforts in the 20th century, fire frequency has been reduced, but fires have tended to burn with greater intensity when they do occur. The frequency of large, severe fires has increased over the past 20 years in pinyon-juniper woodlands and other vegetation communities, across the western United States (Romme et al. 2008).

Implications for pinyon-juniper savanna

Historically, frequent, low-intensity surface fires helped to maintain grasses and the characteristic open stand structure of this type of woodland. Extensive infill of trees into juniper savanna and shrublands has been documented throughout the 20th century, but it is difficult to tell whether this is new expansion of woodland into savanna and shrublands, natural range expansion, or recovery of persistent woodlands after disturbance in the distant past (Romme et al. 2008). An example of this type of pinyon-juniper infill into savanna is occurring at Bandelier National Monument (Floyd et al. 2000). Stand thinning and prescribed burning are two of the management tools applied by land managers in these systems to mimic historic disturbance regimes.

Implications for wooded shrubland

Over the past century, increased tree density and cover has

been observed in wooded shrublands, due in part to live-stock grazing and active fire suppression (Johnsen 1962). The increased fuel loads and canopy closure in these areas may result in larger, more severe fires than those of the 1800s (Gori and Bate 2007). While this trend of increased tree density has been observed in Great Basin shrublands and portions of Arizona and New Mexico, it is balanced by very limited increases in tree density in portions of western Colorado (Romme et al. 2008), and by the drought-induced tree mortality which has been observed in Colorado and New Mexico, and other regions.

Implications for persistent woodland

Tree density and cover have gradually increased over the past century in many pinyon-juniper woodlands, possibly due to favorable climatic conditions during portions of the past century. It is likely that wildfire has had less of an impact on persistent woodland stand dynamics than other natural disturbance factors, such as drought, insects, and disease (Romme et al. 2008). Romme et al. (2008) state that surface fires have had a very limited influence on pinyon-juniper persistent woodland stands in the historical landscape. Aside from small, isolated fires ignited by lightning, persistent woodlands can remain undisturbed by fire for hundreds of years at a time (Romme et al. 2008). As a result of research in Mesa Verde National Park, Floyd et al. (2000) suggest that pinyon-juniper persistent woodlands were never subject to a regime of frequent low-intensity fires, but were shaped by a historic fire regime of rare but stand-replacing fires. In this sense, prescribed fire may not mimic natural disturbance regimes in persistent woodland systems.

Climate change and drought

The Intergovernmental Panel on Climate Change (IPPC) reports with “very high confidence” that terrestrial biological systems on all continents are now being affected by temperature increases, resulting in earlier spring events, shifts in the ranges of plant and animal species, and longer thermal growing seasons, among other impacts (IPPC 2007). Warming temperatures and increases in severe drought events in some regions are likely to lead to increased tree mortality and forest dieback, which in turn affect other disturbance processes, such as fire, erosion, and insect outbreaks (Allen 2007).

These effects have been observed over the past decade in pinyon-juniper woodlands across the American Southwest. Millions of hectares of woodlands in the southwestern United States have been altered by severe drought conditions since the late 1990s (Allen 2007). Extreme heat and lack of mois-

ture have resulted in widespread mortality of many species of grasses, shrubs, trees, and cacti. During 2002 and 2003, greater than 95% mortality of non-seedling pinyon pine trees was observed in study plots at Bandelier National Monument in northern New Mexico (Allen 2007).

On a landscape level, pinyon pines weakened by drought stress have become an easy target for mortality-causing insects like the pinyon Ips bark beetle (*Ips confusus*). Endemic bark beetle populations can increase dramatically when moisture-stress weakens large numbers of trees, over large areas. Without adequate precipitation or snowmelt, trees are not able to repel attacking bark beetles with increased flows of pitch. Once insect populations are large enough, they are able to successfully attack healthy trees, as well as those affected by drought.

The severe drought conditions of the past decade have also set the stage for wildfires like the aforementioned large-scale stand-replacing fires in Mesa Verde National Park, where old growth P-J woodland is being replaced by post-fire shrubland (Floyd et al. 2004). Drought and warming temperatures can increase the flammability of live and dead forest fuels, cause snowmelt to happen earlier in the spring, and lengthen fire seasons (Westerling et al. 2006).

Projections from multiple climate models predict that surface temperatures in the American Southwest will continue to rise, and that annual precipitation in this region is likely to decrease (Christensen et al. 2007). Less is known about how regional precipitation patterns may be affected in the future by climate change-driven fluctuations in sea surface temperatures and atmospheric circulation patterns (Miller 2005).

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For Further Information

The Greater Yellowstone Science Learning Center.<http://www.greateryellowstonescience.org>

National Park Service Inventory & Monitoring Program, Southern Colorado Plateau Network
USDA Forest Service Fire Effects Information System.
<http://www.fs.fed.us/database/feis/>

IPCC (Intergovernmental Panel on Climate Change).
<http://www.ipcc.ch/index.htm>