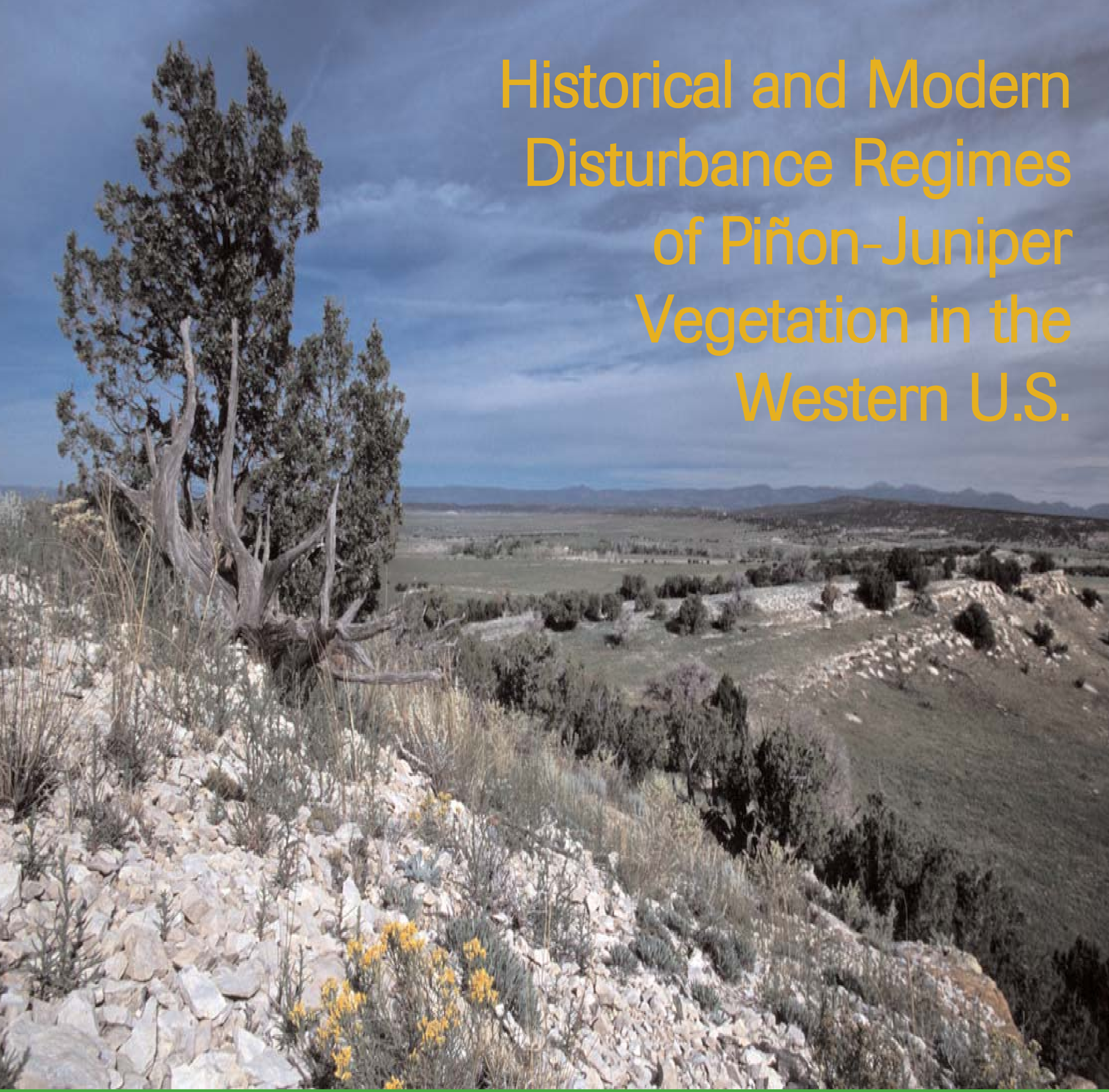
Historical and Modern Disturbance Regimes of Piñon-Juniper Vegetation in the Western U.S.



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Introduction

Piñon-juniper vegetation covers some 100 million acres in the western U.S., where it provides economic products, ecosystem services, biodiversity, and aesthetic beauty in some of the most scenic landscapes of North America. There are concerns, however, that the ecological dynamics of piñon-juniper woodlands have changed since Euro-American settlement, that trees are growing unnaturally dense, and that woodlands are encroaching into former grasslands and shrublands. Yet surprisingly little research has been conducted on historical conditions and ecological processes in piñon-juniper vegetation, and the research that does exist demonstrates that piñon-juniper structure, composition, and disturbance regimes were very diverse historically as well as today.

Uncertainties about historical stand structures and disturbance regimes in piñon-juniper vegetation create a serious conundrum for land managers and policy-makers who are charged with overseeing the semi-arid landscapes of the West. Calls for restoration of historical conditions (i.e., those that prevailed before the changes wrought by Euro-American settlers) are being heard with increasing frequency. However, if those historical conditions are poorly understood it is difficult or impossible to set realistic targets for restoration. In the absence of site-specific information about historical disturbance regimes and landscape dynamics, there is danger that well-meaning "restoration" efforts actually may move piñon-juniper ecosystems farther from their historical condition.

The purpose of this report is to briefly summarize our current understanding of historical stand structures, disturbance regimes, and landscape dynamics in piñon-juniper vegetation throughout the western U.S. The authors gathered for a workshop in Boulder, CO, on August 22-24, 2006, to develop the information presented here. All have conducted research in piñon-juniper vegetation, and together they have experience with a wide diversity of piñon-juniper ecosystems, from New Mexico and Colorado to Nevada and Oregon. Our summary of current knowledge is presented as a series of statements, each followed by our level of confidence in the statement and the geographical area to which it applies. High-confidence statements generally are supported by rigorous field studies; statements of moderate confidence are based on anecdotal evidence or logical deductions, but lack the rigorous studies necessary to confirm or refute the idea. We intentionally refrain from making any specific policy or management recommendations in this paper. Instead we provide the consensus among researchers of what we know (and don't know) about the science of piñon-juniper vegetation. The authors encourage managers and practitioners to give us feedback on the utility and shortcomings of this summary. There is much that we do not know about piñon-juniper vegetation, and new syntheses of this kind will be needed in the future as new knowledge becomes available.

Piñon-Juniper: A Variable & Diverse Type of Vegetation

We identify three fundamentally different types of piñon-juniper vegetation, based primarily on canopy structure, understory characteristics, and historical disturbance regimes. There is of course great diversity within each of the three basic types, but the classification below represents much of the variability in piñon-juniper vegetation across the western U.S. Research is underway to link these vegetation types to specific soil types and other environmental characteristics that would allow for reliable prediction and mapping across large landscapes, but at present we can only identify some very general environmental correlates. Table 1 is a key for distinguishing among the three types in the field.

(1) Persistent Woodlands are found where site conditions (soils and climate) are inherently favorable for piñon and/or juniper. Canopy and understory characteristics vary considerably from place to place, from sparse stands of scattered small trees growing on poor substrates (Figure 1) to relatively dense stands of large trees on productive sites (Figure 2). Tree density and canopy cover also may fluctuate in response to disturbance and climatic variability. Nevertheless, these are plant

Figure 1. *Persistent woodland, growing on shallow rocky soils on the mesa tops, with deeper colluvial soils in the canyon bottom. The canopy is composed of* Pinus edulis *and* Juniperus osteosperma. *The trees are all-aged, including many old individuals, and the woodlands within this view contain no evidence of past fire. Colorado National Monument, Colorado, elevation ca. 6,000 feet. (Photo by W. Romme, 2006)*

communities in which piñon and/or juniper are dominant species, both historically and currently, unless recently disturbed by fire, clearing, or other severe disturbance. Notably, these woodlands do not represent 20th century conversion of formerly non-woodland vegetation types to woodland.

Persistent Woodlands are typically found on rugged upland sites with shallow, coarse-textured soils that support relatively sparse herbaceous cover even in the absence of heavy livestock grazing. However, they also occur in a variety of other settings, such that steep terrain and shallow or rocky substrate are not by themselves adequate indicators. This type of piñon-juniper vegetation is found throughout the West; it appears to be especially prevalent on portions of the Colorado Plateau, where moisture comes predominantly in winter. Indeed, large expanses of the Colorado Plateau are characterized by ancient, sparse-density, persistent woodlands within spectacular rocky landscapes.

(2) Piñon-juniper savannas are usually found on gentle upland and transitional valley locations, where soil conditions favor grasses (or other grass-like plants) but can support at least some tree cover. Some savannas apparently have sparse tree cover because of edaphic or climatic limitations on woody plant growth; many of these savannas have probably changed little during the past century (Figure 3).

Figure 2. *Persistent woodland, growing on a moderately productive site with high canopy cover and sparse herbaceous understory. The canopy is composed of* Pinus edulis *and* Juniperus osteosperma*; the major understory shrub is* Artemisia tridentata. *Trees are all-aged, including many individuals > 300 years old, and the stand contains no evidence of past fire. Navajo Point, Glen Canyon National Recreation Area, Utah, elevation ca. 7,000 feet. (Photo by W. Romme, 2005)*

Other savannas, in contrast, have site conditions that could potentially support denser tree cover, but at these locations savanna structure is maintained by herbaceous competition, recurrent fire, drought, and other disturbances; many of these savannas have converted into denser woodlands during the past century because of release from competitive effects on tree seedling establishment, favorable climatic conditions for tree survival, and lack of fire (Figure 4). Some savannas and woodlands are found today in places that were tree-less grasslands prior to 1900; such sites can sometimes be recognized by remnant grasslands soils and species composition.

Piñon-juniper savannas typically are found on moderately deep, coarse to fine-textured soils that readily support a variety of growth forms including trees, grasses, and other herbaceous plants, and in regions that receive reliable summer rainfall that fosters growth of warm-season grasses. This type of piñon-juniper vegetation appears to be especially prevalent in the basins and foothills of southern New Mexico, where a large portion of annual precipitation comes in the summer via monsoon rains. However, it is relatively rare in the Rocky Mountains, northern Colorado Plateau, and the Great Basin, where precipitation is more winter dominated.

(3) Areas of potential woodland expansion & contraction are found where site conditions are only intermittently suitable for piñon and/or juniper

Figure 3. *Juniper savanna, growing in fine-textured soils in a region of low precipitation where low tree density probably is a result of competition for moisture rather than fire or other disturbances. Trees are predominantly* Juniperus osteosperma*, with occasional* Juniperus monosperma *and* Pinus edulis*. Many of the trees appear to be relatively old (>150 years), i.e., crowns are flattened and branches are large and gnarly (Table 2). Evidence of past fire is scarce. San Juan Basin, northwestern New Mexico, elevation ca. 6,800 feet. (Photo by B. Jacobs, 2006)*

Figure 4. *Piñon-juniper savanna, growing in relatively deep soils on gentle terrain, in a region of summer-dominated precipitation. Trees are predominantly* Juniperus monosperma *with occasional* Pinus edulis. *Most trees are less than 150 years old, but there is at least one older tree per acre. Blue grama (*Bouteloua gracilis*) is the dominant grass; cholla cactus (*Opuntia imbricata*) is also present. With a well-developed herbaceous stratum within a relatively productive environment, low tree density at this site may have been maintained historically by periodic fire. However, fire history studies have not been conducted in this area to confirm or reject this hypothesis. Near Mountainair, New Mexico, elevation ca. 6,400 feet. (Photo by W. Romme, 2006)*

establishment and survival over long time scales. Trees may become more abundant during moist climatic periods or during long disturbance-free intervals, but subsequently die back during drought and associated insect outbreaks or following fire. Many woodlands of this type have a shrub-dominated understory (Figure 5). Some such areas may have a distinctive historical fire regime, and therefore could be classified as a separate piñon-juniper-shrub type if such a distinction is useful for management. This vegetation type overlaps somewhat with disturbance-maintained savannas, but refers primarily to areas that fluctuate between shrubland or grassland structure and tree dominance, as well as other sites where soils or climate are only occasionally suitable for tree growth and survival.

Areas of potential woodland expansion and contraction are found on a wide variety of substrates and climatic conditions. Such areas sometimes are located adjacent to persistent woodlands or savannas, where soil conditions gradually change from favorable to marginal for tree growth. However, precise bioclimatic conditions associated with areas of potential piñon-juniper expansion and contraction are poorly defined at this time. This type of piñon-juniper vegetation is found throughout the West; it appears to be especially prevalent in the Great Basin.

Figure 5. *An area of potential expansion and contraction, on fine-textured soils in a region of moderate, winter-dominated precipitation. The canopy is composed of* Pinus edulis, Juniperus osteosperma, *and* Juniperus monosperma. *The prominent shrub is* Artemisia tridentata. *The trees are all-aged. Note the relatively old-appearing (>150 years, Table 2) piñon trees in the background, with flattened crowns and large branches near the top; and the younger-appearing piñon and juniper trees in the foreground, with spire-shaped crowns. The younger trees are evidence of expansion during the past century, but contraction also has occurred during a severe regional piñon mortality event within the past decade (see Figure 7). Evidence of past fire is scarce. San Juan Basin, northwestern New Mexico, elevation ca. 6,800 feet. (Photo by B. Jacobs, 2006)*

What We Know About Persistent Woodlands

1. Spreading, low-intensity surface fires had a very limited role in molding stand structure and dynamics of persistent piñon-juniper woodlands in the historical landscape. In very sparse woodlands, especially on rocky terrain, fires typically burned individual trees but did not spread extensively because of lack of surface fuels. Surface spread was more likely to occur in higher-density woodlands growing on more productive sites, but even here fire spread was typically from crown to crown, especially when wind-driven. Regardless of tree density, the dominant fire effect was to kill most or all trees and to top-kill most or all shrubs (Figure 6). This statement also is true of most fires today.
   HIGH CONFIDENCE … APPLIES TO PERSISTENT WOODLANDS THROUGHOUT THE WEST

2. Historical fires in persistent piñon-juniper woodlands generally did not "thin from below," i.e., they did not kill

Figure 6. *A recent stand-replacing burn in persistent woodlands, the ca. 25,000-acre Mustang Fire of 2002, photographed in fall of 2006. Note the sharp boundaries between burned and unburned woodlands, and the nearly complete canopy mortality within the burn perimeter — typical characteristics of large fires in persistent piñon-juniper woodlands, both historically and at present. Trees are* Pinus edulis *and* Juniperus osteosperma. *Near Flaming Gorge Reservoir, northeastern Utah, elevation ca. 6,200 feet. (Photo by C. D. Allen, 2006)*

predominantly small trees. Instead, they tended to kill all or most of the trees within the places that burned regardless of tree size. This statement also is true of most fires today.
HIGH CONFIDENCE … APPLIES TO PERSISTENT WOODLANDS THROUGHOUT THE WEST

3. Historical fire rotations (i.e., the time required for the cumulative area burned to equal the size of the entire area of interest) varied from place to place in persistent piñon-juniper woodlands, but generally were very long (e.g., two to six centuries). This statement also is true of most persistent woodlands today.
HIGH CONFIDENCE … APPLIES TO PERSISTENT WOODLANDS THROUGHOUT THE WEST

4. Some persistent woodlands are stable for hundreds or even thousands of years without fire, other than isolated lightning ignitions that burn only a single tree and produce no significant change in stand structure. Many woodlands today show no evidence of past fire, though they may have burned in the very remote past (many hundreds or thousands of years ago). This may be true especially of very sparse woodlands in rocky areas, but is also true of many higher-density woodlands growing on more productive sites.
HIGH CONFIDENCE … BUT PRECISE GEOGRAPHIC APPLICABILITY NOT ADEQUATELY KNOWN

5. In some persistent woodlands, stand dynamics are driven more by climatic fluctuation, insects, and disease than by fire. For example, a massive piñon mortality event occurred recently in the Four Corners region as a result of drought, high temperatures, and bark beetle outbreaks (Figure 7).
HIGH CONFIDENCE … BUT PRECISE GEOGRAPHIC APPLICABILITY NOT ADEQUATELY KNOWN

6. Tree density and canopy coverage have increased in many or most persistent woodlands during the 20th century.
HIGH CONFIDENCE … BUT PRECISE MAGNITUDE OF INCREASE, CAUSES, AND GEOGRAPHIC APPLICABILITY NOT ADEQUATELY KNOWN

7. The gradual increase in tree density and canopy cover during the 20th century in most persistent PJ woodlands is not due entirely, or even primarily, to fire exclusion. Effects of past livestock grazing and/or favorable climatic conditions for tree growth during most of the 20th century probably are more important mechanisms in most areas. However, we do not yet fully understand how grazing, climate, and fire exclusion interact to promote increased tree density, nor can we say with confidence which of these mechanisms is most important in any specific location. In addition, some stands that resemble persistent woodlands – i.e., with dense tree canopies, shallow rocky soils, and sparse herbaceous cover – actually may represent an eroded and degraded state of formerly lower-density woodlands that had grassy understories and could have supported

Figure 7. *Grey piñon skeletons illustrate the severe mortality event that occurred in* Pinus edulis *throughout much of the Four Corners region between 2002 and 2004. Tens of millions of piñon trees died from interactions among drought stress, bark beetle outbreaks, and anomalous high temperatures. Mortality was most severe in northern New Mexico, northern Arizona, southern Colorado, and southern Utah. Bandelier National Monument and Los Alamos National Laboratory, New Mexico, elevation 6,500 feet. (Photo by C. D. Allen, 2006)*

frequent fire. However, research to critically test this interpretation is lacking in most areas.
MODERATE CONFIDENCE … BUT GEOGRAPHIC APPLICABILITY AND SITE SPECIFIC CAUSES NOT ADEQUATELY KNOWN

8. Recent large, severe fires in persistent piñon-juniper woodlands probably are normal kinds of fires, for the most part, because similar fires occurred before 1900 (as documented, e.g., at Mesa Verde and on the Kaiparowitts Plateau). However, the frequency of large severe fires appears to have increased throughout much of the West during the past 20 years, in piñon-juniper and also in other vegetation types. This increased fire activity may be a consequence of warmer temperatures and longer fire seasons, greater fuel continuity developing from increasing tree cover, invasion by highly flammable annual grasses (e.g., cheatgrass, *Bromus tectorum*), or a combination of all these causes. However, with the very long fire rotations that characterize persistent piñon-juniper woodlands, we cannot yet determine if this recent apparent trend represents real, directional change or simply a temporary episode of increased fire activity, similar to comparable episodes in the past.
MODERATE CONFIDENCE … APPLIES TO MOST PERSISTENT WOODLANDS THROUGHOUT THE WEST

What We Know About Piñon-Juniper Savannas

9. In many regions where a large fraction of annual precipitation comes in the summer, savannas and grasslands were more extensive historically than they are today. During the 20th century, many former savannas and grasslands in these regions have been converted to juniper or piñon-juniper woodlands of moderate to high canopy coverage, especially in parts of New Mexcio, Arizona, and perhaps also in southeastern Colorado.
   HIGH CONFIDENCE … BUT PRECISE GEOGRAPHIC APPLICABILITY NOT ADEQUATELY KNOWN

10. Livestock grazing and fire exclusion since the late 1800s are important mechanisms driving the conversion of savanna to piñon-juniper woodland in at least some areas, but probably not all. Twentieth-century climatic conditions also have played a role in at least some areas, but how these potential causes interact is not well understood. On some sites with relatively high effective moisture for trees, tree cover may have become great enough to suppress herbaceous growth, thereby reducing the potential for subsequent surface fires and creating a new fire regime more similar to that of persistent woodlands than to the former savanna fire regime. Disentangling the mechanisms driving tree expansion in former grasslands and savannas is a high-priority research topic.
    MODERATE CONFIDENCE … BUT PRECISE MAGNITUDE OF INCREASE, CAUSES, AND GEOGRAPHIC APPLICABILITY NOT ADEQUATELY KNOWN

What We Know About Areas of Potential Expansion & Contraction

11. Expansion of piñon and/or juniper into previously non-wooded areas (especially former shrublands and grasslands) is occurring extensively in some regions, notably the Great Basin and parts of Arizona and New Mexico, but is of comparatively limited extent in other areas, notably western Colorado. An important consequence of this process is that formerly heterogeneous landscape mosaics – intermingled patches of woodland, shrubland, and grassland – are becoming more homogeneous as trees become established within the former shrubland and grassland patches.
    HIGH CONFIDENCE … BUT PRECISE GEOGRAPHIC APPLICABILITY NOT ADEQUATELY KNOWN

12. Presence of young piñon-juniper woodlands does not necessarily imply expansion into formerly non-woodland vegetation. The young trees may instead represent recovery of persistent woodlands from previous disturbance (e.g., clearing or fire). Thus, knowledge of local history is important.
    HIGH CONFIDENCE … BUT PRECISE GEOGRAPHIC APPLICABILITY NOT ADEQUATELY KNOWN

13. Near the current altitudinal and geographical limits of piñon and juniper, expansion may represent natural, long-term change in the species' range (e.g., piñon expansion in the northern Front Range of Colorado and near Flaming Gorge Reservoir in northeastern Utah during the past several centuries)
    HIGH CONFIDENCE … BUT PRECISE GEOGRAPHIC APPLICABILITY NOT ADEQUATELY KNOWN

14. Expansion of piñon and/or juniper into previously non-wooded areas occurred prior to Euro-American settlement on at least some sites; it is not strictly a 20th century phenomenon, and is not necessarily an abnormal process caused by past land use or fire exclusion. Loss of piñon and/or juniper from marginal sites also occurred historically, and has occurred recently in some areas, e.g., the Four Corners region (Figure 7).
    HIGH CONFIDENCE … BUT PRECISE GEOGRAPHIC APPLICABILITY NOT ADEQUATELY KNOWN

15. Expansion of piñon and/or juniper into previously non-wooded areas may have been more extensive in the 20th century than in the previous few centuries, at least in some regions. Grazing and fire exclusion probably are major causes of expansion of piñon and/or juniper into some savannas, grasslands, and shrublands, but not all. Climate change probably also plays an important role. However, we do not have a good understanding of how these potential causes interact.
    MODERATE CONFIDENCE … BUT PRECISE MAGNITUDE OF INCREASE, CAUSES, AND GEOGRAPHIC APPLICABILITY NOT ADEQUATELY KNOWN

Table 1. A suggested key for identifying the three historical types of piñon-juniper vegetation discussed in this paper. Note: This key has not yet been extensively field tested. The authors will appreciate feedback on how well it works (or does not work).

1a. Total tree canopy cover (piñon and juniper combined) < 10 % 2
1b. Total tree canopy cover (piñon and juniper combined) > 10 % 6

2a. At least one old tree (over 150 years old*) per acre 3
2b. Old trees (over 150 years old*) fewer than one per acre 4

3a. Understory dominated by grassland species, often on deep soils and gentle topography ...... **Savanna** (*relatively stable*)
3b. Understory dominated by shrubs or other species not associated with grassland, often on shallow soils and rugged or rocky topography ...... **Persistent Woodland** (*a very sparse form of persistent woodland*)

4a. Large dead wood (> 10 inches diameter, standing or fallen), conspicuously present, showing evidence of past fire, woodcutting, or other severe disturbance ...... **Persistent Woodland** (*recovering from disturbance*)
4b. Large dead wood (> 10 inches diameter, standing or fallen), conspicuously absent 5

5a. Understory dominated by grassland species, often on deep soils and gentle topography ...... former **Grassland** being converted to **Savanna**
5b. Understory dominated by shrubs or other species not associated with grassland, often on shallow soils and rugged or rocky topography ...... **Area of Potential Expansion and Contraction** (*with recent episode of expansion*)

6a. At least 10% of canopy trees are over 150 years old* ...... **Persistent Woodland**
6b. Fewer than 10% of canopy trees are over 150 years old* 7

7a. Large dead wood (> 10 inches diameter, standing or fallen), conspicuously present, showing evidence of past fire, woodcutting, or other severe disturbance ...... **Persistent Woodland** (*recovering from disturbance*)
7b. Large dead wood (> 10 inches diameter, standing or fallen), conspicuously absent 8

8a. Understory dominated by grassland species, often on deep soils and gentle topography ...... former **Grassland** or **Savanna** being converted to **Woodland**
8b. Understory dominated by shrubs or other species not associated with grassland, often on shallow soils and rugged or rocky topography ...... **Area of Potential Expansion and Contraction** (*with recent episode of expansion*)

* See Table 2 for assistance in estimating tree ages.

Table 2. Tips for estimating tree ages. Tree size is often an unreliable indicator of tree age, and the oldest trees on a site are sometimes among the smaller individuals. The best way to determine tree age is by extracting an increment core and cross-dating the rings. Piñons usually can be dated accurately if the wood is sound, but junipers generally are difficult or impossible to cross-date. Where coring and cross-dating are not feasible, other qualitative features can be used to distinguish between relatively old trees vs. relatively young trees with a moderate degree of confidence:

Characteristic	Relatively Young Trees	Relatively Old Trees
Crown shape	Conical, with pointed tip and lower branches still living	Flattened top, with lower branches dead or previously shed
Branch structure	Branches become progressively smaller from bottom to top of tree	Large, gnarly branches throughout the living portion of the crown
Dead wood	Little dead wood in the bole, few dead branches, little or no sign of past wood cutting	Large dead branches, often broken off or cut by wood gatherers long ago; bark missing from portions of the bole and weathered wood exposed in these places
Bark	Somewhat smooth, with relatively shallow furrows	Often rough and shaggy (junipers only), with relatively deep furrows (piñons and junipers)