DRAFT Piñon-Juniper Framework - New Mexico Forest Restoration Principles

May 3, 2007

This draft document, a four-part framework prepared by the New Mexico Forest Restoration Principles Working Group in 2006-2007, summarizes the current state of our knowledge of the piñon-juniper savannas, shrublands, and woodlands of New Mexico: their ecological context, management needs, and considerations for restoration. This working document is intended for use as preliminary guidance for piñon-juniper management projects, including those whose goal is to produce fuel for electricity generation or home heating. A secondary purpose is to document the extent of our knowledge about the distribution and dynamics of these piñon-juniper types, and to provide a list of ecology and management references (Table 4).

Table 1. Restoration Guidelines

General principles	*Acknowledge diversity and uncertainty*: Piñon-juniper woodlands, shrublands, and savannas are diverse and complex. Knowledge of local reference structure, composition and disturbance regimes is lacking or uncertain for many of the piñon–juniper ecosystem types of the western United States, including many of those that occur in New Mexico. Management plans and practices should acknowledge this lack of information and associated uncertainty. Managers should be mindful of potential effects on species associated with and/or limited to piñon-juniper systems, e.g. piñon jay and juniper titmouse
	Recognize fragility & thresholds; manage for resilience: P-J sites may be particularly susceptible to ecological damage – for example, soil erosion and invasion by non-native plants – from mechanical treatments.
	Develop site-specific knowledge: Managers should develop a comprehensive and site-specific understanding of historical and current conditions before planning or undertaking fire hazard mitigation, biomass harvesting, or ecological restoration. Local fire and vegetation histories and investigations into the causes of ecological change should be in place before restoration prescriptions are developed.
Investigating restoration need by ecological system type and by site	*Affirm, through empirical evidence, the need for restoration*. Fuel reduction and fire mitigation activities may be linked to ecological restoration, but the two goals do not always coincide, especially in piñon-juniper cover types. Due to the lack of local knowledge about the dynamics of P-J systems in many parts of their ranges, areas that are in need of ecological restoration can seldom be readily identified. The recent (2001-2003) mortality episode may, in fact, have accomplished much desirable thinning of stands that had abnormally high tree density due to grazing mismanagement, fire suppression, climate change, or some combination of these. The more serious issue now may be the regional scarcity of healthy piñon trees.
	Identify degraded grasslands in need of restoration: Thinning may be appropriate for restoration of former grasslands that have been encroached upon by piñon and juniper trees because of fire exclusion, and where these trees have not already been killed by drought and associated insect outbreaks.
	Identify degraded P-J savannas, shrublands, and woodlands with a demonstrated restoration need: Likewise, thinning of P-J woodlands may be appropriate where it contributes to restoration of structure, dynamics and fire regimes. Disposition of woody biomass is critical; practitioners may need to leave a substantial portion on-site for restoration of soil and herbaceous cover if appropriate livestock and wildlife grazing rest can not be assured.
Where natural range of variability or successional dynamics are unknown or unclear	Where restoration objectives cannot be identified due to a lack of information about reference condition, current condition and/or historical range of variation, a case can sometimes be made for ecological management to address ongoing ecological degradation (soil erosion, hydrologic dysfunction, etc.) or to protect communities from fire. In these cases, *employ best management practices* to mitigate environmental impacts.
Soil/Site Stability, Hydrologic Function, and Biotic Integrity	Land condition should be assessed comprehensively prior to planning & implementation of conservation, restoration, and management of P-J woodlands, savannas, and shrublands. Mimicking historical stand structure alone may not achieve site restoration. Attributes of condition include soil/site stability, hydrologic function, and biotic integrity. Examples of degradation include gullying, pedestaling, and rilling (soil/site stability); soil compaction & reduced infiltration (hydrologic function); and invasion by non-native species (biotic integrity). Such degradation can hamper achievement of conservation, restoration & other management objectives. Variability in resilience & response. Guidance can be found in Ecological Site Descriptions (http://www.nm.nrcs.usda.gov/technical/), Interpreting Indicators of Rangeland Health (Pellant et al. 2000), Davenport et al. (1998), and other references listed in Tab #4.
Other Vegetation Types	Piñon and juniper trees have encroached upon grasslands throughout New Mexico, sometimes transforming them into P-J woodlands, shrublands or savannas. These "former grasslands" are no longer in their reference condition, having been altered by livestock grazing and/or fire exclusion. Former grasslands are frequently difficult to distinguish from naturally-occurring (i.e. reference condition) P-J woodlands, shrublands, and savannas. Restoration of sites where historical transformation from grassland to P-J dominated types can be confirmed may be possible using fire and/or mechanical thinning, though little research has been conducted on this subject.

Table 2: Ecological Classification Overview

Vegetation Type (Reference Condition)		Piñon-Juniper Persistent Woodland	Piñon-Juniper Open Woodland	Piñon-Juniper Shrubland	Piñon-Juniper Savanna or Juniper Savanna	Grassland**	Crosswalk Lead
Crosswalk to Other Classifications	*Habitat Types (US Forest Service)*						
	Terrestrial Ecosystem Unit Survey (US Forest Service)						
	Biophysical Settings (LANDFIRE)						
	Ecological Sites (NRCS/BLM)						
	Ecological Systems (NatureServe)						

Table 2a. Piñon-Juniper Persistent Woodland

Vegetation Type (Reference Condition)		Piñon-Juniper Persistent Woodland
Distribution		Found where soils & climate are inherently favorable for piñon &/or juniper. Typically found on rugged upland sites. Occurs throughout the West, but especially prevalent on the Colorado Plateau, where large expanses are characterized by ancient, sparse, woodlands in spectacular rocky landscapes.
Reference Conditions	***Soils***	Typically found on shallow, coarse-textured soils that support sparse herbaceous cover, but also occur in a variety of other settings.
	Precipitation Regime	Large portion of annual precipitation comes in winter.
	Fire Regime	Infrequent, high-severity (lethal), carried by tree crowns. Fire rotations varied from place to place, but generally were very long (two to six centuries). Large, intense fires occurred in at least some persistent woodlands.
	Stand Structure	Variable, from sparse stands of scattered small trees growing on poor substrates to dense stands of large trees on productive sites. Tree density & canopy cover may fluctuate in response to disturbance & climatic variability. Piñon & juniper are dominant species unless recently & severely disturbed.
	Stand Dynamics	Stable/stationary tree age structure & little change in shrub or herbaceous layers during the long intervals without fire. Very slow recovery after fire. In some persistent woodlands, stand dynamics are driven more by climatic fluctuation, insects, and disease than by fire.
	Ecological Drivers	Stand dynamics driven by climatic fluctuation, insects, and disease rather than by fire. Some persistent woodlands are stable for 100s or 1000s of years without fire. Many show no evidence of past fire. Dominant fire effect was to kill most or all trees and top-kill most or all shrubs. Spreading, low-intensity surface fires had very limited role.
Current Conditions	***Fire Regime***	Frequency of large, severe fires appears to have increased during the past 20 years, possibly as a consequence of climate change, greater fuel continuity from increased tree cover, invasion by flammable annual non-native grasses, or a combination of these causes.
	Stand Structure	Tree density and canopy coverage may have increased in some persistent woodlands, but precise magnitude, causes, and geographic applicability not well known. These woodlands do not represent 20th century conversion of formerly non-woodland vegetation types to woodland.
	Stand Dynamics	Gradual increase in tree density & canopy cover, probably due to livestock grazing &/or favorable climatic conditions in most areas.
	Ecological Drivers (in addition to those listed in Reference Conditions)	Gradual increase in tree density & canopy cover during 20th century is not due entirely or even primarily to fire exclusion. Effects of livestock grazing &/or favorable climatic conditions are probably 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.

Key Uncertainties	The extent of this vegetation type in New Mexico is uncertain. It is very extensive to the north and west of New Mexico, on the Colorado Plateau and in the Great Basin, where precipitation is winter-dominated, and has been documented to be well represented in north-central and northwestern New Mexico (Brian Jacobs, unpublished data). However, it may be much less extensive in southern New Mexico, where precipitation is summer-dominated. For example, many of the historic photos from the late 1800s in Lincoln County, New Mexico, reveal only small patches of what appears to be piñon-juniper persistent woodland (Fuchs 2002).	
	Some stands that appear to be piñon-juniper persistent woodland today (based on dense tree cover and shallow rocky soils) may in fact be examples of degraded piñon-juniper open woodland. As tree cover increases, herbaceous production decreases; this process combined with heavy livestock grazing may have led to severe erosion and loss of herbaceous cover, such that surface fire can no longer readily spread through the stand. Thus, the fire regime may have been converted from one of frequent, low-severity fires (typical of piñon-juniper open woodland) to a regime of infrequent, stand-replacing fires (typical of piñon-juniper persistent woodland). Note however that the evidence for this interpretation is derived almost entirely through logical deduction; it has rarely been documented empirically in the field.	

Table 2b. Piñon-Juniper Open Woodland

Vegetation Type (Reference Condition)		Piñon-Juniper Open Woodland
Distribution		Found where soils & climate are inherently favorable for piñon &/or juniper. Typically found on productive upland sites. Prevalent on the Colorado Plateau in northern Arizona and northern NM, adjacent to ponderosa pine forests. Characterized by uneven-age open woodlands on rolling uplands.
Reference Conditions	***Soils***	Deeper soils than those that underlie persistent woodlands. Transitional between deep, well-drained soils that support P-J savanna and shallow, coarse soils that support persistent woodland.
	Precipitation Regime	Bi-modal (winter/summer precipitation codominates).
	Fire Regime	Frequent, low-severity surface fires carried by grasses, with occasional mixed-severity patchy fires where high fuel density supports more intense fire.
	Stand Structure	All-aged, open to moderately dense stands, with understory of sparse to moderately dense shrubs, moderately dense to dense herbs, all depending on time since last fire. Cool season grasses frequently occur under tree canopies & warm-season species occur in tree interspaces.
	Stand Dynamics	Stable open to moderately dense woodland structure maintained by frequent fire.
	Ecological Drivers	Stand dynamics primarily driven by fire and by climate fluctuation. Most sites could support denser tree cover but open woodland structure is maintained by herbaceous competition, recurrent fire, drought, and other disturbances. Secondary disturbances such as climatic fluctuation, insects, and disease also shape the composition and density of these sites.
Current Conditions	***Fire Regime***	Frequency of large, severe fires appears to have increased during the past 20 years due to greater fuel continuity from increased tree cover resulting from fire exclusion. Climate fluctuation (wet periods in the 1970s and 1980s) may also have played a role.
	Stand Structure	Tree density and canopy coverage have increased in most P-J open woodlands. These woodlands do not represent 20th century conversion of formerly non-woodland vegetation types to woodland. The age structure of these stands indicates persistent tree dominance on these sites.
	Stand Dynamics	Increase in tree density and canopy cover resulting in loss of stand openings and inter-group spaces. Possibly due to fire exclusion, livestock grazing &/or favorable climatic conditions.
	Ecological Drivers	Livestock grazing & fire exclusion may have increased the density of P-J open woodlands in some areas, but these mechanisms have not been rigorously documented. 20th-century climatic fluctuation may also have played a role in at least some areas, but how these potential causes interact is not well understood.

Key Uncertainties	The evidence for this interpretation of the historical fire regime is derived almost entirely through logical deduction. Although it is entirely reasonable to assume that stands with a robust grass component would have carried fire readily, nevertheless we have almost no empirical fire history data for this vegetation type (Baker and Shinneman 2004). Basal fire scars (the most conclusive evidence of past low-severity fires) are conspicuously rare on old piñon trees; scars are somewhat more common on old junipers, but nowhere near as common as on old ponderosa pine, where historical low-severity surface fire regimes have been best documented. The few fire-scarred piñons that have been dated often come from sites adjacent to ponderosa pine, and thus may not be representative of the large expanses of piñon-juniper vegetation remote from ponderosa pine. A key research question is to determine whether the paucity of fire scars on piñon trees is because the trees simply do not scar well, even when subjected to low-intensity fire, or because they actually experienced few fires.
	The pattern of increasing tree density is well documented (e.g., Fuchs 2002), but the mechanism is unclear. If fire was formerly frequent in this vegetation type, then fire exclusion is likely the major cause of increasing tree density during the 20th century. But if fire was not frequent historically, then another mechanism must be more important. In parts of western Colorado, piñon densities began to increase in the early 1800s -- half a century before the onset of grazing and fire exclusion -- at a time when the climate became more favorable for tree establishment and survival (W. L. Baker, unpublished data). No similar analysis has been conducted in New Mexico to evaluate alternative mechanisms for increasing tree density; rather it is widely assumed (with little direct evidence) that fire exclusion is the principal mechanism. A high priority for research is to conduct research to disentangle the effects of fire exclusion, livestock grazing, and climate change on the dynamics of tree expansion and infill in piñon-juniper vegetation in New Mexico.

Table 2c. Piñon-Juniper Shrub Woodland

Vegetation Type (Reference Condition)		Piñon-Juniper Shrubland
Distribution		P-J oak shrublands can be found in southwestern, west-central (Zuni Mountains), south-central (Sacramento Mountains), and north-central (Sangre de Cristo Mountains) New Mexico. P-J big sagebrush shrublands are limited to north-central and northwestern NM. Oak shrublands and juniper shrublands that are transitional between grasslands and ponderosa pine forest occur at middle elevations throughout the state, often in small patches that do not allow statewide mapping.
Reference Conditions	***Soils***	Deeper soils than those that underlie persistent woodlands. Transitional between deep, well-drained soils that support P-J savanna and shallow, coarse soils that support persistent woodland.
	Precipitation Regime	Winter peak in precipitation.
	Fire Regime	Moderately frequent, mixed-severity, patchy fires carried by trees and shrubs.
	Stand Structure	Variable, including sparse stands of scattered trees with a near-continuous shrub understory, to dense stands of trees with a sparse shrub understory, all depending on time since last fire. Piñon and juniper are dominant species unless recently & severely disturbed, though oaks (Gambel, wavyleaf, and/or shrub) may become co-dominant at some sites.
	Stand Dynamics	Seral trend from herb to shrub to tree dominance, interrupted by fires that return a stand to early seral herb dominance. Post-disturbance succession may include long intervals where shrubs are dominant. Absent further disturbance, these shrub-dominant plants association are encroached upon by juniper and/or piñon trees. P-J shrublands will ultimately be transformed through succession into woodlands, but shrubland patches are maintained over time and space by fire, drought, and insects.
	Ecological Drivers	As with persistent woodlands, stand dynamics are driven by climatic fluctuation, insects, and disease, but fire likely intervenes more frequently to shape stand structure and composition.
Current Conditions	***Fire Regime***	Reduced fire frequency, small increase in fire severity.
	Stand Structure	Tree density and canopy cover have likely increased in many P-J shrublands due to wet climatic episodes in the 1920s and 1970s and due to exclusion of fire through livestock grazing and active fire suppression.
	Stand Dynamics	Increase in tree density & canopy cover, and decreases in shrub and herbaceous cover, due to climatic fluctuation, grazing, and/or fire exclusion
	Ecological Drivers	Insufficient information is available about this type due to a paucity of research.

Key Uncertainties	Although this is a conspicuous vegetation type, we have almost no empirical data on historical fire regimes in piñon-juniper shrubland vegetation. Just across the border in southwestern Colorado, the fire history of piñon-juniper-Gambel oak shrublands has been reconstructed in Mesa Verde National Park (Floyd et al. 2000). In this area, the historical fire rotation was estimated to be about 100 years, with predominantly stand-replacing fire severity, followed by rapid re-sprouting of the shrubs but extremely slow re-establishment of piñon and juniper. A similar historical fire regime may characterize piñon-juniper-Gambel oak shrublands in northwestern New Mexico. However, the Mesa Verde study site is somewhat atypical in that it is a mesa top surrounded by cliffs that could act as relative barriers to fire spread. Thus, fire rotations in other piñon-juniper-Gambel oak shrublands may be shorter, although fire history has not been reconstructed in any other sites. As for historical fire regimes in the many other kinds of piñon-juniper-shrubland in New Mexico, we simply have no empirical data.
	Unlike stands with a well-developed grass understory -- where we can infer that fires might have been frequent in the past -- it is difficult or impossible to infer what historical fire frequency might have been in stands with a shrub-dominated understory. Nevertheless, it is likely that such stands supported an important high-severity component, given the structure of the shrub fuels.

Table 2d. Piñon-Juniper Savanna or Juniper Savanna

Vegetation Type (Reference Condition)		Piñon-Juniper Savanna or Juniper Savanna
Distribution		Usually found on gentle upland & transitional valley sites, where soil conditions favor grasses (or other grass-like plants) but can support at least some tree cover. P-J Savanna is prevalent in the basins & foothills of southern NM. Rare in the Rocky Mountains, northern Colorado Plateau, and the Great Basin, where precipitation is winter dominated.
Reference Conditions	***Soils***	Typically found on moderately deep, coarse to fine-textured soils that readily support a variety of growth forms including trees, grasses, & other herbaceous plants.
	Precipitation Regime	Large portion of annual precipitation comes in summer via monsoon rains.
	Fire Regime	Frequent, low-severity, surface fires, carried by grasses.
	Stand Structure	Sparse to moderately dense trees, sparse to very dense shrubs, moderately dense to sparse herbs, all depending on time since last fire.
	Stand Dynamics	Low tree density and high herbaceous biomass maintained by either recurrent fire or by inherent site-specific climatic or edaphic limitations. See *Primary Drivers: Ecological* section below.
	Ecological Drivers	Some P-J savannas have sparse tree cover because of edaphic or climatic limitations of woody plant growth; many of these have probably changed little during the past century. Other P-J savannas have site conditions that could support denser tree cover, but at these locations savanna structure is maintained by herbaceous competition, recurrent fire, drought, and other disturbances
Current Conditions	***Fire Regime***	Reduced fire frequency and large increases in fire severity at sites where P-J savanna was converted to woodland.
	Stand Structure	At sites where savanna was converted to woodland (as described in the *20th-Century Changes* section below), tree density has increased, and shrub and herb density decreased.
	Stand Dynamics	In many places where savanna structure was previously maintained by herbaceous competition, recurrent fire, drought, and other disturbances, P-J savannas have been converted into woodlands during the past century because of release from competitive effects on tree seedling establishment, favorable climatic conditions for trees, & lack of fire. P-J savannas probably became less extensive overall, but especially in parts of AZ & NM where most precipitation comes in summer. Many P-J savannas were converted to P-J woodlands of moderate to high canopy coverage, & many former grasslands have been converted to savanna or woodland.
	Ecological Drivers	Livestock grazing & fire exclusion are important mechanisms driving the conversion of P-J savanna to P-J woodland in at least some areas, but not all. 20th-century climatic conditions also have played a role in at least some areas, but how these potential causes interact is not well understood.

Key Uncertainties	As with the piñon-juniper open woodland vegetation type, the evidence for this interpretation of the historical fire regime in savannas is derived almost entirely through logical deduction. Although it is entirely reasonable to assume that stands with a robust grass component would have carried fire readily, nevertheless we have almost no empirical fire history data for this vegetation type (Baker and Shinneman 2004). Basal fire scars (the most conclusive evidence of past low-severity fires) are conspicuously rare on old piñon trees; scars are somewhat more common on old junipers, but nowhere near as common as on old ponderosa pine, where historical low-severity surface fire regimes have been best documented.
	The few fire-scarred piñons that have been dated often come from sites adjacent to ponderosa pine, and thus may not be representative of the large expanses of piñon-juniper and juniper vegetation remote from ponderosa pine. A key research question is to determine whether the paucity of fire scars on piñon trees is because the trees simply do not scar well, even when subjected to low-intensity fire, or because they actually experienced few fires.
	The pattern of increasing tree density and expansion into former grasslands is well documented (e.g., Fuchs 2002), but the mechanism is unclear. If fire was formerly frequent in this vegetation type, then fire exclusion is likely the major cause of increasing tree density during the 20th century. But if fire was not frequent historically, then another mechanism must be more important. In parts of western Colorado, piñon densities began to increase in the early 1800s -- half a century before the onset of grazing and fire exclusion -- at a time when the climate became more favorable for tree establishment and survival (W. L. Baker, unpublished data). No similar analysis has been conducted in New Mexico to evaluate alternative mechanisms for increasing tree density; rather it is widely assumed (with little direct evidence) that fire exclusion is the principal mechanism. A high priority for research is to conduct research to disentangle the effects of fire exclusion, livestock grazing, and climate change on the dynamics of tree expansion and infill in piñon-juniper and juniper vegetation in New Mexico.

Table 2e. Grasslands.

Vegetation Type (Reference Condition)		Grassland**
Distribution		Widespread and represented by many different ecological system types, including Semidesert Grassland, Plains and Great Basin Grassland, and Subalpine Grassland (see Brown, ed. 1994).
Reference Conditions	***Soils***	A wide variety of soil types may underlie native grasslands.
	Precipitation Regime	Variable.
	Fire Regime	Variable according to ecological system type and site: may include moderately frequent, lethal surface fires, carried by grasses.
	Stand Structure	Sparse to no trees, dense to sparse grasses
	Stand Dynamics	Not applicable.
	Ecological Drivers	New Mexico's diverse and variable native grasslands are shaped primarily by climatic fluctuation, herbivory, fire, and soil processes (including erosion, deposition, and organic horizon development). Grassland ecological system types are too diverse to be broadly categorized here.
Current Conditions	***Fire Regime***	Reduced fire frequency generally, though information is lacking for many areas because of lack of fire scars and other evidence. Fire frequency and severity may have increased in some semi-arid grasslands that have been encroached upon by non-native grass species such as cheatgrass (*Bromus tectorum*).
	Stand Structure	Shrubs and trees have encroached upon some grasslands, thereby decreasing herbaceous biomass. But note that some grasslands are not vulnerable to tree encroachment because the environment is too dry to support them.
	Stand Dynamics	The extent, causes and mechanisms of woody plant encroachment in grasslands have researched (by hypothesis testing through repeatable methods rather than anecdotal accounts) at only a small number of sites in New Mexico, and are therefore little understood.
	Ecological Drivers	Non-native invasive species have changed the dynamics and structure of some grasslands in ways too diverse and complex to describe here.
Key Uncertainties		As with piñon-juniper open woodland and savanna, the pattern of tree expansion into former grasslands is well documented (e.g., Fuchs 2002), but the mechanism is unclear. If fire was formerly frequent in this vegetation type, then fire exclusion is likely the major cause of increasing tree density during the 20th century. But if fire was not frequent historically, then another mechanism must be more important. Late 19th century fires in some desert grasslands of southeastern Arizona are documented from newspaper accounts (Bahre 1991), and it is inferred that fires must have been relatively frequent to prevent woody encroachment (McPherson 1995). However, Wright (1980) states that the pre-1900 role of fire in other grasslands of southern Arizona and New Mexico is simply unknown -- and that fire was possibly unimportant ecologically in at least some kinds of desert grassland (e.g., black grama communities).

	In parts of western Colorado, piñon densities began to increase in the early 1800s -- half a century before the onset of grazing and fire exclusion -- at a time when the climate became more favorable for tree establishment and survival (W. L. Baker, unpublished data). No similar analysis has been conducted in New Mexico to evaluate alternative mechanisms for increasing tree density; rather it is widely assumed (with little direct evidence) that fire exclusion is the principal mechanism. A high priority for research is to conduct research to disentangle the effects of fire exclusion, livestock grazing, and climate change on the dynamics of tree expansion and infill in piñon-juniper and juniper vegetation in New Mexico.

Table 3. A DRAFT key for identifying piñon-juniper vegetation types (adapted from a paper in preparation by Brian Jacobs).

Note on May 3, 2007: Our scientific advisors will revise this key after the P-J ecological classification has been reviewed and approved.

1. Total tree canopy cover (piñon and juniper combined) < 5 % …… 2
1. Total tree canopy cover (piñon and juniper combined) > 5 % …… 3

    2. Understory dominated by species of nearby grasslands …… **Savanna**
    2. Understory not dominated by species of nearby grasslands …… 6

3. Old trees (over 150 years old*) > 5 % canopy cover …… **Persistent Woodland**
3. Old trees (over 150 years old*) < 5 % canopy cover …… 4

    4. Large dead wood (> 10 inches diameter), standing or fallen, conspicuously present …… **Persistent Woodland (recovering from disturbance)**
    4. Large dead wood (> 10 inches diameter), standing or fallen, conspicuously absent …… 5

5. Understory dominated by species of nearby grasslands …… **Savanna (with recent conversion to dense woodland)**
5. Understory not dominated by species of nearby grasslands …… **Area of Potential Woodland Expansion and Contraction (with recent episode of expansion)**

    6. At least some old trees (over 150 years old*) present …… **Persistent Woodland (a very sparse form of Persistent Woodland)**
    6. Old trees (over 150 years old*) absent …… 7

7. Large dead wood (> 10 inches diameter), standing or fallen, conspicuously present …… **Persistent Woodland (recovering from disturbance) … or … Area of Potential Woodland Expansion and Contraction (with recent episode of contraction)**
7. Large dead wood (> 10 inches diameter), standing or fallen, conspicuously absent …… **Area of Potential Woodland Expansion and Contraction (with recent episode of expansion)**

* 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. Where coring is 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 wood exposed

Table 4. Principal References.

The references listed below served as our primary sources in developing the Restoration Guidelines and Ecological Classification (Table 1, 2 and 2a-2e in this workbook). For more information, refer to the comprehensive scientific and technical reference list on piñon-juniper forest, woodland and savanna that is being compiled by the New Mexico Forest and Watershed Institute at Highlands University.

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