

Pinyon-Juniper Natural Range of Variation Sierra Nevada and South Cascades

Prepared by:

Heather Stone, Inyo National Forest
Michèle Slaton, Inyo National Forest

U.S. Department of Agriculture, Forest Service,
Pacific Southwest Region, Ecology Program

June 2013

Pinyon-Juniper Natural Range of Variation

Table of Contents

Introduction.....	2
Physical setting and geographic distribution.....	2
Holocene history	3
Ecological setting	4
Cultural/socioeconomic setting.....	5
Methods.....	5
Reference conditions	5
Information sources.....	5
NRV Descriptions	6
Function.....	6
Climate	6
Invasions.....	8
Dispersal and establishment	9
Disturbances	10
Structure	19
Structural Class Types, Density, and Cover.....	19
Patch size	20
Bare soil.....	20
Composition	21
Geographic distribution of major species.....	21
Proportion of seral stages	22
Proportion of life forms: Trees, shrubs, grasses, forbs	22
Species diversity	23
Summary of NRV deviations	24
Acknowledgements.....	25
Literature Cited	25
Tables	32
Figures.....	39

Introduction

Physical setting and geographic distribution

Pinyon-juniper vegetation covers 40 million hectares (100 million acres) across the western US (Romme et al. 2009), and 8.3 million ha (20 million acres) in the Great Basin (Suring et al. 2005). It is composed of different dominant species depending on location (Figure 1). In the assessment area, dominant tree species are primarily single leaf pinyon (*Pinus monophylla*), Utah juniper (*Juniperus osteosperma*), and western juniper (*J. occidentalis*).

The mix of these species changes from south to north in the assessment area and across the west. Each species has a distinct climatic tolerance:

- Single leaf pinyon: Occurs primarily in the southern Great Basin from the Humboldt Basin in northern Nevada to southern California. Single leaf pinyon is very tolerant of summer drought, in contrast to other pinyon species in the southwest and Colorado Plateau. It does not appear to be as limited by temperature (Cole et al. 2008). However, it is less tolerant of moisture stress and drought than juniper species (Nowak et al. 1999). In the southeastern subregion (east of the Sierra crest and south of approximately Reno, NV), the woodlands are dominated by single leaf pinyon with some Utah juniper either within the pinyon woodland or alone on more arid sites.
- Western juniper: Occurs in the Sierra Nevada of California and in southeastern Oregon with winter-spring precipitation regimes generally ranging from 25-40 cm/yr and some extremes outside this range (Romme et al. 2009). In the northern subregion of the assessment area on the Modoc Plateau the woodlands are dominated by western juniper and with a rare single leaf pinyon component.
- Utah juniper: Overlaps the range of single leaf pinyon in the southern Great Basin and extends further east onto the Colorado Plateau. Utah juniper is more tolerant of drought than pinyon pine and sometimes occurs in the assessment area alone below pinyon pines or on more xeric sites (Nowak et al. 1999).

Pinyon-juniper vegetation occurs on a wide variety of substrates and topographic settings, with distribution controlled primarily (Climate section in Introduction, Gruell et al. 1994, Harper and Davis 1999, Miller and Heyerdahl 2008b, Romme et al. 2009). There is a pronounced precipitation gradient across the range of pinyon-juniper. The Great Basin is characterized by a winter-spring precipitation pattern with warm dry summers, whereas on the Colorado Plateau there are peaks in precipitation both in winter and summer, and in the Southwest there are summer monsoons (Figure 1). The pinyon-juniper woodlands of the southwest (Arizona and New Mexico) and the Colorado Plateau are dominated by different species than those in the assessment area, which structurally and ecologically. This assessment focuses only on woodlands from the western and north-western Great Basin.

Within the assessment area, most of the pinyon-juniper vegetation occurs in the eastern and northern subregions. Table 1 shows the current extent of major vegetation alliances that are dominated by pinyon and juniper as mapped by the Forest Service Region 5 vegetation mapping program (CALVEG). These areas include a large proportion of shrubland sites occupied by re-

cently expanded pinyon and juniper. This dynamic will be discussed below and in the Sagebrush chapter. Two alliances with juniper that occur within the assessment area are not included in this analysis: the yellow pine-western juniper alliance from the Modoc Plateau and the mountain juniper (*J. grandis*) alliance (also known as Sierra juniper) from the southern Sierra Nevada. For information about the NRV for yellow pine-western juniper, see the yellow pine-mixed conifer section. For information on the NRV of mountain juniper, see the Subalpine chapter.

Holocene history

The distribution of pinyon and juniper has been very dynamic over the Holocene period. The dominant species were present in parts of the assessment area at the end of the last glacial period, about 12,000 years ago, with the exception of pinyon pine, which was in a glacial refugium further south (Nowak et al. 1994a, Mensing 2001). Pinyon-juniper woodlands reached a maximum abundance during the Neoglacial period (3,500 to 2,600 ybp) and then declined during the droughts that followed; likely due in part to increases in fire as evidenced by greater amounts of charcoal in pollen records. During the Little Ice Age, 650 to 100 years ago it began a re-expansion, the end of which coincided with EuroAmerican settlement (Wigand et al. 1995, Tausch et al. 2004). Details of the Holocene climate and pinyon-juniper dynamics are in Table 2. The major movements of each species are summarized below:

- Utah juniper: At the end of the Pleistocene, Utah juniper was present on the valley floor and Tablelands of the Owens Valley, in the Mono Basin, and in the Painted Hills east of Reno, NV (Jennings and Elliott-Fisk 1993, Koehler and Anderson 1994, Nowak et al. 1994b, Jennings 1995, Wigand et al. 1995, Mensing 2001) and in the Mono Basin (Davis 1999). During the Holocene it moved up in elevation with some fluctuations with changes in climate. In the latter part of the Holocene it was largely replaced in many places with pinyon when it arrived (Tausch et al. 2004). Currently it dominates the woodlands in northern Nevada, but is typically a minor part of the pinyon-juniper woodlands of the western Great Basin from the vicinity of Reno, NV south (Miller et al. 1999). On some more arid sites (lower or higher in elevation or on sandy substrates) there are some woodlands dominated by Utah juniper alone.
- Western juniper: At the end of the Pleistocene, western juniper was present on the west side of the Sierra Nevada (in Kings Canyon) and further east in the Great Basin (Wigand et al. 1995). During the Holocene it migrated northward, and appeared at Lava Beds in northern California 5,200 ybp and at Hart Mountain in southeastern Oregon 4,000 ybp (Wigand et al. 1995). Western juniper is now common in the Sierra Nevada to the west and in northeastern California and southeastern Oregon, where it forms the dominant species, with pinyon as a more minor element.
- Single leaf pinyon: At the end of the Pleistocene, single leaf pinyon pine was in a southern refugium in the area of the modern Mojave Desert and the southern San Joaquin Valley. During the Holocene, pinyon pine began a northward expansion, with more rapid expansion in the eastern Great Basin than in the west. In the western Great Basin, data from packrat middens shows slow northward migration in a variable pattern. In the White Mountains, pinyon had arrived as early as 9,000 years before present (ybp), but not in neighboring highlands until later (Jennings 1995). In the Bodie Hills just to

the north, it arrived around 5,000 ybp (Halford 1998). Sites at Hawthorne, NV, Slinkard Valley, CA and areas near Reno, NV show that pinyon arrived between 2,000 and 3,000 ybp (Nowak et al. 1994b). After the arrival of pinyon in the region, it began to replace juniper in the existing woodlands (Jennings and Elliottfish 1993, Nowak et al. 1994b).

Ecological setting

- Pinyon-juniper is generally associated with woody sagebrush species (*A. tridentata* and *A. arbuscula*) and perennial bunchgrasses, with a north-south precipitation gradient as the main driver of herbaceous cover. The major species for each subregion are listed in Table 3.

There are a wide variety of stand structures and site types within the vegetation that is called pinyon-juniper. In a review of the literature on disturbance regimes in pinyon-juniper, Romme et al. (2009) described three different types of pinyon-juniper woodlands with distinct ecological dynamics:

- Persistent woodlands: Long lived pinyon-juniper woodlands that typically have sparse understories and occur on poor substrates in the assessment area. (On the Colorado Plateau this type can occur on more productive sites as well and result in stands with large dense trees and much of the literature comes from these woodlands. See methods section below for the literature used.)
- Savannas: Romme et al. define savannas as having low to moderate pinyon-juniper densities with a near continuous grass layer where shrubs play a minor role. This type of savanna is currently most common outside the assessment area in the southwest with summer monsoon precipitation patterns. Age structures in current pinyon-juniper woodlands within the assessment area suggest this type of structure during the pre-settlement period, in western juniper in the northern part of the assessment area (Miller and Wigand 1994a, Gruell 1999, Miller et al. 1999, Johnson and Miller 2008, Miller and Heyerdahl 2008b).
- Wooded shrublands (expansion): Variable tree densities with a successional dynamic between shrublands and trees occurring on substrates that favor shrubs which tend to be on sites with less available moisture for the trees. Tausch et al. (2009) have classified the stages of increase in tree density in 3 phases where Phase I is still dominated by shrubs, Phase II trees and shrubs are co-dominant, and in Phase III trees are dominant and typically the understory is very limited or non-existent. This type is described in more detail in the Sagebrush chapter.

This assessment will focus on the persistent woodland type and scattered savanna-like structures that have been described in the assessment area. The expansion of pinyon-juniper into shrublands is a very important dynamic in the assessment area and throughout the Great Basin, and it is described in more detail in the Sagebrush chapter.

Cultural/socioeconomic setting

Pinyon-juniper woodlands are an important ecological type for native peoples pre-historically and continue to be today. The Paiute, Shoshone and Washoe in the western Great Basin and Sierra Nevada used the pinyon pine extensively and still collect products from the trees, includ-

ing pine nuts, pitch, and wood products (Steward 1933, Anderson and Moratto 1996, Anderson 2005). Historically, pine nuts were a primary staple in Native American diets and a trade item with neighboring groups to the west. Juniper was also used for bow wood and medicinal uses (Anderson 2005). Pinyon, and to a lesser extent juniper, were used for fuel in areas close to mines during historic era (Young and Svejcar 1999). This use occurred mainly near mines and settlements, and the stumps can still be found today.

As soon as EuroAmerican settlers arrived, grazing became an important use of the landscape. Forage is generally not abundant in persistent woodlands, but the intermixed shrublands were heavily grazed starting in about 1860 by both sheep and cattle (Beesley 1996). Throughout the Intermountain west during the middle of the 1900's, there were many projects to improve forage for grazing. This often involved removing pinyon and juniper by chaining or burning, although these methods were used less in the assessment area than in the Southwest.

Recreation, hunting, aesthetics and wildlife habitat: In the arid regions where this ecosystem type occurs, pinyon and juniper are often the only tree species. They are valued for recreation, hunting, aesthetics, and the habitat they provide for wildlife. However, there has been an increase in efforts to remove trees through cutting, fire or mastication, in order to reverse expansion into shrubland sites, to restore the NRV, and promote wildlife dependent on sagebrush-steppe. These projects are being conducted on both public and private lands.

Methods

Reference conditions

Few modern references for the NRV in pinyon-juniper can be found today, due to extensive fire suppression and grazing that have affected these ecosystems across their range. The pre-settlement period can be used to some extent as a reference, but the climatic differences between current conditions and the cooler and wetter pre-settlement period make this imperfect. Stand demographics and fire history data were used from persistent woodlands, because their long-lived trees contain a record of conditions during this pre-settlement period. The best analog for current and expected future climactic conditions is probably the Post-neoglacial drought and the Medieval Warm Period, approximately 1600 to 650 ybp as described by Tausch et al. (2004). Packrat midden and pollen record data were used to understand conditions during the post-neoglacial drought and the Medieval Warm Period. However, this reference period is also imperfect because the dominant species of pinyon-juniper have continued to migrate over the Holocene.

Information sources

Differences between the northern and southern regions are noted where information is available. For the northern area, studies were emphasized that were done in northern California and in southeastern Oregon, where western juniper is the dominant tree species. For the southern area, studies are emphasized that were done in the eastern Sierra from Reno south and central Nevada south to the Spring Mountains near Las Vegas where single leaf pinyon is generally the dominant tree species and there is a more minor component of Utah juniper. Very few studies are available that inform NRV from the southwestern Sierra Nevada. In general, studies from the Southwest

(Arizona and New Mexico) and the Colorado Plateau were only used where there is no other evidence available due to the differences in species, structure, and climate in these areas. The variables assessed are listed in Table 4.

NRV Descriptions

Function

Climate

The history of movement of pinyon and juniper throughout the Holocene demonstrates that climate is an important influence on the potential NRV in pinyon-juniper woodlands. During the Holocene, pinyon and juniper have expanded throughout the Great Basin and moved up and down in elevation with fluctuations in temperature. Precipitation has been a particularly important factor. Pinyon and juniper increased in extent during periods of higher precipitation and, in the southern part of the assessment area, pinyon replaced juniper in many locations. Shifts in the timing of precipitation have led to an increase in the dominance of single leaf pinyon (Woolfenden 1996, Tausch 1999, Miller and Tausch 2001, Tausch et al. 2004).

The climate effects on the fire regime have also been important in controlling the distribution and structure of pinyon-juniper woodlands. In periods of drought, fires appear to have been more frequent and reduced the extent of pinyon-juniper and favored open savanna-like structures (Tausch 1999, Tausch et al. 2004).

Understanding the climate controls on the distribution and structure of pinyon-juniper woodlands is important to determining what the NRV. During the early Holocene, glaciers were more extensive, treelines were depressed. Within the assessment area, vegetation zones shifted northward and upward as warming progressed, and desert species increased at lower elevations during the early Holocene. The Mid Holocene was characterized by fluctuations in temperature, and the Xerothermic period of that time represents a climate scenario similar to that forecasted for the upcoming decades. More recently, the Medieval Warm period also showed temperature and precipitation patterns similar to those expected this century. The Late Holocene was characterized by a relatively brief cooling period, the Little Ice Age, when glaciers expanded slightly, greater precipitation resulted in expansion of trees and grasses, and temperatures were cooler. The rapid warming that has occurred over the last century is strongly contrasted with the ecological patterns manifested during the Little Ice Age that preceded it. In addition to increasing temperatures, the latter half of the 1900s was the wettest half-century in the last 2 millennia (Graumlich 1993). Recent warming has also undermined an otherwise long-term cooling trend that would be expected based on periodicity of glacial periods (See Introduction chapter).

1. Current conditions and comparison to NRV

The current climate is different from the available reference information for pinyon-juniper. Increased precipitation during the late 1800s and early 1900s likely contributed to the most rapid rates of expansion, and the more arid conditions currently may be an influence on the lower rates

of expansion since 1950 (Tausch 1999, Miller and Tausch 2001, Tausch et al. 2004, Miller et al. 2008).

2. Future

Models using scaled down results from several of the predicted climate change scenarios over the next century for California and Nevada can be used to predict the consequences for vegetation. Multiple studies have found that sagebrush and pinyon-juniper ecosystems will decline and become more fragmented over the next century (Lenihan et al. 2008, Ackerly et al. 2010, Mallek and Safford 2011, Finch 2012, Schlaepfer et al. 2012).

A recent review of the modeling and predictions for vegetation under climate change in the Interior American West found that pinyon-juniper ecosystems are expected to move upslope and northward, continuing the overall trend of their movement during the Holocene (Finch 2012). Lenihan et al. (2008) used the MC1 model to evaluate three different climate scenarios for the state of California and found that woodlands (including pinyon-juniper woodlands) decreased and were replaced by grasslands. This model uses three different modules to account for the effects of biochemistry, biogeography, and fire disturbance. The reductions in shrublands and woodlands that were predicted in this study were primarily due to increased fire frequency, which may lead to conversion of woodlands to grasslands (Lenihan et al. 2008).

Succession

1. NRV

Successional processes under NRV differ by woodland type. Based on the age structures of old pinyon-juniper stands, it appears that persistent woodlands tend to have continuous recruitment of new individuals, sustaining stands without disturbance, and resulting in a mixed age class distribution, with some trees as old as 300-400 years old (Burkhardt and Tisdale 1969b, Romme et al. 2009). Single leaf pinyon can reach ages up to 600 and western juniper can reach ages greater than 1000 years (Miller et al. 1999). Stands can be completely replaced by disturbances (fire, drought, disease) and a pinyon-juniper community regenerates (Knapp and Soule 1999, Romme et al. 2009).

There is very little information on the successional patterns in savanna –like structures in the assessment area. It is hypothesized that they were maintained by fire and the layer that regenerated after fire was dominated by grasses (Gruell 1999, Miller and Heyerdahl 2008b).

Expansion into shrublands and the shrubland successional pattern is addressed in more detail in the Sagebrush chapter. After disturbance, shrubland sites typically support grasses and forbs, with shrubs becoming established over a period of years, and pinyon and juniper often developing in the absence of disturbance over a longer time frame. Western juniper establishment in the northern part of the assessment area typically takes 25 or more years (Miller and Heyerdahl 2008b) and can reach tree dominance within 60 to more than 120 years, depending on the moisture availability of the site (Miller et al. 1999, Miller and Rose 1999, Johnson and Miller 2006). Over long time scales, the expansion of pinyon and juniper during the Holocene resulted in replacement of shrublands (see Table 2). However, many authors argue that during the pre-settlement period, the abundance of pinyon and juniper on shrubland sites was controlled by more

frequent fire regimes which would consume young pinyon and juniper before the surface fuels that carry fire were outcompeted by the tree layer (Gruell et al. 1994, Gruell 1999, Johnson and Miller 2006, Bauer and Weisberg 2009).

2. Current conditions and comparison to NRV

Persistent woodlands are in similar condition to NRV except for some infilling (See density below). Modeling based on Landfire models of NRV for distribution of seral classes can be used to estimate the current departures in savanna-like ecosystems and wooded shrublands from NRV. At Mount Grant in NV, at the edge of the assessment area, a study found that the pinyon-juniper woodlands with long fire return intervals were close to the NRV. However, the expansion woodlands in mountain big sagebrush, low sagebrush, and Wyoming sagebrush were moderately departed, due to overrepresentation of late seral classes with high tree cover (Provencher et al. 2008). Similar results were found in North Spring Valley in NV (Forbis et al. 2007).

3. Future

The current trends may continue, but predictions for changes in the frequency of fire and climate change may reduce the amount of conversion of shrublands to woodlands within the assessment area. See the fire and climate discussions.

Invasions

1. NRV

Herbaceous invasives were absent from pinyon-juniper during the NRV period.

2. Current conditions and comparison to NRV

Cheatgrass (*Bromus tectorum*) is common in pinyon and juniper stands. A review of non-native species in pinyon-juniper woodlands found that cheatgrass was the most common non-native species, followed by tall tumblemustard (*Sisymbrium altissimum*) (Johnson et al. 2006). Non-native species cover is highest in early and mid-seral stages and tends to decline in late seral stands. The presence of non-native species is by definition a departure from NRV.

3. Future

Annual grass abundance is likely to increase in the future throughout the assessment area. In the northern part of the assessment area, cheatgrass is likely to continue to increase. In the southern part of the assessment area, cheatgrass may increase or move further north and up in elevation to be replaced by red brome (*Bromus rubens*) from the Mojave Desert to the south (Bradley 2009, 2010). Increases in annual grasses would have impacts on fire regime and succession.

Dispersal and establishment

1. NRV

There is very little information about dispersal and establishment of pinyon and juniper from the reference periods for NRV, but some conclusions can be drawn from their ecology. Pinyon and juniper have important relationships with animal dispersal agents. Pinyon pine is dispersed by caching carried out by corvids (Clark's nutcrackers, pinyon jays, and scrub jays) and by small mammals. Birds can carry pine nuts up to 22 km (Chambers et al. 1999). During the reference period, Native Americans may have also been a dispersal agent for long distance dispersal (Betancourt 1986).

Juniper is dispersed by passing through the gut of birds and small mammals. Multiple species of birds have been documented to disperse juniper seeds. Coyotes are important for dispersal of western juniper, whereas Utah juniper is dispersed by cottontails and jack rabbits (Chambers et al. 1999). For both pinyon and juniper, some short distance dispersal occurs through downslope movement from the tree itself (Burkhardt and Tisdale 1976).

Pinyon pine trees have short-lived seeds that must germinate within one year. Single leaf pinyon pines have variable seed crops with a masting cycle of about 2-3 years. Pinyon seeds require burial for germination. The most favorable microsites are under shrubs or trees (Chambers et al. 1999). Juniper has long-lived seeds with delayed germination, and seed production has no distinct masting pattern. Microsites under trees and shrubs are favorable for establishment, but juniper seedlings can establish in interspaces (Chambers et al. 1999).

2. Current conditions and comparison to NRV

The mechanisms of dispersal are essentially the same today as under NRV, with the exception of caching and long distance dispersal by Native Americans who still gather pine nuts today but do not cache them in the same way. Current conditions for dispersal and establishment differ from NRV because a greater seedbank has been established as pinyon and juniper density has increased. There is evidence that this newly established greater seedbank is partly responsible for the rapid rates of establishment observed in several studies (Chambers et al. 1999, Johnson and Miller 2008).

3. Future

If climate change results in a separation of the primary corvid dispersal agents of pinyon pine from their distribution, there could be effects on dispersal and establishment.

Disturbances

Extreme climate events

1. NRV

Severe climatic events are an important disturbance in pinyon-juniper woodlands, especially in the long-lived persistent woodland type, and have occurred throughout the reference period. Mortality due to climatic events can be stand-replacing in the persistent woodland type, and may help control the extent of the wooded shrubland type.

Large tree die-offs due to drought or early/late frost from the pre-settlement period to the present have been documented in persistent woodland types (Knapp and Soule 2005, Soule and Knapp 2007, Romme et al. 2009, Clifford et al. 2011). Disease and insect outbreaks are often secondary factors in this mortality (Knapp and Soule 1999, Romme et al. 2009). Both chronic low-level mortality and episodic, widespread mortality and recruitment have been documented (Knapp and Soule 1999, Romme et al. 2009). Droughts can also shift the patterns of dominance from pinyon to juniper (Romme et al. 2009).

Large scale climate related mortality has been well studied in the Southwest and the Colorado Plateau in persistent woodlands, but less so in the Great Basin and the assessment area. The frequency of early frosts may be a factor in the expansion of wooded shrublands. In north-central Oregon, an early frost in 2002 caused mortality and foliar damage that was more severe in younger, smaller trees and on the more mesic north facing slopes that have been the sites of recent expansion (Soule and Knapp 2007). Several authors argue that climate and disease-related mortality are more important disturbance regimes than fire in the persistent woodland type (Romme et al. 2009, Clifford et al. 2011).

2. Current conditions and comparison to NRV

Documentation of recent pinyon and juniper mortality due to climatic events shows that this disturbance regime is still active under current conditions (Knapp and Soule 2005, Soule and Knapp 2007, Romme, Allen et al. 2009, Clifford, Cobb et al. 2011). However, information is lacking on the frequency or extent of this type of mortality under reference conditions to compare to current conditions.

3. Future

There is evidence that extreme climate events may become more frequent (Easterling et al. 2000, Mallek and Safford 2011, Finch 2012). Our certainty on how important they will be for pinyon and juniper in the assessment area in the future is very low.

Fire

1. NRV

Fire behavior and fire regime vary between the three different types of woodlands, with the presence of a sagebrush or grass understory the primary components carrying fire. Where there is no understory, crown fire dominates (Romme et al. 2009). The correlation between understory composition and charcoal in the Holocene record supports the idea that canopy structure is the primary determinant of fire regime in pinyon-juniper woodlands (Miller and Wigand 1994a, Tausch 1999, Tausch et al. 2004).

Where there is a significant understory component, there are climatic controls on fire occurrence. In the northern area, where the understory has a large grass component, it has been found that drought years with antecedent wet years increase the probability of fire (Miller and Rose 1999). In the southern area, where the understory is dominated by shrubs, one study found that a single drought year increased the probability of fire, regardless of antecedent conditions (Bauer and Weisberg 2009).

Fire Severity. Low intensity surface fires were rare during the pre-settlement period in persistent woodlands and in wooded shrublands. Most fires were stand replacing (Baker and Shinneman 2004, Romme et al. 2009). Miller and Heyerdahl (2008b) documented both stand replacing and mixed severity fire over the pre-settlement to modern period in a persistent western juniper woodland in northern California. Bauer and Weisberg (2009) documented mostly stand replacing fires with some low severity fires over the past 700 years in a single leaf pinyon woodland in the Shoshone Mountains in NV. Some authors have described low severity fire or mixed severity fire in persistent woodlands (Burkhardt and Tisdale 1976, Johnson and Miller 2008), but the difference may be in the scale and definition of these types of fire. Persistent woodlands may still have had patches of unburned or high severity fire within the matrix of these fires (Burkhardt and Tisdale 1976). There is less confidence about the fire regimes associated with savanna types (Romme et al. 2009).

Fire Size. There is evidence of large scale fires occurring in the pre-EuroAmerican contact period in persistent woodlands of the Southwest (Romme et al. 2009). Miller and Heyerdahl (2008a) documented that the fire regime in a northern California site differed by substrate on a 4,000 ha (9884 acre) landscape, indicating that many of the fires were small and restricted to one plant community. In a central Nevada pinyon woodland in the Shoshone Mountains, a detailed study of fire history over the last 700 years found a maximum fire size of 35 ha (86 acres), with most fires less than 10 ha (25 acres) (Bauer and Weisberg 2009).

Fire return interval (FRI) Van de Water and Safford (2011) reviewed the fire regime literature for the Sierra Nevada and calculated an average, minimum and maximum value for the FRI in the major ecosystems. For pinyon-juniper, they calculated a mean of 151 years (50-250 years). This lumps all types of pinyon-juniper woodlands together, resulting in averages that may not be meaningful to a particular site. Fire histories including the pre-settlement reference period are possible in persistent woodlands, and, to some degree, in savannas because long lived trees can record fires. In wooded shrubland types, the young age of the trees means that FRI must be inferred from other sources such as adjacent persistent woodlands or other forest types. Because

there may be great variability in FRI depending on site characteristics, we have not attempted to estimate one FRI, but rather have summarized the available information from studies that are applicable to the assessment area and that are based on quantitative data.

Fire regimes in persistent woodlands were variable across the landscape, due to differences in terrain, substrate, adjacent vegetation communities, and productivity of the site (Miller and Heyerdahl 2008b, Romme et al. 2009). The relevant studies are listed below by species and section of the assessment area:

Northern area (western juniper) persistent woodlands

- Estimated FRI >250 years from a northern California site (only two fires sampled, estimate from tree ages) (Miller and Heyerdahl 2008b).
- Average FRI of 30 years from 1650-1860 for stands described as persistent western juniper woodlands on the Owyhee Plateau in Idaho. This number is calculated from the data in Burkhardt and Tisdale (1976). They sampled in small patches of old juniper stands on rocky outcrops and it is not clear if the fire scars they record reflect an understory low severity fire regime in the persistent woodlands or the fire regime in the adjacent sagebrush systems.

Southern area (single leaf pinyon and Utah juniper) persistent woodlands

- 427 year fire cycle in central Nevada single leaf pinyon and Utah juniper woodland (Bauer and Weisberg 2009). There was large temporal variation throughout the record, with fire cycle variation ranging 187 to 502 years. The time period from 1300-1570 had a 187 year fire cycle. This may be the most applicable to the NRV for current conditions, because the climate conditions were similar; however, it also has the greatest uncertainty because of the mortality rate of the very old trees used to calculate this fire cycle.

Fire regimes in wooded shrublands are determined by the sagebrush community during the early phases of expansion of pinyon-juniper. The FRI of sagebrush systems varies greatly, and depends on the species and subspecies of sagebrush and the site characteristics. Reviews of FRI under NRV in sagebrush systems have found a range of values. One estimate that lumped all types of big sagebrush (*Artemisia tridentata*) together found a range of FRI from 15-85 years (Van De Water and Safford 2011). Another review that distinguished between subspecies of big sagebrush found an FRI ranging from 12 to 25 years on productive montane sagebrush (*A. t. spp. vaseyana*) sites, all the way up to greater than 200 years in xeric montane sagebrush sites. On Wyoming sagebrush (*A. t. spp. wyomingensis*) sites where FRI is more difficult to determine, the authors found FRI to be on the order of 100 years (Crawford et al. 2004). For more detail on wooded shrubland fire regimes see the Sagebrush chapter. If fire and other disturbances are excluded from the site long enough to reach a phase where there is no understory, a threshold may be passed where the fire regime is more similar to persistent woodlands (Miller and Tausch 2001, Tausch et al. 2009).

Northern area (western juniper) savannas and wooded shrublands

- Estimated FRI from <25 years to >80 years in northern California in a montane sagebrush system with juniper encroachment. Variation depended on the substrate (Miller and Heyerdahl 2008b).
- The FRI of 30 years from Burkhardt and Tisdale (1976) for persistent woodlands may reflect more frequent fire in the adjacent montane sagebrush and low sagebrush (*A. arborescens*) shrublands that are now expansion woodlands.
- Mean FRI of 13 years (range of 3-32) at Hart Mountain and Sheldon National Wildlife Refuges (OR and NV), a productive wooded mountain sagebrush site at the ecotone with ponderosa pine. Based on tree ages, the FRI on low sagebrush sites appeared to be longer (Gruell 1999).

Southern area (single leaf pinyon and Utah juniper) savannas and wooded shrublands

- A mean FRI of 33 years (15-90 years) from fire histories in Great Basin National Park in eastern Nevada from stands that appear to have been open savanna-like shrubland types in the pre-settlement period and are now continuous woodlands (Gruell et al. 1994). The sagebrush taxa at the sites were not reported. The authors observed that substrate and aspect explained the variation in FRI from low in highly productive sites with deep soils and higher in low productivity sites.
- In the Sweetwater Mountains and Bodie Hills of CA and NV fire scarred pinions from 300-400 years in age indicate the presence of scattered pinyon on fire resistant sites with one fire scar each showing survival of at least one fire (Gruell 1999).
- More frequent fires in shrublands adjacent to persistent woodlands were also documented in Bauer and Weisberg (Bauer and Weisberg 2009).

2. Current conditions and comparison to NRV

All of the NRV fire histories above were reconstructed for the pre-settlement period, and charcoal evidence from the Holocene shows that fire frequencies varied with climatic conditions and with the distribution of conifers in the Great Basin (Miller and Wigand 1994a, Nelson and Pierce 2010). As a result, these fire return intervals may not be entirely appropriate to today's climatic conditions.

The differences between NRV and current conditions vary, depending on woodland type. In persistent woodlands it appears that the current fire regime is similar to NRV in terms of fire severity and FRI (Miller and Heyerdahl 2008b, Bauer and Weisberg 2009, Romme et al. 2009). Fires continue to generally be stand replacing, and the long FRI means that there has been no effect of fire suppression. There may be increases in fire size due to expansion of pinyon and juniper (see geographic distribution below), causing greater continuity of fuels, especially in the assessment area where, historically, small patches of isolated woodlands were more common (see patch size below).

Fire histories in savanna-like juniper woodlands in the northern part of the assessment area show a dramatic reduction in fire frequency after 1860 (Burkhardt and Tisdale 1976, Gruell et al. 1994, Gruell 1999, Miller and Rose 1999, Miller and Heyerdahl 2008b, Bauer and Weisberg 2009). In wooded shrublands, trees were not present during the pre-settlement period to enable fire history reconstructions, but many authors have estimated a similar reduction in fire return interval (Miller and Tausch 2001, Johnson and Miller 2006, 2008, Miller et al. 2008). See the Sagebrush chapter for a more detailed discussion for wooded shrublands.

3. Future

Fire frequencies are expected to increase in the future following current trends that already show increased fire frequencies. Increasing burned area has been documented across the western US, especially since 1980 (Stephens 2005, Westerling et al. 2006, Littell et al. 2009). This trend is also true at the ecoregional scale, where not only increasing area burned but also increasing fire severity has been documented (Littell et al. 2009, Miller et al. 2009).

Climate change models predict further increases in fire area and severity over the next 30 years and beyond (Westerling et al. 2011). The increases in the size and severity of fires already observed in the region are consistent with these modeling results suggesting that climate change is already affecting local fire regimes (Westerling et al. 2006, Miller et al. 2009, Mallek and Safford 2011, Westerling et al. 2011). Mechanistic modeling of future vegetation patterns that includes fire has shown that both pinyon-juniper woodlands and sagebrush shrublands may be reduced in the future due to increased fire frequencies (Lenihan et al. 2008).

Cheatgrass invasion is also likely to influence the fire regime. Cheatgrass invasion may increase in pinyon-juniper woodlands in the future (Bradley 2010), causing changes in the fire regime to more frequent and possibly larger fires.

Insects and disease

1. NRV

A variety of diseases and insects affect pinyon and juniper and can cause mortality, often in association with drought or other stressors (Weber et al. 1999, Romme et al. 2009). The most common diseases are rust fungi (Weber et al. 1999). Mistletoe also affects pinyon and juniper (Lei 1999) and pinyon is attacked by pine beetles (*Ips confusus*) usually in association with both drought and root rot stress to the stand (Santos and Whitham 2010). There is no information on how common mortality from disease and insects was during the reference periods for NRV, but it appears from stand histories where large die-offs occurred without fire, that a combination of drought and disease may have been an important factor in stand dynamics (Knapp and Soule 1999, Romme et al. 2009). Because mortality from insects and disease is greater in dense stands (Santos and Whitham 2010), it may also have helped to control density.

2. Current conditions and comparison to NRV

Because we have no information about the frequency and extent of mortality due to insects and disease under NRV, it is impossible to make a comparison to the importance of these disturbances in pinyon and juniper stands today. Disturbance from insects and disease was a part of NRV and continues today (Lei 1999, Romme et al. 2009, Santos and Whitham 2010).

3. Future

Mortality due to insects and disease may increase in the future due to climate change and reverse some of the expansion and infilling of pinyon-juniper that has been observed since the pre-settlement period. This has already been documented in some locations where insect and disease outbreaks due to drought returned the pinyon-juniper density to 1936 levels in a study site in Arizona (Clifford et al. 2011).

Grazing

1. NRV

The NRV for grazing in pinyon-juniper woodlands during the Holocene and pre-settlement periods is a low level of native herbivore grazing primarily by mule deer. The systems of the Sierra Nevada and Great Basin evolved with large herbivores, but the Pleistocene megafauna were extinct by the end of the Pleistocene (Kinney 1996). Bison were native to only Surprise Valley in the northeastern portion of the bioregion, at 5800 ybp (Tausch 1999), and from Lower Klamath Lake at 1330 ybp (Grayson 2006).

Grazing in persistent woodlands would have been at very low levels because of the lack of a well-developed understory. Persistent woodlands are used by ungulates mostly for shade and cover. More grazing would have occurred in savannas and wooded shrublands because of the grasses and shrubs available as forage.

2. Current conditions and comparison to NRV

Almost all landscapes containing pinyon-juniper in the assessment area have a history of heavy domestic livestock grazing that began around 1860-1870 and included use by sheep, cattle, horses and goats in some locations (Beesley 1996, Kinney 1996). Grazing was unregulated until after the creation of the Forest Reserves and continued to be heavy until after World War II. Modern grazing is at a much lower level and not all landscapes are currently grazed (Menke et al. 1996).

Impacts from the introduction of domestic livestock have been suggested as one of the mechanisms for the changes in structure and extent of pinyon-juniper woodlands since Euro-American settlement. However, at rare sites that have not experienced grazing, such as inaccessible mesas and Research Natural Areas (RNAs) that have been protected from grazing, pinyon and juniper expansion has been documented to be the same as adjacent grazed sites (Soule and Knapp 1999, Tausch and Nowak 1999, Barger et al. 2009). One study of RNAs in Oregon found that expansion and infilling occurred both in grazed and protected sites, but at a higher rate in the grazed sites (Soule et al. 2004). The protected areas in this study were only recently protected, so grazing effects from the turn of the century may have also been a factor. The likelihood of major domestic grazing effects to NRV differs by woodland type.

- Persistent woodlands: Effects of domestic grazing are minor because of the lack of an understory. One reference site in southern Utah that was protected from grazing due to inaccessibility on a mesa has been studied and the age structure and history of infilling was found to be the same as paired neighboring heavily grazed woodlands of *P. edulis* (Barger et al. 2009). A study of western juniper in Research Natural Areas in central Oregon showed no difference in infilling between ungrazed and grazed sites, although the woodland type was not specified (Soule and Knapp 1999).
- Savannas and wooded shrublands: The introduction of domestic livestock has a greater potential in these systems to have affected the observed departures from NRV because grazing could change the competitive dynamics between grasses, shrubs and trees, and because grazing has the potential in these systems to reduce the fuel loading in the primary layers carrying fire (Miller and Wigand 1994a, Soule et al. 2004, Jacobs 2011).

This effect may be the most pronounced in the northern part of the assessment area where perennial grasses are more abundant.

- Grazing has increased since the reference period in all pinyon-juniper systems, although use in persistent woodlands is still low. The effects of this change from NRV are most likely to be in savanna and wooded shrubland types.

3. Future

Pinyon and juniper systems are likely to continue recovery from the heavy grazing from 1860-1935 if they are managed at levels similar to current grazing.

Woodland management

1. NRV

There are a variety of woodland management techniques that have the potential to affect pinyon and juniper woodlands. Most did not occur during the reference period, with the exception of Native American traditional management.

There is evidence that Native American peoples in the region managed the pinyon pine stands that were very important to their culture and livelihood. They pruned the trees, raked away the litter, weeded around them, and burned to increase productivity and protect them from wildfire (Griffin 2002, Anderson 2005). There are also oral accounts of the use of fire for hunting deer and rabbits in the pinyon-juniper vegetation zone (Steward 1933, Irwin 1980). It is unknown how extensive these management activities were and how much they might have affected the range of variability in pre-European contact woodlands landscape-wide (Griffin 2002, Parker 2002). However, they probably affected the structure and composition of localized persistent woodlands that were traditional gathering or hunting areas, making them more open and less vulnerable to fire, and restricting some pinyon-juniper expansion.

Pinyon and juniper woodlands were cut during the early EuroAmerican settlement period to supply fuelwood, especially in mining districts (Young and Svejcar 1999). This use was localized around settlements and occurred until the 1920s, when fossil fuels replaced wood (Young and Svejcar 1999). Historically, it was common throughout the west to remove pinyon and juniper with techniques such as chaining, cutting, and prescribed fire with the objective of increasing forage for grazing. However, the extent of these treatments across the assessment area is unknown.

2. Current conditions and comparison to NRV

Current pinyon and juniper woodland management in the assessment area is focused on restoring wooded shrublands by removing pinyon and juniper using prescribed fire, cutting, and masturbation of trees. Grazing is at a much lower level than its maximum in the late 1800s and early 1900s. Ecological restoration treatments aimed at reducing the expansion of pinyon and juniper are not occurring at a rate high enough to counter the continuing trend of pinyon juniper expansion (Bunting et al. 2007).

3. Future

The future of pinyon and juniper woodland management depends on the decisions made by federal land management agencies because the majority of these ecosystems occur on federal lands.

Structure

Structural Class Types, Density, and Cover

1. NRV

Stand demographics and fire histories indicate that during the presettlement period there were stands that ranged from closed canopy to savanna-like with very scattered trees. The extent of each is uncertain. Persistent woodlands with closed canopies were common at least on fire resistant sites (Barger et al. 2009). The extent and structure of savanna-like stands is uncertain, but multiple stand demographies show very scattered pre-settlement trees and suggest that savanna-like stands were much more common (Johnson and Miller 2008, Bauer and Weisberg 2009, Romme et al. 2009). Most of these stands are western juniper, but Gruell found savanna-like pre-settlement structures in single leaf pinyon and Utah juniper in the Sweetwater Mountains and Bodie Hills of CA and NV as well (Miller and Wigand 1994a, Gruell 1999, Tausch 1999, Johnson and Miller 2008, Miller and Heyerdahl 2008b).

Tree densities and cover that are lower than current conditions have been documented for the pre-settlement period in all types of woodlands throughout the Great Basin (Romme et al. 2009). This is true both in the western juniper dominated woodlands of the northern California and southeast Oregon (Johnson and Miller 2006, 2008, Miller and Heyerdahl 2008b) and in the pinyon dominated woodlands of the southeastern Sierra and Nevada (Burwell 1998, Miller et al. 2008, Bauer and Weisberg 2009).

In the northern part of the assessment area, where savanna-like structures may have been common, pre-settlement stands on low sagebrush tablelands had up to 20% cover, but typically were below 5% cover (Miller et al. 1999). In persistent woodlands throughout the assessment area, especially in the southern end, cover and density were highly variable, depending on the productivity of the site (Romme et al. 2009).

2. Current conditions and comparison to NRV

Persistent woodlands are not changed from NRV. Savanna-like structures with mature trees are now rare in comparison to NRV. Wooded shrublands have stand structures that are variable depending on the seral stage and are as a whole, much more common than under NRV (see the geographic distribution, topographic and edaphic setting and seral stage discussions).

Pinyon-juniper woodlands of all types are currently more dense, with higher canopy cover than during the reference periods for NRV (Johnson and Miller 2006, 2008, Miller and Heyerdahl 2008b). The expansion of pinyon and juniper into shrublands has been attributed to anthropogenic changes to the fire regime since settlement, but for persistent woodland types, this has not been found to be a likely explanation, because the fire regime is primarily stand replacing, not a frequent low-severity regime that would allow for infilling when interrupted. Changes in climate, or other disturbances, such as grazing, may explain the infilling process. However, on the Colorado Plateau, where the grazing hypothesis was studied, there was no evidence for a grazing effect in persistent woodlands (Burwell 1998, Miller et al. 2008, Bauer and Weisberg 2009).

3. Future

The trend for increasing density may continue as a result of ongoing expansion of pinyon and juniper into available sites over the Holocene. It will depend on trends in climate and disturbance regimes such as fire.

Patch size

1. NRV

Patch sizes of woodlands probably varied greatly under NRV. Miller and Heyerdahl (2008b) showed that substrate and community composition differences resulted in varied fire regimes at a fine scale in a northern California landscape (1999). Other stand demographies and fire histories in pinyon and juniper woodlands have also found fine scale patch variation.

2. Current conditions and comparison to NRV

The expansion and infilling of pinyon-juniper since the 1860s has resulted in more uniform and larger patch sizes (Burkhardt and Tisdale 1969a, Burkhardt and Tisdale 1976, Gruell et al. 1994, Burwell 1998, Gruell 1999, Bauer and Weisberg 2009). This could in part be the result of pinyon and juniper continuing to infill available sites over the Holocene period (See Table 2), but in part it may also be due to the anthropogenic factors that many authors have suggested are associated with expansion. This means that there are more continuous woodlands throughout the assessment area, which has consequences for the fire regime, and for wildlife corridors.

3. Future

The future trends in patch sizes will depend on the disturbance regimes of fire and climate and the resulting trends in expansion. If fire frequencies increase, patch sizes may be reduced, leaving pinyon juniper on in more isolated fire protected patches, and creating a structure more similar to that from the reference period. If the current trends in expansion are not countered by disturbance, then the trend for increasingly uniform stands with large patch sizes will continue.

Bare soil

1. NRV

There is no direct information about the amount of unvegetated cover (bare soil, rock, and gravel etc.) under NRV. Conclusions about changes from NRV are inferred from the changes in understory cover and the introduction of non-native annual grasses. Under NRV pinyon and juniper woodlands would have had an important component of bare interspaces between individual plants.

2. Current conditions and comparison to NRV

From the decreases in understory cover from NRV and the increases in annual grass cover, we can infer that unvegetated interspaces have been reduced from NRV. This effect is stronger in savanna-like sites and wooded shrublands, which occur on more productive sites. On the less productive, persistent woodland sites, the reductions may be minor.

3. Future

See the future trends for density and invasive species.

Composition

Geographic distribution of major species

1. NRV

Many studies have documented the expansion of pinyon-juniper throughout the Great Basin since Euro-American contact (Miller and Rose 1999, Johnson and Miller 2006, Weisberg et al. 2007, Johnson and Miller 2008, Miller et al. 2008, Bauer and Weisberg 2009, Romme et al. 2009). Using tree ages in sites across ID, OR, UT and NV, Miller et al. (2008) found that two-thirds of current woodlands were treeless. The expansion started between 1850 and 1870, and was most rapid between 1900 and 1920 in most sites, but in ID began earlier (1880). Expansion and infilling has slowed since 1950 in these sites. The sites sampled mostly represent western juniper, but one single leaf pinyon and Utah juniper site in central NV was sampled.

The widespread expansion since the reference period means that the current distribution of pinyon-juniper is greater than NRV, but part of this expansion may be continued adjustment to Holocene climate changes and response to the wetter climatic conditions that were simultaneous with Euro-American settlement (Table 2). Fire suppression, grazing removal of fine fuels, and climate change have all been suggested as causes of this expansion (Miller and Rose 1999, Miller and Tausch 2001, Jacobs 2011). Atmospheric fertilization by CO₂ has also been suggested as a factor in later infilling and expansion, although it does not coincide with the beginning of expansion in 1870 (Knapp et al. 2001).

Under NRV in the assessment area it appears that persistent woodlands occupied mostly fire safe sites on low productivity substrates where a lack of understory would protect it from fire (Miller and Wigand 1994b, Miller et al. 1999, Tausch et al. 2004). These were rocky outcrops, ridgelines and shallow rocky soils. It was also limited to a relatively narrow elevational band, although it has moved up and down slope in response to climatic changes throughout the Holocene (see Table 2).

2. Current conditions and comparison to NRV

Pinyon and juniper are currently much more widespread than what their distribution is estimated to have been in the pre-settlement period, and possibly even greater than the maximum extent of these species during the Holocene. It has moved both upslope and downslope and on to generally more mesic productive sites previously occupied by sagebrush steppe, often filling in between existing persistent woodlands on the poorer soils on the intervening ridges or rocky outcrops (Tausch et al. 1981, Burwell 1998, Johnson and Miller 2006, Weisberg et al. 2007, Jacobs 2011).

It is unclear how much of this change is due to climate and how much is due to anthropogenic alteration of disturbance regimes. Jacobs argues that the expansion onto novel sites on more productive soils indicates that the changes are due to factors other than climate, such as grazing and changed fire regimes (2011).

Estimates are that only about 3% of the current woodlands overlap with those present during the pre-settlement period in the northern part of the assessment area; most current woodlands were treeless during the reference period (Miller et al. 1999). The same authors estimated 5% overlap in the southern part of the assessment area, although that value may be locally higher where there

are fire protected sites due to low productivity (Miller et al. 1999). In sampling multiple stands in southeast Oregon and southwest Idaho, Johnson and Miller (2008) found that 16-67% of the stands contained pre-settlement western juniper and that only 1-10% of the trees were of pre-settlement age.

The different species that make up pinyon-juniper woodlands do not respond to climate and disturbances in the same way, and so cannot be expected to move together as intact communities. For example, single leaf pinyon and Utah juniper now co-occur in the southern part of the assessment area, but single leaf pinyon is less tolerant of drought stress and less resistant to fire than Utah juniper (Tausch and West 1988, Nowak et al. 1999).

3. Future

Using the climatic envelope for pinyon and juniper, modeling predicts that pinyon-juniper expansion into shrublands may continue with climate change throughout the assessment area (Bradley 2010). Other dynamics may counter this trend, including herbaceous invasions, fire, and disease. Modeling of fire also suggests that increasing fire frequencies and fire sizes may result in reduced pinyon-juniper (Lenihan et al. 2008). Other authors have also suggested that pinyon and juniper extent may be reduced in the future if our climate becomes increasingly warmer and drier, because wet conditions appear to have favored pinyon and juniper expansion in the first part of the 1900s (Tausch 1999, Finch 2012). Predictions for changes in fire regimes and climate in the future may reverse some of the current trends for expansion of pinyon and juniper onto more productive site types.

Proportion of seral stages

1. NRV

Persistent woodlands appear to have current distributions of seral stages similar to NRV, but savanna-like and wooded shrublands are modeled to have had a greater proportion of early seral stages than they currently do (Forbis et al. 2007, Provencher et al. 2008).

2. Current conditions and comparison to NRV

In persistent woodlands current conditions appear to be similar to NRV, but in the savanna-like and wooded shrubland types, late seral stages where trees dominate the site and exclude understory species are over-represented (Forbis et al. 2007, Provencher et al. 2008).

3. Future

Current trends are likely to continue unless predicted changes in climate and increases in fire frequency are large enough to reverse these trends.

Proportion of life forms: Trees, shrubs, grasses, forbs

1. NRV

Persistent woodlands tend to have a very sparse understory dominated by a few shrubs. The infilling and increases in density since the pre-settlement period have likely reduced the cover of shrubs, grasses and forbs in the understory in comparison to pre-settlement and Medieval Warm

Period conditions. During the Medieval Warm Period, there is some evidence from pollen studies that there was a greater proportion of grasses in the community, possibly as the result of more frequent fires (Miller and Wigand 1994a, Tausch et al. 2004).

Given the uncertainty about the expression savannas under NRV within the assessment area, it is difficult to assess any changes in the proportion of understory life forms in this type. If savannas were a stable type under NRV, then infilling has likely dramatically lowered the proportion of shrubs, grasses, and forbs. Some authors suggest that with frequent fire, the understory of these systems would have been dominated by grasses (Gruell 1999, Miller et al. 1999). The expansion dynamic in wooded shrublands has reduced the amount of shrubs, grasses, and forbs in wooded shrublands compared to pre-settlement conditions. See the Sagebrush chapter for a more detailed discussion.

2. Current conditions and comparison to NRV

The changes in current conditions in comparison to NRV are all inferred from the trend for increasing density and reduced understory cover including shrubs, grasses and forbs. This departure from NRV is likely the strongest in wooded shrublands and savanna-like types. The loss of grasses is likely the strongest in savanna-like structures in the northern part of the assessment area. Persistent woodlands are close to NRV because the understory is sparse under NRV.

3. Future

See the trends predicted for density which controls the proportion of life forms.

Species diversity

1. NRV

There is little direct information about diversity under NRV in pinyon-juniper woodlands. The trends in diversity are inferred from the structural changes in density and understory cover (see those discussions).

2. Current conditions and comparison to NRV

The trend for expansion and infilling of pinyon and juniper in sagebrush steppe systems has likely led to a decrease in species diversity at the stand level, but no change at the landscape level (Bunting et al. 1999). Species from the sagebrush steppe have not been extirpated from the assessment area, but several are threatened. In persistent woodlands, this effect is likely not very pronounced because understory cover under NRV was low. In savanna-like structures and wooded shrublands, the effect is strong.

3. Future

The future trends in diversity will depend on the future trends in density and cover and on impacts to individual species from changes in climate. See those discussions.

Summary of NRV deviations

The determinations of NRV and departures from current conditions are summarized in Table 5, with the confidence of the finding. Below are the main findings:

- Pinyon-juniper vegetation occurs in two to three different structural types in the assessment area that have different NRV due to site productivity, history, associated species, and fire regimes. The most common types are persistent woodlands and wooded shrublands that are the result of expansion of pinyon-juniper. A third type, savanna-like shrublands, may have also existed under NRV but is uncommon today.
- Persistent woodlands occurring on poor substrates with limited understories are generally close to NRV. There has been infilling since the pre-settlement period, resulting in increased density and tree cover in some sites.
- Wooded shrublands have increased dramatically over the pre-settlement period and have reached levels as high as, or higher than, anything that occurred during the Holocene. Pinyon-juniper on shrubland sites has increased via expansion outward from pre-settlement woodlands, up and down slope, and into more productive site types as well as infilling of previously low density woodlands.
- Departures from NRV are likely from a combination of anthropogenic factors and changes in climate. Alterations in disturbance regimes such as fire and grazing are commonly thought to be at least partially responsible.

Acknowledgements

We thank Wally Woolfenden and David Tart for their reviews of this paper.

Literature Cited

Ackerly, D. D., S. R. Loarie, W. K. Cornwell, S. B. Weiss, H. Hamilton, R. Branciforte, and N. J. B. Kraft. 2010. The geography of climate change: implications for conservation biogeography. *Diversity and Distributions* **16**:476-487.

Anderson, M. K. 2005. Tending the wild: Native American knowledge and the management of California's natural resources. University of California Press, Berkeley, CA.

Anderson, M. K. and M. J. Moratto. 1996. Native American land-use practices and ecological impacts. Pages 187-206 *Sierra Nevada Ecosystem Project: final report to congress. Volume II: Assessment of scientific basis for management options*. University of California, Davis, Centers for Water and Wildlands Resources, Davis, CA.

Anderson, R. S. 1990. Holocene forest development and paleoclimates within the central Sierra Nevada, California. *The Journal of Ecology*:470-489.

Anderson, R. S. 2004. Response of Sierra Nevada Vegetation and Fire Regimes to Past Climate Changes. Pages 47-50 *in* D. D. Murphy and P. A. Stine, editors. *Proceedings of the Sierra Nevada Science Symposium, PSW-GTR-193*. USDA Forest Service, Pacific Southwest Research Station, Albany, CA.

Antevs, E. 1938. Rainfall and tree growth in the Great Basin. Carnegie Institution of Washington American Geographical Society of New York, Baltimore.

Baker, W. L. and D. J. Shinneman. 2004. Fire and restoration of pinon-juniper woodlands in the western United States: a review. *Forest Ecology and Management* **189**:1-21.

Barger, N. N., H. D. Adams, C. Woodhouse, J. C. Neff, and G. P. Asner. 2009. Influence of Livestock Grazing and Climate on Pinyon Pine (*Pinus edulis*) Dynamics. *Rangeland Ecology & Management* **62**:531-539.

Bauer, J. M. and P. J. Weisberg. 2009. Fire history of a central Nevada pinyon-juniper woodland. *Canadian Journal of Forest Research-Revue Canadienne De Recherche Forestiere* **39**:1589-1599.

Beesley, D. 1996. Reconstructing the Landscape: An Environmental History 1820-1960. Pages 3-24 *Sierra Nevada Ecosystem Project: final report to congress. Volume II: Assessment of scientific basis for management options*. University of California, Davis, Centers for Water and Wildlands Resources, Davis, CA.

Betancourt, J. L. 1986. Paleoecology of pinyon-juniper woodlands: summary. *Proceedings - Pinyon-juniper conference*. Intermountain Research Station.

Bradley, B. A. 2009. Regional analysis of the impacts of climate change on cheatgrass invasion shows potential risk and opportunity. *Global Change Biology* **15**:196-208.

Bradley, B. A. 2010. Assessing ecosystem threats from global and regional change: hierarchical modeling of risk to sagebrush ecosystems from climate change, land use and invasive species in Nevada, USA. *Ecography* **33**:198-208.

Brunelle, A. and R. S. Anderson. 2003. Sedimentary charcoal as an indicator of late-Holocene drought in the Sierra Nevada, California, and its relevance to the future. *Holocene* **13**:21-28.

Bunting, S. C., J. L. Kingery, and E. Strand. 1999. Effects of succession on species richness of the juniper woodland/sagebrush steppe mosaic. Pages 76-81 *in* S. Monsen and R. Stevens, editors. *Proceedings: Ecology and management of pinyon-juniper communities within the Interior West. RMRS-P-9.* USDA, Forest Service, Rocky Mountain Research Station.

Bunting, S. C., E. K. Strand, and J. L. Kingery. 2007. Landscape characteristics of sagebrush-steppe/juniper woodland mosaics under various modeled prescribed fire regimes. Pages 50-57 *in* R. E. Masters and K. E. M. Galley, editors. *23rd Tall Timbers Fire Ecology Conference: Fire in Grasslands and Shrubland Ecosystems*, Tall Timbers Research Station, Tallahassee, FL.

Burkhardt, J. W. and E. W. Tisdale. 1969a. Nature and successional status of western juniper vegetation in Idaho. *Journal of Rangeland Management* **22**:264-270.

Burkhardt, J. W. and E. W. Tisdale. 1969b. Nature and successional status of western juniper vegetation in Idaho. *Journal of Range Management* **22**:264-&.

Burkhardt, J. W. and E. W. Tisdale. 1976. Causes of juniper invasion in southwestern Idaho. *Ecology* **57**:472-484.

Burwell, T. 1998. Successional patterns of the lower montane treeline, Eastern California. *Madrono* **45**:12-16.

Chambers, J. C., E. W. Schupp, and S. B. Vander Wall. 1999. Seed dispersal and seedling establishment of pinon and juniper species within the pinon-juniper woodland. Pages 29-34 *in* S. B. Monsen and R. Stevens, editors. *Proceedings: ecology and management of pinyon-juniper communities within the Interior West. RMRS-P-9.* US Department of Agriculture, Forest Service, Rocky Mountain Research Station, Ogden, UT.

Clifford, M. J., N. S. Cobb, and M. Buenemann. 2011. Long-Term Tree Cover Dynamics in a Pinyon-Juniper Woodland: Climate-Change-Type Drought Resets Successional Clock. *Ecosystems* **14**:949-962.

Cole, K. L., J. Fisher, S. T. Arundel, J. Cannella, and S. Swift. 2008. Geographical and climatic limits of needle types of one- and two-neededled pinyon pines. *Journal of Biogeography* **35**:257-269.

Crawford, J. A., R. A. Olson, N. E. West, J. C. Mosley, M. A. Schroeder, T. D. Whitson, R. F. Miller, M. A. Gregg, and C. S. Boyd. 2004. Synthesis Paper - Ecology and management of sage-grouse and sage-grouse habitat. *Journal of Range Management* **57**:2-19.

Easterling, D. R., G. A. Meehl, C. Parmesan, S. A. Changnon, T. R. Karl, and L. O. Mearns. 2000. Climate extremes: Observations, modeling, and impacts. *Science* **289**:2068-2074.

Finch, D. M., editor. 2012. Climate change in grasslands, shrublands, and deserts of the interior American west: A review and needs assessment. US Forest Service, Rocky Mountain Research Station, Fort Collins, CO.

Forbis, T. A., L. Provencher, L. Turner, G. Medlyn, J. Thompson, and G. Jones. 2007. A method for landscape-scale vegetation assessment: Application to Great Basin rangeland ecosystems. *Rangeland Ecology & Management* **60**:209-217.

Graumlich, L. J. 1993. A 1000-Year Record of Temperature and Precipitation in the Sierra Nevada. *Quaternary Research* **39**:249-255.

Grayson, D. K. 2006. Holocene bison in the Great Basin, western USA. *Holocene* **16**:913-925.

Griffin, D. 2002. Prehistoric human impacts on fire regimes and vegetation in the northern Intermountain West. Pages 77-100 in T. R. Vale, editor. *Fire, native peoples, and the natural landscape*. Island Press, Washinton, D.C.

Gruell, G. E. 1999. Historical and modern roles of fire in pinyon-juniper. Pages 24-28 in S. B. Monsen and R. Stevens, editors. *Proceedings: ecology and management of pinyon-juniper communities within the Interior West*. RMRS-P-9. US Department of Agriculture, Forest Service, Rocky Mountain Research Station, Ogden, UT.

Gruell, G. E., L. E. Eddleman, and R. Jaindl. 1994. Fire history of the pinyon-juniper woodlands of Great Basin National Park, NPS/PNROSU/NRTR-94/01. Page 27. US Department of the Interior, National Park Service, Seattle, WA.

Halford, K. 1998. The paleoecology of the Dry Lakes Plateau, Bodie Hills, California: New evidence from the western Great Basin for the northward migration of pinyon pine (*Pinus monophylla*) during the mid-Holocene. Great Basin Anthropology Conference.

Harper, K. T. and J. N. Davis. 1999. Biotic, edaphic, and other factors influence pinyon-juniper distribution in the Great Basin. Pages 51-54 in S. B. Monsen and R. Stevens, editors. *Proceedings: ecology and management of pinyon-juniper communities within the Interior West*. RMRS-P-9. US Department of Agriculture, Forest Service, Rocky Mountain Research Station, Ogden, UT.

Harvey, A., P. Wigand, and S. Wells. 1999. Response of alluvial fan systems to the late Pleistocene to Holocene climatic transition: contrasts between the margins of pluvial Lakes Lahontan and Mojave, Nevada and California, USA. *Catena* **366**:255-281.

Irwin, C. N., editor. 1980. *The Shoshone Indians of Inyo County, California: The Kerr manuscript*. Ballena Press and The Eastern California Museum, Independence, CA.

Jacobs, B. F. 2011. Spatial patterns and ecological drivers of historic pinon-juniper woodland expansion in the American southwest. *Ecography* **34**:1085-1095.

Jennings, S. A. 1995. Late Quaternary changes in pinyon and juniper distributions in the White Mountain Region of California and Nevada. *Physical Geography* **16**:276-288.

Jennings, S. A. and D. L. Elliott-Fisk. 1993. Pack-rat midden evidence of late Quaternary vegetation change in the White Mountains, California. *Quaternary Research* **39**:214-221.

Jennings, S. A. and D. L. Elliottfisk. 1993. Pack-rat midden evidence of late quaternary vegetation change in the White Mountains, California-Nevada. *Quaternary Research* **39**:214-221.

Johnson, D. D. and R. F. Miller. 2006. Structure and development of expanding western juniper woodlands as influenced by two topographic variables. *Forest Ecology and Management* **229**:7-15.

Johnson, D. D. and R. F. Miller. 2008. Intermountain presettlement juniper: Distribution, abundance, and influence on postsettlement expansion. *Rangeland Ecology & Management* **61**:82-92.

Johnson, M., L. J. Rew, B. D. Maxwell, and S. Sutherland. 2006. The role of wildfire in the establishment and range expansion of nonnative plant species into natural areas. Center for Invasive Plant Management, Montana State University, MT.

Kinney, W. C. 1996. Conditions of Rangelands before 1905. Pages 31-45 *Sierra Nevada Ecosystem Project: Final report to Congress, Vol. II, Assessments and scientific basis for management options*. University of California, Davis: Centers for Water and Wildland Resources.

Knapp, P. A. and P. T. Soule. 1999. Geographical distribution of an 18th-century heart rot outbreak in western juniper (*Juniperus occidentalis* spp. *occidentalis* Hook.). *Journal of Arid Environments* **41**:247-256.

Knapp, P. A. and P. T. Soule. 2005. Impacts of an extreme early-season freeze event in the interior Pacific Northwest (30 October 3 November 2002) on western juniper woodlands. *Journal of Applied Meteorology* **44**:1152-1158.

Knapp, P. A., P. T. Soule, and H. D. Grissino-Mayer. 2001. Detecting potential regional effects of increased atmospheric CO₂ on growth rates of western juniper. *Global Change Biology* **7**:903-917.

Koehler, P. A. and R. S. Anderson. 1994. Full-glacial shoreline vegetation during the maximum highstand at Owens Lake, California. *Great Basin Naturalist* **52**:142-149.

Lei, S. A. 1999. Host-parasite relationships between Utah juniper and juniper mistletoe in the Spring Mountains of Southern Nevada. Pages 99-104 in S. B. Monsen and R. Stevens, editors. *Proceedings: ecology and management of pinyon-juniper communities within the Interior West*. RMRS-P-9. US Department of Agriculture, Forest Service, Rocky Mountain Research Station, Ogden, UT.

Lenihan, J. M., D. Bachelet, R. P. Neilson, and R. Drapek. 2008. Response of vegetation distribution, ecosystem productivity, and fire to climate change scenarios for California. *Climatic Change* **87**:S215-S230.

Littell, J., D. McKenzie, D. Peterson, and A. Westerling. 2009. Climate and wildfire area burned in western U. S. ecoprovinces, 1916-2003. *ECOLOGICAL APPLICATIONS* **19**:1003-1021.

Mallek, C. and H. Safford. 2011. A summary of current trends and probable future trends in climate and climate-driven processes in the Inyo National Forest and adjacent lands. Page 21. USDA Forest Service, Pacific Southwest Regional Ecology Program.

Menke, J. W., C. Davis, and P. Beesley. 1996. Rangeland Assessment. in V. I. Sierra Nevada Ecosystem Project: Final report to Congress, Assessments, Commissioned Reports, and Background Information., editor. University of California, Davis: Centers for Water and Wildland Resources.

Mensing, S. A. 2001. Late-Glacial and Early Holocene vegetation and climate change near Owens Lake, eastern California. *Quaternary Research* **55**:57-65.

Miller, J. D., H. D. Safford, M. Crimmins, and A. E. Thode. 2009. Quantitative Evidence for Increasing Forest Fire Severity in the Sierra Nevada and Southern Cascade Mountains, California and Nevada, USA. *Ecosystems* **12**:16-32.

Miller, R., R. Tausch, and W. Waichler. 1999. Old-growth juniper and pinyon woodlands. Pages 375-384 in S. B. Monsen and R. Stevens, editors. *Proceedings: ecology and management of pinyon-juniper communities within the Interior West.* RMRS-P-9. US Department of Agriculture, Forest Service, Rocky Mountain Research Station, Ogden, UT.

Miller, R. F. and E. K. Heyerdahl. 2008a. Fine-scale variation of historical fire regimes in sagebrush-steppe and juniper woodland: an example from California, USA. *International Journal of Wildland Fire* **17**:245-254.

Miller, R. F. and E. K. Heyerdahl. 2008b. Fine-scale variation of historical fire regimes in sagebrush-steppe and juniper woodland: an example from California, USA. *International Journal of Wildland Fire* **17**:245-254.

Miller, R. F. and J. A. Rose. 1999. Fire history and western juniper encroachment in sagebrush steppe. *Journal of Range Management* **52**:550-559.

Miller, R. F. and R. J. Tausch. 2001. The role of fire in juniper and pinyon woodlands: A descriptive analysis. in *Proceedings of the invasive species workshop: The role of fire in the control and spread of invasive species.* Fire Conference 2000: The first national congress on fire ecology, prevention and management. Tall Timbers Research Station, Tallahassee, FL.

Miller, R. F., R. J. Tausch, E. D. McArthur, D. D. Johnson, and S. C. Sanderson. 2008. Age structure and expansion of pinon-juniper woodlands: a regional perspective in the Intermountain West. RMRS-RP-69. Page 15 pgs. US Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fort Collins, CO.

Miller, R. F. and P. E. Wigand. 1994a. Holocene changes in semiarid pinyon-juniper woodlands. *Bioscience* **44**:465-474.

Miller, R. F. and P. E. Wigand. 1994b. Holocene changes in semiarid pinyon-juniper woodlands. Pages 465-474. *Bioscience*.

Nelson, N. A. and J. Pierce. 2010. Late-Holocene relationships among fire, climate and vegetation in a forest-sagebrush ecotone of southwestern Idaho, USA. *Holocene* **20**:1179-1194.

Nowak, C. L., R. S. Nowak, R. J. Tausch, and P. E. Wigand. 1994a. A 30,000 year record of vegetation dynamics at a semi-arid locale in the Great Basin. *Journal of Vegetation Science* **5**:579-590.

Nowak, C. L., R. S. Nowak, R. J. Tausch, and P. E. Wigand. 1994b. Tree and shrub dynamics in Northwestern Great Basin woodland and shrub steppe during the late-Pleistocene and Holocene. *American Journal of Botany* **81**:265-277.

Nowak, R. S., D. J. Moore, and R. J. Tausch. 1999. Ecophysiological patterns of pinyon and juniper. Pages 35-46 in S. Monsen and R. Stevens, editors. *Proceedings: ecology and management of pinyon-juniper communities within the Interior West.* RMRS-P-9. US Department of Agriculture, Forest Service, Rocky Mountain Research Station, Ogden, UT.

Parker, A. J. 2002. Fire in Sierra Nevada forests: evaluating the ecological impact of burning by Native Americans. Pages 233-267 in T. R. Vale, editor. *Fire, native peoples, and the natural landscape.* Island Press, Washington, DC.

Provencher, L., J. Campbell, and J. Nachlinger. 2008. Implementation of mid-scale fire regime condition class mapping. *International Journal of Wildland Fire* **17**:390-406.

Romme, W. H., C. D. Allen, J. D. Balley, W. L. Baker, B. T. Bestelmeyer, P. M. Brown, K. S. Eisenhart, M. L. Floyd, D. W. Huffman, B. F. Jacobs, R. F. Miller, E. H. Muldavin, T. W. Swetnam, R. J. Tausch, and P. J. Weisberg. 2009. Historical and Modern Disturbance Regimes, Stand Structures, and Landscape Dynamics in Pinon-Juniper Vegetation of the Western United States. *Rangeland Ecology & Management* **62**:203-222.

Santos, M. J. and T. G. Whitham. 2010. Predictors of *Ips confusus* Outbreaks During a Record Drought in Southwestern USA: Implications for Monitoring and Management. *Environmental Management* **45**:239-249.

Schlaepfer, D. R., W. K. Lauenroth, and J. B. Bradford. 2012. Effects of ecohydrological variables on current and future ranges, local suitability patterns, and model accuracy in big sagebrush. *Ecography* **35**:374-384.

Soule, P. T. and P. A. Knapp. 1999. Western juniper expansion on adjacent disturbed and near-relict sites. *Journal of Range Management* **52**:525-533.

Soule, P. T. and P. A. Knapp. 2007. Topoedaphic and morphological complexity of foliar damage and mortality within western juniper (*Juniperus occidentalis* var. *occidentalis*) woodlands following an extreme meteorological event. *Journal of Biogeography* **34**:1927-1937.

Soule, P. T., P. A. Knapp, and H. D. Grissino-Mayer. 2004. Human agency, environmental drivers, and western juniper establishment during the late holocene. *Ecological Applications* **14**:96-112.

Stephens, S. L. 2005. Forest fire causes and extent on United States Forest Service lands. *International Journal of Wildland Fire* **14**:213-222.

Steward, J. H. 1933. Ethnography of the Owens Valley Paiute. University of California Publications in American Archaeology and Ethnology **33**:233-350.

Suring, L. H., M. M. Rowland, M. J. Wisdom, L. Schueck, and C. W. Meinke. 2005. Vegetation communities. Pages 94-113 in M. J. Widom, M. M. Rowland, and L. H. Suring, editors. *Habitat threats in the sagebrush ecosystem: methods of regional assessment and applications in the Great Basin*. Alliance Communications Group, Lawrence, KS.

Tausch, R., S. Mensing, and C. Nowak. 2004. Climate change and associated vegetation dynamics during the Holocene - the paleoecological record. Pages 24-48 in J. C. Chambers, J. R. Miller, and (eds.), editors. *Great Basin ecosystems: ecology, management, and restoration*. Island Press.

Tausch, R. J. 1999. Historic pinyon and juniper woodland development. Pages 12-19 in S. B. Monsen and R. Stevens, editors. *Proceedings: ecology and management of pinyon-juniper communities within the Interior West*. RMRS-P-9. US Department of Agriculture, Forest Service, Rocky Mountain Research Station, Ogden, UT.

Tausch, R. J., R. F. Miller, B. A. Roundy, and J. C. Chambers. 2009. *Pinon and Juniper Field Guide: Asking the right questions to select appropriate management actions*. Page 95 in U. D. o. t. Interior and U. G. Survey, editors. U.S. Geological Survey, = Reston, Virginia.

Tausch, R. J. and R. S. Nowak. 1999. Fifty years of ecotone change between shrub and tree dominance in the Jack Spring Pinyon Research Natural Area. Pages 71-77 in E. D. McArthur, W. K. Ostler, and C. L. Wambolt, editors. *Proceedings: shrubalnd ecotones*. RMRS-P-11. US Department of Agriculture, Forest Service, Rocky Mountain Research Station, Ogden, UT.

Tausch, R. J. and N. E. West. 1988. Differential establishment of pinyon and juniper following fire. *American Midland Naturalist* **119**:174-184.

Tausch, R. J., N. E. West, and A. A. Nabi. 1981. Tree age and dominance patterns in Great Basin pinyon-juniper woodlands. *Journal of Range Management* **34**:259-264.

Van De Water, K. M. and H. D. Safford. 2011. A summary of fire frequency estimates for California vegetation before Euro-American settlement. *Fire Ecology*.

Weber, D. J., E. D. Bunderson, J. N. Davis, D. L. Nelson, and A. Hreha. 1999. Diseases and environmental factors of the pinyon-juniper communities. Pages 118-120 in S. B. Monsen and R. Stevens, editors. *Proceedings: ecology and management of pinyon-juniper communities within the Interior West*. RMRS-P-9. US Department of Agriculture, Forest Service, Rocky Mountain Research Station, Ogden, UT.

Weisberg, P. J., E. Lingua, and R. B. Pillai. 2007. Spatial patterns of pinyon-juniper woodland expansion in central Nevada. *Rangeland Ecology & Management* **60**:115-124.

Westerling, A. L., B. P. Bryant, H. K. Preisler, T. P. Holmes, H. G. Hidalgo, T. Das, and S. R. Shrestha. 2011. Climate change and growth scenarios for California wildfire. *Climatic Change* **109**:445-463.

Westerling, A. L., H. G. Hidalgo, D. R. Cayan, and T. W. Swetnam. 2006. Warming and earlier spring increase western US forest wildfire activity. *Science* **313**:940-943.

Wigand, P. E. 1987. Diamond Pond, Harney County, Oregon - Vegetation history and water table in the eastern Oregon desert. *Great Basin Naturalist* **47**:427-458.

Wigand, P. E., M. L. Hemphill, S. E. Sharpe, and S. Patra. 1995. Great Basin semi-arid woodland dynamics during the late Quaternary. Climate change in the four corners and adjacent regions: implications for environmental restoration and land-use planning. *Workshop Proceedings*. Campbell College Center, Mesa State College, Grand Junction, CO.

Woolfenden, W. B. 1996. Quarternary Vegetation History. Pages 47-70 *Sierra Nevada Ecosystem Project: final report to congress. Volume II: Assessment of scientific basis for management options*. University of California, Davis, Centers for Water and Wildlands Resources, Davis, CA.

Young, J. A. and T. J. Svejcar. 1999. Harvesting energy from 19th century Great Basin woodlands. Pages 47-50 in S. B. Monsen and R. Stevens, editors. *Proceedings: ecology and management of pinyon-juniper communities within the Interior West*. US Department of Agriculture, Forest Service, Rocky Mountain Research Station, Ogden, UT.

Figure captions

Figure 1. Distribution of pinyon and juniper species reproduced from Romme et al. 2009 with permission from the authors. a, Distribution of four dominant juniper species in relation to seasonal precipitation patterns. For specifics, see Romme et al. 2009. b, Distribution of three dominant pinyon species (and *J. scopulorum*) in relation to seasonal precipitation patterns. Monsoon Index represents July to September precipitation as a percentage of annual total (calculated from 800 m PRISM data) and highlights a pronounced northwest to southeast moisture seasonality gradient from winter to summer moisture dominance.

Tables

Table 1. Acres of current pinyon or juniper dominated vegetation alliances mapped by CALVEG in assessment area. This represents all types of vegetation currently dominated by pinyon-juniper, including persistent woodlands and recent expansion into shrublands.

Assessment subregion	Single leaf pinyon (<i>Pinus monophylla</i>)	Utah juniper (<i>Juniperus osteosperma</i>)	Western juniper (<i>Juniperus occidentalis</i>)	Total
East	513,694	3,701	29,268	546,664
North			575,947	575,947
Central	13,621		24,308	37,929
South	278,836		21,569	300,405
Total	806,152	3,701	651,091	1,460,944

Table 2. Changes in climate and hydrology during the Holocene, and associated ecological changes. See also the Sagebrush chapter, which gives more detail about the associated sagebrush ecosystems during the same time periods. Abbreviations GB = Great Basin; SN = Sierra Nevada; PJ = pinyon-juniper.

Time period	Climate and hydrology	Ecological change/event	References
Early Holocene (10000-6900 ybp)	<ul style="list-style-type: none"> Precip mainly in winter; modern lakes higher, often connected (Carson basin, Walker Lake) Trend is toward drying, but variation in aridity debated Climate changes through Holocene are reflected in alluvial fan development, with more aridity and less vegetation on fans than previous period Great Basin floodplain aggradation 	<ul style="list-style-type: none"> Treeline depressed by 1000 m in SN relative to today at beginning of Holocene As warming progressed, vegetation moved N and upward in GB; conifers replaced by sagebrush at the lower treeline from Owens Valley to Lake Tahoe; Utah juniper limited to Mojave and southern GB at beginning of Holocene, occurs on the floor of the Owens Valley during the Pleistocene and early at the beginning of this period. Moves up into the White Mts. around 8000 ybp. White Mts. midden from 8790-7810 ybp similar to current community: pinyon pine-black sagebrush. Current community also includes bitterbrush-mt. mahogany which are missing from the middens. Alabama Hills – juniper and pine replaced by mt. mahogany, bitterbrush, ephedra, saltbush, ambrosia, and other desert species, like boxthorn, hopsage (no lower sagebrush belt here) 	Anderson 1990, 2004 Brunelle & Anderson 2003 Burwell 1998 Davis 1982 Harvey et al. 1999 Johnson and Miller 2006, 2008 Lyford et al. 2003 Mehringer 1985 Miller and Heyerdahl 2008a Miller et al. 2004 Tausch et al. 2004 Weisberg et al. 2007 Woolfenden 1996
Mid Holocene (6900-3200 ybp)	<ul style="list-style-type: none"> Early Mid - precip shift to summer; mudflows frequent, larger; soil horizonation, depositing salt, carbonate Mid – Xerothermic/ Hypsithermal - drier, warmest Hol. period; lakes desiccated, Lake Tahoe dropped; eolian processes increased Late Mid - Neoglacial - wettest Hol. period; more freeze-thaw and colluvium, alluvial fan deposits; more precip mainly in winter 	<ul style="list-style-type: none"> Western juniper reached NE CA Xerothermic - Treelines up to 500 m higher than present Decline in Native American activity in GB during Xerothermic droughts 5640 ybp there was PJ near head of Silver Cyn in Whites, where limber pine-bristlecone pine now occur Neoglacial – PJ in GB and western juniper in north expanded rapidly at low to mid elevations to similar extent and density seen today Increase in herbaceous understory and grasses in wetter periods correlated to fire 	Anderson 1990, 2004 Antevs 1938 Brunelle & Anderson 2003 Davis 1982 Lyford et al. 2003 Miller & Wigand 1994 Tausch 1999 Tausch et al. 2004 Wigand 1987(Tausch 1999) Wigand et al. 1995 Woolfenden 1996

Late Holocene (3200 ybp-present)		
2600 -2000 ybp	<ul style="list-style-type: none"> Post-Neoglacial drought; marked by shift from moist to dry with temperatures uncertain Decrease in PJ woodlands Additional upper treeline declines in the SN 	Miller et al 2004 (Tausch 1999)
Medieval warm period 1000-1200 AD (1000-800 ybp)	<ul style="list-style-type: none"> Steady trend toward warming and drying following Neoglacial, culminates in Medieval warm period Abundance of PJ reduced but migration northward and upward continues with warmer temperatures. Droughts at 1150 and 800 ybp confirmed by submerged trees in Lake Tahoe; Mono Basin drought; fires followed by debris flows in east subregion in warm periods Coarse:fine charcoal drops, indicating shift to finer fuels; Increased grass abundance and associated increase in fire 	Davis 1982 Tausch et al. 2004 Wagner et al. 2012 Wigand 1987 Wigand et al. 1995 (Tausch et al. 2004)
Little Ice Age 1550-1850 AD	<ul style="list-style-type: none"> Shift in seasonality of precipitation with greater proportion in late spring and summer Treelines depressed, including White Mts. Utah juniper expanded in NW GB Pinyon pine expanded to lower areas previously dominated by Utah juniper PJ occurred as scattered trees in open savannas and isolated woodland stands on fire protected sites 	Bauer & Weisberg 2009 Davis 1982 Lyford et al 2003 Miller and Wigand 1994b Miller et al. 2004 Tausch et al. 2004 Wigand 1987
1850 AD-present	<ul style="list-style-type: none"> Streamflow increased in winter and spring, snowpack reduced; stream channels widen, more soil erosion; low precip 1870-1904, high 1905-1930, low 1931-1955 in W GB PJ expansion into sagebrush, mainly at middle and low elevations Expansion of western and Utah juniper greatest in early 1900s 	Antevs 1938 Burkhardt & Tisdale 1976 Chambers et al. 2008(Wigand et al. 1995) Johnson & Miller 2008 Robertson & Kennedy 1954 Wigand et al. 1995

Table 3. Associated species by vegetation alliance (CALVEG) and assessment subregion.

Assessment subregions	Vegetation alliance (CALVEG)	Associated species (CALVEG descriptions)
North and Northeast	Western juniper	Big Sagebrush (<i>Artemisia tridentata</i>), Low Sagebrush (<i>A. arbuscula</i>), Wax Currant (<i>Ribes cereum</i>), and Mahala Mat (<i>Ceanothus prostratus</i>), Bitterbrush (<i>Purshia tridentata</i>), Rabbitbrush (<i>Chrysothamnus</i> spp.), Wheatgrass (<i>Elymus spicatus</i>) Fescue (<i>Festuca</i> spp.), Squirretail (<i>Elymus elymoides</i>), Ross' Sedge (<i>Carex rossii</i>), and Cheatgrass (<i>Bromus tectorum</i>)
Southeast	Single leaf pinyon	Great Basin shrubs such Big Sagebrush (<i>Artemisia tridentata</i>), Black Sagebrush (<i>A. nova</i>), Bitterbrush (<i>Purshia tridentata</i>), Curleaf Mountain Mahogany (<i>Cercocarpus ledifolius</i>), Mormon Tea (<i>Ephedra</i> spp.), and Rabbitbrush (<i>Chrysothamnus</i> spp.), perennial grasses such as Needlegrass (<i>Stipa</i> spp.) and Bluegrass (<i>Poa secunda</i> and <i>P. fedleriana</i>) (CALVEG alliance descriptions); Utah juniper is often present
South	Single leaf pinyon	Same species as the eastern section (southern) above along with occasional hardwoods such as Canyon and Interior Live Oaks and Black Oak (<i>Quercus chryssolepis</i> , <i>Q. wislizenii</i> , <i>Q. kelloggii</i>)

Table 4. Variables assessed for NRV of pinyon-juniper systems.

Ecosystem attribute	Variable
Function	Climate Succession Invasions Dispersal and establishment Disturbances: Extreme climate events Fire: Fire Return Interval (FRI) Severity Size Insects and disease Grazing Woodland management (Native American management, woodcutting, range improvement practices, ecological restoration projects)
Structure	Structural class type (closed canopy, open savanna) Density and Cover Patch size Bare soil
Composition	Geographic distribution Proportion of seral classes Proportion of life forms (tree, shrub, grass, forb) Species diversity

Table 5. Summary of current conditions compared to NRV by woodland type. Abbreviations:
Persistent woodlands (P), Savanna-like shrublands (S), Wooded shrublands (Expansion) (E).

Ecosystem Attribute	Indicator Group	Indicator	Variable	Within NRV	Confidence	Notes
Function	Disturbance	Extreme weather (drought and frost)	Mortality (patch size, frequency, density)	All - Yes	All- Moderate	Mortality due to extreme weather conditions was common under NRV and is observed today in both large patches and scattered trees.
		Fire	FRI	P-Yes S-No E-No	P-High S-Low E-Moderate	FRI in persistent woodlands is long enough to still be within NRV but likely increased in the other systems. Supported by reference information from the Medieval Warm Period.
		Severity (low, high)	P-Yes S-Yes E-Yes	P-High S-Moderate E-High		NRV is high severity stand replacing fires for all except possibly savanna types where there is uncertainty.
		Size (area)	P-Var. S-? E-Maybe	P-Moderate S- E-Low		Distribution of fire sizes is likely different at least in expansion types with more large fires due to more continuous fuels and the introduction of cheatgrass. More continuous woodlands may also be allowing for larger fires in persistent woodlands.
		Insects and disease	Qualitative	All- Yes	All- Moderate	Mortality due to insects and disease was common under NRV and often associated with extreme weather events (see above).
		Grazing	Qualitative	P- ? S and E- No	S and E- Low	Lack of a good reference without grazing makes evaluation of the effects of grazing difficult with contradictory results in the literature. Most likely affects are through the fire regime (see above). Persistent woodlands are less likely to be affected due to lower productivity.
		Woodland management	Qualitative	All-Mixed		Most common current activities do not cause departures from NRV. Restoration activities are not being done at a large enough scale to move back towards NRV.
	Succession	Successional patterns	Qualitative	All-?		Departures from disturbance regimes have altered the proportion of seral classes and invasive species may be altering succession in some places creating new pathways and states.
	Dispersal and establishment	Dispersal and establishment patterns	Qualitative	P-Yes S-No E-No	P-Moderate S-Moderate E-Moderate	Departures due to greater density and establishment rate.
	Invasion	Invasion patterns	Species presence/absence, cover, extent	All - Yes	All-High	Invasive species are present and by definition are outside of NRV. The cover and extent is less for persistent woodlands.

Composition	Biogeography	Geographic distribution	Regional extent	P-Yes S-No E-No	P-High S-Moderate E-Low	Savanna types are less common and expansion types are greatly increased. Reference conditions in the Medieval Warm Period support this.
		Topographic and edaphic settings	Aspect, elevation, moisture availability, soil depth and productivity	P-Yes S-No E-No	P-Moderate S-High E-High	Savannas are reduced and replaced with expansion woodlands which also occupy settings that did not have PJ under NRV.
	Physiognomy	Proportion of seral classes	%	P-Yes S-No E-No	P-High S-Moderate E-High	Late seral classes are greatly over represented in savannas and expansion woodlands, although succession is less well understood for savannas.
		Proportion of life forms (tree, shrub, grass, forb)	%	P-No S-No E-No	P-Low S-High E-High	Infilling in all systems has reduced proportion of understory life forms, although the amount of understory in persistent woodlands under NRV is uncertain.
	Diversity	Species diversity (landscape)	Number of species	All- Yes	All- Moderate	Species diversity is mostly maintained at the landscape level although some species associated with shrublands are threatened.
		Species diversity (stand)	Number of species	P-No S- No E- No	P-Moderate S- High E- High	Within stand species diversity has been reduced due to infilling and canopy closure.
Structure	Physiognomy	Structural class type	Closed canopy, open, savanna	P-Variable S-No E-No	P-Moderate S-High E-High	Most stands have experienced infilling but some persistent woodlands on very poor substrates may have been stable.
		Patch size	Area	P-? S-No E-No	S-Low E-High	Patch size of expansion woodlands is greatly increased and savannas have been lost. Patches of persistent woodlands may be the same size but infilling between has created larger continuous stands.
		Density and Cover	Trees per acre/% cover	P-Variable S-No E-No	P-Moderate S-High E-High	Density and cover have increased in almost all stands except possibly persistent woodlands on very poor substrates.
	Soil	Bare soil	% cover	P-Yes S-No E-No	P-Moderate S-High E-High	Where understory cover has been reduced by canopy closure (see above) bare soil is increased.

Figures

Figure 1.

