Pinyon-Juniper Ecosystems on the Uncompahgre Plateau: Assessment of our Current Knowledge and Information Needs

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Contents:

I. Introduction & Background

Pinyon-juniper is one of the major vegetation types on the Uncompahgre Plateau (UP) in western Colorado. Pinyon-juniper woodlands of various kinds cover some 500,000 acres, and form a more-or-less continuous belt around the plateau at elevations between 5,500 and 8,000 feet (Foster-Wheeler S3-6, 2002). Pinyon and juniper trees also extend into sagebrush-grasslands at the lower edge of the pinyon-juniper zone, and into mountain shrub communities at the upper edge.

Objectives: The purpose of this report is (i) to summarize our current knowledge about the ecology of this vegetation on the UP, based on pertinent literature; and (ii) to identify information gaps that could be filled to aid in management. The report also includes an appendix which briefly summarizes the content and utility of three previous pinyon-juniper assessments that have been conducted for the UP during the past 10-15 years.

It is important to emphasize that pinyon-juniper is not a single vegetation entity. Several distinct kinds of plant communities have been recognized; all have pinyon and/or juniper trees, but very different overall stand structure, species composition, and stand dynamics. When drawing lessons for the UP from the large body of pinyon-juniper literature, it is critical to recognize the differences among pinyon-juniper types and to rely on information that is pertinent to our local vegetation. For example, much has been written about pinyon-juniper in the Great Basin and in southern Arizona—but those pinyon-juniper ecosystems are so different from the pinyon-juniper on the UP that we cannot uncritically apply that literature to our area.

Classification of pinyon-juniper vegetation throughout the West: At the scale of the entire continental distribution of pinyon-juniper vegetation (Oregon to Mexico, California to Colorado), three fundamentally different types can be recognized (Romme et al. 2007, 2008, 2009):

Persistent woodlands … pinyon-juniper stands that rarely burn and may be very old. These stands are commonly located on shallow soils with sparse understories, but also are well represented on deeper soils with well-developed understories. This type of pinyon-juniper vegetation is especially prevalent on the Colorado Plateau, and is the dominant pinyon-juniper type on the UP.

Wooded shrublands … these are basically shrub communities that also contain variable numbers of pinyon and/or juniper trees. The tree component increases during wet and disturbance-free periods, and decreases during dry periods or after disturbance. This type of pinyon-juniper vegetation is especially prevalent in the Great Basin, but is also present on the UP in association with sagebrush-grasslands and mountain shrub communities.

Pinyon-juniper savannas … these are basically grasslands that also contain variable numbers of pinyon and/or juniper trees. As in wooded shrublands, the tree component increases during wet and disturbance-free periods, and decreases during dry periods or after disturbance.

This type of pinyon-juniper vegetation is especially prevalent in the U.S.-Mexico borderlands area. It is rare or absent on the UP.

Moving to the UP itself, pinyon-juniper woodlands can be usefully classified in two ways: by species composition, or by stand dynamics.

Classification of pinyon-juniper vegetation on the UP by species composition: Pinyon-juniper vegetation has been classified somewhat differently by different authors and for different purposes, but all such classifications are fundamentally similar. Maps of the distribution of these various pinyon-juniper community types exist in agency databases. For example, RMLANDS (2005) recognizes three major types of pinyon-juniper vegetation on the UP, based on species composition:

Pinyon-juniper woodland (covers ca. 20% of the UP)… canopy of pinyon and Utah or Rocky Mountain juniper, with highly variable understory of shrubs (bitterbrush, Mormon tea, black sagebrush), warm-season and cool-season grasses (galleta, muttongrass), and forbs (penstemon, hairy goldenaster). Crytogamic crusts (cyanobacteria, algae, lichen, moss, fungi, or liverwort) cover much of the soil surface except where disturbed by trampling.

Pinyon-juniper-sagebrush woodland (covers ca. 14% of the UP)… canopy of pinyon and Utah juniper, with understory of big sagebrush and various grasses (western wheatgrass, squirreltail) and forbs (hairy goldenaster, penstemon). Crytogamic crusts cover much of the soil surface except where disturbed by trampling.

Pinyon-juniper-oak-serviceberry woodland (covers ca. 6% of the UP)… canopy of pinyon and Utah or Rocky Mountain juniper, with understory of Gambel oak, serviceberry, and other shrubs, and various forbs (lupine, peavine) and grasses (muttongrass). Crytogamic crusts cover the soil surface in a few places, but are not as common as in the other two types.

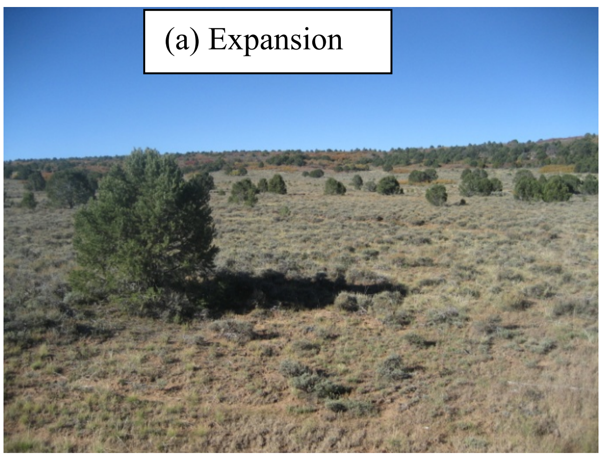
Classification of pinyon-juniper vegetation on the UP by stand dynamics: Pinyon-juniper stands of any of the compositional types described above can also be classified according to the trajectory of change that is occurring in the stand. This classification may be especially pertinent to management decisions. However, we do not have comprehensive maps of the specific locations of these kinds of stands. Four general types of pinyon-juniper stand dynamics can be recognized (see Figure 1 for pictures of examples):

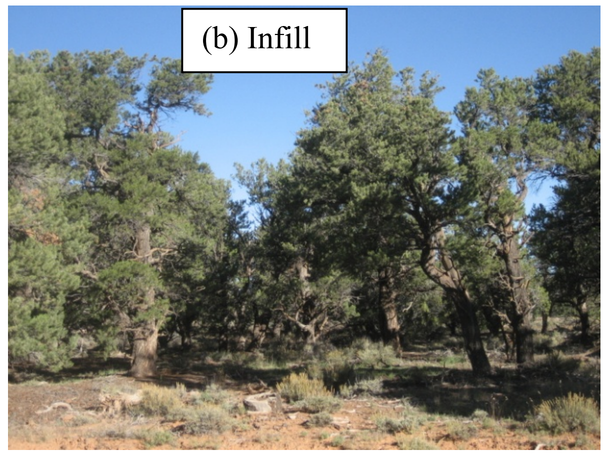
Expansion … establishment of pinyon and/or juniper trees in former grasslands or shrublands. The term is usually used in connection with expansion that occurred during the modern period (post-1880), although it is an ecological process that no doubt has occurred in earlier times as well. This process is ongoing in places on the UP, but the extent and specific locations of expansion are not well documented. (This process is often referred to as "invasion," but I prefer the less pejorative term expansion.)

Infill … the process of increasing tree density within existing woodlands. The key distinction between infill and expansion is that infill is occurring in places that were already woodland (presumably with lower tree density) prior to the modern period. Infill has occurred in many or even most pinyon-juniper stands on the UP during the past century

Recovery … the process of tree re-establishment following a severe disturbance to a pinyon-juniper stand, such as stand-replacing fire or chaining. If one does not look closely for the presence of charred snags or piles of coarse dead wood, it can be easy to mistake areas of recovery for expansion. The key difference is that recovery occurs after disturbance of a previously existing woodland, whereas expansion involves establishment of a new woodland in a place that was formerly shrubland or grassland. Recovering pinyon-juniper woodlands are moderately common on the UP, especially on flat or gently sloping terrain.

Stability … Some pinyon-juniper stands may change relatively little over long time periods, as old trees die and young trees replace them. Such stands probably are rare on the UP, since stasis is an uncommon condition in forests and woodlands as a whole.





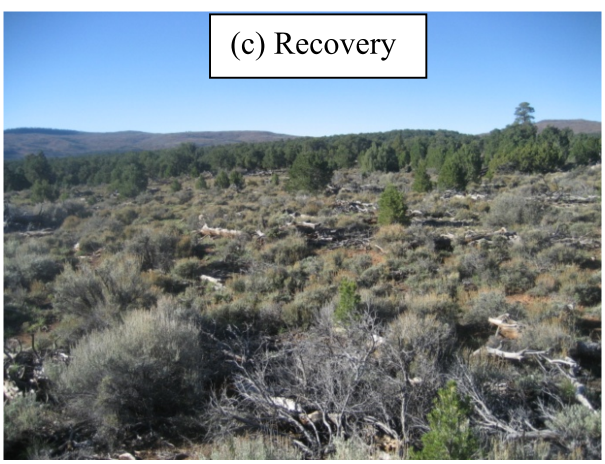


Figure 1. Three common types of pinyon-juniper stand dynamics on the UP. (a) *Expansion*: young trees are scattered within a sagebrush-grassland in the foreground, and in oak shrubland in the background. (b) *Infill*: the large trees are centuries old, but the smaller trees established in the 20th century. (c) *Recovery*: Coarse wood in the foreground is evidence of a chaining operation; the undisturbed stand is visible in the background.

II. Summary of our Current Knowledge

This information is presented as a set of nine statements. Each statement includes (i) the statement's applicability to the various kinds of pinyon-juniper vegetation on the UP; (ii) what I regard as the level of confidence we should have in the statement; and (iii) a brief summary of the key literature that supports the statement and that influences my assessment of the level of confidence.

Following the approach used in a recent review of pinyon-juniper vegetation across the western U.S. (Romme et al. 2009), statements of **high confidence** generally are supported by some combination of (i) *rigorous surveys* that include adequate sampling and appropriate analysis of, e.g., cross-dated fire-scars, tree age structures, and plant community composition; (ii) *experimental tests of patterns or mechanisms* that incorporate adequate replication and appropriate scope of inference; and (iii) *systematic observations of recent wildfires, prescribed fires, or other disturbances (e.g., insect outbreaks)*, either planned before the event and documented by experienced, objective observers, or based on rigorous post-disturbance analyses using adequate and spatially explicit data. Statements of **moderate** or **low confidence** generally are supported by (i) *correlative studies* that identify statistically significant associations between two variables but do not prove a cause-effect relationship; (ii) *anecdotal observations of vegetation patterns or disturbance processes* by experienced, objective observers, but not conducted in a systematic manner, e.g., opportunistic observations of wildfires or insect-caused mortality; and (iii) *logical inference,* i.e., deductive inferences from related empirical or experimental studies that are logical but not yet tested empirically. Depending on the details, other kinds of evidence may support **high**, **moderate**, or **low confidence**: (i) *comparison of historic and recent photographs of the same scene,* which documents changes in pattern or structure, but says little about the mechanism(s) causing the changes; and (ii) *written historical documentation* in the form of reports, articles, letters, and other accounts by reliable observers.

Statement 1: Historical Fire Regimes

Prior to Euro-American settlement (ca. 1880), fires were ignited somewhere within the UP landscape every year. At the scale of individual stands (ca. 1-10 acres), however, fires in pinyon-juniper woodlands and in associated sagebrush and mountain shrubland vegetation usually recurred at long intervals (many decades or centuries) and were typically stand-replacing. Spreading, low-severity fires, which thin from below and leave the tree or shrub canopy intact, were of very limited extent and had a negligible influence on vegetation structure, composition, or dynamics in these vegetation types.

Applicability and Confidence: This statement applies to all of the kinds of pinyon-juniper woodlands and associated sagebrush and mountain shrubland vegetation on the UP.

The statement is supported by a large body of rigorous research conducted both on the UP per se and in other areas of similar vegetation and environment on the Colorado Plateau; therefore I give it a ***high confidence*** rating.

Explanation: Until about a decade ago, it was widely believed that historical fire regimes in pinyon-juniper woodlands were very similar to those in southwestern ponderosa pine forests, i.e., that fires recurred frequently (intervals of a few years to a few decades at the stand level) and burned primarily at low severity, killing small trees and reducing woody fuels but not killing the canopy. This interpretation was based not on rigorous research, but on anecdotal observations and untested assumptions; unfortunately it was widely (and uncritically) accepted. This view is reflected in the early LANDFIRE assessments of fire regime condition class, based on VDDT modeling, which concluded that most contemporary pinyon-juniper woodlands were far outside the historical range of variation because they had missed several fire events in the 20th century (Schmidt et al. 2002, http:/www.frcc.gov). The pinyon-juniper section of the 2002 Foster-Wheeler report on the UP also presents this view of historical fire regimes (notably, however, the authors of that report acknowledged that they had no relevant UP research to draw upon at the time, and had to use general sources). Rigorous research during the past 10-15 years, some of which was conducted on the UP, has shown that this early view of historical fire regimes in pinyon-juniper vegetation is fundamentally wrong.

Spreading, low-intensity surface fires (as opposed to stand-replacing fires) have been observed only rarely in piñon-juniper vegetation during the modern period since Euro-American settlement (Baker and Shinneman 2004). Definitive fire-history evidence of a spreading low-intensity surface fire would include cross-dated fire scars at two or more locations along with intervening age-structure evidence that trees generally survived the fire (Baker and Shinneman 2004). However, few places provide such evidence. On the contrary, fire scars are conspicuously absent or rare in the great majority of pinyon-juniper stands (Baker and Shinneman 2004. A major reason why low-severity fires apparently are unimportant in persistent woodlands and in wooded shrublands (the kinds of pinyon-juniper vegetation that we have on the UP), is that the fuel structure typically is not conducive to a spreading, low-severity fire that would spread via fine fuels without killing the dominant trees or shrubs. Fine fuels are usually discontinuous (Floyd et al. 2000, 2008; Baker and Shinneman 2004) and the major fuel components are the crowns of live shrubs and trees which, if ignited, tend to burn completely with considerable heat release (Floyd et al. 2000, 2004; Baker 2006). Thus, fires typically kill all of the trees and top-kill all of the shrubs and herbs within the areas that burn; usually the only surviving aboveground vegetation is in patches that do not burn.

In contrast to the lack of evidence for spreading *low-severity* fires, there is abundant evidence that fires in pinyon and juniper woodlands since Euro-American settlement have been *predominantly high severity*, commonly killing all the trees and top-killing the shrubs and herbs within a fire perimeter, but often leaving some unburned islands of woodland (Baker and Shinneman 2004; Eisenhart 2004; Floyd et al. 2004; Shinneman and Baker 2009a).

Studies on the UP and elsewhere on the Colorado Plateau have determined that intervals between successive fires at the scale of an individual pinyon-juniper stand were typically 400+ years (Baker and Shinneman 2004; Floyd et al. 2004, 2008; Shinneman and Baker 2009a). In Colorado National Monument, at the very northern end of the UP, Kennard and Moore (2013) documented juniper trees up to 900+ years old, and suggested that very dry sites, where trees are at low density and ground layer vegetation is sparse, may escape fire for 1000 or more years. Long fire intervals at the scale of individual stands also were characteristic of the kinds of sagebrush and mountain shrub communities that we have on the UP, viz., 70-200 years in high-elevation sagebrush and 100-240 years in low-elevation sagebrush (Baker 2006), and ca. 100 years in high-elevation mountain shrub (Floyd et al. 2000).

Statement 2: Historical (pre-1880) Impacts of Drought & Insects

Prior to Euro-American settlement (ca. 1880), insects and drought also produced changes in the structure, composition, and dynamics of pinyon-juniper woodlands, and in some types of woodlands (notably old-growth persistent woodlands) were more frequent disturbances than fire. In all types of pinyon-juniper vegetation, however, the changes produced by these other disturbances were generally of lesser magnitude or intensity than those produced by fire.

Applicability and Confidence: This statement applies to all of the pinyon-juniper vegetation on the UP.

The statement is supported by a large body of rigorous research conducted both on the UP per se and in other areas of similar vegetation and environment on the Colorado Plateau; therefore I give it a ***high confidence*** rating.

Explanation: Old pinyon-juniper stands on the UP and elsewhere on the Colorado Plateau commonly contain numerous large dead tree boles, both standing and on the ground (Eisenhart 2004, Floyd et al. 2004, 2008, 2013; Shinneman and Baker 2009a). The state of weathering indicates that these trees died many decades or even centuries ago. These dead trees are evidence of mortality events that occurred in the distant past, events that thinned the stands but did not kill all of the canopy as would have occurred with fire. Although we cannot know precisely when the trees died (without strenuous tree-ring analyses), it is likely that they were killed by drought, possibly in combination with the kinds of native tree-killing insects that killed pinyon trees in this region in the first decade of the 21st century (see below).

A severe "megadrought" in the late 16th century has been documented throughout most of the western U.S., including Colorado (Swetnam and Betancourt 1998, Gray et al. 2003), and is thought to be the reason that we find few pinyon trees older than about 400 years in this region even though pinyon can live for >800 years (Swetnam and Brown 1992). Palmer Drought Severity Indices, reconstructed from tree-rings, also document several drought episodes lasting one or two decades in the 17th and 18th centuries (Cook et a. 2004, Shinneman and Baker 2009a)

Statement 3: Contemporary Fire Regime

4a: Fires have been somewhat less frequent during the modern period (post-1880) than they were historically (pre-1880), in part because of direct fire suppression and land use, but … 4b: fire behavior and effects remain similar, i.e., fires still tend to be stand-replacing burns.

Applicability and Confidence: These statements apply to all of the woodlands and associated sagebrush and mountain shrub vegetation on the UP.

The idea that fires have been less frequent in the 20th century than they were historically because of our activities on the land (4a) receives a **low confidence** rating. We have pretty good fire records for the 20th and 21st centuries, but no extensive or detailed study of pre-1880 fire history exists for the UP pinyon-juniper zone. We must rely instead on logical deduction: unfortunately, reasoning from one set of initial assumptions leads to the conclusion that fires are now less frequent, but from another set of initial assumptions we can conclude that we have no reason to believe such an idea. These contrasting arguments are summarized below.

However, the idea that fire effects today are similar to effects of historical fires (4b) receives a **high confidence rating** based on rigorous studies of historical fires and observations of recent fires—which have been predominantly stand-replacing burns.

Explanation: Were fires less frequent on the UP in the 20th century than they were in previous centuries? We know that grazing in some other vegetation types (notably ponderosa pine) reduced fine fuels and led to an abrupt cessation of frequent fires in the late 19th century; we know that heavy livestock grazing occurred in pinyon-juniper vegetation on the UP; and we know that active fire suppression was a policy in the pinyon-juniper zone (and elsewhere) for most of the 20th century. From these facts we could argue that fires must have been less frequent in the UP's pinyon-juniper vegetation in the 20th century than in previous centuries.

However, we also know that fire frequency in pinyon-juniper vegetation is controlled more by climate and weather than by fine fuel abundance (Romme et al. 2009), and that weather conditions during much of the 20th century were relatively wet and not very conducive to fire (Morgan et al. 2008, Littell et al. 2009, Shinneman and Baker 2009a). Moreover, during the weather conditions in which large severe fires typically occur in pinyon-juniper vegetation, fire suppression is often ineffective, even with today's advanced fire-fighting technology (witness the large fires on Mesa Verde in the 1990s and 2000s which were vigorously fought but could not be controlled during the extreme fire weather conditions under which they burned; Floyd et al 2004). From these facts we could argue that 20th century grazing and fire suppression prevented some fires that would have remained small even without suppression, but did not prevent large fires burning under severe fire weather conditions. The latter, of course, are the kind of fires that account for most of the cumulative area burned over the course of a century.

Despite the uncertainty about how fire frequency in pinyon-juniper woodlands may have changed, or not changed, during the past century, it is clear that modern fires (the large ones) tend to be severe, i.e., to be stand-replacing (Shinneman and Baker 2004, Floyd et al. 2004).

Statement 4: Contemporary Impacts of Drought & Insects

A severe regional drought affected most of the southwestern U.S. in the first decade of the 21st century, and resulted in extensive mortality of pinyon trees on the UP and elsewhere on the Colorado Plateau. Trees died both from direct drought stress and from attack by bark beetles (notably pinyon ips). Junipers suffered little mortality, however, and in many stands relative density and basal area have now shifted toward a greater dominance of junipers. This recent mortality event probably was similar in severity and in causal factors to historical (pre-1880) mortality events.

Applicability and Confidence: Pinyon-juniper stands across the UP were affected to some degree by this event, but the magnitude of pinyon mortality and of change in stand composition varied greatly. Mortality appears to have been *most severe on the east side of the UP*, and on sites having *deeper soils* At the scale of individual stands, mortality was *greater among larger trees*, but was apparently *unrelated to tree density* or basal area at the outset of the mortality event.

We can have **high confidence** in the causes of mortality (drought and bark beetles), based on local ground-based surveys by entomologists and ecologists at the time. We can also have **high confidence** in the observation that mortality was generally greater on the east side of the UP, which was based on extensive aerial reconnaissance and a rigorous ground survey. The pattern of greater pinyon mortality on deeper soils receives only **low confidence**, however, because it is based on only one rigorous field study. The idea that mortality was not influenced by stand density or basal area receives **moderate confidence** because it is based on rigorous studies elsewhere on the Colorado Plateau but not by studies on the UP per se. Finally, we can have **moderate confidence** in the idea that the recent mortality event was similar to historical events; rigorous paleoecological studies confirm the occurrence of severe droughts in the past, but we have no quantitative information on how many trees died on the UP in those past events.

Explanation: The drought that afflicted most of the southwestern U.S. in the first decade of the 21st century was one of the most severe droughts of the past several centuries (though not as severe or as prolonged as the "megadrought" of the late 16th century). Pinyon trees died in great numbers throughout the Four-Corners region (Figure 2). Far smaller numbers of junipers died (Mueller et al. 2005, Selby 2005, Floyd et al. 2009). Mortality resulted not only from direct moisture stress but also from higher than usual temperatures which further stressed the trees and facilitated outbreaks of pinyon ips bark beetles (Breshears et al. 2003).

Selby measured tree mortality in 68 plots along gradients of elevation and topography in the southern portion of the UP, and documented significantly greater mortality among larger trees and in stands on the east side of the UP. Selby also examined results of USFS aerial damage surveys of the entire UP, which confirmed the pattern of greater mortality on the east side. She found contradictory results for the elevational gradient, however: the ground surveys showed greater mortality at lower elevations whereas the aerial damage surveys indicated greater mortality at higher elevations. I do not know how to resolve this discrepancy.

Eisenhart (2004), in her broad-scale ground surveys of pinyon-juniper stands on the UP, reported "moderate-to-high" mortality of pinyon on lower-elevation sites having soil depths greater than 50 cm Eisenhart (2004; p 176). Nearby sites with shallower soils were dominated by junipers, which exhibited little mortality. Eisenhart speculated that pinyon is able to become established on deeper soils at lower elevations during wet climatic periods (e.g., the late 20th century), but dies when drought returns.

A basic tenet in silviculture is that denser stands, when subjected to drought or insect attack, are more likely to suffer high mortality rates than are less dense stands, because of greater tree-to-tree competition for resources in the dense stands. This pattern was seen in the late 1990s, which was near the beginning of the recent pinyon mortality event in the Southwest (Negron and Wilson 2003, Shaw et al. 2005). However, toward the end of the event, in the mid-2000s, the relationship between stand density and percent mortality was no longer evident in three rigorously sampled study areas in the Four-Corners region, including Mesa Verde (Mueller et al. 2005, Floyd et al. 2009). Apparently the abundance of ips bark beetles was so great, and the drought effects were so severe, that trees were vulnerable regardless of whether they were crowded or not. The question whether tree density influenced the severity of pinyon mortality on the UP per se was not addressed rigorously, but it seems likely that patterns on the UP were comparable to those in the ecologically similar places that were studied.

It is impossible to know just how similar the recent mortality event on the UP was to historical (pre-1880) events with respect to numbers of trees killed or changes in tree densities, because we cannot precisely reconstruct tree densities or magnitudes of mortality that occurred centuries ago. Nevertheless, we can be confident that this recent event was *qualitatively* similar to previous mortality events that occurred during drought periods. There is evidence that pinyon densities regularly increase during decadal-scale wet periods, and then crash when the inevitable drought period eventually arrives. Meanwhile juniper increases slightly during dry periods but maintains a relatively more constant density overall (Shinneman and Baker 2009a). The new pinyon trees that establish during wet periods may be growing primarily on marginal sites that are suitable only during times of greater precipitation, and as such are not strongly competing with older trees growing on better sites; those individuals growing on marginal sites are more likely to be the ones that die during drought and insect outbreaks (Greenwood and Weisberg 2008). Eisenberg's (2004) observation of high pinyon mortality on deeper soils at lower elevations is consistent with this idea: shallow soils would never support pinyon at low elevations, but pinyon could survive on the deeper soils as long as above-average precipitation occurs.

Figure 2. Pinyon mortality on the UP (photos by Diane Selby, 2005). **Left**: Dead and dying pinyon trees. **Right**: Exit holes created by emergence a new generation of pinyon ips bark beetles

Statement 5: <u>Impacts of Livestock Grazing</u>

Community composition and cover have been altered to at least some degree in most pinyon-juniper stands by livestock grazing. However, it is important to emphasize that the details, origins, and overall significance of these changes are highly variable across the UP. Grazing-related impacts that we see today do not necessarily reflect current grazing practices but may be legacies of very heavy grazing in the early and middle 20th century.

Applicability and Confidence: This statement applies to all of the various kinds of pinyon-juniper vegetation on the UP, except perhaps for places that have not been reached by livestock (e.g., inaccessible Sewemup Mesa on the northwest side of the UP).

We can have **high confidence** in the idea that most of the pinyon-juniper vegetation on the UP has been altered to at least some degree by livestock grazing, based on the ubiquity of grazing during the 20th century as well as extensive and consistent observations by knowledgeable and objective observers. We also have one rigorous study that addressed this issue on the UP. However, the details and overall significance of the changes wrought by grazing are highly variable from place to place, depending on local environmental context and intensity of grazing.

Explanation: Large numbers of livestock (mostly cattle but also some sheep) were introduced on the UP soon after removal of the Ute people in 1881 (Marshall 1998) and have been present ever since. Livestock production was a major management objective on the UP's federal lands for most of the 20th century, and many projects were implemented to improve forage conditions in pinyon-juniper woodlands, e.g., chaining and seeding of non-native pasture grasses (Shinneman et al. 2008).

Impacts of livestock grazing in semi-arid ecosystems have received much research attention. Citing the pertinent literature, Shinneman et al. (2008; p 208) summarize the major potential impacts on the UP as follows: reduction in native plant species abundance; damage to soil crusts; and alterations in stand structures, natural disturbance regimes, water and nutrient cycles, and light availability.

Shinneman et al. (2008) conducted an extensive survey of grazing impacts in the semi-arid landscape of the UP, including pinyon-juniper woodlands, sagebrush shrublands, and grasslands. They measured plant community composition in 302 sites distributed across the UP, of which 63 sites were in reference areas where grazing intensity was absent or light because of topographic inaccessibility or management policy; all of the remaining sites received some level of grazing. They then used ordination analysis to quantify how different the sites were from each other. The reference sites all clustered together, indicating high similarity in species composition, but most of the other sites differed to a greater or lesser degree from the reference sites; sites that differed greatly from the reference sites were regarded as degraded.

Shinneman et al. (2008) detected several consistent differences between the reference sites and the grazed sites that were classified as degraded. Overall native species diversity was higher in reference sites. Reference sites were characterized by greater mean cover of native graminoids, notably muttongrass and other cool-season grasses. Mean forb cover also was higher in reference sites, as was mean cover of biotic soil crusts. (The soil crusts perform several ecological functions—they stabilize soils, fix carbon and nitrogen, increase water retention, and enhance germination of many native plants (Belnap et al. 2001, cited in Shinneman and Baker 2008)—but they are easily damaged by trampling.)

Although this study by Shinneman and Baker demonstrated that grazing can influence the structure and composition of pinyon-juniper stands, their study did not result in a comprehensive map showing where on the landscape the impacts are most or least severe. Thus, we cannot assume that any particular place on the UP has been degraded by livestock without actually visiting the spot. In addition, their study was not able to distinguish between long-persisting legacies of early 20th century grazing and contemporary grazing impacts.

Statement 6: Vegetation Dynamics following Recent Fires

The floristic composition of most recently burned areas is different from what it would have been after historical fires (pre-1880) because of the presence and abundance of non-native plant species, notably cheatgrass, but also many others. Cheatgrass generally is most abundant in burns that occur at lower elevations. In some places non-natives are the dominant post-fire species; they may alter or even prevent the natural long-term development of the native plant community.

Applicability and Confidence: We can have **high confidence** that non-native plants are present in substantial numbers in most recently burned pinyon-juniper stands, based on two rigorous studies on the UP plus extensive observations by knowledgeable and objective observers. However, it is important to emphasize that the specific mix, abundance, and long-term significance of non-native plants can vary greatly.

The idea of greater abundance of cheatgrass in lower-elevation burns receives only a **low confidence** rating. A rigorous study of postfire cheatgrass in another part of the Colorado Plateau and numerous studies in the Great Basin support this idea, but a rigorous study on the UP per se found no relationship between cheatgrass abundance and elevation.

The idea that non-native plants will alter or even prevent normal long-term development of the native plant community also receives a **low confidence** rating. It is a reasonable expectation based on the abundance and known competitive abilities of non-natives on some burned sites, as well as the potential of cheatgrass to produce shorter fire intervals. However, we lack rigorous long-term observations of pinyon-juniper community development in areas with and without abundant non-native species, from which we would be able to quantify the impact of the non-natives over the long run.

Explanation: Native plants are responding to recent fires in much the same way as they did to historical fires, by sprouting from surviving belowground structures, by germination of soil seed banks, and by dispersal of viable seeds into burned areas from outside (Baker 2009). However, recovery of a pinyon-juniper woodland after stand-replacing fire in this region can require decades or centuries (Erdman 1969, 1970; Floyd et al. 2000). Where a hot fire killed all aboveground vegetation, the bare soil and sunlight provide ideal germination sites for non-native plant species, especially during the first few years post-fire (Floyd et al 2006) (Figure 3).

The abundance and species composition of non-native plants that become established after a fire vary greatly from place to place, depending on local seed sources and environmental context. On Mesa Verde, for example, muskthistle was not recorded in any mid-20th century burns, simply because this native of Eurasia had not yet reached southwestern Colorado; by the 1990s and 2000s, however, muskthistle had become one of the most conspicuous species in pinyon-juniper burns (Romme et al. 2003). Also in Mesa Verde, non-native plants have been most abundant after recent fires in lower-elevation pinyon-juniper woodlands where the native plant community contains relatively few sprouting species; in pinyon-juniper-oak-serviceberry woodlands at higher elevations, where sprouting species are a major component of the native plant community, non-native plants have been far less successful, and many burned sites remain dominated by native species.

Cheatgrass is a non-native species that has received special attention in both burned and unburned settings because of its potential to alter fundamental ecological processes in semi-arid systems (Anderson and Inouye 2001). Cheatgrass competes strongly with native plants for soil moisture, alters nitrogen cycling (Evans et al. 2001), and it creates a flashy fuel upon drying that can readily carry fire (Link 2006). In parts of the Great Basin and elsewhere in the West where cheatgrass has become abundant, fire intervals are now much shorter than they were before cheatgrass (D’Antonio et al. 1992); many of the native plants (notably some of the bunchgrasses) are declining because they cannot tolerate such frequent burning (e.g., Brooks et al. 2013, Balch et al. 2012)

The spatial patterns of postfire cheatgrass invasion are not well characterized at the landscape scale, nor are the ecological factors controlling local invasion potential, especially after fire. Research to date indicates that a combination of local environmental characteristics, climate (before, after, and in the year of the fire), and propagule availability can influence the occurrence and magnitude of postfire cheatgrass invasion, but results are limited and not always consistent (Rew and Johnson 2010).

In a survey of 19 areas burned within the previous decade on the UP, Shinneman and Baker (2009b) found higher postfire cheatgrass cover in sagebrush-grassland than in piñon-juniper woodland, on sites having higher pre-fire cover of annual forbs and lower cover of biological soil crust, in burns occurring after a year of lower precipitation or followed by years of higher precipitation, and with increasing time since fire. Slope, elevation, aspect, and geologic substrate were not significant predictors in that study, nor were distance to edge of burn or to roads (Shinneman and Baker 2009b). In contrast, studies in other areas have indicated that vulnerability to cheatgrass is greater at lower elevations (Sherrill and Romme 2012), on south-facing slopes (Billings 1990, Condon *et al*. 2011), on sites located closer to paved roads (Gelbard and Belnap 2003, Anacker *et al*. 2010), and in places where perennial herbaceous cover is lower (Chambers *et al*. 2007, Condon *et al*. 2011). Sherrill and Romme (2012) also reported that postfire cheatgrass establishment in Dinosaur National Monument and surrounding semi-arid county was most abundant when the year after the fire was relatively dry. At the scale of an individual burn on the UP, Getz and Baker (2008) found greater cover of cheatgrass near the edge of the burn, and suggested that this pattern reflected lower heat release as the fire was dying down, which meant greater survival of cheatgrass seeds in the soil seed bank.

We have no long-term studies of post-fire community development in pinyon-juniper woodlands of this region from which we can evaluate whether the current post-fire abundance of non-native plant species will continue into the future, precluding “normal” recovery of the native plant community, or will be only a transient stage of little long-term significance. It is clear that the non-natives can remain abundant or even dominant for a decade or longer: Shinneman and Baker (2009b) found a trend of increasing cheatgrass abundance in stands ranging from 1 to 9 years postfire on the UP, and places that burned in the mid-1990s on Mesa Verde were still dominated by non-native species in the mid-2000s (Figure 3).

Figure 3. Non-native plant species in recent burns on Mesa Verde; similar conditions exist in some recent burns on the UP. **Left**: muskthistle, tumble mustard, and Russian thistle in the 1996 Chapin 2 burn, photographed in 2005. **Right**: Lisa Floyd and David Hanna examining nearly 100% cover of cheatgrass in the 2000 Bircher fire, photographed in 2003.

Statement 7: <u>Patterns of Infill & Expansion of Pinyon & Junipers</u>

(8a) Tree density and canopy cover have increased in many stands during the past century through the process of <u>infill</u> of already-established woodlands; <u>infill</u> has been primarily by pinyon, and has occurred in most pinyon-juniper stands across the UP. (8b) Pinyon and/or juniper also have <u>expanded</u> into some former shrublands and grasslands; tree <u>expansion</u> has occurred primarily on sites with deep soils. (8c) At the scale of the UP landscape, however, the 20th century saw a slight <u>net decrease</u> in canopy cover of pinyon-juniper because of somewhat greater loss of woodlands to fire and mechanical clearing than gain through infill and expansion.

Applicability and Confidence: These patterns apply to pinyon-juniper vegetation across the UP.

We can have **moderate confidence** in the widespread occurrence of *infill* (8a), which is based on two rigorous investigations of tree age structures in a large number of stands on the UP as well as similar studies elsewhere on the Colorado Plateau, but is challenged by the results of comparing historic aerial photos.

The pattern of *expansion* occurring primarily on depositional sites with deep soils receives a **moderate confidence** rating, since it is based on one rigorous study on the UP plus one (with the same conclusions) for the Four-Corners region as a whole. However, no systematic survey has been conducted to document the magnitude and specific locations of tree expansion on the UP.

The idea of a small net decrease in canopy cover of pinyon-juniper woodlands during the 20th century (8c) receives a **moderate confidence** rating. It is based on one rigorous study of historic photos on the UP, plus similar findings elsewhere on the Colorado Plateau. However, no systematic survey has been conducted that would allow us to measure the actual acreage and locations affected by processes of woodland gain and loss during the past century.

Explanation: Extensive field sampling of age and size structures in pinyon-juniper stands across the UP by Eisenhart (2004) and by Shinneman and Baker (2009a) has documented the substantial numbers of pinyon trees that established after 1880, along with smaller numbers of junipers that established in the same period. However, the degree to which 20th century infill may have altered overall stand densities and stand structure at the landscape level is uncertain, because we have no comparable quantitative measures of tree mortality during the 20th century. In fact, careful measurements taken from matched aerial photos in 1937 and 1994 indicate a small net decrease in total canopy cover in pinyon-juniper woodlands of the UP (Manier et al. 2005).

Extensive surveys of spatial patterns of 20th century pinyon and juniper expansion throughout the Four-Corners region have revealed a much higher likelihood of new trees establishing on depositional substrates having deeper soils than on nearby upland areas (Jacobs et al. 2008, Jacobs 2011). Eisenhart (2004) also emphasized seeing young pinyon trees on sites having deep soils. However, no rigorous survey of the extent or spatial patterns of tree expansion has been conducted on the UP.

Comparisons of matched aerial photos taken in 1937 and 1994 revealed a small net decrease in total canopy cover in pinyon-juniper woodlands of the UP during that time period (Manier et al. (2005). Interestingly, the decrease was greatest in the higher elevation portion of the pinyon-juniper zone; canopy cover in the lower pinyon-juniper actually increased somewhat, a finding that was corroborated by Shinneman and Baker's (2009a) finding of young pinyon trees in old, low-elevation juniper stands that contained no old pinyon. Arendt and Baker (2013) also documented a small net decrease since the early 1900s in the extent of pinyon-juniper woodlands in and around Dinosaur National Monument, located at the northern end of the Colorado Plateau; their study was based on comparing original government land survey records to modern aerial photos.

The photos and survey records reveal spatial and temporal patterns of change, but cannot reveal the mechanism(s) driving the change. We know that many areas on the UP were chained beginning in the 1950s to improve forage conditions, and that fires or other forms of clearing may have also reduced woodland cover. The extent of formation of new woodlands through expansion into shrublands and grasslands probably was not sufficient to counteract these losses on the UP: Jacobs (2011) noted that the most dramatic tree expansion has occurred not in southwestern Colorado, but in summer-wet regions of New Mexico and Arizona, and has involved a different juniper (one-seed juniper) than we have on the UP. Again, however, no rigorous survey of the specific locations or acreage of tree expansion and woodland loss has been conducted on the UP.

The idea of a net decrease in pinyon-juniper canopy cover on the UP during the past century is contrary to what we would have expected based on the patterns documented in the

Great Basin; in many parts of the latter area, woodlands have expanded and thickened greatly. This is a good example of why we need to be careful in extrapolating from other regions where pinyon-juniper ecosytems are very different from those on the UP.

Statement 8: Mechanisms of Infill & Expansion of Pinyon & Junipers

Infill and expansion have been driven primarily by climatic changes that began in the early 1800s and continued through the 20th century; grazing and lack of fire augmented the climate effects in some stands, but these are secondary mechanisms when viewed at the scale of the entire UP landscape.

Applicability and Confidence: This statement applies to pinyon-juniper vegetation across the UP.

We can have **moderate confidence** in the idea that infill and expansion have responded primarily to climate drivers during the past century. Two rigorous studies on the UP support this conclusion, as do studies of the mechanisms underlying infill and expansion throughout the West. The confidence level is only moderate, however, because grazing effects and rising atmospheric CO2 (which can have a fertilizing effect and can increase plants' drought tolerance) have been shown in some places in the West to be important drivers of infill and expansion.

Explanation: Romme et al. (2009) review the evidence for the various mechanisms that have been proffered to explain what is driving woodland infill and expansion. The primary drivers probably vary among geographical regions; thus we must be careful in extrapolating from studies in the Great Basin or elsewhere than the Colorado Plateau. We also must be careful not to mistake the recovery of chained or harvested woodlands for establishment of new woodland in what was formerly non-woodland vegetation.

Twentieth century fire suppression cannot be the primarily mechanism of infill and expansion on the UP, because pre-20th century fires were infrequent at the stand level, and were typically stand-replacing rather than thinning stands.

The coincidence in time between the onset of grazing and of increasing tree density in many areas suggests a direct cause-effect relationship. However, empirical evidence for or against the grazing mechanism is sparse and mixed. On the UP, the density of tree seedlings and saplings (mostly pinyon) was nearly three times greater in grazed areas than in ungrazed reference sites (Shinneman and Baker 2009a). But in similar persistent woodlands in the southwestern portion of the Colorado Plateau (Grand Staircase – Escalante), pinyon densities and establishment dates were essentially the same in a little-grazed reference site and nearby grazed woodlands (Barger et al. 2009).

The onset of extensive infill and expansion of piñon and juniper in the late nineteenth century in many areas coincided not only with the beginning of grazing and fire exclusion, but also with a significant climatic event, namely the end of the "Little Ice Age" and the beginning of a general warming trend with changes in precipitation patterns that continued through the twentieth century. Both Eisenhart (2004) and Shinneman and Baker (2009a) found that the increase in pinyon populations on the UP began around AD 1800—some 80 years before the arrival of European settlers and their livestock. On the UP and elsewhere in the Southwest, the early 19th century was a time of transition from an extended drought period to a wetter period that continued well into the 20th century (Shinneman and Baker (2009a). Many years in the early 1900s were notably wet throughout the Southwest, and the last four decades of the twentieth century were among the wettest in the period of record (Gray et al. 2004). Studies in the Great Basin (e.g., Knapp and Soulé 2008) suggest that increasing atmospheric CO2 throughout the 20th century have also enhanced tree establishment and growth through a fertilizing effect (CO2 is the main ingredient in sugar production via photosynthesis); however, it is not yet clear whether this effect is widespread or especially important in explaining the dynamics of infill and expansion. Climate apparently influences pinyon and juniper demography primarily through its effects on survival rather than on seed production or dispersal: Graeve (2012) documented more-or-less continuous recruitment of pinyon seedlings during the last 30 years on the UP, with little variation in numbers even in years that were unusually wet or dry.

In sum, it appears that after 1880 grazing plus a paucity of fire (a result not of direct fire suppression but of climate conditions not conducive to extensive burning) may have enhanced the climate drivers that favored infill and expansion of pinyon and juniper on the UP. Thus, a major tree recruitment event probably would have occurred even without the effects of EuroAmerican settlers, but grazing may have augmented that climate-driven process.

Statement 9: Implications of Ongoing Climate Change

Over the next several decades, we can expect to see on the UP: (9a) a trend of increasing average temperatures, both highs and lows, in winter and summer, and with lots of year-to-year variation; and (9b) a trend of increasing frequency and size of large fires in the pinyon-juniper zone (and elsewhere on the plateau), again with lots of year-to-year variation. We also may see (9c) a trend of decreasing effective precipitation, leading to more frequent and severe droughts and insect outbreaks.

Applicability and Confidence: These projections apply to the entire UP.

We can have **high confidence** in the expected temperature trend (9a), which is supported by the whole body of climate change research. The expected increase in large fires (9b) also receives a **high confidence** rating; it is supported by two rigorous studies in western North America showing a big increase in burning during warmer years--even years that were only a little warmer than average--as well as studies from around the world that produced similar findings. However, I give only a **low confidence** rating to the idea of intensifying drought and insect outbreaks (9c), because the global climate models cannot yet project precipitation patterns at the scale of the UP with great confidence, and because effective precipitation from the plant's perspective is influenced by other factors than total inches of rain and snow.

Explanation: Projections of future global climate are summarized in IPCC (2007). In general, projections of future temperatures are considered quite robust at the global and regional scales, but much uncertainty remains about future precipitation trends. Notably, precipitation in southwestern Colorado is powerfully influenced by hemisphere-scale atmospheric processes like the El-Nino Southern Oscillation (Swetnam and Betancourt 1998), and future changes in these processes are not yet well depicted in the global climate models. Nevertheless, the U.S. Environmental Protection Agency forecasts more frequent and severe droughts for the American Southwest in coming years (http://www.epa.gov/climatechange/impacts-adaptation/southwest.html). Breshears et al. (2003) suggested that the severe drought of the early 2000s was an example of a "global change type drought," i.e., the kind of drought and drought impacts that we can expect in a warmer future.

It has been suggested that the continuing increase in atmospheric CO2 may partially counteract the effects of lower precipitation and higher temperatures by increasing water-use efficiency of the plants, i.e., the amount of water that is lost as plants take in CO2 for photosynthesis. Leaf stomates must be open to take in CO2, but water is also lost through open stomates; if there is a greater concentration of CO2 in the atmosphere, adequate amounts theoretically can be absorbed with less opening of the stomates, meaning less water loss. However, the likely significance of this process in lessening drought impacts under future climates is unknown.

Two rigorous statistical analyses show that large fire years in recent decades in the western U.S. have also been years of above-average temperatures (Westerling et al. 2006, 2011). Several studies forecast increasing fire activity as the West becomes warmer in coming decades (e.g., Flannigan et al. 2009, Westerling et al. 2011).

III. Information Needs for Management Purposes

Throughout most of the 20th century, pinyon-juniper was largely viewed as a troublesome vegetation type. Although it had some utilitarian value for fence posts and fuel wood, the trees were too small to provide any real timber value, and the old woodlands produced little forage for livestock or big game. Consequently, much of the management emphasis in the 20th century was on control—even eradication—of pinyon and juniper. Hence the programs of chaining, planting non-native forage grasses, and the like, that were common during the 20th century.

In the last couple of decades, however, society has increasingly embraced the non-utilitarian values of native vegetation, including pinyon-juniper. Aesthetic and biodiversity values of pinyon-juniper vegetation are now widely acknowledged and appreciated. For example, in a recent report on the state of Colorado's biodiversity, prepared by the Colorado Natural Heritage Program and The Nature Conservancy, pinyon-juniper is highlighted as an important ecological system for biodiversity and conservation. Pinyon-juniper woodlands cover only 10% of the Colorado landscape but are home to 31% of the plant species in the "most threatened" categories (Rondeau et al. 2011; p. 9), along with numerous plant and animal species that are not threatened but are distinctive and largely restricted to this habitat. Pinyon-juniper on the Colorado Plateau is listed as a "weakly conserved" ecological system, as are its associated sagebrush and mountain shrub communities (Rondeau et al. 2011; p. 5).

Given this recent sea change in thinking about pinyon-juniper woodlands, I suggest (below) four high-priority information needs for management purposes. These suggestions are based on the assumption that commodity production will continue to be a high priority on the UP, but that conservation of high-quality woodlands and restoration of degraded woodlands will receive equal, or perhaps even slightly greater emphasis than commodity production in coming decades. (Of course, choosing management priorities is far outside the scope or intent of this report; rather the statement in this paragraph reflects what I perceive to be a predominant attitude of American society today.)

An excellent paradigm exists for guiding ecological restoration of southwestern ponderosa pine forests, and these ideas are being applied currently on the UP. However, techniques for restoration of pinyon-juniper woodlands and associated sagebrush and mountain shrub communities are only beginning to be developed. In many or most cases, restoring a degraded understory requires more emphasis and effort than modifying the canopy (Baker 2006, Shinneman et al. 2008, Shinneman and Baker 2009a, Floyd and Romme 2012).

Any new insights into the ecology of pinyon-juniper woodlands on the UP would be potentially useful, of course, but I have tried to select topics of immediate practical utility in managing this landscape. Note that I am focusing solely on ecological questions: I have not addressed any social or economic issues in this report, although those subjects obviously are also very important. The topics below are listed in what I think might be the order of priority, from most high to least high (I think they're all of high priority), but of course this ranking is merely a prompt for discussion among the stakeholders.

(1?) Legacies and Current Influence of Grazing in Woodlands with Sagebrush

Rationale: We know that livestock grazing has altered the structure and composition of woodlands containing sagebrush in the understory and of sagebrush-grasslands in many parts of the West. The most important effects have included reduced native herbaceous cover and diversity, increased non-native herbaceous cover and density, and loss of biotic soil crusts. Shinneman et al. (2008) showed that some of these changes have occurred in some places on the UP; additional observations suggest that grazing-related changes may be especially prevalent in sagebrush-grasslands and in pinyon-juniper woodlands with a sagebrush component. However, we do not have a good understanding of exactly where on the UP the most serious degradation has occurred, of the relative influence of grazing vs. other factors at any particular location, or how feasible it is to improve current conditions.

When talking about grazing effects, it is important to distinguish between persistent legacies of the very heavy grazing that occurred in the early and middle parts of the 20th century, and effects of current grazing practices that involve smaller numbers of animals and grazing restrictions dictated by the condition of the forage plants. Much or even most of the grazing-related "damage" that we may see today may hark back to those early days, rather than being a reflection of the impact of current grazing programs.

Objective: An extensive survey of current understory conditions in sagebrush-grasslands and in woodlands with a sagebrush component would locate specific places where plant communities are in good or poor condition. An examination of current and recent grazing records (e.g., numbers and kinds of livestock, seasons when grazing occurs, how the animals are transported to pastures and managed when they arrive) would help in distinguishing between legacies of early grazing and effects of current practices. A broad-scale map could then be developed using a modeling-GIS tool such as MAXENT (Elith et al. 2011), which identifies from the field data the combination of environmental characteristics that is most strongly associated with the phenomenon of interest, and then locates this combination in GIS layers to produce a map of expected locations through the landscape. Alternatively, logistic regression techniques could be used to generate a similar product.

This project would tell us just how extensive are the places that have been degraded by livestock grazing, and where those sites are located. In places where degraded conditions are found, a next step would be to develop specific restoration programs to bring affected stands back to a more desirable condition. [A restoration plan probably would be a separate project; it might involve, e.g., planting native seed to replace native species that have been lost, treating non-natives with herbicides (e.g., Baker et al. 2009), and/or modifying grazing protocols in an area. Where degraded conditions are found to be strongly related to current grazing, future grazing programs can be modified accordingly.]

Costs: A 2-person team could conduct the field work in 4 weeks; the lead investigator would need another 3 weeks to analyze the data and write a report. Approximate costs would be:

-- *Salaries*: 7 weeks for a lead investigator (who would need to be very familiar with local rangeland ecosystems and grazing systems, and with GIS-modeling techniques) … plus 2 weeks for a field assistant (who would not necessarily need to have the skills of the lead investigator)

-- *Travel*: 1000 miles in a rugged 4WD vehicle

-- *Housing*: This cost would be minimized if the team could camp for some of the field work, but some sort of housing would be needed if the team does not live locally.

-- *Materials & supplies*: software and computer costs; plus measuring tapes, clipboards, plant press, and other inexpensive incidentals

(2?) Vegetation Composition & Dynamics following Recent Fires

Rationale: We have indications that the plant communities in at least some recently burned areas are dominated by non-native plants rather than the "normal" post-fire native flora, and we know that we will almost certainly have more fire in coming decades, both wildfire and prescribed fire. But we do not know whether the altered composition we are seeing in some recently burned areas represents a long-persisting "degraded" state or only a transient and relatively insignificant phase in the long-term post-fire development. Nor do we know just what the major non-native species are in burns of different sizes, severities, or environmental contexts, or what proportion of recently burned areas is showing strongly altered composition as opposed to a "normal" flora. This kind of information would inform us as to whether post-fire vegetation development is in fact a serious problem that could call for management efforts to restore these burned areas, as well as the relative emphasis that should be placed on non-native plant invasion in planning and implementing prescribed burns.

Objective: A systematic survey of plant community composition in areas where UP pinyon-juniper vegetation has burned within the past 15-25 years would provide this information. The survey could be conducted in all such burned areas, or more practically, in a subset of those areas that represents the range of variation in elevation, substrate, topography, and size of burned patch. Note that the study by Shinneman and Baker (2009b) provides a good start on this project. However, Shinneman and Baker's study focused on cheatgrass per se, whereas this proposed new study would emphasize overall community composition in burned areas, and Shinneman and Baker collected their field data in 2003. Additional fires have burned since that time, and re-sampling of the same sites would provide insights into how community composition changes over decadal time scales.

Costs: A 2-person team could conduct the field work in 4 weeks; the lead investigator would need another 2 weeks to analyze the data and write a report. Approximate costs would be:

-- *Salaries*: 6 weeks for a lead investigator (who would need to be very familiar with the local flora, and would be competent in data analysis and report writing) … plus 4 weeks for a field assistant (who would not necessarily need to have the skills of the lead investigator)

-- *Travel*: 1000 miles in a rugged 4WD vehicle

-- *Housing*: This cost would be minimized if the team could camp for some of the field work, but some sort of housing would be needed if the team does not live locally.

-- *Materials & supplies*: measuring tapes, clipboards, plant press, and other inexpensive incidentals

(3?) Method for Estimating Tree Age from Visual Characteristics

Rationale: It is easy to distinguish very young from very old pinyon and junipers simply by looking at them, but middle-aged trees (ca. 50-150 years) can be difficult age on the basis solely of their size and growth form (see, for example, Figure 4). This is a problem when trying to determine whether an area is being transformed from shrubland or grassland into a new woodland through *expansion* of pinyon and/or juniper, or whether the place is actually a *persistent woodland* composed of small trees because of local site conditions. Throughout the West, well-intentioned but misguided "restoration" projects have sometimes destroyed old high-quality woodlands instead of removing trees from places where trees were actually expanding into non-woodland vegetation; this has occurred simply because the operators did not realize that small or sparse trees can be old and persistent. Estimating the magnitude of 20^{th}-century infill in persistent woodlands is also difficult because small trees can be quite old. Pinyon can be accurately aged using increment cores, but collecting cores is time-consuming; coring and cross-dating junipers is even more challenging.

Objective: A key to pinyon and juniper age, based on easily observed visual characteristics like branching structure and overall crown shape, would aid managers and researchers who need to evaluate local woodland age, history, and trajectory for a variety of purposes (e.g., identifying places of woodlands expansion, or magnitude of 20^{th} century infill). The key would be developed by sampling a set of pinyon and junipers that represent a range of ages and site conditions, and relating the accurate age of each tree (based on an increment core) to the tree's morphological characteristics. The key would contain verbal descriptions of key features to look for, plus abundant photographs. Huckaby et al. (2003) developed just such a key for estimating the age of ponderosa pine trees in the Front Range; that effort could serve as a model for this one.

Costs: One experienced person probably could do all of the sampling, analysis, and writing that would go into this project; however, two would be good to have just for safety in the field and for assistance with coring and cross-dating. The cost estimates below are based on two people:

-- *Salaries*: 6 weeks for a lead investigator (3 weeks of field work plus 3 weeks of analysis and writing) … plus 3 weeks for a field assistant (who would not necessarily need to have the skills of the lead investigator)

-- *Travel*: 500 miles in a 2WD vehicle

-- *Housing*: This cost would be minimized if the team could camp for some of the field work, but some sort of housing would be needed if the team does not live locally.

-- *Incidental materials & supplies*: digital camera, increment cores, microscope for cross-dating cores, clipboards and other incidentals

Figure 4. Estimating tree age from visual characteristics. (a) *Old tree* (pre-1880 origin) … indicated by the large bole diameter, high crown base, and flat top. (b) *Young tree* (post-1880) … indicated by the small stem diameter, crown extending to the ground, and round top. (c) *Tree of uncertain age* … large size suggests an old tree, but crown extending to the ground and round top suggest a young tree; this is the kind of tree for which we need a study and a key for field estimate of age.

(4?) Extent & Spatial Patterns of 20th Century Woodland Expansion

Rationale: We know the general environmental contexts in which 20th century woodland expansion has, and has not occurred in the Four-Corners and Colorado Plateau region, but we do not know the exact places where this process has occurred on the UP. Consequently, we do not know to what extent 20th century woodland expansion may have altered historical vegetation patterns on the UP, or how this ongoing process is likely to affect future vegetation pattern.

Objective: A map showing where 20th century woodland expansion has occurred would allow a quantitative estimate of how much expansion has occurred, and would identify the specific settings in which expansion has been most prevalent (i.e., the combination of elevation, substrate, and topography that is most strongly associated with tree expansion). This could be accomplished most effectively as a combination of field and modeling-GIS components. The field component would entail extensive reconnaissance to locate and characterize places where expansion has occurred; the field key to tree ages (described above) would be a necessary tool for this field work. The GIS component would employ a modeling-GIS tool such as MAXENT (Elith et al. 2011), which identifies from the field data the combination of environmental characteristics that is most strongly associated with the phenomenon of interest, and then locates this combination in GIS layers to produce a map of expected locations through the landscape. Alternatively, logistic regression techniques could be used to generate a similar product.

Costs: A 2-person team could conduct the field work in 3 weeks; the lead investigator would need another 3 weeks to conduct the modeling and write a report. Approximate costs would be:

-- *Salaries*: 6 weeks for a lead investigator (who would need to be very familiar with pinyon-juniper vegetation and with the modeling-GIS techniques) … plus 3 weeks for a field assistant (who would not necessarily need to have the skills of the lead investigator)

-- *Travel*: 1000 miles in a rugged 4WD vehicle

-- *Housing*: This cost would be minimized if the team could camp for some of the field work, but some sort of housing would be needed if the team does not live locally.

-- *Materials & supplies*: software and computer costs; plus measuring tapes, clipboards, and other inexpensive incidentals for field work

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V. Literature Cited

<u>Note</u>: References marked with an asterisk (*) are studies that were conducted exclusively or primarily on the UP per se.

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VI. Appendix: Previous assessments of UP Pinyon-Juniper

I am aware of three previous assessments of pinyon-juniper vegetation on all or a portion of the UP. Each of these previous assessments had a somewhat different perspective and objective than does this present assessment, and each remains useful, even though a considerable body of new information has become available since these were produced. Two other assessments have been made for a larger region that includes the UP but does not focus on the UP per se: the Comprehensive Analysis for the San Juan and the Grand Mesa-Uncompahgre-

Gunnison National Forests, Colorado (2006), and the Landscape Condition Analysis for the South-Central Highlands (2009).

A brief summary of the content and continuing utility of the three previous assessments that focused specifically on the UP is as follows:

A. Foster-Wheeler report (2002): An environmental consulting company (Foster-Wheeler) was commissioned to summarize and evaluate the UP's geology; climate; human history; vegetation, flora, and disturbance processes; terrestrial and aquatic wildlife; soils and erosion; and water quantity, quality, and uses. Pinyon-juniper is included along with all of the other major vegetation types in this very lengthy synthesis. Regarding pinyon-juniper, the report contains a great deal of useful background information, especially with regards to plateau geology, climate, human history, vegetation composition and distribution, and characteristic or sensitive flora and fauna. However, the report is not very useful in its treatment of pinyon-juniper disturbance regimes because it was written before any rigorous research had been conducted on this topic on the UP. As the authors of the report explicitly acknowledge, their information came from pinyon-juniper studies elsewhere, notably the Great Basin which we now know has a very different kind of pinyon-juniper ecosystem than that of the UP. Since release of the Foster-Wheeler report, a considerable body of rigorous research has been conducted on the UP and in nearby portions of the Colorado Plateau having similar ecology. Therefore, I recommend that the Foster-Wheeler report be used for background information, but not for understanding ecological processes and dynamics in UP pinyon-juniper.

B. Spring Creek / Dry Creek environmental assessment 2003: This document was prepared by the staff of the BLM Uncompahgre Field Office and GMUG National Forests, in cooperation with Colorado DOW, Public Lands Partnership, Uncompahgre Plateau Project, Western Area Power Administration, and Tri-State Power Cooperative. Its purpose is to provide the ecological basis for vegetation treatments (mechanical and prescribed fire) within two watersheds to improve ecological health, improve the vegetative mosaic, improve wildlife habitat, and to reduce hazardous wildfire fuels. The Spring Creek and Dry Creek watersheds are 5th level hydrologic units located on the southeast side of the UP, comprising a total area of approximately 255,712 acres. The assessment covers the full spectrum of vegetation types from the base of the UP to the top, but pinyon-juniper vegetation receives considerable emphasis. This document is a very useful source of background information on the UP in general, much of which is similar to the information in the Foster-Wheeler report, but the Spring Creek / Dry Creek environmental assessment is much more focused on this particular geographic portion of the UP. The Spring Creek / Dry Creek environmental assessment was prepared at a time when rigorous research on pinyon-juniper vegetation dynamics on the UP and Colorado Plateau was just beginning to appear, and the authors of the report did a nice job of going beyond Foster-Wheeler and incorporating this new thinking into their evaluation of the condition and dynamics of the UP's pinyon-juniper vegetation. Nevertheless, quite a lot of additional relevant research has been published subsequent to the release of the Spring Creek / Dry Creek environmental assessment. The implementation of the Spring Creek / Dry Creek project to date is summarized in the following tables (provided by Ken Holsinger).

Treatment Type	ACRES Treated (Completed & Partial)
Maturing/Rx Burn	483.8
Mech/Chem/Rx Burn	474.8
Mech/Matur/Chem	267
Mech/Matur/Rx Burn	1311.9
Mechanical	7939.9
Mechanical/Chemical	668.2
Mechanical/Maturing	1015.2
Mechanical/Rx Burn	5190.1
Patch Burn/Hand Cut	115.5
Rx Burn	928.7
Thin/Rx Burn	16.9
Thin/Rx Burn/Matur	388.3
Total	18800.3

Status as of 12/16/2013	Sum_ACRES
Completed	12098.2
Not Started	17375.4
Partially Completed	6702.1

C. RMLANDS 2005: RMLANDS (2005) is a stochastic landscape model that simulates disturbance and post-disturbance recovery of vegetation within a heterogeneous landscape. The model was parameterized on the basis of available information about pre-1900 disturbance regimes in this region. Its simulations were designed to provide a quantitative description of landscape structure dynamics for the pre-1900 reference period. The present distribution of age classes was then evaluated within this context to determine whether the current landscape is similar to or very different from historical landscape conditions. The results suggested that the current landscape structure of pinyon-juniper woodlands is considerably different from the historical structure; notably today's landscape appears less heterogeneous and appears to contain a greater proportion of older age classes.

However, two important limitations affected this analysis. First, historical landscape structure is an inherently difficult thing to measure quantitatively in this or almost any ecosystem, and so it could not be measured directly. Instead, it was inferred by simulating many centuries of fire and post-fire vegetation development. Thus, the picture of historical landscape structure was strongly influenced by the quality of the data on historical disturbance regimes (notably fire rotations and rates of transition from one post-fire stage to the next). The second limitation was the paucity of spatially explicit data on current stand ages across the landscape.

The only empirical information available at the time was preliminary data from the UP and surrounding region (Eisenhart 2004).

Research from the UP that was published after RMLANDS had been completed in 2005 (notably Shinneman and Baker 2009a) revealed that historical fire rotations in pinyon-juniper vegetation were substantially longer than what was simulated. Longer simulated fire rotations would have resulted in an older stand age distribution and a greater proportion of stands in the late-seral (tree-dominated) stage than was reported—meaning that the current landscape is more similar to the historical landscape than the original results suggested.

Despite these data-related shortcomings, RMLANDS is a powerful exploratory tool that could be used for future assessments of landscape structure, vegetation dynamics, wildlife habitat, and rare plant communities.