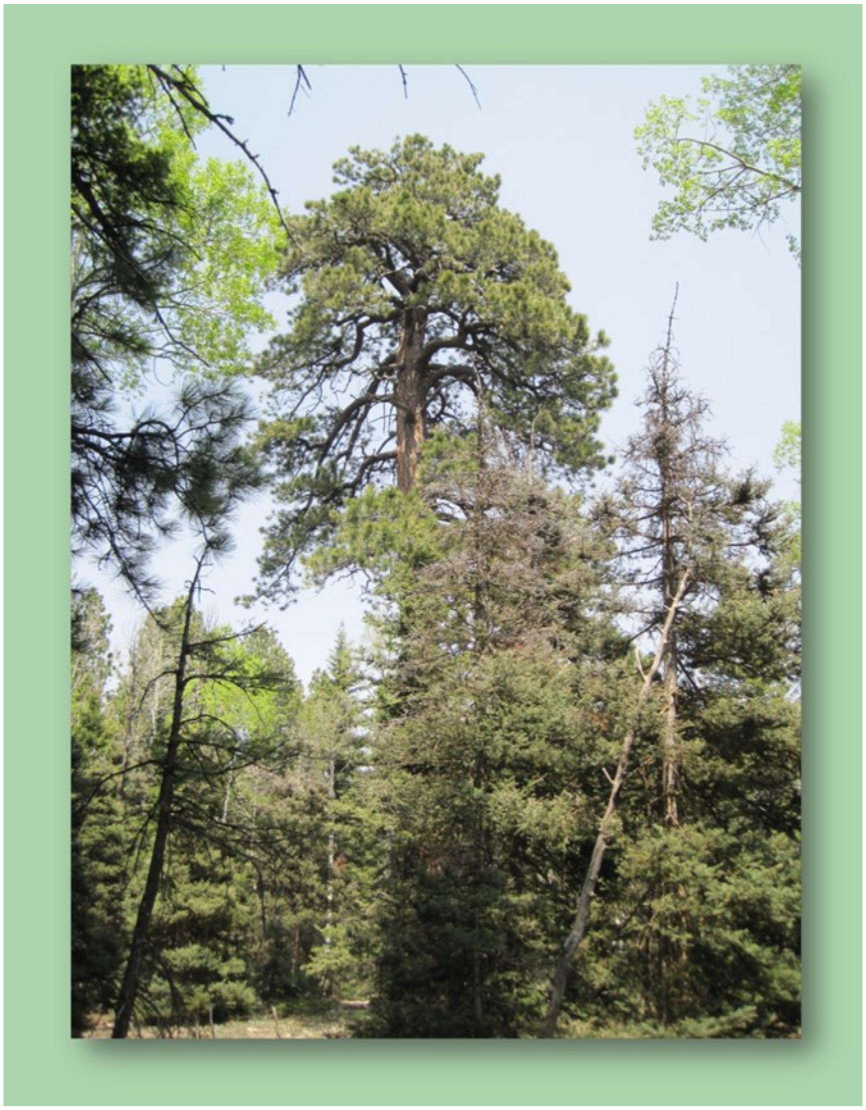
# *The Forests They Are A-Changin'*—
Ponderosa pine and mixed conifer forests on the Uncompahgre Plateau in 1875 and 2010-13



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COLORADO FOREST RESTORATION INSTITUTE
Colorado State University
FOREST SERVICE U S DEPARTMENT OF AGRICULTURE
USDA
THE UNCOMPAHGRE PLATEAU COLLABORATIVE RESTORATION PROJECT


Dedicated in loving memory of Lynn Hoyt,
long-time member, leader, and loyal friend of the
Uncompahgre Partnership and Public Lands Partnership.
In the eloquent words of Art Goodtimes,

*"She wasn't the kind to argue so much*
*as ask important questions…*
*A good citizen.*
*Wish we had more like her."*

# Summary

Knowledge of historical stand structure and composition is important for designing treatments and developing desired (or undesirable) conditions for forest restoration. Direct engagement of partners in collecting this type of data builds relationships, improves trust, and creates confidence in the results.

During summer 2012 and 2013, the Uncompahgre Partnership and undergraduates from Colorado State University collected data on historical and current forest conditions. We call this work “forestry forensics” because it involves searching for clues about historical forest conditions in the form of stumps, logs, snags, and old heritage trees. This work builds off an assessment of historical forest structure conducted by the Uncompahgre Partnership and Colorado Forest Restoration Institute in 2008 (Binkley and others 2008) and monitoring data collected in 2009 and 2010 (Keralis and others 2011).

Key findings from our assessment are as follows:

- One of the most dramatic changes over time is the reduction of small meadows (*i.e.*, openings). Today, the area covered by mini-meadows is less than half of what it was in 1875. Mini-meadows used to cover a larger portion of the forest than trees.
- We did not detect uniform spatial patterns (*i.e.*, even spacing between trees) for historical forest conditions. All plots in ponderosa pine and mixed-conifer forests showed spatial clustering of trees or random spatial patterns. Spatial clustering means that a majority of trees occur in groups of 2 or more. In contrast, random spatial patterns are characterized by several tree clumps as well as many scattered, single trees.
- Forest structure and composition on the Uncompahgre Plateau were highly variable in 1875 and are still highly variable today.
- Basal areas and tree densities ranged widely across landscape units, but there were no consistent differences among areas.
- Many forests of today contain 2-4 times more trees than they did in 1875. The largest increases are for small and medium- diameter trees (<12” dbh), but there are also a few more large-diameter trees per acre.
- Blue spruce (*Picea pungens)*, Engelmann spruce (*Picea engelmanni*), and subalpine fir (*Abies lasiocarpa*) are more abundant today than they were in the past, whereas ponderosas pine (*Pinus ponderosa*) and Douglas-fir (*Pseudotsuga* menziesii) are less abundant in some forests.
- The structural diversity that existed and exists in forests across the Plateau leaves room for creativity and flexibility in ecological restoration. It is appropriate to use a mix of approaches (thinning, burning, thinning and burning) to create a range of post-treatment basal areas and spatial patterns.
- Forest restoration treatments recently conducted on the Plateau have reduced stand densities, increased variability

within and between stands, and re-created clumped spatial patterns in many locations.

Several caveats accompany the information presented in this report. Our data only characterize trees with diameters ≥6". It was too time consuming to collect data on the density of small trees for current conditions, and it is likely that many small trees present in 1875 have died and decayed beyond recognition. In addition, we did not characterize historical densities of aspen (*Populus tremuloides*). This species has soft wood that rapidly decays, resulting in the disappearance of most aspen remnants from 1875. The same might be true for medium-diameter (6-12" dbh) subalpine fir.

We have more certainty in our estimates of historical tree densities and spatial patterns than our estimates of basal area. We had to assume a constant relationship between tree age and size to "grow back" the diameter of living trees and estimate the diameter of snags, logs, and stumps in 1875. This assumption introduces some error to our estimates of historical basal area. However, we believe the trends and overall distribution of basal areas are robust.

We hope that our data and interpretations can be useful to natural resource managers and their partners as they contemplate future management directions on the Uncompahgre Plateau. An enhanced understanding and appreciation of forest change and variability can provide a context for ecological restoration. Restoring the past is neither desirable nor possible, but information about historical forests can help us identify undesirable current conditions—conditions that we want to move forests away from through collaborative land stewardship.

*At left:* Members of the Uncompahgre Partnership prepare for a community workday in July, 2013. The purpose of the workday was to estimate historical forest structure and composition on the Plateau.

# Acknowledgements

This project was made possible by a coordinated effort of dedicated volunteers, interns, and agency partners. We appreciate your enthusiasm, hard work, and valuable insights. Big thanks to everyone who participated in community workdays to assess historical forest structure. We are grateful to undergraduate field technicians from Colorado State University and forestry interns from Montrose High School who conducted weeks of additional data collection. Colorado State University students Justin Ziegler and Steve Hasstedt generously shared their data and assisted with analysis. We appreciate financial support from the Warner College of Natural Resources, Colorado Forest Restoration Institute, and Uncompahgre Partnership.

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*Above:* Diverse ecosystems thrive on the Uncompahgre Plateau, including expansive grasslands and shrublands, magnificent aspen stands, and productive forests of ponderosa pine and mixed conifers.

## Background

*Changing forests across the West*—Many forests of the western United States bear a legacy of extensive livestock grazing from the early 1900s and a century of active fire suppression. These changes are especially apparent in ponderosa pine and dry mixed-conifer forests (Covington and Moore 1994; Fulé and others 1997; Reynolds and others 2013). Gone from these forests are frequent, low-severity fires that kill understory vegetation but leave canopy trees unscathed. Many ponderosa pine and dry mixed-conifer forests missed 2-3 fires over the past century (Romme and other 2008). However, some stands probably experienced long fire-free periods in the past, and several stands might have burned more often in the 20th century than previously.

Today, most wildland fires are suppressed. Those that escape beyond control often burn with high severity, causing high mortality to trees of all sizes. Large, high-severity wildfires are generally undesirable to forest users, including recreationists and some wildlife species. However, some moderately-sized patches of tree mortality are not unnatural or uncharacteristic of ponderosa pine and dry mixed-conifer forests. Mixed-severity fires occasionally visited these forests, killing patches of large trees (Sherriff and Veblen 2006).

The disruption of natural fire regimes in western forests has generally led to increased stand densities. Some mixed conifer forests on the Uncompahgre Plateau have basal areas that are almost three times greater than conditions in 1875 (Keralis and others 2011). There is a greater abundance of saplings and understory shrubs, both of which can carry surface fires into tree canopies. Dead pine needles, branches, and coarse woody debris have also accumulated on the forest floor (Covington and Moore 1994; Fulé and others 1997; Battaglia and Shepperd 2007).

These changes in forest structure increase fire hazards and the risk of active crown fires. Roccaforte and others (2008) modeled fire behavior for a landscape dominated by ponderosa pine in northwestern Arizona under severe weather conditions (*i.e.*, very high wind speeds and low humidity). They found that the area capable of supporting active crown fires increased from 0-500 acres in the 1870s to 1,300-2,400 acres in the mid-2000s.

*Above*: Small ponderosa pine, Douglas-fir, and subalpine fir trees have grown in the mini-meadows that once surrounded this large, heritage ponderosa pine.

Changes have also occurred in wet mixed-conifer forests, although potentially not as pronounced as in ponderosa pine or dry mixed-conifer forests. High-grade logging during the early 1900s probably resulted in more substantial changes to wet mixed-conifer forests than altered fire regimes. These forests occur at slightly higher elevations and in areas with greater annual precipitation. Wet conditions in these forests result in greater fuel moisture and lower fire frequencies (*e.g.,* many decades to centuries). Fuels are abundant in these forests, but fires can only build enough energy to spread under severely dry weather conditions. It is likely that wet mixed-conifer forests would have carried at least one fire over the past century if not for livestock grazing and fire suppression (Romme and others 2009).

*Collaborative forest restoration*—The Uncompahgre Plateau Collaborative Forest Landscape Restoration Project (CFLRP) is one of several nationally-funded projects to restore national forests through collaborative, science-based management. The goals of the Uncompahgre Plateau CFLRP are to "enhance the resiliency, diversity, and productivity of the native ecosystems on the Uncompahgre Plateau using best available science and collaboration." The collaborative group, referred to as the Uncompahgre Partnership, proposes to restore over 570,000 acres of the Uncompahgre National Forest. The project builds on two decades of collaboration among local citizens, the U.S. Forest Service, Colorado Division of Parks & Wildlife, Colorado Forest Restoration Institute, Public Land Partnership, Tri-State Generation & Transmission Co., off-road vehicle groups, and environmental organizations.

Most restoration activities of the Uncompahgre Plateau CFLRP are occurring in ponderosa pine and dry mixed-conifer forests. The Uncompahgre Plateau CFLRP seeks to restore ponderosa pine and mixed-conifer forests by addressing changes in forest structure and disturbance regimes. Specific

*At left:* The Uncompahgre Partnership advances collaborative forest restoration by learning together, working together, and adapting together. The U.S. Forest Service recognized the Partnership's exemplary work with the 2012 Chief's Award for Sustaining Forests and Grasslands.

goals for restoration in ponderosa pine and dry mixed-conifer forests are to: (1) reduce tree densities, especially in smaller size classes; (2) reduce surface fuels with prescribed burning or mechanical removal; and (3) create open spaces (*i.e.*, mini meadows) between groups of trees. Linked to these goals is the desire to enhance wildlife habitat and to return low- and moderate-severity fires to the landscape.

Effective forest restoration builds on a clear understanding of historical and current forest conditions, as well as clear ideas about undesirable risks and approaches to mitigate risks. Here we summarize ecological knowledge accumulated by the Uncompahgre Partnership on historical forest structure and composition. This data, along with the team spirit established through citizen-science workdays, have helped the Partnership develop consensus on how to move ahead with forest restoration.

<u>*Taking snap shot of the past*</u>—Several caveats accompany the information presented in this report. Historical reconstructions provide a snapshot of conditions existing at one point in time. However, forest landscapes are dynamic and ever changing. Widespread fires occurred in 1842 and 1879 across large swaths of the Plateau. Therefore, our historical estimates of forest structure and composition might reflect ongoing recovery from large wildfires. Managers and community members should keep this in mind when planning future restoration projects. Our estimates of historical structure and composition represent conditions that existed on the Uncompahgre Plateau, but they do not represent all conditions that occurred in ponderosa pine and mixed-conifer forests over the past several centuries.

Our data only characterize trees with diameters ≥6”. It was too time consuming to collect data on small trees for current conditions, and it is likely that many small trees present in 1875 have died and decayed beyond recognition. In addition, we did not characterize historical densities of aspen. This species has soft wood that rapidly decays, resulting in the disappearance of most aspen remnants from 1875. The same might be true for medium-diameter (6-12” dbh) subalpine fir.

We have more certainty in our estimates of historical tree densities and spatial patterns than our estimates of basal area. We had to assume a constant relationship between tree age and size to “grow back” the diameter of living trees and estimate the diameter of snags, logs, and stumps in 1875. This assumption introduces some error to our estimates of historical basal area. However, we believe the trends and the overall distribution of basal areas are robust.

## Approach

During summer 2012, we characterized current and historical conditions in 14 plots in ponderosa pine forests, 12 in dry mixed-conifer, and 11 in wet mixed-conifer. Three plots were on Kelso Mesa, and the rest were in the Escalante project area (Fig. 1). We characterized stand types based on the abundance of ponderosa pine, Douglas-fir, and Engelmann spruce (Table 1).

Our methods for characterizing historical (circa 1875) forest structure closely followed those of Binkley and others (2008). We measured diameter at breast height (dbh) and determined the location of live heritage trees (≥150 years old), snags, stumps, and logs in 164 ft. x 164 ft. plots (*i.e.*, 1/2-acre). We also estimated the time since death for snags, stumps, and logs. Aspen were excluded from the historical assessment because we expect that aspen logs may have decayed beyond recognition over the past century. Trees of questionable

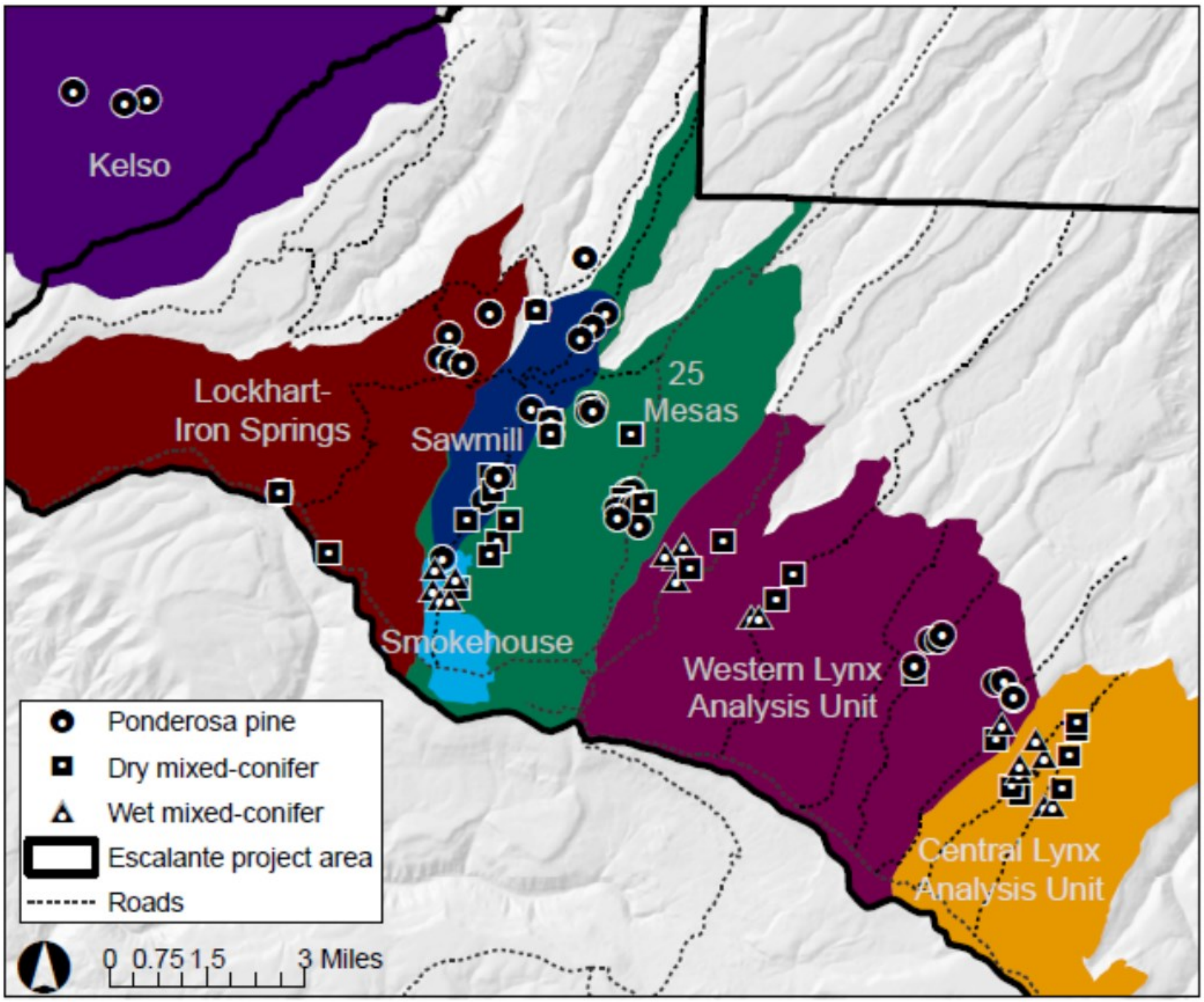



***Figure 1.*** Location of the 99 sample plots for forestry forensics work on the Uncompahgre Plateau. Colored regions represent landscape units in the Escalante project area.

***Table 1.*** We categorized stands into three forest types (ponderosa pine, dry mixed-conifer, and wet mixed-conifer) based on the abundance of ponderosa pine, Douglas-fir, and Engelmann spruce.

| Stand type | Ponderosa pine | Douglas-fir | Engelmann spruce |
|---|---|---|---|
| | | *Percentage of basal area in 1875* | |
| **Ponderosa pine** | >50 | <25 | <20 |
| **Dry mixed-conifer** | <75 | >25 | <50 |
| **Wet mixed-conifer** | <5 | <50 | >40 |

***Table 2.*** Data collected from 2008-2013 on current, historical, and/or post-treatment conditions on the Uncompahgre Plateau. Current conditions were collected in untreated stands and post-treatment conditions from recently treated stands.

| Sampling year(s) | Data collected | Ponderosa pine | Dry mixed-conifer | Wet mixed-conifer |
|---|---|---|---|---|
| | | | *Number of plots* | |
| 2012 & 2013 | Current and historical | 14 | 12 | 11 |
| 2008 | Historical only | 14 | 12 | 0 |
| 2009 & 2010 | Current only | 9 | 3 | 6 |
| 2012 | Post-treatment only | 9 | 2 | 0 |
| 2013 | Pre- and post- treatment | 3 | 3 | 1 |
| | **Total** | 49 | 32 | 18 |

ages were cored and aged in the lab so we could determine if they were alive in 1875. We also determined current forest structure and composition by conducting four point- samples with a 20 basal-area-factor prism.

This summary includes data collected in 2008 on historical conditions (Binkley and others 2008) and in 2009 and 2010 on current conditions (Keralis and others 2011). In addition, we present data collected on post-treatment conditions by the Colorado Forest Restoration Institute and CSU student Justin Zeigler in 2012-13 (Table 2).

Our reconstruction of historical structure required estimation of tree sizes in 1875. We improved on the relationships developed by Binkley and others (2008) by collecting and aging many additional trees. We determined the relationship between tree size and age (Fig. 2) to estimate the size of snags, stumps, and logs in 1875. We developed a relationship between dbh in 1875 and 2012 of large heritage trees (Fig. 3) to grow back living trees.

Our estimates of historical basal area are lower than those reported by Binkley and others (2008). This earlier work had fewer trees for estimating the relationship between tree sizes and ages. We re-estimated basal areas from data collected by Binkley and others (2008) using our relationship between tree sizes and ages (Fig. 2).

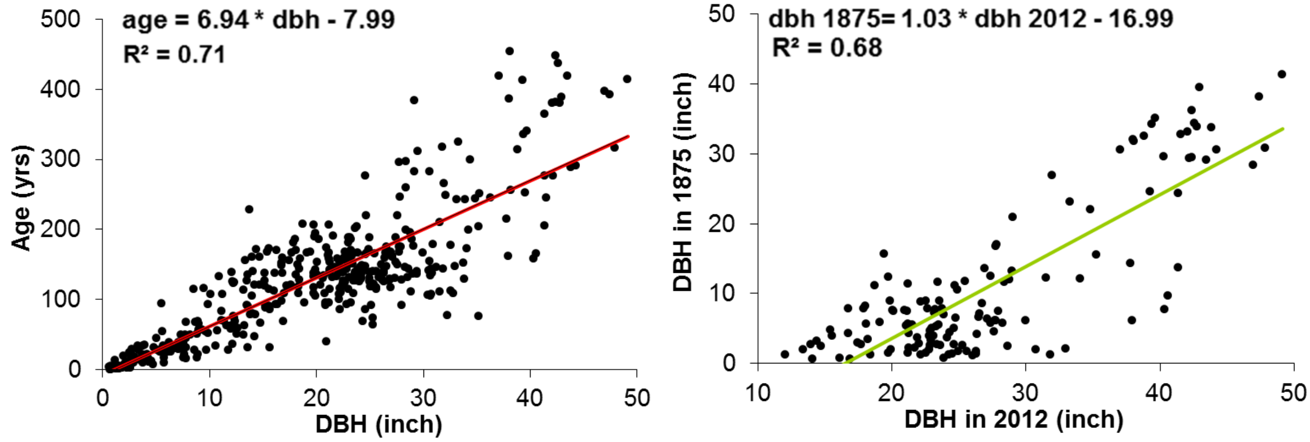



***Figure 2.*** We used the relationship between tree diameter and age to estimate the diameter of stumps, logs, and snags in 1875 (graph at left; n = 275 conifer trees) and the relationship between dbh in 2012 and 1875 to estimate the diameter of living trees (graph at right; n = 138 conifer trees ≥150 years old).

We analyzed historical and current spatial patterns for the plots where we mapped tree locations to a precision of +/- 3 ft. We used Ripley's K function[1] to determine whether conifer trees with dbh ≥6" were uniformly spaced, randomly located within sample plots, or clustered into groups (Fig. 3) . We followed the approach of Lydersen and others (2013) by (1) accounting for edge effects, (2) using the square root transformation (*i.e.*, L-function), and (3) assessing spatial patterns at distances ≤25% of the shorted plot length (about 40 ft.).

We also used the methods of Lydersen and others (2013) to determine the (1) number of trees in groups, (2) size of mini-meadows between tree groups, and (3) percent openness (*i.e.*, 100% – canopy cover). We defined tree groups as consisting of two or more trees ≤20 ft. apart, a reasonable estimate of crown width for ponderosa pine trees (Sánchez Meador and others 2011). Mini-meadows were defined as areas not under tree crowns (*i.e.*, ≥10 ft. away from trees) and at least 40 ft. in width. These specifications made mini-meadows at least as wide as the crown of very large conifer trees (Lydersen and others 2013). We could only estimate the minimum size of mini-meadows because about 90% of these open areas extended beyond the edge of our plots.

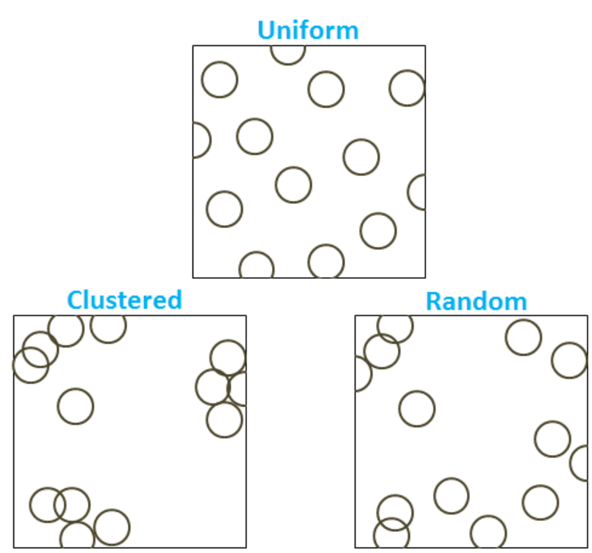



***Figure 3.*** An example of uniform, random, and clustered spatial patterns. Trees are evenly spaced under uniform spatial patterns. Spatial clustering means that a majority of trees occur in groups of 2 or more. In contrast, random spatial patterns are characterized by several trees in clumps as well as many scattered, single trees.

[1]Ripley's K determines the number of trees occurring within different distances of each other and then compares this distribution to one arising from a random scattering of trees across the plot.

## Findings for ponderosa pine forests

<u>*Spatial patterns*</u>—Trees were not uniformly spaced in 1875 for any of our plots in ponderosa pine forests. Uniform spatial patterns were only evident for one plot in 2010-13.

About 75% of our plots in ponderosa pine (19 of 26 plots) had random spatial patterns in 1875 (conifers with dbh ≥6"). Random spatial patterns occur when some trees are located in clumps, and others occur as single trees variably spaced across the plot. Clustering was apparent at the other 25% of ponderosa pine plots. Four of these plots exhibited spatial clustering between 1 to 15 ft. (*i.e.*, trees in groups were located 1 to 15 ft. apart), and the other three sites demonstrated clustering between 15 to 40 ft.

Random and clustered spatial patterns were also evident for current conditions. Two of four plots had clustered patterns, one showed random spatial patterns, and one had a uniform pattern.

*Above:* A clump of heritage ponderosa pine trees and a mini-meadow in a ponderosa pine forest on the Uncompahgre Plateau.

The percentage of single trees declined substantially between 1875 and 2010-13, whereas the number of tree groups and the size of these groups increased. Over half of trees stood as isolated individuals in 1875 (average of 60%, range of 35-100% of trees) compared to less than a third of trees in 2010-13 (average of 30%, range of 10-40% of trees). The remaining trees were clustered into about 3 groups/acre in 1875 (range of 0-10 groups/acre) and about 10 groups/acre in 2010-13 (range of 7-13 groups/acre). The average size of groups was about 3-4 trees/group for both time periods, but there were more groups with ≥5 trees in 2010-13 (Fig. 4).

Mini-meadows covered about 70% of the area in ponderosa pine plots in 1875 (range of 55-90%). We estimate that plots con-

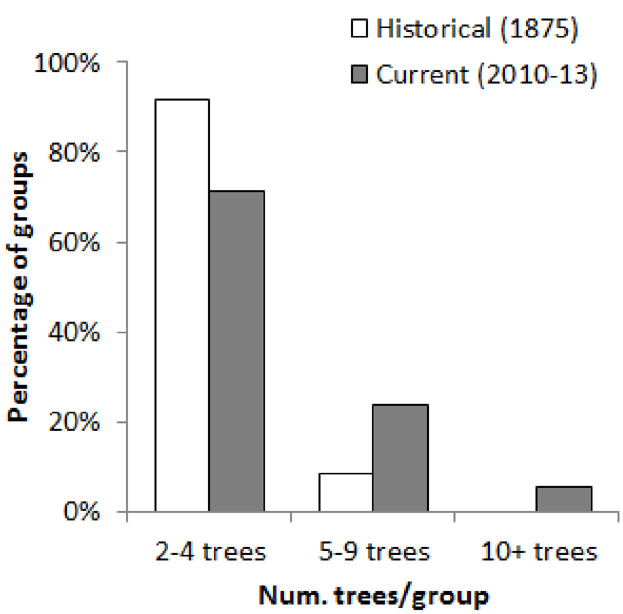



***Figure 4.*** Prevalence of tree groups by size class across plots in ponderosa pine forests in 1875 (n=47 groups across 22 plots) and 2010 -13 (n= 25 groups across 4 plots).

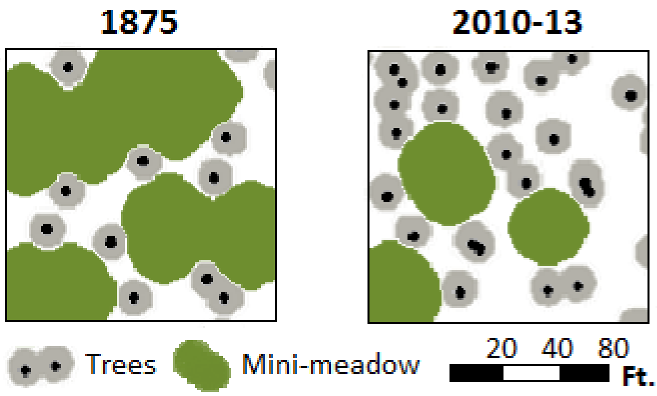



***Figure 5****.* Arrangement of trees and mini-meadows in 1875 and 2010-13 for a plot in ponderosa pine on Sawmill Mesa.

tained 2-5 meadows/acre, with openings averaging at least a quarter of an acre in size. These open areas were likely occupied by grasses and forbs, Gambel oak (*Quercus gambelii*), or aspen. Aspen groups usually contain 2-4 trees (see pg. 24), which would cover an area of about 0.01-0.03 acres, depending on crown width. Therefore, it is unlikely that aspen groups completely filled these mini-meadows.

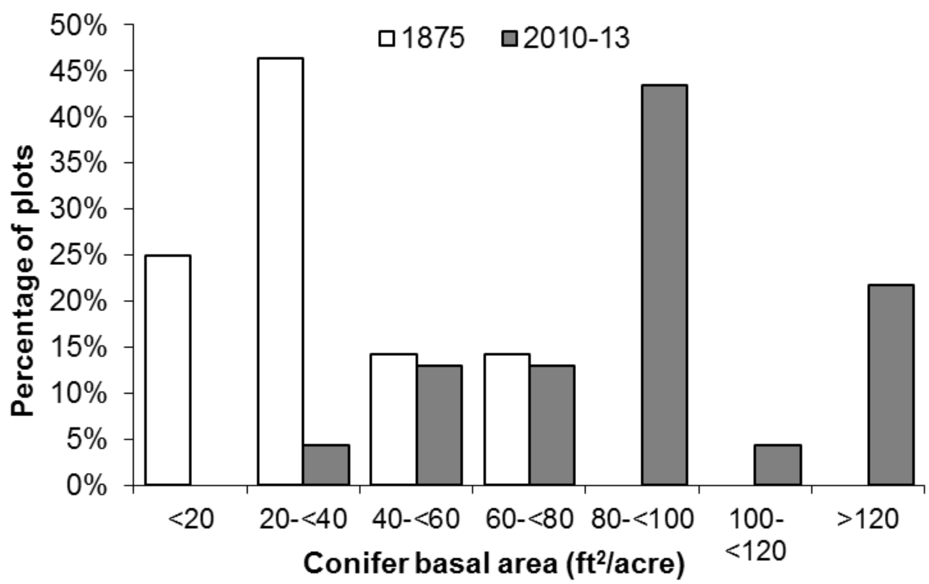
Forest openness and mini-meadows declined over the century as tree densities increased. By 2010-13, forest openness only averaged 25% of plot area (range of 20-45%). The number of mini-meadows increased to 4-7/acre, but these meadows were more fragmented and smaller (Fig. 5), averaging ≥0.06 acres in size.

*Conifer basal area*—Ponderosa pine forests we sampled had an average basal area of 35 $ft^2$/acre (range of 10-70 $ft^2$/acre) in 1875 for conifer trees with dbh ≥6". These estimates are at the lower end of historical basal areas reported for ponderosa pine forests in the southwest (50% of estimates fall between 40-70 $ft^2$/acre; Reynolds and others 2013).

The average conifer basal area more than doubled to 90 $ft^2$/acre by 2010-2013 (range of 35-180 $ft^2$/acre) (Fig. 6). Current conditions in 7 of 23 plots fall within the historical range of basal area, whereas the other 16 are well outside that range.

*Tree density and distribution of size classes*
The average density of conifer trees (dbh ≥6") increased from 20 trees/acre in 1875

***Figure 6****.* Distribution of conifer basal area for plots in ponderosa pine forests in 1875 (n = 28 plots) and 2010-13 (n = 23 plots). Estimates only include trees with dbh ≥6".



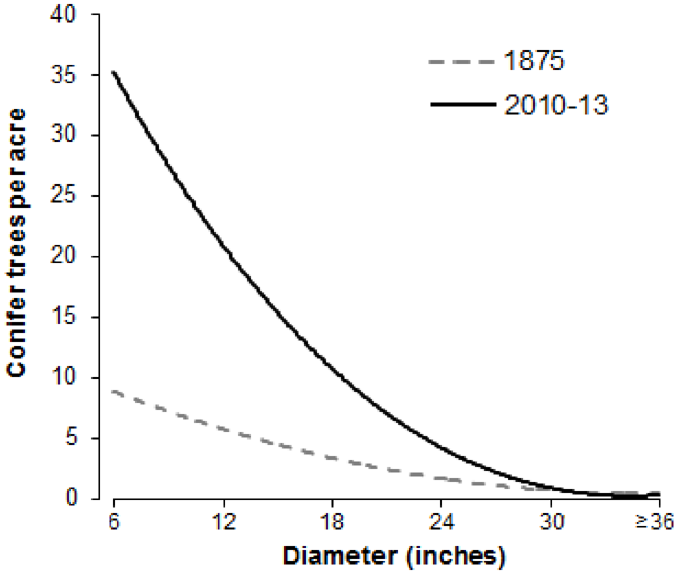



***Figure 7**.* Distribution of conifer tree density by size class for plots in ponderosa pine forests in 1875 and 2010-13.

*Above:* Ponderosa pine forest with several heritage trees and numerous younger, small ponderosa pines.

(range of 5-50 trees/acre) to 70 trees/acre in 2010-2013 (range of 10-200 trees/acre). Historical tree densities on the Uncompahgre Plateau are also on the lower end of historical values reported for ponderosa pine forests in the southwest (50% of estimates fall between 25-55 trees/acre; Reynolds and others 2013).

Conifer density was relatively the same in 1875 and 2010-2013 in three of the 14 plots where we measured both historical and current conditions. Conifer density increased by about 10 trees/acre in two of these plots, and increased between 30-60 trees/acre in nine plots. Increases in average tree density from 1875 to 2010-2013 occurred for every diameter class <30" and remained relatively unchanged for trees with dbh ≥30" (Fig. 7).

*Variation among treatment units*—Variation in historical basal area and tree density were high across landscape units (Fig. 8). However, there were no consistent and significant differences among landscape units in basal area or tree density. Both historical tree density and basal area showed no trends with elevation, latitude, or longitude.

*Species composition*—Average species composition in ponderosa pine plots was similar in 1875 and 2010-2013 (Fig. 9). More than 70% of conifer basal area was ponderosa pine for both time periods, with minor components of subalpine fire, Engelmann spruce, blue spruce, and Douglas-fir. However, 50% of plots (7 of 14) experienced declines in the abundance of ponderosa pine and increases in Douglas-fir, blue spruce, Engelmann spruce, and/or subalpine fir. The average percentage of basal area represented by conifer species other than ponderosa pine increased from about 10% in 1875 (range of 0 to 50%) to about 25% in 2012 (range of 0 to 80%).

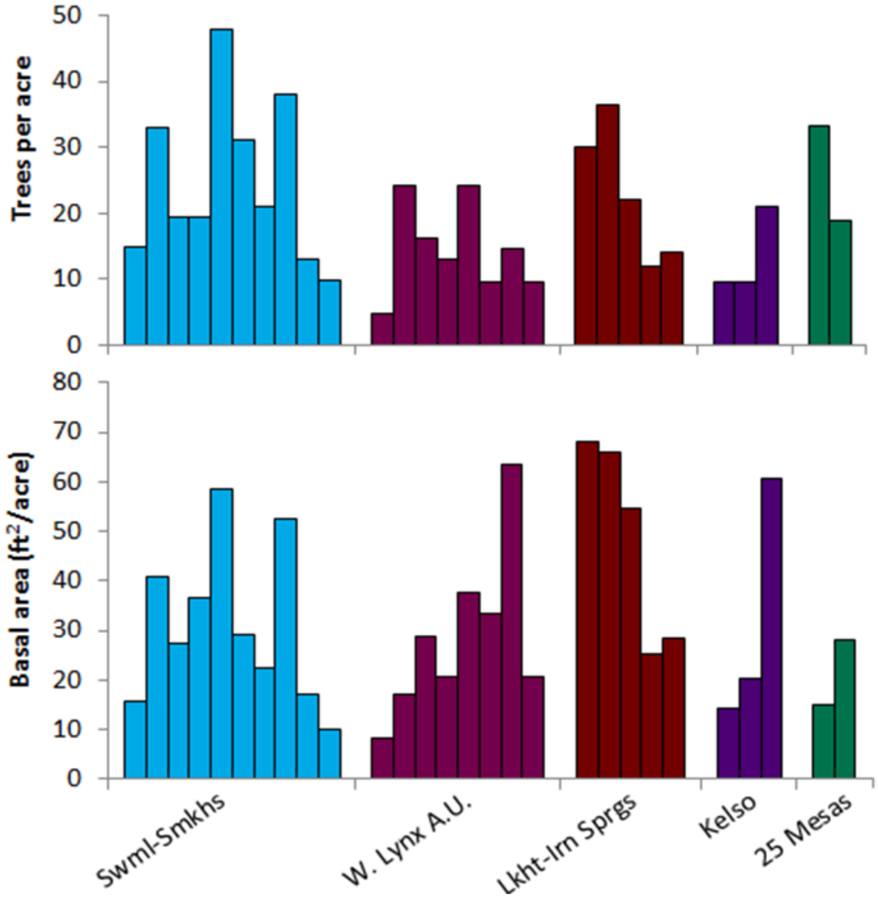



***Figure 8:*** Historical trees per acre and basal area for individual plots in ponderosa pine forests across five landscape units in the Escalante Project Area (see Fig. 1 for location of units). Plots are ordered by increasing elevation.

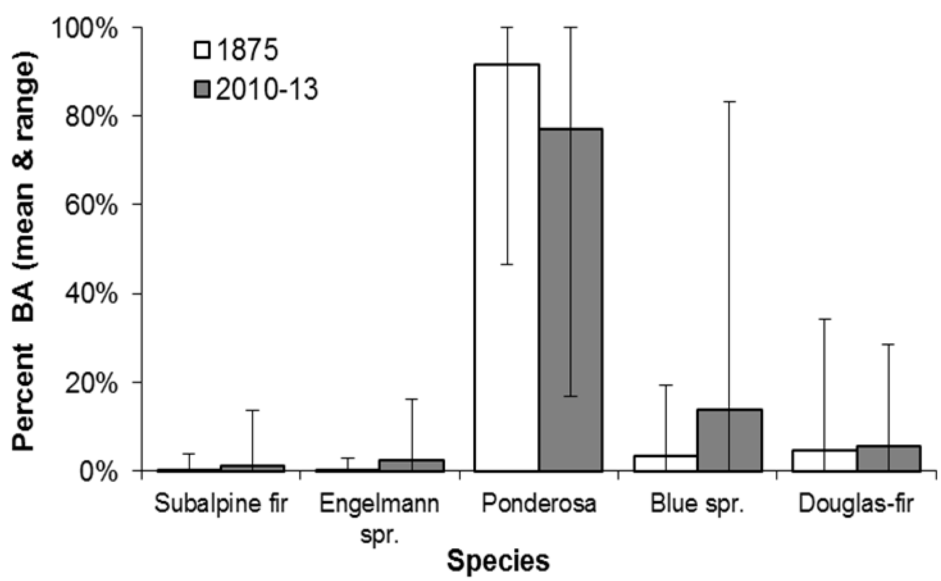



***Figure 9.*** Average (+/- minimum and maximum) percent of basal area (BA) for plots in ponderosa pine forests represented by different conifer species in 1875 and 2010-13.

## Findings for dry mixed-conifer forests

*Spatial patterns*—No plots in dry mixed-conifer showed a uniform distribution of trees for historical conditions. This was also true for current forest conditions.

Clustering of conifer trees (dbh ≥6”) was more common in 1875 on dry mixed-conifer plots than on ponderosa pine plots. Almost half of dry-mixed conifer plots (11 of 24) had trees clustered between 1 to 40 ft. Small-scale clustering (<15 ft.) was observed at one-fifth of plots. The other 55% of plots (13 of 24) showed random spatial patterns, meaning there were many scattered singled trees, along with several tree groups.

Clustering was evident at 40% of plots (2 of 5) that we stem mapped for current conditions. Trees were randomly scattered across the other three plots.

The percentage of single trees declined substantially between 1875 and 2010-13. However, the number of tree groups and the size of these groups increased. Half of the trees stood as isolated individuals in 1875 (average of 50%, range of 20-100% of trees) compared to less than a fifth of trees in 2010-13 (average of 15%, range of 5-45% of trees). The remaining trees were clustered into about 5 groups/acre in 1875 (range of 0-13 groups/acre) and about 12 groups/acre in 2010-13 (range of 7 to 16 groups/acre). The average size of groups was smaller in 1875 (about 3 trees/group) than in 2010-13 (about 7 trees/group) (Fig. 10).

*Above* A clump of heritage ponderosa pine and Douglas-fir trees in a dry mixed-conifer forests on the Uncompahgre Plateau.

Mini-meadows covered about 65% of the area in dry mixed-conifer plots in 1875 (range of 45-80%). These open areas were likely occupied by grasses and forbs, Gambel oak, or aspen. We estimate that stands contained 2-7 meadows/acre, with open-

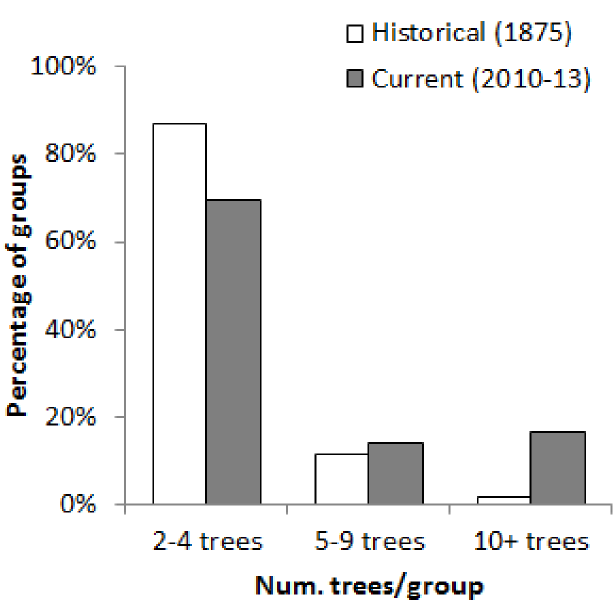



***Figure 10.*** Prevalence of tree groups by size class across plots in dry mixed-conifer forests in 1875 (n=62 groups across 22 plots) and 2010-13 (n= 36 groups across 5 plots).

ings averaging at least a fifth of an acre in size.

Stand openness and mini-meadows declined over the century as tree densities increased. By 2010-13, stand openness averaged only 25% (range of 5-70%). The number of mini-meadows decreased to 2/acre, and these meadows were more fragmented and slightly smaller, averaging ≥0.15 acres in size.

<u>*Conifer basal area*</u>—The average basal area of conifers in dry mixed-conifer forests increased from about 40 $ft^2$/acre in 1875 to about 80 $ft^2$/acre in 2010-13 (Fig. 11). Our historical estimates of basal area are on the lower end of values reported for dry mixed-conifer forests in the southwest (50% of estimates fall between 55-90 $ft^2$/acre; Reynolds and others 2013). Low basal area of conifers might reflect an on-going recovery from widespread fires that occurred in 1842 and 1879, underscoring the limitation of any single snap-shot year for characterizing landscape patterns.

Current basal areas at 60% of our plots fall within the historical range, but the basal areas at the other 40% of plots are well outside that range. Stand basal areas were also much more variable in 2010-13. The range increased by about 130% between 1875 (range of 10 to 100 $ft^2$/acre) and 2010-13 (range of 0 to 210 $ft^2$/acre). From 1875 to 2010-13, basal area of conifers more than doubled in 5 of 12 plots where we measured both historic and current conditions. Basal areas in three plots declined by a third or more between 1875 and 2010-13.

Two of the plots experiencing declines in conifer basal area also showed evidence of logging. These harvests occurred about 75 years ago and removed large diameter Douglas-fir and ponderosa pine trees. Aspen nearly dominated one of these stands by 2012, likely due to reduced conifer competition after logging.

<u>*Tree density and distribution of size classes*</u>— The average density of conifer trees (dbh ≥6”) increased from 30 trees/acre in

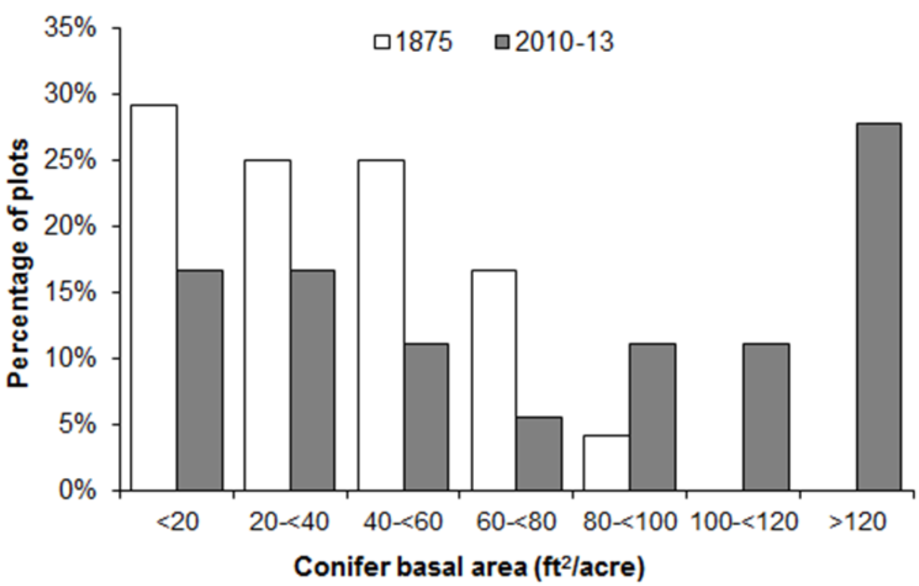



***Figure 11***. Distribution of conifer basal area for plots in dry mixed- conifer forests in 1875 (n = 24 plots) and 2010-13 (n = 18 plots). Estimates only include trees with dbh ≥6”.

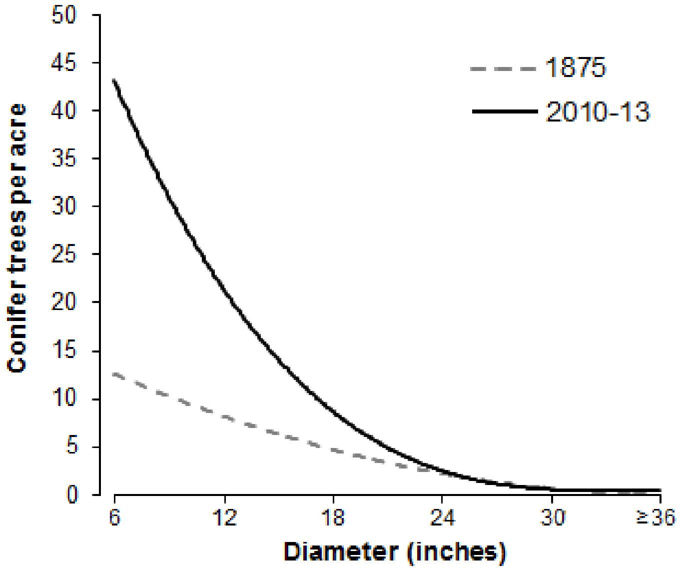



***Figure 12.*** Distribution of conifer tree density by size class for plots in dry mixed-conifer forests in 1875 and 2010-13.

*Above*: Dry mixed-conifer forests contain a variety of conifer species, with ponderosa pine and Douglas-fir being the most common.

1875 (range of 10-60 trees/acre) to 75 trees/acre in 2010-13 (range of 0-210 trees/acre). Our historical estimates of tree density are also on the lower end of the range reported for dry mixed-conifer forests in the southwest (50% of estimates fall between 40-65 trees/acre; Reynolds and others 2013).

Between 1875 and 2010-13, conifer density (dbh >6") increased by more than 50 trees/acre in 4 of 12 plots where we measured both historic and current conditions. Conifer density increased by 15-45 trees/acre in five plots, was unchanged in one plot, and declined by about 15 trees/acre in two plots. The average number of conifer trees/acre increased between 1875 and 2010-13 for all diameter classes <24", but densities of larger trees were relatively unchanged (Fig. 12).

*Variation among treatment units*—Variation in historical basal area and tree density were high within landscape units (Fig. 13). However, there were no consistent and significant differences among landscape units in basal area or tree density. Both historical tree density and basal area showed no trends with elevation, latitude, or longitude.

*Species composition*—The average species composition in dry mixed-conifer stands became more diverse between 1875 and 2010-13 (Fig. 14). Ponderosa pine and Douglas-fir comprised over 95% of conifer basal area in 1875 (range of 80 to 100%) but just under 60% in 2010- 2013 (range of 0 to 100%).

In contrast, subalpine fir and Engelmann spruce increased in relative abundance, from an average of 5% (range of 0 to 20%)

in 1875 to 40% (range of 0 to 100%). The large increase in abundance of these species might be attributable to reduced competition from Douglas-fir and ponderosa pine following changes in livestock grazing, fire regimes, and/or forest management. At the same time, we might have slightly under-estimated the abundance of subalpine fir in 1875 if some remnants already decayed by the time of our sampling.

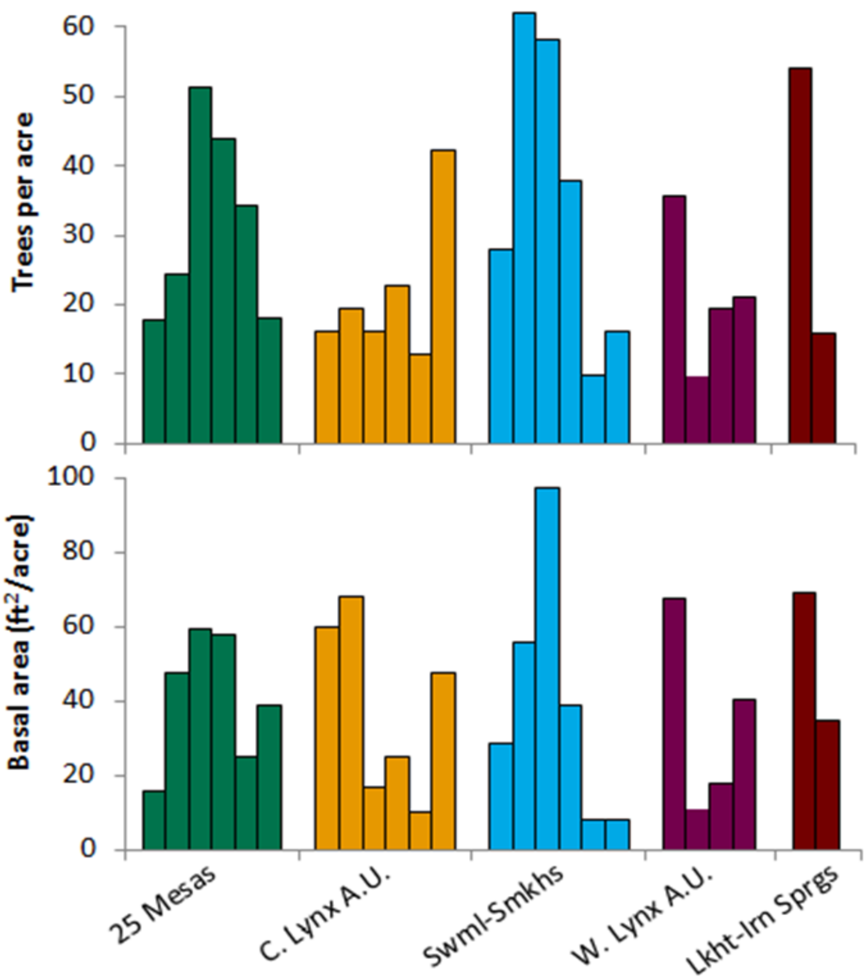
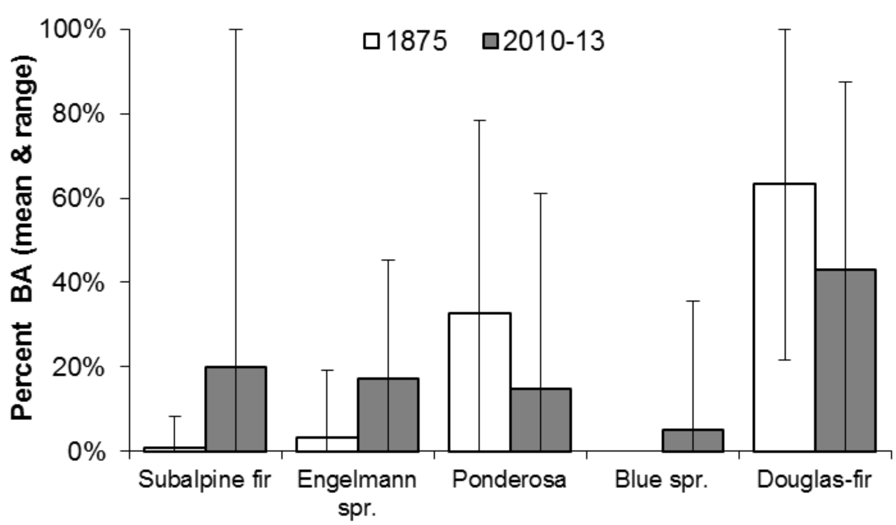



***Figure 13:*** Historical trees per acre and basal area for individual plots in dry mixed-conifer forests across five landscape areas in the Escalante Project Area (see Fig. 1 for location of units). Plots are ordered by increasing elevation.

***Figure 14****.* Average (+/- minimum and maximum) percent of basal area (BA) for plots in dry mixed-conifer forests represented by different conifer species in 1875 and 2010-2013.



## Findings for wet mixed-conifer forests

*Above*: Wet mixed-conifer forests are characterized by the presence of Engelmann spruce. Douglas-fir and subalpine fir are also common occupants.

<u>*Spatial patterns*</u>—Just as with the other forest types, no plots in wet mixed-conifer showed a uniform distribution of trees. This was true for historical and current forest conditions.

About 70% of plots (5 of 7) in wet mixed-conifer forests had random spatial patterns in 1875 (conifers with dbh ≥6"). Random spatial patterns occur when some trees are in clumps and others stand as isolated individuals, with variable distances between them. Clustering was apparent at the other 2 plots in wet mixed-conifer forests. One of these plots exhibited tree clustering at short distances (*i.e.*, trees in groups were located 1 to 15 ft. apart) and the other plot showed clustering at moderate distances (30-45 ft.).

Clustering was evident at 2 of the 3 plots we stem mapped for current conditions. Tree clustering on these sites occurred between 15 to 45 ft. A random spatial pattern was evident at the other wet mixed-conifer site.

The percentage of single trees declined substantially between 1875 and 2010-13, whereas the number of tree groups and the size of these groups increased (Fig. 15). Over half of trees stood as isolated individuals in 1875 (average of 70%, range of 15-100% of trees) compared to only a tenth of trees in 2010-13 (average of 10%, range of 5-15% of trees). The remaining trees were clustered into about 4 groups/acre in 1875 (range of 0 to 13 groups/acre) and about 16 groups/acre in 2010-13 (range of 13-20 groups/acre). The average size of groups was smaller in 1875 (about 3 trees/group) than in 2010-13 (about 5 trees/group), and

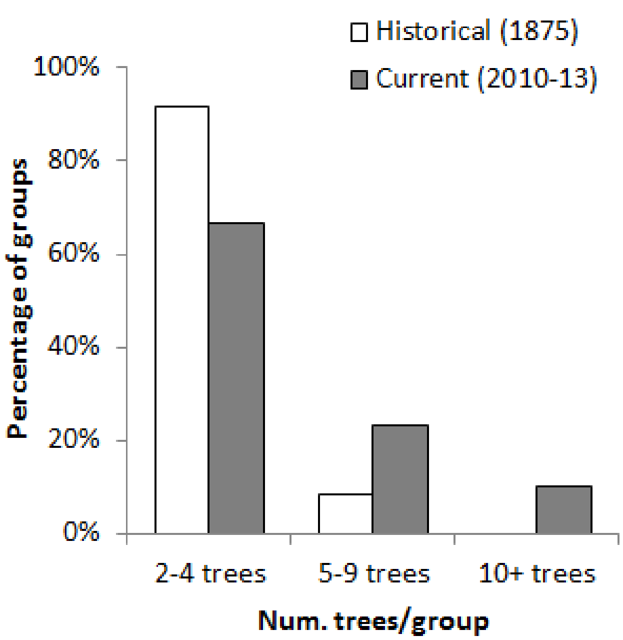



***Figure 15***. Prevalence of tree groups by size class across plots on wet mixed-conifer forests in 1875 (n=24 groups across 11 plots) and 2010-13 (n= 30 groups across 3 plots).

larger clumps were more abundant in 2010-13 (Fig. 13).

Mini-meadows covered about 70% of the area in wet mixed-conifer plots in 1875 (range of 25-85%). These open areas were likely occupied by grasses and forbs, Gambel oak, or aspen. We estimate that plots contained 2-5 meadows/acre, averaging at least a quarter of an acre in size.

Forest openness and mini-meadows declined over the century as tree densities increased. By 2010-13, forest openness averaged only 20% of plot area (range of 15-30%). The number of mini-meadows slightly increased to 3-5/acre, but these meadows were more fragmented and smaller, averaging ≥0.05 acres in size.

*Conifer basal area*—Average conifer basal area on wet mixed-conifer forests more than quadrupled from 20 ft$^2$/acre in 1875 to 90 ft$^2$/acre in 2010-13 (Fig. 16). The range of conifer basal areas was highly variable in both 1875 (range of 1 to 90 ft$^2$/acre) and 2010-13 (30 to 225 ft$^2$/acre). The mean estimate of basal area for 1875 is surprisingly low for the wet mixed-conifer forest type, but it is important to remember that this estimate excludes aspen. Low basal area of conifers might also reflect an ongoing recovery from widespread fires that occurred in 1842 and 1879, underscoring the limitation of any single snap-shot year for characterizing landscape patterns.

Between 1875 and 2010-13, basal area of conifers more than doubled in 9 of the 11 plots where we measured both historical and current conditions. Basal area decreased 25-50% in the other two plots. The plots with lower conifer basal area in 2010-13 showed evidence of logging about 75 years ago. The harvests targeted large diameter Douglas-fir and Engelmann spruce trees.

*Tree density and distribution of size classes*—The average density of conifer trees (dbh ≥6”) increased from 20 trees/acre in 1875 (range of 5-55 trees/acre) to 90

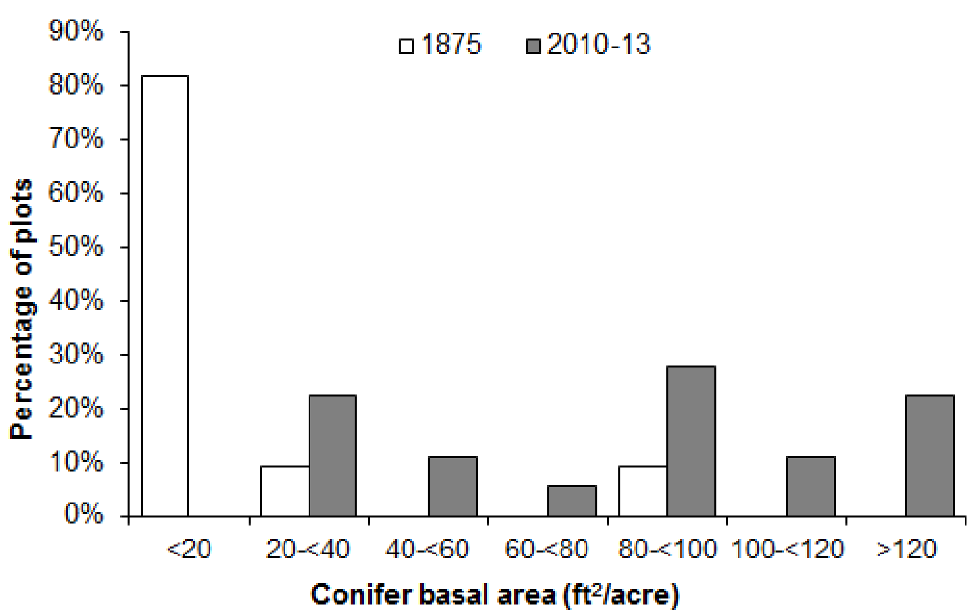



***Figure 16.*** Distribution of conifer basal area for plots in wet mixed- conifer forests in 1875 (n = 11 plots) and 2010-13 (n = 18 plots). Estimates only include trees with dbh ≥6”.

trees/acre in 2010-13 (range of 10-160 trees/acre). Conifer density (dbh >6") did not decline in any wet mixed-conifer plots from 1875 to 2010-13. Conifer density increased by more than 50 trees/acre in 7 of 11 plots, and it increased by about 30 trees/acre in three plots. Conifer density was unchanged on the remaining plot. All diameter classes <30" dbh increased in density between 1875 and 2010-13, but densities of the largest trees were relatively unchanged (Fig. 17).

*Variation among treatment units*—Variation in historical basal area and tree density were high within landscape units (Fig. 18). However, there were no consistent and significant differences among landscape units in basal area or tree density. Both historical tree density and basal area showed no trends with elevation, latitude, or longitude.

*Species composition*—Forest composition was highly variable in both 1875 and 2010-13 (Fig. 19). Engelmann spruce remained the dominant conifer species on many plots. Engelmann spruce was the only conifer species on three plots in 1875 and one plot in 2010-13. Blue spruce was the only conifer species on two plots in 1875, and subalpine fir was the only conifer species on one plot in 2010-13. The other plots had various mixtures of several conifer species.

Blue spruce and Douglas-fir became less abundant between 1875 and 2010-13, each declining from an average abundance of 25% in 1875 to 15% in 2010-13. Several sites showed evidence of logging over a century ago that selectively removed large Douglas-fir trees.

In contrast, the relative abundance of subalpine fir increased over time. The average abundance was 1% of basal area in 1875, rising to about 20% in 2010-13. Subalpine fir may have become more abundant over time because selective logging reduced competition from other conifer species. In addition, we might have slightly underestimated the abundance of subalpine fir in 1875 if some remnants already decayed by the time of our sampling.

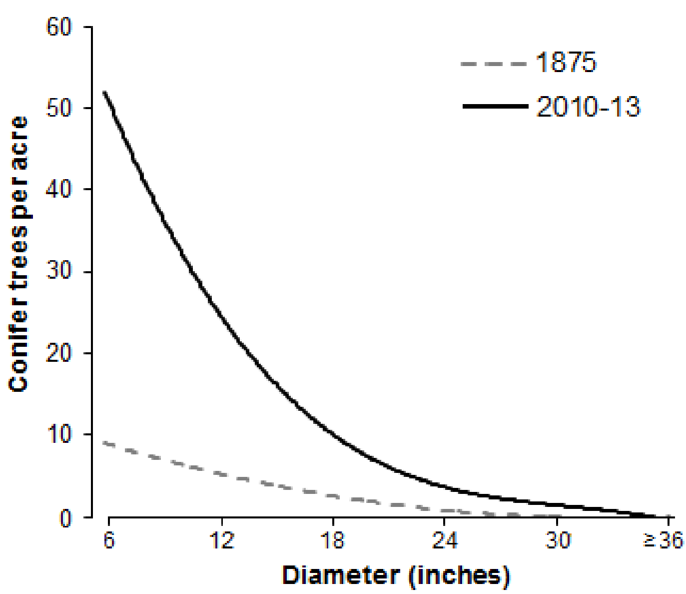



***Figure 17.*** Distribution of conifer tree density by size class for plots in wet mixed-conifer forests in 1875 and 2010-13.

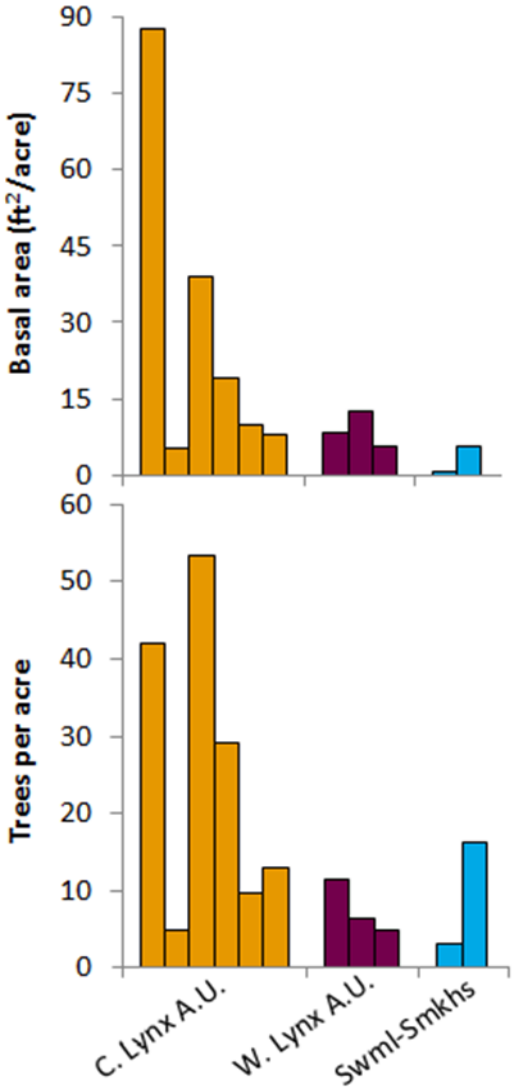
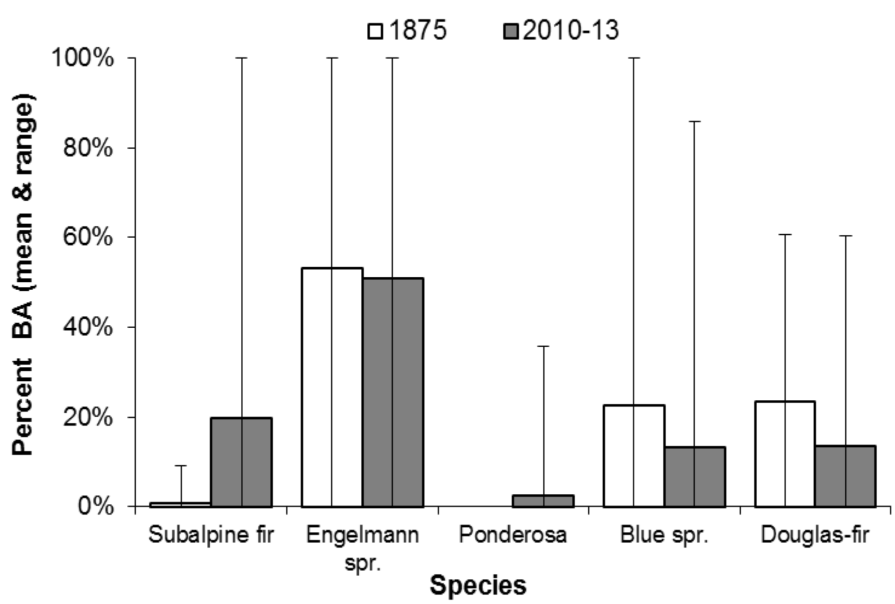



***Figure 18**:* Historical trees per acre and basal area for individual plots in wet mixed-conifer forests across three landscape areas in the Escalante Project Area (see Fig. 1 for location of units). Plots are ordered by increasing elevation.

***Figure 19.*** Average (+/- minimum and maximum) percent of basal area (BA) for plots in wet mixed-conifer forests represented by different conifer species in 1875 and 2010-2013.



# Findings for aspen

We can only report on current conditions of aspen in forests on the Uncompahgre Plateau. Historical signs of aspen likely decayed over the past century. Twenty of 22 living aspen trees that we cored were ≤130 years, indicating that they were not above breast height in 1875. It is possible that widespread fires in 1842 and 1879 killed most of the large aspens (Binkley and Romme 2012).

*Spatial patterns*—Aspen were randomly distributed across 70% of the plots in untreated stands (7 of 10) sampled in 2010-13. A random distribution of aspen means that some trees are located in clumps, and others occur as single trees variably spaced across the plot. Spatial clustering at the remaining three sites occurred between both 1 to 15 ft. and 15 to 40 ft.

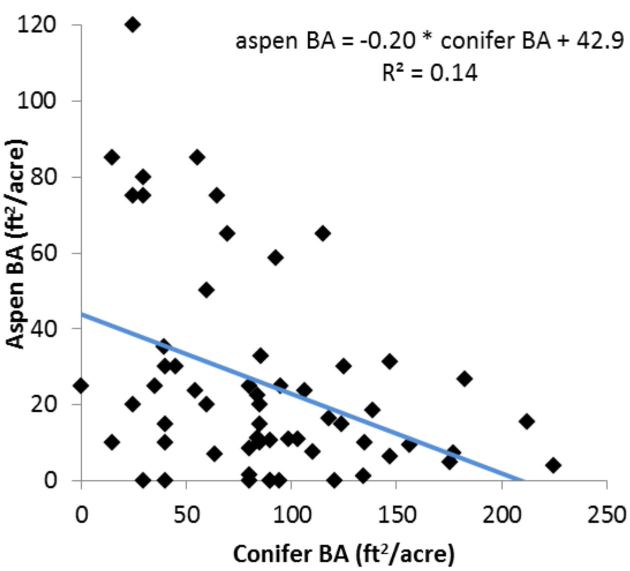



***Figure 20.*** Basal area (BA) of aspen (dbh ≥6") declined with conifer basal area in 2010-13. Data are from ponderosa pine, dry mixed-conifer, and wet mixed-conifer stands combined (n=59 plots).

*Above*: Aspen is a sun-loving species that often benefits from logging and high-severity fires that result in reduced competition from conifers.

Random spatial patterns were still common after restoration treatments, occurring in 65% of plots (7 of 11). Aspen clustering between 1 to 15 ft. and 15 to 40 ft. was evident at 4 of 11 plots after treatment.

Aspen occurred primarily in groups of 2 or more, with only 40% standing as single trees (range of 20-65%). Plots had an average of 5 aspen groups/acre (range of 2-10 groups/acre). A vast majority of aspen groups contained 2-4 trees (85% of aspen groups across forest types), and the other 15% of groups contained 5-9 trees.

*Aspen basal area*—In 2010-13, average basal area of aspen trees (dbh ≥6") was very similar in wet mixed-conifer plots and dry mixed-conifer plots at about 30 $ft^2$/acre (range of 0 to 120 $ft^2$/acre). The average basal area of aspen was much lower in ponderosa pine plots at 15 $ft^2$/acre (range of 0 to 60 $ft^2$/acre).

Basal area of aspen had a negative relationship with basal area of conifer trees in 2010

-13 (Fig. 20). It is possible that plots with high conifer basal area in 1875 had low aspen basal area. Similarly, another study on the Uncompahgre Plateau observed inverse relationships between conifer and aspen abundance. Smith and Smith (2005) found that the relative abundance of aspen trees (dbh > 8 inches) declined from 70% to 45% between 1979 and 2001. At the same time, the relative abundance of conifer trees increased from 30% to 55%.

_Tree density and distribution of size classes_— Aspen were present in 95% of wet mixed-conifer and dry mixed-conifer plots (34 of 36 plots), but only present in 80% of ponderosa pine plots (18 of 23 plots). Average stem densities of aspen (dbh ≥ 6") was about 55 trees/acre (range of 0 to 190 trees/acre) in both types of mixed-conifer forests. Average densities were lower in ponderosa pine forests at 35 trees/acre (range of 0-120 trees/acre).

Across all forest types, the average density of aspen stems was 45 trees/acre, with density declining rapidly with diameter (Fig. 21). Medium-sized aspen (6-12" dbh) were present in 80% of plots, with an average density of 40 trees/acre. Aspens with dbh <6" were only present in 40% of plots.

Binkley and Romme (2012) also observed the absence of young aspen from many stands on the Plateau. Intense grazing by livestock, deer, and elk is partially to blame. Aspen is a sun loving species, so increases in stand density over the past century also suppress aspen regeneration.

Larger aspen (dbh of 24-30") were even less common, being present in only 2% of plots (1 of 59). The average density of large aspen was 0 trees/acre, and the maximum observed density was 2 trees/acre. Over the coming decades, we can expect substantial declines in large aspen on the Plateau as old trees die and there are fewer young aspen moving into larger cohorts (Binkley and Romme 2012).

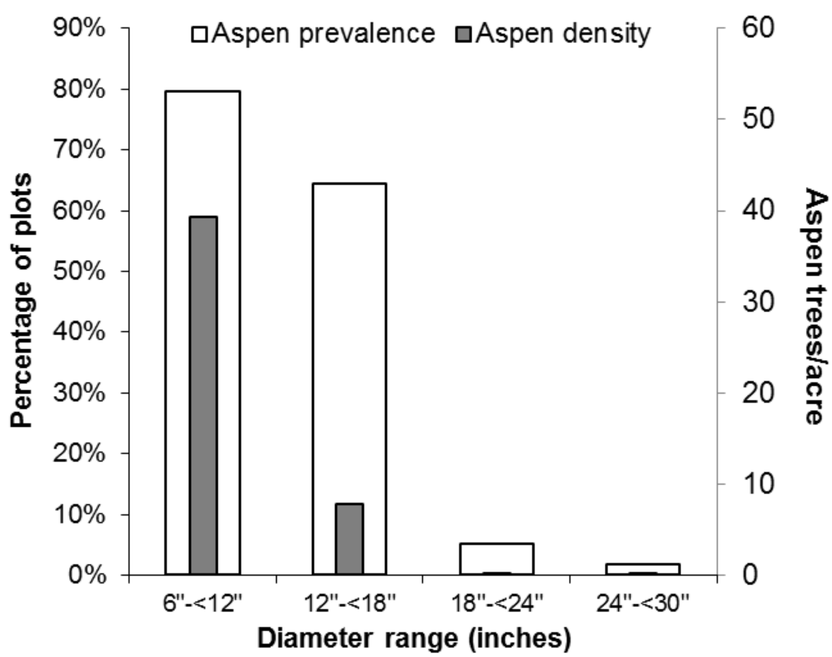



***Figure 21.*** The prevalence of aspen in forest stands and average stem densities by diameter range in ponderosa pine, dry mixed-conifer, and wet mixed-conifer plots combined (n=59 plots).

## Impacts of restoration treatments

The Uncompahgre National Forest began restoration treatments on 25 Mesas in 2009 and on Monitor Mesa in 2012 (Fig. 1). Treatments are occurring within ponderosa pine, dry mixed-conifer, and wet mixed-conifer stands. We analyzed all three forest types together since there were too few observations to assess each individually. We also compared post-treatment conditions to historical and untreated, current conditions for all three forests types together.

<u>*Spatial patterns*</u>—Trees were uniformly spaced in only one plot in post-treatment forests. About 60% of restored forests exhibited spatial clustering of conifer trees (dbh ≥ 6”). Tree clumping at short distances (1-15 ft.) occurred on all but one of these plots. This means that treatments resulted in a larger percentage of trees located ≤40 ft. apart than would occur if trees were randomly scattered across the plot. Clustering was more abundant on plots in post-treatment stands than under untreated, current conditions (50%, 6 of 12 plots) or historical conditions (35%, 20 of 57 plots).

*Above*: A restoration treatment on 25 Mesas reduced basal area and tree density. The treatment increased spatial variability by retaining groups of large diameter trees, such as that pictured in the foreground.

Plots in restored forests had more single trees than in unrestored forests (average of

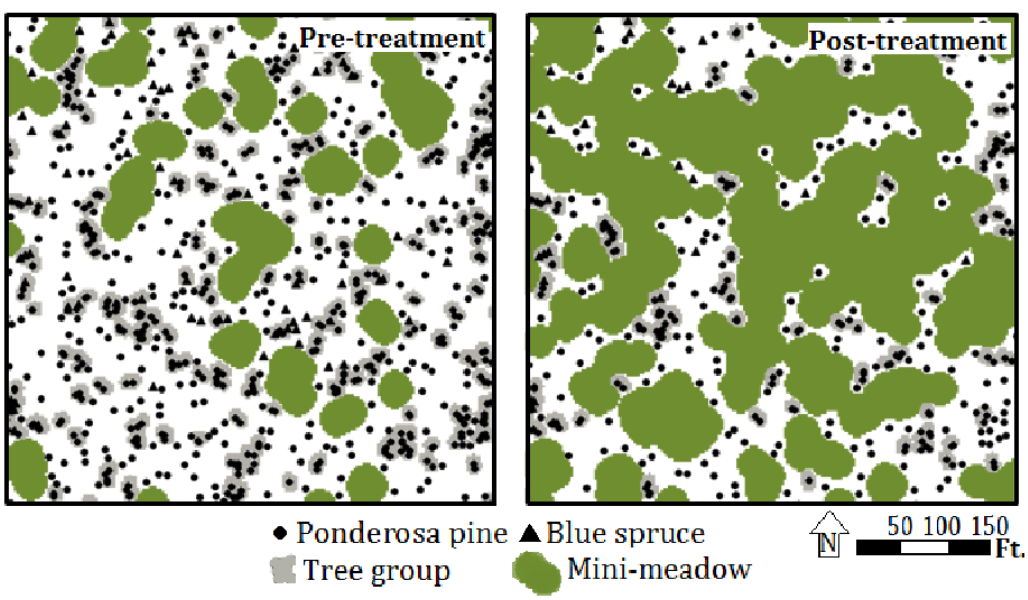



***Figure 22.*** Trees were spatially clustered at distances of 1-40 ft. before and after treatment on UncMesas Unit 1 (within the 25 Mesas project area). However, mini-meadows covered three times as much area in the restored stand. Data courtesy of Colorado State University student Justin Ziegler.

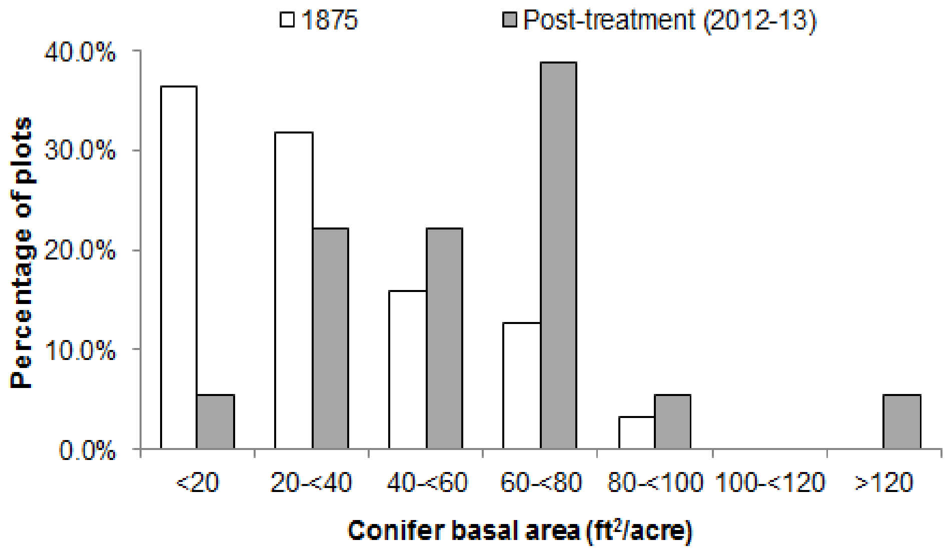



***Figure 23.*** Distribution of conifer basal area in 1875 (n = 63 plots) and in restored forests in 2010-13 (n = 18 plots). Estimates are for all forest types combined, and only include trees with dbh ≥6”.

40% versus 20% of trees), but fewer than under historical conditions (average of 60% of trees). There were two times as many tree groups/acre on plots in restored forests (average of 8 groups/acre) compared to historical conditions (average of 4 groups/acre). Untreated forests had an average of 12 groups/acre in 2010-13. Groups on restored forests contained a similar number of trees as historical conditions (average of 4 trees/group versus 3 trees/group).

Mini-meadows covered about 45% (range of 20-80%) of the area in restored plots (Fig. 22), a value lower than current conditions (average of 25%, range of 5-70%). However, the coverage of mini-meadows was still lower than historical conditions (average of 70%, range of 25-90% across forest types). The abundance of mini-meadows on plots in restored stands was similar to historical conditions (3 meadows/acre), and they were of similar sizes (≥0.25 acres). The overall openness of plots in restored stands was lower than historical conditions due to smaller distances between tree groups and single trees. This rendered more area unsuitable for mini-meadows due to shading from surrounding trees (Fig. 22). Restored forests also had a greater abundance of large groups with ≥10 trees (5% of groups in restored stands vs. <1% of groups in 1875).

<u>*Conifer basal area*</u>—Restoration treatments on the Plateau have greatly reduced conifer basal area. Conifer basal area declined by an average of 70 $ft^2$/acre (range of 50 to 100 $ft^2$/acre) on the seven plots where we measured both pre– and post-treatment conditions. This amounted to an average reduction in basal area of 60% (range of 40 to 90%).

Post-treatment basal areas in all but one of 18 plots were within the historical range of variation (Fig. 23). The one plot with conifer basal area >120 $ft^2$/acre is probably not representative of the entire treatment area.

The average post-treatment basal area was still higher than historical conditions. Across all 18 areas we sampled, the average post-treatment basal area was 55 $ft^2$/acre.

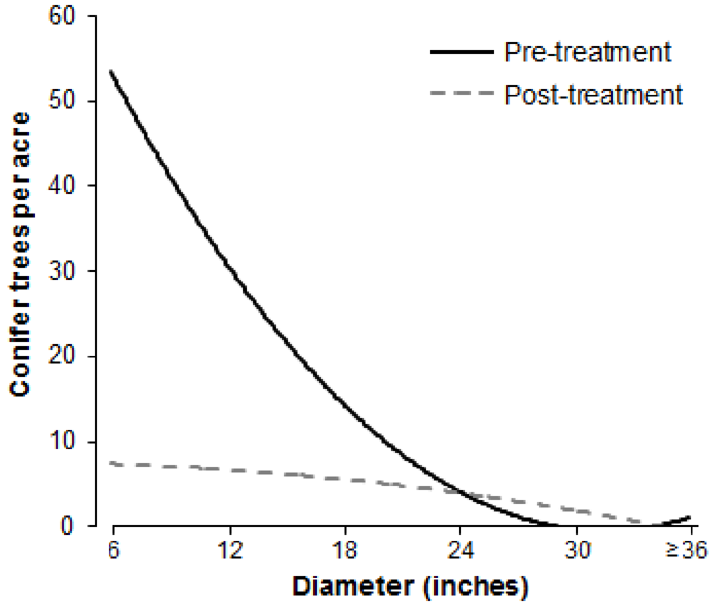



***Figure 24.*** Distribution of conifer tree density by size class before and after restoration treatment (n=7 stands).

This is almost two times greater than the average basal area in 1875 (30 ft²/acre across forest types). Aspen retained on the plots contributed an additional 7 ft²/acre of basal area (range of 0 to 23 ft²/acre).

<u>*Tree density and distribution of size classes*</u>—The average reduction in conifer density (dbh ≥ 6") from pre– to post-treatment was 80 trees/acre (range of 25 to 145 trees/acre). This represented a 70% reduction in conifer density (range of 45 to 90%).

The average post-treatment conifer density across all 18 sites was 30 trees / acre (range of 10 to 70 trees/acre), which is well within the historical range of variation for the three forest types combined (average of 25 trees/acre, range of 5 to 60 trees/acre). Aspen trees (≥6" dbh) remaining after treatment contributed an additional 14 trees/acre on average (range of 2 to 50 trees/acre).

Restoration treatments resulted in lower tree densities across diameter classes, but the largest reductions were for trees with dbh <18" (Fig. 22). These smaller trees represent ladder fuels, so their removal reduces hazards associated with crown fires.

*Above* A restoration treatment on Monitor Mesa reduced conifer density by 70% (from 115 to 35 trees/acre). This created room for mini-meadows and aspen saplings to establish, both of which provide quality forage for wildlife.

# Management implications

*Undesirable conditions*—We encourage collaborative groups to define forest conditions they find undesirable. Managers, researchers, and interested citizens can identify and experiment with actions that push forests away from undesirable conditions. The overall goal is to reduce the likelihood of undesirable outcomes, such as large, high-severity crown fires, and the unacceptable loss of important parts of the landscape. On the Uncompahgre Plateau, this would include the continued disappearance of mini-meadows in ponderosa pine forests.

Undesirable conditions also help collaborators acknowledge that Nature puts finishing touches on even the most well-crafted plans. This approach encourages creative and flexible management to provide for a variety of future landscapes. In contrast, desired future conditions aim at a few limited, and potentially unachievable, forest structures and compositions.

Here we suggest undesirable conditions for ponderosa pine, dry mixed-conifer, and wet mixed-conifer forests (Table 3). It is exciting to report that restoration treatments on the Plateau are largely moving forests away from these conditions!

*Additional considerations*—A key message from this analysis is that historical forest structure and composition was highly variable on the Plateau. Forests are still diverse today, they are just consistently more dense and less open than historical forests. The great diversity that existed and exists

*Above:* Mini-meadows, such as that pictured above, were abundant in ponderosa pine and dry mixed-conifer forests in 1875. Abundant regeneration and high survivorship of trees over the past century have turned mini-meadows into dense forests across much of the Plateau.

***Table 3.*** Uncharacteristic conditions for ponderosa pine, dry mixed-conifer, and wet mixed-conifer forests on the Uncompahgre Plateau based on historical conditions summarized in this report. Forest conditions that were uncommon in the past can inform undesirable conditions (*i.e.*, conditions to avoid or "push" forests away).

| **Forest characteristic for conifer trees with dbh ≥ 6"** | **Ponderosa pine** | **Dry mixed-conifer** | **Wet mixed-conifer** | **All three forest types** |
|---|---|---|---|---|
| | *Conditions to manage away from:* | | | |
| Clustering of trees at 0-40 ft. | < 20% of stands | < 40% of stands | < 15% of stands | Uniform tree spacing |
| Abundance of single trees (*i.e.*, trees not in groups) | < 40% of trees | < 30% of trees | < 40% of trees | ——— |
| Density of tree groups | > 8 groups/acre | > 10 groups/acre | > 10 groups/acre | < 2 groups/acre |
| Abundance of groups with ≥ 5 trees/groups | > 15% of groups | > 25% of groups | > 15% of groups | < 5% of groups |
| Aerial cover of mini-meadows/aspen clumps | < 50% | < 40% | < 30% | > 90% |
| Ave. size of mini-meadows/ aspen clumps | < 0.25 acre | < 0.20 acre | < 0.25 acre | All openings are similarly sized |
| Basal area | > 70 $ft^2$/acre | > 100 $ft^2$/acre | > 100 $ft^2$/acre | < 10 $ft^2$/acre |
| Tree density | > 40 trees/acre | > 60 trees/acre | > 60 trees/acre | > 30 trees/acre dbh <12"<br>< 3 trees/acre dbh >24" |
| Species composition | < 50% BA is p. pine | < 75% BA is p.pine and D. fir | Consistently favoring one spp. or spp. mix | > 25% BA is sub-alpine fir |

*BA = basal area; p. pine = ponderosa pine; D.fir = Douglas-fir; spp. = species*

in forests across the Plateau leaves room for creativity and flexibility in ecological restoration. It is appropriate to use a mix of approaches (thinning, burning, thinning and burning) and to create a range of post-treatment basal areas and spatial patterns.

In some cases, fire may be a good enough tool for restoration goals, if applied carefully during the right weather conditions. In most cases, however, mechanical treatments are necessary to change the fuel structure and protect large heritage trees (*i.e.*, ≥150 years old) before returning fire to the Plateau.

We provide some additional considerations for restoration treatments on the Plateau:

- Mini-meadows are the most scarce characteristic in current forests relative to historical forests. Restoration treatments should explicitly consider how marking patterns will affect the size, shape, and arrangement of mini-meadows. Treatments that focus exclusively on tree spatial patterns can result in narrow and sinuous mini-meadows that do not provide ideal conditions for the establishment of grasses, forbs, and aspen (*e.g.*, Fig. 22).

- Trees were not arranged in uniform spatial patterns under historical conditions. All of the remaining plots showed random or clustered spatial patterns. This finding suggests that restoration treatments should not result in evenly spaced trees. Uniform spatial patterns might be ideal for increasing wood production or reducing the risk of crown fires (Hoffman and others 2013), but historical forests did not have trees arranged in this manner.

- There is no need for different types and patterns of restoration treatments on each mesa or in each sale unit (*i.e.*, 1000-acre scale). Variation among plots within landscape units was high in 1875 and in 2010-13, but variation among landscape units was low. This means the focus of landscape restoration should emphasize variation within sale units, rather than taking different approaches in different treatment units.

- Forest conditions result from many factors and processes that forest management cannot control. These include competition among tree species and individual trees, environmental conditions in a stand (*e.g.*, soil moisture content), and weather patterns over centuries. We should not expect (or desire) consistent results from restoration treatments.

- Returning wildfire to the Uncompahgre Plateau is an important step towards reducing the need for management intervention. Fires create unique patterns across far larger areas than we could hope to treat mechanically.

- Heritage trees have survived centuries of change on the Plateau. Large, old trees are a living legacy of the past, and they have substantial social and ecological value. The abundance of large trees has not substantially increased over the past century. Clear and strong evidence of an economic need of benefit should accompany their removal.

*At right:* Large heritage trees provide important wildlife habitat, serve as seed sources, and represent a unique part of the Uncompahgre Plateau's natural history.

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**About the Colorado Forest Restoration Institute:** The Colorado Forest Restoration Institute (CFRI) was established in 2005 as an application-oriented program of the Department of Forest & Rangeland Stewardship in the Warner College of Natural Resources at Colorado State University. CFRI's purpose is to develop, synthesize, and apply locally-relevant science-based knowledge to achieve forest restoration and wildfire hazard reduction goals in Colorado and the Interior West. We do this through collaborative partnerships involving researchers, forest land managers, interested and affected stakeholders, and communities. Authorized by Congress through the Southwest Forest Health and Wildfire Prevention Act of 2004, CFRI is one of three institutes comprising the Southwest Ecological Restoration Institutes, along with centers at Northern Arizona University and New Mexico Highlands University.

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