ECOLOGICAL IMPACTS OF THE COLLABORATIVE FOREST RESTORATION PROGRAM

A THESIS
Presented to the Graduate Division
College of Arts & Sciences
New Mexico Highlands University

In Partial Fulfillment
Of the Requirement for the Degree
Master of Science in Natural Science
Concentration: Environmental Science and Management

By
Kathryn R. Mahan
May 2019

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Approved by Examining Committee:

____
Dr. Joshua L. Sloan
Department Chair
Department of Natural Resources Management

____
Dr. Blanca Céspedes
Chair of Committee
Department of Natural Resources Management

____
Dr. Warren K. Lail
Interim Dean
College of Arts and Sciences

____
Dr. Joshua L. Sloan
Member
Department of Natural Resources Management

____
Dr. Warren K. Lail
Interim Dean of Graduate Studies

____
Dr. R. Kent Reid
Member
New Mexico Forest and Watershed
Restoration Institute

ABSTRACT

This thesis analyzes ecological monitoring data collected between 2003 and 2018 from projects in New Mexico's Collaborative Forest Restoration Program (CFRP). This data is used to assess success of the CFRP using program objectives defined in the original legislation, including wildfire threat reduction, ecosystem restoration, preservation of old/large trees, and reforestation. The hypothesis was that CFRP has not met all of its ecological program objectives at the 10 year mark.

The data include metrics such as trees per acre, canopy cover, live crown base height, seedling and sapling densities, and surface fuels. These data were categorized by forest type (wet mixed-conifer, dry mixed-conifer, ponderosa pine, and piñon-juniper) and time relative to treatment (pre-treatment, immediately post-treatment, five years post-treatment, and 10 years post-treatment). Analysis of Variance (ANOVA) and Tukey's Honest Significant Difference (HSD) were used to detect significant differences between measurement periods within forest types. Analyses showed that program success at achieving ecological objectives has been mixed.

Since CFRP's creation, no such analysis has been performed. In addition to the data, this thesis covers the background of CFRP, some of the ongoing challenges, and makes recommendations for next steps. It is the goal of this thesis to provide meaningful information to forest managers in the Southwest and CFRP participants on the ecological strengths and weaknesses of the program.

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Glossary

Acronym, Abbreviation, or Term	**Explanation or Definition**
Acre	Unit of measure 43560 square feet; 10 square chains
Aerial cover	Percent of ground covered when viewed from above (e.g. bird's eye view)
Annual plant	Plant that completes its lifecycle within one growing season (one year)
ANOVA	Analysis of Variance, a statistical method for detecting significant differences between two or more means by testing the null hypothesis that the means are equal; ANOVA does not provide any information about where the inequalities may be
Aspect	The compass direction that a slope faces, expressed as, e.g. "northern aspect"
AVG	Average
BA/AC or BAAC	Basal area per acre is a way of quantifying forest density; basal area calculated by combining the cross-sectional area of all trees in a given area at 4.5 feet above ground level (DBH) and expressed as square feet per acre (typically an open forest is 40-90 sqft/ac, while a dense forest is 100-160 sqft/acre or more)
Bole	Main trunk of a tree or woody plant
Breakpoint diameter	Diameter above which trees become measured in detail in a monitoring protocol; the "cutoff" for saplings vs. trees
Brown's transects	Protocol for monitoring fuel loads
Cactus	Succulent plant with a thick, fleshy stem; commonly with spines
Canopy	"Roof" of forest formed by crowns of trees; measured as percent cover using a densiometer
CFLRP	Collaborative Forest Landscape Restoration Program
CFRP	Collaborative Forest Restoration Program
Chain	66 feet
Conifer	Evergreen trees which do not lose their needles every year, e.g. pine, spruce, fir
Crown	The part of the tree including branches and leaves
DBH	Diameter at breast height (4.5 feet above ground level on the high side of the tree), typically measured on the bole
Deciduous	Trees that lose leaves every year, e.g. apple, mountain mahogany

Acronym, Abbreviation, or Term	**Explanation or Definition**
Densiometer	A device with a spherical mirror used to estimate canopy cover
DIA	Diameter
Down Woody Debris or DWD	Also known as Coarse Woody Debris or Large Woody Debris; the remains of fallen trees and branches on the forest floor (important for fuels models and wildlife habitat)
DRC	Diameter at root collar (measured close to the ground, used for woodland species only)
Dry mixed-conifer or DMC	A forest which remains proportionally dominated by ponderosa pine but with a large component of aspen, oak, limber pine, or firs
Duff	A layer of partially decomposed organic material (e.g. leaves, needles, twigs) found between the mineral soil and the litter layer of the forest floor
ERI	Ecological Restoration Institute
FEAT	Fire Ecology Assessment Tool
FFI	FEAT/FIREMON Integrated
FHTET NIDRM	Forest Health Technology Enterprise Team National Insect and Disease Risk Maps (part of USDA – Forest Service's Forest Health Program)
FIA	Forest Inventory and Analysis
Fine Woody Debris	Small pieces of woody material (e.g. twigs, branches) on the forest floor
FIREMON	Fire Effects Monitoring and Inventory System
Foliage	Leaves of a tree or plant
Forb	An herb, a flowering plant, other than grass
Forest Stewards Guild	a nonprofit organization providing land management and consulting services
Forest type	A designation or name given to a forest based on the most abundant tree type or types in the stand
GIS	Geographic Information System, a system for mapping, analyzing and presenting spatial data
Graminoid	Grasses or grass-like plants
Ground cover	Percent of ground covered by material at point of interception (more like an ant's eye view)
Herb	Seed-bearing plant, no woody stem, dies to the ground after flowering
Herbaceous plants	Generally, plants with flexible stems
HT	Height

Acronym, Abbreviation, or Term	**Explanation or Definition**
Ladder fuels	Vegetation (live or dead) that provides fuel for fire to climb from the understory into the canopy; includes dead lower branches on a living tree
LiCrBHt	Live Crown Base Height, distance from ground to start of live crown
Litter	Small dead plant material such as leaves, bark, and needles
MC	Mixed-conifer
NMFWRI	New Mexico Forest and Watershed Restoration Institute
NMSLO	New Mexico State Land Office
Overstory	Top layer of cover in a forest
Perennial plant	A plant with a lifecycle of more than two years
PJ	Piñon-Juniper, a forest type consisting mainly of piñon and a species of juniper, elevations 4000 to 8000 ft
Planar intercept	A measurement of ladder fuels typically included as part of a Brown's transect
Plant basal area	The area of the ground occupied by the base of the plant stem
PLANTS symbol	Abbreviation of scientific name used in Plant List of Accepted Nomenclature, Taxonomy, and Symbols (USDA database)
PP or PIPO	Ponderosa pine, a forest type consisting of mainly ponderosa pine, sometimes with oak or grass understory; common up to 9, 000 ft
QMD	Quadratic mean diameter, a measure of central tendency for tree size calculated using weighted DBH or average basal area per acre
Sapling	An individual of a woody species with height over 4.5 feet but whose diameter at DBH or DRC (wherever it must be measured) is less than 1 inch (this value may change depending upon objectives); falls between a seedling and a tree
SE	Standard error, a measure of how the sample mean differs from the population mean
Seedling	An individual of a woody species with height less than 4.5 feet
Shrub	A woody plant smaller than a tree at maturity and which has several main stems arising at or near the ground; whether certain plants are considered "shrubs" vs. "trees" may depend upon monitoring objectives, so for this project the USDA PLANTS definitions are used
Sick	A term used for a woody plant displaying characteristics of a pest infestation, injury, or disease that is negatively impacting overall health and vigor, e.g. a mistletoe infestation

Acronym, Abbreviation, or Term	Explanation or Definition
Slope	A measurement in percent of the steepness of a surface; (rise/run x 100); a slope of 45 degrees equals 100%
Snag	A standing dead tree
Spruce-fir	A forest dominated by Engelmann spruce, Douglas-fir, aspen, corkbark or subalpine fir, usually 8000 to 12 000 ft
SPSS	Statistical Package for Social Sciences, a software used to perform statistical analyses
Stand	A group of trees that are sufficiently the same in species composition and arrangement of age classes and condition so that they can be managed as a unit
Surface fuels	Vegetative materials near the ground which will carry fire
Time lag fuel	A classification system of dead fuels based on the time it takes for fuel moisture to respond to environmental moisture; corresponds to fuel diameter 1 hour fuel – 0 to ¼ inch diameter 10 hour fuel – ¼ to 1 inch diameter 100 hour fuel – 1 to 3 inch diameter 1000 hour fuel – 3 to 8 or more inch diameter 1000 hour fuels are "logs" in forest systems and can be important for habitat.
TPA	Trees per acre (Trees/acre), a way of quantifying the density of trees
Tree	A woody perennial plant; for measurement purposes, an individual that is over 4.5 feet tall and 1 inch or over at DBH/DRC (definition may change depending upon monitoring objectives); unless otherwise specified, includes "live" and "sick" individuals
Tukey HSD	Tukey's Honest Significant Difference, a multiple pairwise comparison statistical analysis
Understory	The area below the forest canopy that comprises shrubs, snags, and small trees
USDA	United States Department of Agriculture
USFS	United States Forest Service, aka USDA-FS
Wet mixed-conifer or WMC	A forest type consisting of an assortment of conifer species (e.g. firs, pines, spruces, sometimes aspen); dominated by aspen, fir, or blue spruce closer to 5500 to 10000 ft[1]
Woody	A plant containing secondary xylem (wood) as structural tissue; typically perennial

[1] All forest type definitions in the Glossary are adapted from (Dick-Peddie, 1993)

Acronym, Abbreviation, or Term	**Explanation or Definition**
WUI	Wildland-Urban Interface, human development in and near undeveloped wildland vegetation
$\overline{x}$	Mean

AGENCY ACKNOWLEDGEMENTS

The very nature of this project continues the collaborative spirit of the CFRP. Parties NMFWRI has been directly involved with during the course of this research include: New Mexico Highlands University, the Carson, Cibola, Gila, Lincoln, and Santa Fe National Forests, the USFS Regional Office, New Mexico State Land Office, and Forest Stewards Guild. Future collaboration among these parties is ensured by the monitoring mandate in the CFRP legislation and by NMFWRI's commitment to explore opportunities to serve as a repository for future data, thereby making future analysis of this kind more readily accessible.

DEDICATION

I would like to acknowledge the assistance of the many people whose encouragement, help, and cooperation allowed the completion of the project. First and foremost: my husband Jamie for steadfast support in the face of compromise and sacrifice; my parents Monte and Nancy for a lifelong expectation of accomplishment and the means to make it so; and my daughter Rayyah, whose very being is infused with the influences of this project, may she one day forgive me. Professionally, I am indebted to Dr. Kent Reid and Dr. Blanca Céspedes for their support and efforts in helping me reach contacts to obtain data; Dr. Joshua Sloan for statistical assistance and structure; Eytan Krasilovsky, Mark Meyers, and Reuben Montes for significant efforts to provide data and answer questions; Ian Fox, Shawn Martin, Michael Lujan, Scott Curan, Amy Waltz, and Frances Martinez for their cooperation; and all the NMFWRI staff and field crew members past and present, especially Christopher Martinez, Zane Jones, Ernesto G. Sandoval, Raymundo F. Melendez, and Carmen Briones for helping to maintain rigorous quality control on in-house data as well as bringing a strong work ethic, humor, empathy, wonder, and personality to the field.

I. - Introduction

Forested Land in New Mexico and the CFRP

According to the 2008-2014 USDA-Forest Service Forest Inventory and Analysis program's inventory of New Mexico's forest resources, the 77.8-million-acre state is 32 percent forested (24.7 million acres) (Goeking & Menlove, 2017, p. 4). This acreage includes more than 6.5 billion live trees, of which the most abundant species is Gambel oak (*Quercus gambelii* Nutt.) with 1.6 billion trees. Fifty-seven percent of this forested land is managed by public or tribal agencies, with 17 percent administered by the USDA Forest Service (Goeking & Menlove, 2017, p. i).

A legacy of logging, grazing, and fire suppression has altered the species composition and physical structure of New Mexico's forests. For example, forests are denser with fewer old, large trees and more smaller-diameter stems. Biodiversity in the understory, overall habitat quality, and presumably the ability to provide ecosystem services have declined (Reynolds et al., 2013, p. 1). Insect epidemics and large, severe fires have become more frequent in these systems in recent decades and may continue to worsen as climate change impacts increase (Reynolds et al., 2013, p. 29). Restoration, or assisting the recovery of degraded, damaged, or destroyed ecosystems, is believed to increase an ecosystem's resiliency to disturbance, (Reynolds et al., 2013, p. 1) and is the goal of many Southwest forest managers.

One such restoration effort is the Collaborative Forest Restoration Program (CFRP). Since 2001, the USDA Forest Service (USFS) in New Mexico has administered grants for forest restoration projects to collaborative groups through the Collaborative Forest Restoration Program (CFRP). These projects must address a variety of ecological, economic, and social objectives including wildfire threat reduction, creation of local employment, and stakeholder diversity (USDA Forest Service, n.d.).

Ecological monitoring has been a grant requirement by law since the beginning. Initial years of the program (2001-2008) saw a wide variety of monitoring protocols implemented by grantees, with varying degrees of reliability. Between 2007 and 2009, the USFS re-evaluated the monitoring as part of a “Lessons Learned” review of the CFRP (USDA Forest Service, 2009). At this time, they adopted recommendations for standard metrics that all grantees would be required to monitor. Also at this time, the New Mexico Forest and Watershed Restoration Institute (NMFWRI) was tasked with conducting monitoring at 5, 10, and 15 years post-treatment on selected CFRP projects with reliable pre-treatment data. NMFWRI has been carrying out this function with protocols containing the standard metrics since 2009. Another 10 years has passed since these revisions were made, and to-date, no program-wide analysis of the ecological monitoring data has been published.

Hypothesis and Expected Results

It is the goal of this thesis to use the available ecological monitoring data from the CFRP to investigate the following core research question: Has the CFRP program met its ecological restoration objectives, as defined in the law which created it, the Community Forest Restoration Act (PL 106-393)? Based on field crew observations, the project's formal hypothesis was that CFRP program has *not* met its ecological restoration objectives in all areas at the 10 year mark. Expected results of the analysis included time since treatment differences (e.g. different responses immediately post-treatment vs 10 years post-treatment). The discussion addresses possible causes of differences (or lack of differences) between measurement periods, as well as what these results mean for forest managers.

Importance of this Work

According to the USFS (USDA Forest Service, n.d.), since the program began in 2001, the "Collaborative Forest Restoration Program (CFRP) has funded over 200 projects including close to 600 partners in planning and implementing collaborative forest restoration and small diameter utilization projects in 20 counties across New Mexico. These projects have restored over 33,000 acres and created over 750 jobs."

However, the CFRP program has now passed its 15th birthday (2016) and to date, there is no comprehensive review of its success with respect to its accomplishment of the ecological objectives of the program. There are many reasons for this, discussed more in the next section. However, an analysis of the ecological measurements of completed CFRP projects can at this time include 10 year post-treatment data on some projects, a unique dataset which has not been previously available to managers. This is an opportunity to learn not only about the monitoring process, which has already had its evolution and shortcomings documented to some extent (USDA Forest Service, 2009), but about the ecological impacts of the projects themselves. Project impacts have traditionally been examined at the small spatial scales at which treatments have been conducted, and within the three years grantees monitor. This project is an opportunity to look for cumulative project impacts across the larger landscape of New Mexico and over a longer period of time.

One outcome of this research is the availability of scientific information for making management decisions in the implementation and maintenance of current and future CFRP and other restoration projects in the Southwest. A long-term dataset such as this is unique and may offer valuable insight into ecosystem recovery and processes that more common, shorter-term monitoring programs cannot. This information, if considered as part of the adaptive management decision-making process, will contribute to the improvement of management outcomes. Further, this data offers an up-to-date evaluation of the CFRP program's success in meeting its ecological objectives as defined by law.

Prior Research

There is a body of research available examining the overall efficacy of community-based forestry and multiparty monitoring programs (Cheng, Danks, & Allred, 2011; DeLuca, Aplet, Wilmer, & Burchfield, 2010; Fernandez-Gimenez, Ballard, & Sturtevant, 2008); however, resources are limited when it comes specifically to the CFRP. Most of the available documents are agency reports, white papers, or technical guides (see example: Derr & Krasilovsky, New Mexico Forest Restoration Series Working Paper 2 Social and Economic Issues in Landscape Scale Restoration, 2008; Derr, McGrath, Estrada, Krasilovsky, & Evans, 2008; Ecological Restoration Institute, 2005; Ecological Restoration Institute, 2006; Ecological Restoration Institute, 2005; Ecological Restoration Institute, 2005; Ecological Restoration Institute, 2005; Moote, et al., 2010; Smith, Dunn, & Zaksek, 2008; Savage, et al., 2007; Savage, Parsons, Knutson, Derr, & Krasilovsky, 2009). Peer-reviewed journal articles including any mention of CFRP are more likely to cite it as an example program than to analyze its results in any detail (Cheng, Danks, & Allred, 2011; Fernandez-Gimenez, Ballard, & Sturtevant, 2008). In particular, there is a gap in the study of the program's ecological monitoring results.

CFRP was authorized by the US Congress in 2000 and began in New Mexico in 2001. The excitement with which it was met remains in the record. Local papers and magazines billed the collaborative effort as a "new way" for the Forest Service and the public to interact, because the public could make proposals *to* the USFS instead of receiving them *from* the agency (Foster, 2003). Journal articles published on collaborative forestry cited it briefly as an example of something that was working. Praise for the program included its social learning, governance by stakeholder committee (Cheng, Danks, & Allred, 2011), and the handbooks it published for developing multiparty monitoring projects (Fernandez-Gimenez, Ballard, & Sturtevant, 2008). A 2009 USFS report considered the project's successes to include the acres treated, projects funded, jobs created, and an improved spirit of cooperation (USDA Forest Service, 2009). Media and professional interest in CFRP seems to have waned somewhat since 2009 judging by mention in publications; this coincides with the start of the Collaborative Forest Landscape Restoration Program (CFLRP). This suggests it is not likely to expect the data gaps to be closed by someone else in the near future, though the CFRP program continues.

Among the unique features of the CFRP is the monitoring mandate included in the law. All grantees must use a multiparty monitoring team to do the following: monitor short- and long- term ecological effects of the restoration treatments for at least 15 years (individual grantees must monitor pre-treatment and immediate post-treatment); use collected ecological data to identify the existing and desired future ecological conditions of the project area; and report on the impacts and effectiveness of their project and assess how effectively the project's stated goals are being met.

The monitoring component, however, has always been a challenge. In 2002, a collaborative group created guidelines for socioeconomic, ecological, and multiparty monitoring. Between 2003 and 2007, the Ecological Restoration Institute was funded by a CFRP grant to create handbooks and provide monitoring training. In 2007, the New Mexico Forest and Watershed Restoration Institute was assigned this task under its Federal Workplan, and this has continued until the present.

Despite this, in 2008, a meta-analysis of the 102 projects completed at that time found that only forty percent of projects had planned or implemented reliable ecological monitoring (Derr, McGrath, Estrada, Krasilovsky, & Evans, 2008). In 2009, the USFS wrote a "Lessons Learned" document and reflected that monitoring had "evolved the most in the program's almost 10-year history". This document explained that in early projects, grantees did not understand the requirements or purpose of monitoring. It also recognized that the guidebooks initially compiled by the Ecological Restoration Institute (ERI) contained so much information as to be overwhelming to grantees, necessitating the creation of a “Short Guide”. It conceded that the theoretical (“Why do we have to monitor?”) and technical (“How do we monitor?”) hurdles still remained, and recommended that NMFWRI take on long-term monitoring of CFRP as well as becoming a centralized repository for monitoring data. The report was self-conscious and open about the quality of data collected, noting that “[t]here will always be incompatibility between community-based monitoring and landscape-level or regional usefulness”(p. 27).

Melissa Savage wrote a page for the 2009 “Lessons Learned” report which included the following powerful observations:

> Data management has also proven difficult—keeping track of data, not losing it, and getting it to someone who can analyze it. That’s another way monitoring benefits from higher capacity help. And then it’s very important to think about what we do with the end result. Typically the final report gets sent in and shelved and not read. The partners should be encouraged to look at the final results and gain some insight into what restoration might mean for their communities and forests. So far it hasn’t usually happened that way. (p. 28)

As has been stated, to-date there has been no comprehensive review of the CFRP’s effectiveness with respect to its accomplishments of the ecological objectives of the program. There are, however, several resources available to allow evaluation of restoration in Southwest forests, at least for ponderosa pine and dry mixed-conifer forest types. Publications like the RMRS-GTR-310 provide historical reference ranges for these forest types (Reynolds et al., 2013, pp. 18-20, 28). Restoration in other forest types, such as piñon-juniper, wet mixed-conifer or spruce-fir appears to be less well researched.

II. - Methods

Available Data and Expertise

The New Mexico Forest and Watershed Restoration Institute (NMFWRI), which is located at New Mexico Highlands University, is a statewide effort that engages government agencies, academic and research institutions, land managers, and the interested public in the areas of forest and watershed management.

The NMFWRI staff includes a monitoring department with a full-time Monitoring Program Manager and an Ecological Monitoring Specialist, as well as Monitoring and Data Technicians. As the Ecological Monitoring Specialist for the NMFWRI, the author has monitored over 20 CFRP projects, in stages ranging from pre-treatment to 10 years post-treatment. NMFWRI as an agency has collected data on over 35 CFRP projects and is intimately familiar with the limitations, shortcomings, and potential of the program and the existing dataset.

The current NMFWRI long-term monitoring database is under construction but at time of writing includes 31 CFRP projects and over 150 different entries. Each separate entry represents a treatment unit at a specific monitoring date. Some CFRP projects have multiple units while for others the treatment unit is synonymous with the project. These monitoring entries include pre-treatment and immediate post-treatment collections, as well as 5-year and 10-year post-treatment revisits. Most pre- and immediate-post-treatment monitoring was performed by grantees and the Forest Stewards Guild; all long-term post-treatment revisits were conducted by NMFWRI. Altogether, these entries include data from more than 1600 individual plot measurements.

Between February 2017 and February 2019, every attempt was made to collect all available data. The starting point was the list of projects proposed for long-term monitoring in Working Paper 5 (Derr, McGrath, Estrada, Krasilovsky, & Evans, 2008, pp. 20-21). Requests were emailed and messages left with CFRP Coordinators on the Carson, Cibola, Gila, Lincoln, and Santa Fe National Forests and with the Regional Office in Albuquerque. Requests for information were also made with the New Mexico State Land Office, Forest Stewards Guild, the Las Vegas office of the Pecos/Las Vegas Ranger District, the Tierra y Montes Soil and Water Conservation District, the Ecological Restoration Institute at Northern Arizona University, and tribal contacts[2]. All efforts were made to collect data, maps, reports, prescriptions, and photographs, and to verify quality control procedures were implemented for data collection and entry. For instance, questions or concerns were followed up with agency contacts. In the case of NMFWRI, all data used in this analysis were screened by at least two staff members using a quality control checklist.

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[2] Tribes requested that the data collected be kept confidential, so tribal entities are not specifically identified

Nevertheless, data from many projects was unavailable for inclusion in the database, primarily because CFRP Coordinators on the Forests either did not respond to requests or were not able to provide all the data requested.

Research Approach and Metrics

CFRP projects must address the following objectives (USDA Forest Service, n.d.) :

- Wildfire threat reduction
- Ecosystem restoration, including non-native species reduction
- Reestablishment of historic fires regimes
- Reforestation
- Preservation of old and large trees
- Small diameter tree utilization
- Creation of forest-related local employment
- Stakeholder diversity

It was therefore logical to assess the success of the program's ecological restoration goals using the program's own specific objectives.

Metrics and Definitions of Success

In December 2008, the New Mexico Forest and Watershed Restoration Institute published Derr et al.'s New Mexico Forest Restoration Series Working Paper 5 Monitoring The Long Term Ecological Impacts of New Mexico's Collaborative Forest Restoration Program, in which five indicators were recommended for use in monitoring by all grantees. These indicators include:

- Canopy cover (%)
- Understory cover (% ground and/or shrub)
- Surface fuels (tons/acre)
- Crown base height (ft)
- Stand composition and structure
    - Tree species
    - Size (DBH, DRC inches)
    - Density (stems/acre live and dead, basal area)

This thesis used CFRP projects that had these indicators measured to assess the achievement of program objectives. Note that some goals are either social metrics or cannot be assessed using the five common indicators and are therefore beyond the scope of this project. Reestablishment of historical fire regimes is one such ecological objective that cannot be assessed with available data. For an explanation of which metrics were available to assess specific program objectives, see Table II.2 on page 25. The thesis formally tested for differences in these metrics, e.g. whether trees per acre differed between measurements periods.

Despite a formal test for differences, the question of interpreting the results in terms of restoration success remained. In other words, because the goal of the thesis was to find out if CFRP "worked," it was necessary to define what something "working" looked like in terms of the available metrics. The law clearly stated the projects were to be evaluated, and subsequent publications recommended common metrics for all projects, but no document in the CFRP literature specified exactly what changes in the metrics would mean for project (or program) success. For example, if the formal tests detected a difference in trees per acre between measurement periods, did that indicate success? Table II.2 on page 26 is a coarse overview of what changes could be expected if restoration projects were successful. “Key” responses are highlighted in green to align with the Metrics table. Formal tests detected individual differences between measurement periods, as well as the direction of difference (e.g. whether a pre-treatment metric was significantly different from an immediate post-treatment metric, and if so, which value was greater). These results were compared to the directions of expected change shown in the table.

Analysis Limitations and Key Assumptions

NMFWRI has been responsible, as part of its Federal Workplan, for long-term vegetation monitoring of selected CFRP’s since 2007 (see initial list in Derr et al., 2008). Consequently, NMFWRI is likely in the best position to begin to draw some conclusions about the ecological impacts of these projects.

However, there are some notable limitations to this effort, including the fact that NMFWRI is not always (or even often) involved in the collection of or provided with pre-treatment data, project prescriptions, or other detailed information without considerable, sometimes intensive, efforts to obtain this information. Typically, grantees have assumed the role of collecting pre-treatment and immediate post-treatment data, and, if the project was selected for long-term monitoring, NMFWRI took over five years post-treatment. There have been cases where a project has been recommended for long-term monitoring but never monitored because NMFWRI has not been able to obtain any information about the work, including maps, shapefiles, or reports from either grantees, collaborators, or the Forest Service CFRP Coordinators.

In working on this project, every attempt has been made to collect all available data from CFRP Coordinators on the Gila, Lincoln, Carson, Cibola, and Santa Fe National Forests. On the Gila, the CFRP Coordinator did not respond to requests; on the Lincoln and the Carson, Coordinators acknowledged the request but did not provide data; on the Cibola and Santa Fe, Coordinators provided some information but were not able to provide all of the data requested.

The next limitation is that, even when this data is provided, it has sometimes been collected with non-standard collection methods that make comparison difficult. One positive development here is the involvement of Forest Stewards Guild in immediate pre-treatment and post-treatment monitoring on several projects. The Forest Stewards Guild uses the five indicators recommended for use in monitoring by all grantees by Derr et al. (see above for list and more information) when conducting pre- and post-treatment monitoring, although their methods for obtaining these metrics differ from NMFWRI's.

In line with Derr et al., NMFWRI uses a standard protocol based on the common stand exam for post-treatment monitoring, including all of the recommended metrics (Appendix B: Monitoring Protocols Used by FWRI on CFRP Projects). The common stand exam is a method used by most federal agencies, so it seemed to offer the promise of compatibility with other monitoring groups. Further, in the "Lessons Learned" reviews conducted by the USFS, NMFWRI was assigned the responsibility to provide grantees with technical assistance for monitoring upon request and hoped to utilize a standard monitoring protocol with interested grantees. Two publications which came out around the same time (Derr, McGrath, Estrada, Krasilovsky, & Evans, 2008; USDA Forest Service, 2009) recommended that NMFWRI take on the role of establishing a data repository for all monitoring data, which also reinforced the need for compatible collection.

Over the last 10 years, success has been mixed on all three fronts. The gap in data sharing and lack of protocol standardization among grantees remains. The Forest Stewards Guild has been providing more technical assistance than NMFWRI. However, due to the long-term monitoring effort, NMFWRI is nevertheless in the best position to examine what data is available and compatible. Therefore, this thesis uses NMFWRI's data and resources to obtain the best vegetative data and other information available about these projects in order to analyze the overall success of the ecological restoration component of the CFRP.

In doing so, the following assumptions are made:

1. Data provided from other agencies or groups was collected properly according to the protocols they provide. Quality control measures were in effect.
2. NMFWRI quality control procedures are sufficient.

Other limitations:

There are existing critiques for how to improve the CFRP, as mentioned in the Past Work section. This thesis will examine and include these as they pertain to ecological monitoring and the challenges experienced. However, it is beyond the scope of this project to attempt to review in detail the many publications on the role of citizen science, collaboration, long-term monitoring, or other social science aspects of this program.

Study Design

The defined population of interest for this study was all potential treated CFRP projects. The sample included projects with available data. Potential sources of bias included: the availability of data (willingness of grantees to monitor and provide reports to the National Forests; willingness of CFRP Coordinators to share data with NMFWRI), access to sites for re-measurement, and differences between data collection crews, agencies, and protocols. Randomization was used, or was assumed to have been used, in the distribution of measurement units (plots or transects) within the projects. The assumption was made that where different protocols were used, use of a standard, unbiased measurement protocol would yield any crew the same results.

This project's analysis was at the CFRP project, stand, or level of silvicultural treatment ("unit") at a given point in time. Each project, stand, or silvicultural treatment unit was considered to be its own experimental unit. The measurement units included the plots or transects upon which data collection was based. The analysis used an average of all measurement unit data across the experimental unit. Even where sites were spatially adjacent, the analysis assumed independence, i.e. treated stands/projects/units were not likely to be heavily influenced by transition zones or other nearby treated stands/projects/units.

Analysis divided projects into groups by forest type (as it was documented pre-treatment), with time relative to treatment as the explanatory variable. There were four levels in the time factor, including: pre-treatment, immediate post-treatment, 5 years post-treatment, and 10 years post-treatment. Pre-treatment data could be collected up to the season before treatment, while immediate post-treatment data is data that was collected within two years of treatment completion. Five year and 10 year post-treatment visits were conducted within a one-year window (i.e. five year data could be collected four to six years post-treatment, and 10 year data could be collected nine to 11 years post-treatment). The majority of all data was collected during the summer field season, i.e. late May to early August.

Extensive literature review was conducted in search of established forest type definitions based on quantifiable species composition, but none was available. All definitions found used plant associations and relative prevalence or dominance of species rather than any specific ratio or percentage (see for example: Dick-Peddie, 1993; Reynolds et al., 2013; USDA Forest Service Southwest Region, 1997). Initial forest type definitions were drafted based on examination of percent dominance of species in monitoring data on projects that NMFWRI, Forest Stewards Guild, or another agency had already classified as particular forest types using more subjective measures. These included four types: mixed-conifer, ponderosa pine, piñon-juniper, and bosque. Due to small sample size in available data, the bosque category was removed. The remaining three forest type definitions were refined into four, and projects re-classified accordingly, following the construction of normal quantile plots. The final working definitions are as follows:

Piñon-juniper woodlands are the most widespread forest type in New Mexico, covering 13.5 million acres (55 percent of all forested land) (Goeking & Menlove, 2017, p. i). Various subtypes of piñon-juniper woodlands exist, but for purposes of this analysis, will not be distinguished. A project was considered to belong to the piñon-juniper, or PJ, type if the dominant species pre-treatment included piñon (typically *Pinus edulis* Engelm.) and/or juniper *(Juniperus spp.*), with less than 25 percent of the total live trees per acre consisting of ponderosa pine.

Ponderosa pine forests are the third most common forest type, covering 2.6 million acres in New Mexico, or 11 percent of the total forested area (Goeking & Menlove, 2017, p. 8). This forest type is characterized by the dominance of ponderosa pine (*Pinus ponderosa* Lawson & C. Lawson), and can be further classified by understory dominance. Grasses or oak (*Quercus spp.*) are common, but for this project, all ponderosa pine will be analyzed together. A project was considered to belong to the ponderosa pine, or PP, type if the dominant species pre-treatment was ponderosa pine, ponderosa pine composed 25 percent or more of the total live trees per acre, and regeneration was dominated by ponderosa pine, oak, or was absent.

Wet mixed-conifer forests are dominated by Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) or white fir *(Abies concolor* (Gord. & Glend.) Lindl. ex Hildebr.) with components of ponderosa pine, limber pine *(Pinus flexilis* James)[3], as well as Engelmann spruce *(Picea engelmannii* Parry ex Engelm.), subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.), and a complex understory. Mixed-conifer forests can be classified as “dry” or “wet,” or divided into subclasses based on species composition. Dry mixed-conifer, DMC, can be thought of as the transition between ponderosa pine and wet mixed-conifer. A project fit this category with one of two definitions: 1) if it had over 25 percent ponderosa pine with secondary dominance by Douglas-fir, white fir or limber pine; 2) if it had greater than 25 but less than 60 percent ponderosa pine and regeneration dominated by Douglas-fir, white fir, or limber pine. This category was added, and percentage cutoffs refined, based on distinct populations appearing in normal quantile plots.

A project was considered to belong to the wet mixed-conifer, or WMC type, if the dominant species pre-treatment was Douglas-fir or white fir, with less than 25 percent of ponderosa pine in the total live trees per acre. Projects with significant percentages of aspen (*Populus tremuloides* Michx.*)* or spruces (*Picea spp.*) were not included in this type.

The four forest types and four measurement periods are presented in Table II.3 on page 27. Replication of measurement periods within each forest type is shown in Table II.4, page 28, as the number of experimental units falling into each classification.

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[3] Note: because of confusion over the nomenclature in much of the collected data, *Pinus flexilis* and *Pinus strobiformis* Engelm. (Southwestern white pine) are not distinguished in this analysis

Response variables included: trees per acre, snags per acre, sick trees per acre, basal acre per acre, QMD for all live trees, average height of live trees, average live crown base height, live saplings per acre, live seedlings per acre, overstory canopy cover percent, grass and forb cover percent, bare soil/rock cover percent, and total tons of surface fuels per acre. However, not every project had data for every response variable.

The project's formal null hypothesis was that there are no differences between forest type metric means at different times relative to treatment. The expected results include the detection of time since treatment differences.

Analysis and Statistical Protocol

After gathering the information available, the next step was to build and clean a composite database for all projects. This was accomplished in Microsoft Excel (2007) by compiling and/or calculating results for all available metrics from the available copies of reports and/or database files (typically in Access, FFI, or Excel). Notes on treatment, agency contacts, monitoring protocols, species composition, and other relevant information were also entered. Next, the database was refined to include only projects that fell into one of the four forest types under consideration and had been measured at the specified time intervals.

Normal quantile plots were used to test the assumption of normality within each treatment level. Normal quantile plots graph ordered observations from the dataset against the ordered quantiles (normal scores) that could be expected if the data were from a population with a normal distribution. A nearly straight line of data on the plot suggested normality. Some scatter indicated the presence of random noise in the sample, while a clearly defined curve indicated a deviation from normality (Oehlert, 2010, p. 115). Possible outliers also stood out on these plots. Plots were generated using IBM Corporation SPSS version 22.

Residual plots were used to test the assumption of constant variance (homogeneity of variance). Residuals were calculated by finding the mean of each treatment group, and then subtracting that mean from the individual observations, thereby giving a measure of difference from the mean. The plots display residual values against categories (in this case, time relative to treatment). The plots look like vertical lines. If the different treatments have constant variance, the vertical spread for each group should be about the same (Oehlert, 2010, pp. 118-119).

A modified Levene's test for homogeneity of variance was also performed. Levene's test examines the null hypothesis that there is no difference between sample variances of treatment levels. The first step was to calculate the median residuals, i.e. determine the absolute value of deviation from the group median for each data point. These residuals were tested in SPSS. The null of no difference between variance was rejected if $p < 0.05$. This test was conducted to quantify the homogeneity of variance, but the decision about the assumption of constant variance primarily used the residual plots. This is because the p-values of the Levene's test do not give any information about how or why the variance may differ between groups, and may be too sensitive to certain violations of constant variance (Oehlert, 2010, pp. 118-119).

The assumption of independence was the final condition needed to run an ANOVA. The concern with this data was autocorrelation because the factor was time. However, it was not so clear-cut. Many projects had just one or two measures so they are not present in every "time" category. In fact, only nine experimental units out of 59 have all data for all four measurement periods, and even on those, not all variables were recorded each time. Initially a repeated measures ANOVA was considered, but the unbalanced design made this difficult. Instead, autocorrelation was tested by looking for drifting or alternating patterns on plots of residuals against time, which would suggest either positive or negative dependence. The Durbin-Watson statistic was also calculated using SPSS. The Durbin-Watson statistic is always between zero and four; a value of two is considered to indicate no autocorrelation, and values beyond the 1.5 to 2.5 range mean there may be a noticeable impact of dependence (Oehlert, 2010, pp. 120-121).

The final step before the ANOVA was the examination and treatment of possible outliers. Outliers appeared as extreme data points in both the normal quantile plots and the residual plots. Following identification, the individual points were investigated. Original sources were consulted to confirm the values had been calculated and entered into the database correctly. Once that was confirmed, the project itself was examined for characteristics that made it different from the rest of the population. For example, one project had been burned in a wildfire post-treatment, and data points from this project consistently appeared as outliers. Whenever data was removed from analysis, the removal and the justification were documented. Following any change to the dataset, all of the above plots and tests were re-created.

Next, four one-way ANOVAs were performed, one for each forest type. The analysis of variance (ANOVA) is a way of testing the null hypothesis that all data can be described by the same mean, i.e. no difference between treatment groups. For this project, a type III sum of squares was used to account for the unbalanced design. The null hypothesis was rejected if $p < 0.05$.

Finally, the Tukey Honest Significant Difference (Tukey HSD) multiple pairwise comparison was used to examine which means were different. Because of the unbalanced design, an approximation known as the Tukey-Kramer test was used. This test uses simultaneous confidence intervals for the differences between pairs of means based on the Studentized range distribution; if the interval does not include zero, then the null hypothesis of no difference is rejected.

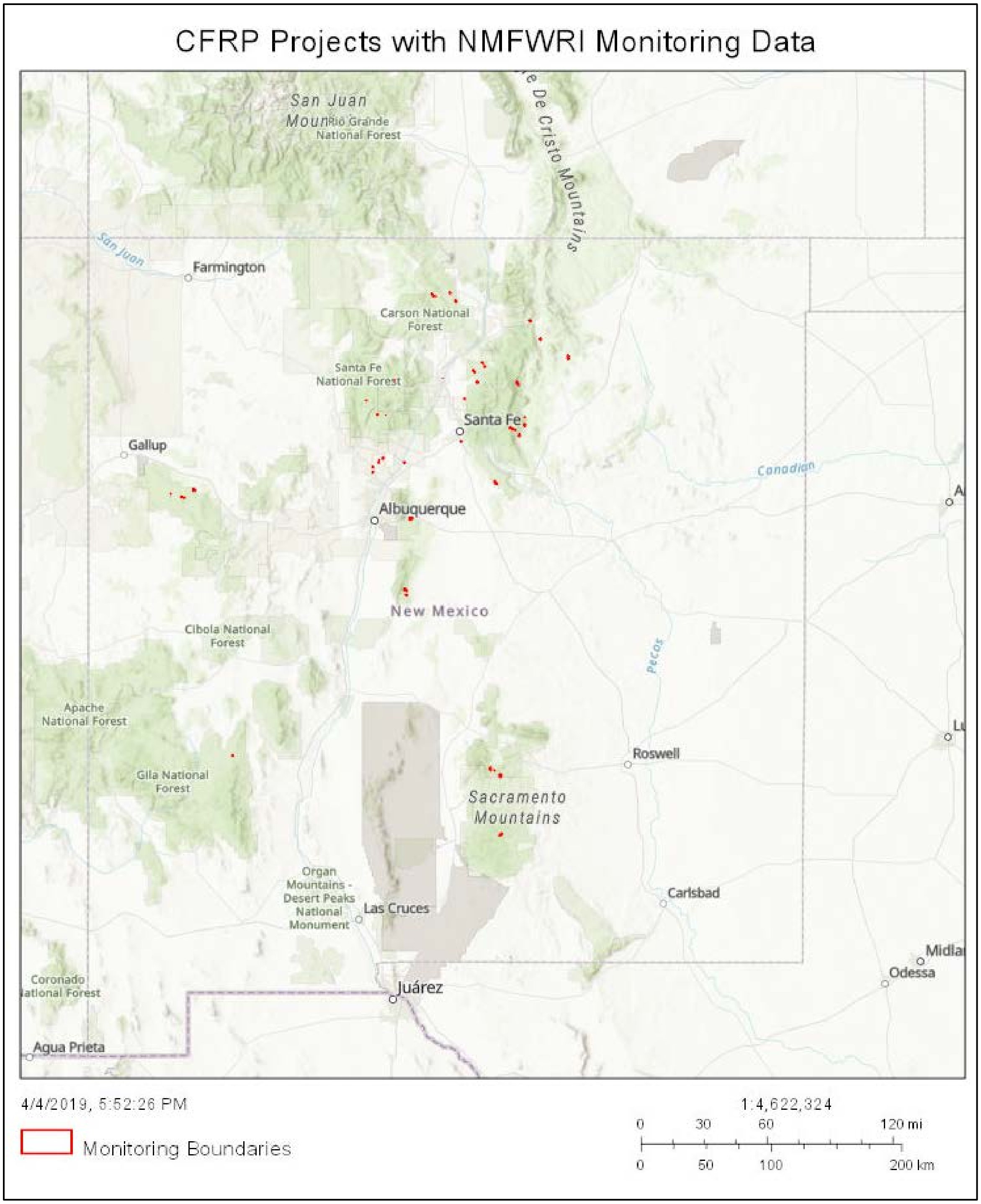

Figure II.1 Map of CFRP projects NMFWRI has monitored(NMFWRI, 2019). Projects represented are current through field season 2018.

Table II.1 Metrics available for use in Collaborative Forest Restoration Program (CFRP) objective evaluation. The metrics displayed were collected on the majority of CFRP projects. Program objectives are from the Community Forest Restoration Act.

Program Objective	Metrics Used to Evaluate									
	Canopy cover (%)	Understory cover (%)	Surface fuels (tons/ac)	Crown base height (ft)	Species composition	Tree size (DBH, DRC)	Density (live/dead stems)	Basal area/ac (ft^2)	Reference ranges[4]	Beyond Scope of this Project
Wildfire threat reduction			Yes	Yes			Yes	Yes		
Ecosystem restoration,	Yes	Yes			Yes				Yes	
Reestablishment of historic fire regimes										Yes, insufficient info
Reforestation					Yes	Yes	Yes	Yes		
Preservation of old/ large trees					Yes	Yes	Yes			
Small diameter tree utilization										Yes, social metric
Forest-related local employment										Yes, social metric
Stakeholder diversity										Yes, social metric

[4] Based on the available data, it may be possible to compare CFRP treatment means to the historical reference ranges provided in the GTR 310 for the following measures: Trees per acre, Basal area, Openness (inverse of canopy cover), and Snags per acre

Table II.2 Expected responses of metrics to effective restoration treatments (Bettinger, Boston, Siry, & Grebner, 2008; Bradley, 2009; Ecological Restoration Institute, 2005; Reid, 2019).

	Live trees per acre	Snags per acre	Sick trees per acre	Canopy Cover	Basal area	Tree Size (QMD)	Tree Height	Live Crown Base	Seedlings /Saplings	Shrubs (Under-story)	Surface Fuels	1000-hr fuels
Wildfire Threat Reduction	Decrease or no change[5]	generally decrease	decrease	Decrease or no change	decrease	increase[6]	generally increase[7]	increase[8]	decrease	generally decrease	decrease	decrease
Ecosystem Restoration		increase or decrease	possible initial increase[9] then decrease		decrease	increase	generally increase		decrease	decrease or increase[10]		decrease but need for habitat
Reforestation	Increase or no change								increase			
Preservation of old/large trees			decrease			increase	generally increase					

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[5] Total trees per acre may be unchanged long term but the percent of large dbh trees may increase (most NM forests are overstocked with small diameter trees)

[6] Increase is expected as small diameter trees are removed and remaining trees are released

[7] Increase is expected as smaller, ladder-fuel trees removed

[8] Increase is expected as ladder fuels reduced and small trees removed

[9] Disturbance may cause release of mistletoe in stand, but should decrease as stand health improves

[10] Depending upon system

Table II.3 Combinations of forest types and measurement periods. Forest types (Piñon-Juniper (PJ), Ponderosa Pine (PP), Dry Mixed-Conifer (DMC), and Wet Mixed-Conifer (WMC)) and measurement periods (pre-treatment, immediate post-treatment, 5 year post-treatment, and 10 year post-treatment).

	Pre-tx	**Immediate post**	**5 year post**	**10 year post**
PJ	PJ, pre-tx	PJ, immediate post	PJ, 5-yr-post	PJ, 10-yr-post
PP	PP, pre-tx	PP, immediate post	PP, 5-yr-post	PP, 10-yr-post
DMC	DMC, pre-tx	DMC, immediate post	DMC, 5-yr-post	DMC, 10-yr-post
WMC	WMC, pre-tx	WMC, immediate post	WMC, 5-yr-post	WMC, 10-yr-post

Table II.4 Experimental units matrix. This table represents the number of experimental units that fall into each measurement period (pre-treatment, immediate post-treatment, 5 year post-treatment, and 10 year post-treatment) and each forest type (Piñon-Juniper (PJ), Ponderosa Pine (PP), Dry Mixed-Conifer (DMC), and Wet Mixed-Conifer (WMC)).

	Pre-tx	**Immediate post**	**5 year post**	**10 year post**
PJ	12	13	14	14
PP	19	12	23	19
DMC	7	5	6	2
WMC	3	3	6	6

III. – Results

A summary of all results is presented in Table III.1 on page 40. The remainder of this chapter is the presentation of results by forest type. All boxplots were produced in SPSS version 22. Lettering indicates which values were significantly different from one another according to the Tukey HSD post hoc comparison. Values marked with the same letter are not significantly different from one another, while values with different letters are different.

During the course of the analysis, it was found that the values for understory cover (grass/forb and bare soil/rock) had several outliers and did not meet all assumptions for the ANOVA. This is likely because this metric is highly sensitive to precipitation, seasonal variation, prescribed fire and other disturbance. While species composition information was available for many projects, it would require a different type of statistical analysis. Therefore, while both understory cover and species composition are part of the recommended set of monitoring variables, they were removed from this analysis pending further investigation.

Wet Mixed-Conifer Results

A one-way ANOVA was conducted to compare the impact of Time Relative to Treatment on trees per acre pre-treatment, immediately post-treatment, 5 years post-treatment, and 10 years post-treatment (see Table III.2 on page 41).

There was not a significant effect of Time Relative to Treatment on trees per acre at the $p < 0.05$ level. Results were also not significant at the $p < 0.05$ level for: QMD for live trees, average height of live trees, average live crown base height, live saplings per acre, live seedlings per acre, live shrubs per acre, sick trees per acre, snags per acre, overstory canopy cover percent, tons per acre total surface fuels, and tons per acre 1000-hour fuels. For these variables, there was not sufficient evidence to reject the null hypothesis of no difference between Time Relative to Treatment. No post hoc comparisons were conducted.

There was, however, a significant effect of Time Relative to Treatment on basal area per acre at the $p < 0.05$ level (Figure III.1, page 42). Post hoc comparisons using the Tukey HSD test indicated that the basal area per acre pre-treatment ($\bar{x}$ = 137.15, SE = 32.85) was significantly different from 5 years post-treatment ($\bar{x}$ = 74.83, SE = 8.03) and 10 years post-treatment ($\bar{x}$ = 72.83, SE = 7.59). Basal area per acre for immediate post-treatment ($\bar{x}$ = 99.50, SE = 4.50) did not differ significantly from any other category, nor did 5 year post-treatment differ from 10 year post-treatment.

Dry Mixed-Conifer Results

A one-way ANOVA was conducted to compare the impact of Time Relative to Treatment on various metrics pre-treatment, immediately post-treatment, 5 years post-treatment, and 10 years post-treatment (see Table III.1 on page 40). All metrics with significant effects are graphed on pages 44 to 49.

There was a significant effect of Time Relative to Treatment on trees per acre at the $p < 0.05$ level. Post hoc comparisons using the Tukey HSD test indicated that the trees per acre pre-treatment ($\bar{x}$ = 385.0, SE = 87.60) was significantly different from 5 years post-treatment ($\bar{x}$ = 89.77, SE = 21.95). Trees per acre for pre-treatment was not significantly different from any other category, nor were there any significant differences found with the immediate post-treatment ($\bar{x}$ =101.67, SE = 21.15) or the 10 year post-treatment ($\bar{x}$ = 149.00, SE = 68.00) categories.

There was a significant effect of Time Relative to Treatment on basal area per acre at the $p < 0.05$ level. Post hoc comparisons using the Tukey HSD test indicated that the basal area per acre pre-treatment ($\bar{x}$ = 127.20, SE = 12.96) was significantly different from immediate post-treatment ($\bar{x}$ = 63.17, SE = 10.35) and 5 years post-treatment ($\bar{x}$ = 54.92, SE = 9.01). Basal area per acre for pre-treatment did not differ significantly from 10 years post-treatment ($\bar{x}$ = 65.00, SE = 4.00), nor did immediate post-treatment, 5 year post-treatment and 10 year post-treatment differ significantly from one another.

There was a significant effect of Time Relative to Treatment on QMD at the $p < 0.05$ level. Post hoc comparisons using the Tukey HSD test indicated that the QMD pre-treatment ($\bar{x}$ = 8.43, SE = 0.62) was significantly different from QMD 5 years post-treatment ($\bar{x}$ = 11.58, SE = 0.28). QMD for pre-treatment and 5 years post-treatment did not differ significantly from any other category, nor did immediate post-treatment ($\bar{x}$ =10.73, SE = 0.35) or 10 years post-treatment ($\bar{x}$ = 10.45, SE = 1.15) differ from one another.

There was a significant effect of Time Relative to Treatment on average height of live trees at the $p < 0.05$ level. Post hoc comparisons using the Tukey HSD test indicated that the average height pre-treatment ($\bar{x}$ = 32.20, SE = 2.40) was significantly different from height 5 years post-treatment ($\bar{x}$ = 41.25, SE = 0.87). Height for pre-treatment and 5 years post-treatment did not differ significantly from any other category, nor did immediate post-treatment ($\bar{x}$ = 39.4, SE = 1.40) or 10 years post-treatment ($\bar{x}$ = 35.50, SE = 6.50) differ from one another.

There was a significant effect of Time Relative to Treatment on live crown base height at the $p < 0.05$ level. Post hoc comparisons using the Tukey HSD test indicated that the live crown base height pre-treatment ($\bar{x}$ = 15.13, SE = 1.48) was significantly different from live crown base height 5 years post-treatment ($\bar{x}$ = 21.37, SE = 1.57). Live crown base height for pre-treatment and 5 years post-treatment did not differ significantly from any other category, nor did immediate post-treatment ($\bar{x}$ =18.57, SE = 1.10) or 10 years post-treatment ($\bar{x}$ = 16.50, SE = 0.50) differ from one another.

There was a significant effect of Time Relative to Treatment on percent overstory canopy cover at the $p < 0.05$ level. Post hoc comparisons using the Tukey HSD test indicated that the percent overstory canopy cover pre-treatment ($\bar{x}$ = 69.86, SE = 7.21) was significantly different from immediate post-treatment ($\bar{x}$ = 39.75, SE = 6.43) and 5 years post-treatment ($\bar{x}$ = 35.83, SE = 4.71). Canopy cover for pre-treatment did not differ significantly from 10 years post-treatment ($\bar{x}$ = 52.50, SE = 0.50), nor did immediate post-treatment, 5 year post-treatment and 10 year post-treatment differ significantly from one another.

There was not a significant effect of Time Relative to Treatment on live saplings per acre, live seedlings per acre, shrubs per acre, sick trees per acre, snags per acre, tons per acre total surface fuels, and tons per acre 1000-hour fuels. For these variables, there was not sufficient evidence to reject the Null hypothesis of no difference between Time Relative to Treatment. No post hoc comparisons were conducted.

Ponderosa Pine Results

A one-way ANOVA was conducted to compare the impact of Time Relative to Treatment on various metrics pre-treatment, immediately post-treatment, 5 years post-treatment, and 10 years post-treatment (see Table III.4 on page 50). All metrics with significant effects are graphed on pages 51 to 57.

There was a significant effect of Time Relative to Treatment on trees per acre at the $p < 0.05$ level. Post hoc comparisons using the Tukey HSD test indicated that the trees per acre pre-treatment ($\bar{x}$ = 221.34, SE =48.89) was significantly different from immediate post-treatment ($\bar{x}$ = 86.48, SE = 18.37), 5 years post-treatment ($\bar{x}$ = 83.46, SE = 10.38) and 10 years post-treatment ($\bar{x}$ = 93.66, SE = 16.31). However, the immediate post-treatment, 5 year post-treatment, and 10 year post-treatment trees per acre values did not differ significantly from one another.

There was a significant effect of Time Relative to Treatment on basal area per acre at the $p < 0.05$ level. Post hoc comparisons using the Tukey HSD test indicated that the trees per acre pre-treatment ($\bar{x}$ = 104.34, SE = 9.66) was significantly different from immediate post-treatment ($\bar{x}$ = 53.53, SE = 16.16), 5 years post-treatment ($\bar{x}$ = 49.03, SE = 5.04) and 10 years post-treatment ($\bar{x}$ = 52.66, SE = 5.55). However, the immediate post-treatment, 5 year post-treatment, and 10 year post-treatment basal area per acre values did not differ significantly from one another.

There was a significant effect of Time Relative to Treatment on average height of live trees at the $p < 0.05$ level. Post hoc comparisons using the Tukey HSD test indicated that the average height pre-treatment ($\bar{x}$ = 57.25, SE = 6.98) was significantly different from the 5 years post-treatment ($\bar{x}$ = 36.73, SE = 2.38) and 10 years post-treatment ($\bar{x}$ = 35.63, SE = 2.73). Average tree height for immediate post-treatment ($\bar{x}$ = 33.50, SE = 1.50) did not differ significantly from any other category, nor did the 5 year post-treatment differ from the 10 year post-treatment.

There was a significant effect of Time Relative to Treatment on live saplings per acre at the $p < 0.05$ level. Post hoc comparisons using the Tukey HSD test indicated that the density of saplings per acre pre-treatment ($\bar{x}$ = 158.27, SE = 49.50) was significantly different from immediate post-treatment ($\bar{x}$ = 29.83, SE = 11.50) and 10 years post-treatment ($\bar{x}$ = 13.68, SE = 7.74), but not from 5 years post-treatment ($\bar{x}$ = 69.49, SE = 30.10). The immediate post-treatment, 5 year post-treatment, and 10 year post-treatment saplings per acre values did not differ significantly from one another.

There was a significant effect of Time Relative to Treatment on live seedlings per acre at the $p < 0.05$ level. Post hoc comparisons using the Tukey HSD test indicated that the density of seedlings per acre pre-treatment ($\bar{x}$ = 5224.68, SE = 2101.70) was significantly different from immediate post-treatment ($\bar{x}$ = 651.02, SE = 450.38), 5 years post-treatment ($\bar{x}$ = 608.01, SE = 183.64) and 10 years post-treatment ($\bar{x}$ = 986.89, SE = 214.81). However, the immediate post-treatment, 5 year post-treatment, and 10 year post-treatment seedlings per acre values did not differ significantly from one another.

There was a significant effect of Time Relative to Treatment on percent overstory canopy cover at the $p < 0.05$ level. Post hoc comparisons using the Tukey HSD test indicated that the percent overstory canopy cover pre-treatment ($\bar{x}$ = 45.56, SE = 7.69) was significantly different from the immediate post-treatment ($\bar{x}$ = 21.95, SE = 3.25) canopy. It did not differ from the cover 5 years post-treatment ($\bar{x}$ = 34.55, SE = 2.62) or 10 years post-treatment ($\bar{x}$ = 37.69, SE = 4.29), nor did the immediate post-treatment, 5 year post-treatment and 10 year post-treatment values differ significantly from one another.

There was a significant effect of Time Relative to Treatment on tons per acre of 1000-hour fuels at the $p < 0.05$ level. Post hoc comparisons using the Tukey HSD test indicated that the tons per acre 1000-hour fuels pre-treatment ($\bar{x}$ = 3.20, SE = 2.27) was significantly different from the tons per acre of 1000-hour fuels immediate post-treatment ($\bar{x}$ =12.87, SE = 4.48), but not from 5 years post-treatment ($\bar{x}$ = 3.72, SE = 0.71) or 10 years post-treatment ($\bar{x}$ = 4.57, SE = 1.09). However, immediate post-treatment did differ significantly from both 5 year post-treatment and 10 year post-treatment values. Five year post-treatment values did not differ significantly from 10 year post-treatment values.

There was not a significant effect of Time Relative to Treatment on QMD, average live crown base height, shrubs per acre, sick trees per acre, snags per acre, and tons per acre total of surface fuels. For these variables, there is not sufficient evidence to reject the null hypothesis of no difference between Time Relative to Treatment levels.

Piñon-Juniper Results

A one-way ANOVA was conducted to compare the impact of Time Relative to Treatment on various metrics pre-treatment, immediately post-treatment, 5 years post-treatment, and 10 years post-treatment (see Table III.5 on page 58). All metrics with significant effects are graphed on pages 59 to 66.

There was a significant effect of Time Relative to Treatment on trees per acre at the $p < 0.05$ level. Post hoc comparisons using the Tukey HSD test indicated that the trees per acre pre-treatment ($\bar{x}$ = 195.58, SE = 49.61) was significantly different from the 5 years post-treatment ($\bar{x}$ = 59.39, SE = 18.31) and 10 years post-treatment ($\bar{x}$ = 56.25, SE = 18.42). Trees per acre for immediate post-treatment ($\bar{x}$ = 107.87, SE = 32.11) did not differ significantly from any other category, nor did the 5 year post-treatment differ from the 10 year post-treatment.

There was a significant effect of Time Relative to Treatment on basal area per acre at the $p < 0.05$ level. Post hoc comparisons using the Tukey HSD test indicated that the basal area per acre pre-treatment ($\bar{x}$ = 153.6, SE = 45.40) was significantly different from immediate post-treatment ($\bar{x}$ = 20.58, SE = 17.11), 5 years post-treatment ($\bar{x}$ = 20.07, SE = 4.18) and 10 years post-treatment ($\bar{x}$ = 25.3, SE = 5.29). However, the immediate post-treatment, 5 year post-treatment, and 10 year post-treatment basal area per acre values did not differ significantly from one another.

There was a significant effect of Time Relative to Treatment on QMD for all live trees at the $p < 0.05$ level. Post hoc comparisons using the Tukey HSD test indicated that the QMD from the immediate post-treatment category ($\bar{x}$ = 4.78, SE = 1.76) was significantly different from the QMD 10 years post-treatment ($\bar{x}$ = 12.84, SE = 1.80), but not from pre-treatment ($\bar{x}$ = 6.22, SE = 1.12) or 5 years post-treatment ($\bar{x}$ = 10.47, SE = 1.45). QMD pre-treatment did not differ significantly from any category, nor did the 5 year post-treatment differ from the 10 year post-treatment.

There was a significant effect of Time Relative to Treatment on live saplings per acre at the $p < 0.05$ level. Post hoc comparisons using the Tukey HSD test indicated that the density of saplings per acre pre-treatment ($\bar{x}$ = 150.75, SE = 54.79) was significantly different from immediate post-treatment ($\bar{x}$ = 46.86, SE = 44.38), 5 years post-treatment ($\bar{x}$ = 11.43, SE = 6.53), and 10 years post-treatment ($\bar{x}$ = 0.00, SE = 0.00). However, the immediate post-treatment, 5 year post-treatment, and 10 year post-treatment basal area per acre values did not differ significantly from one another.

There was a significant effect of Time Relative to Treatment on live shrubs per acre at the $p < 0.05$ level. However, post hoc comparisons using the Tukey HSD test showed no significant differences between categories. This is reasonable given that the ANOVA and Tukey HSD test use different methods.

There was a significant effect of Time Relative to Treatment on sick trees per acre at the $p < 0.05$ level. Note that sick trees were not recorded on any pre-treatment or immediate post-treatment sites for this forest type, so the differences exist between the 5 year post-treatment ($\bar{x}$ = 1.57, SE = 0.67)and 10 year post-treatment ($\bar{x}$ = 0 , SE = 0) categories. No post hoc comparison with Tukey HSD was performed.

There was a significant effect of Time Relative to Treatment on snags per acre at the $p < 0.05$ level. Post hoc comparisons using the Tukey HSD test indicated that the snags per acre pre-treatment ($\bar{x}$ = 66.85, SE = 17.77) was significantly different from immediate post-treatment ($\bar{x}$ =22.09, SE = 8.93), 5 years post-treatment ($\bar{x}$ = 10.64, SE = 5.49) and 10 years post-treatment ($\bar{x}$ = 5.61, SE = 2.84). However, the immediate post-treatment, 5 year post-treatment, and 10 year post-treatment snags per acre values did not differ significantly from one another.

There was a significant effect of Time Relative to Treatment on percent overstory canopy cover at the $p < 0.05$ level. Post hoc comparisons using the Tukey HSD test indicated that the percent overstory canopy cover pre-treatment ($\bar{x}$ = 28.60, SE = 9.29) was significantly different from 5 years post-treatment ($\bar{x}$ = 5.99, SE = 1.99) and 10 years post-treatment ($\bar{x}$ = 6.41, SE = 1.97). Canopy cover for immediate post-treatment ($\bar{x}$ = 11.88, SE = 5.40) did not differ significantly from any other category, nor did the 5 year post-treatment differ from the 10 year post-treatment.

There was not a significant effect of Time Relative to Treatment on average height of live trees, average live crown base height, live seedlings per acre, tons per acre of total surface fuels, and tons per acre of 1000-hour fuels. For these variables, there is not sufficient evidence to reject the Null hypothesis of no difference between Time Relative to Treatment.

Table III.1 Analysis of Variance (ANOVA) results for all metrics and forest types. Four one-way ANOVAs were conducted, one for each forest type. P values less than 0.05 (starred) are significant and provide evidence for a difference between measurement periods.

Metric	**Wet Mixed-Conifer ANOVA results at p < 0.05 for Null of no difference between means in measurement periods**	**p value**	**Dry Mixed-Conifer ANOVA results at p < 0.05 for Null of no difference between means in measurement periods**	**p value**	**Ponderosa Pine ANOVA results at p < 0.05 for Null of no difference between means in measurement periods**	**p value**	**Piñon-Juniper ANOVA results at p < 0.05 for Null of no difference between means in measurement periods**	**p value**
Trees per Acre	*fail to reject Null*	*0.379*	reject Null	0.013*	reject Null	0.001*	reject Null	0.009*
Basal Area per Acre	reject Null	0.017*	reject Null	0.001*	reject Null	0*	reject Null	0*
Quadratic Mean Diameter	*fail to reject Null*	*0.726*	reject Null	0.003*	*fail to reject Null*	*0.195*	reject Null	0.019*
Tree Height	*fail to reject Null*	*0.06*	reject Null	0.041*	reject Null	0.001*	*fail to reject Null*	*0.987*
Live Crown Base Height	*fail to reject Null*	*0.217*	reject Null	0.043*	*fail to reject Null*	*0.125*	*fail to reject Null*	*0.825*
Saplings per Acre	*fail to reject Null*	*0.503*	*fail to reject Null*	*0.593*	reject Null	0.009*	reject Null	0*
Seedlings per Acre	*fail to reject Null*	*0.953*	*fail to reject Null*	*0.967*	reject Null	0.005*	*fail to reject Null*	*0.055*
Shrubs per Acre	*fail to reject Null*	*0.424*	*fail to reject Null*	*0.165*	*fail to reject Null*	*0.457*	reject Null	*0.047*
Sick Trees per Acre	*fail to reject Null*	*0.345*	*fail to reject Null*	*0.442*	*fail to reject Null*	*0.326*	reject Null	*0.027*
Snags per Acre	*fail to reject Null*	*0.757*	*fail to reject Null*	*0.147*	*fail to reject Null*	*0.691*	reject Null	0*
Overstory Canopy Cover Percent	*fail to reject Null*	*0.168*	reject Null	0.00*5	reject Null	0.014*	reject Null	0.002*
Total Surface Fuels	*fail to reject Null*	*0.564*	*fail to reject Null*	*0.058*	*fail to reject Null*	*0.266*	*fail to reject Null*	*0.256*
1000-hr Fuels	*fail to reject Null*	*0.813*	*fail to reject Null*	*0.156*	reject Null	0.004	*fail to reject Null*	*0.311*

Table III.2 Analysis of Variance (ANOVA) results for Wet Mixed-Conifer. The table is from a one-way ANOVA for an unbalanced design.

Metric		Sum of Squares	df	Mean Square	F	Sig.
Trees per Acre	Treatment	26304.029	3	8768.010	1.115	.379
	Error	102247.500	13	7865.192		
	Total	128551.529	16			
Basal Area per Acre	Treatment	7368.048	3	2456.016	5.029	.017
	Error	5860.412	12	488.368		
	Total	13228.459	15			
QMD for all Live Trees (in)	Treatment	12.149	3	4.050	.443	.726
	Error	118.777	13	9.137		
	Total	130.925	16			
Average Height of Live Trees (ft)	Treatment	1072.974	2	536.487	3.780	.060
	Error	1419.333	10	141.933		
	Total	2492.308	12			
Average Live Crown Base Height (ft)	Treatment	158.054	3	52.685	1.714	.217
	Error	368.910	12	30.743		
	Total	526.964	15			
Live Saplings per Acre	Treatment	329826.276	3	109942.092	.828	.503
	Error	1593017.708	12	132751.476		
	Total	1922843.984	15			
Live Seedlings per Acre (trees)	Treatment	414394.190	3	138131.397	.109	.953
	Error	12620660.167	10	1262066.017		
	Total	13035054.357	13			
Shrubs per Acre	Treatment	38924438.427	2	19462219.214	.956	.424
	Error	162910348.800	8	20363793.600		
	Total	201834787.227	10			
Sick Tees per Acre	Treatment	150.030	3	50.010	1.245	.345
	Error	401.682	10	40.168		
	Total	551.712	13			
Snags per Acre	Treatment	1080.114	3	360.038	.398	.757
	Error	11774.442	13	905.726		
	Total	12854.555	16			
Overstory Canopy Cover (%)	Treatment	1184.361	3	394.787	2.000	.168
	Error	2368.200	12	197.350		
	Total	3552.561	15			
Total Surface Fuels (tons per acre)	Treatment	433.990	3	144.663	.711	.564
	Error	2439.880	12	203.323		
	Total	2873.870	15			
1000-hour fuels (tons per acre)	Treatment	116.428	3	38.809	.316	.813
	Error	1349.748	11	122.704		
	Total	1466.176	14			

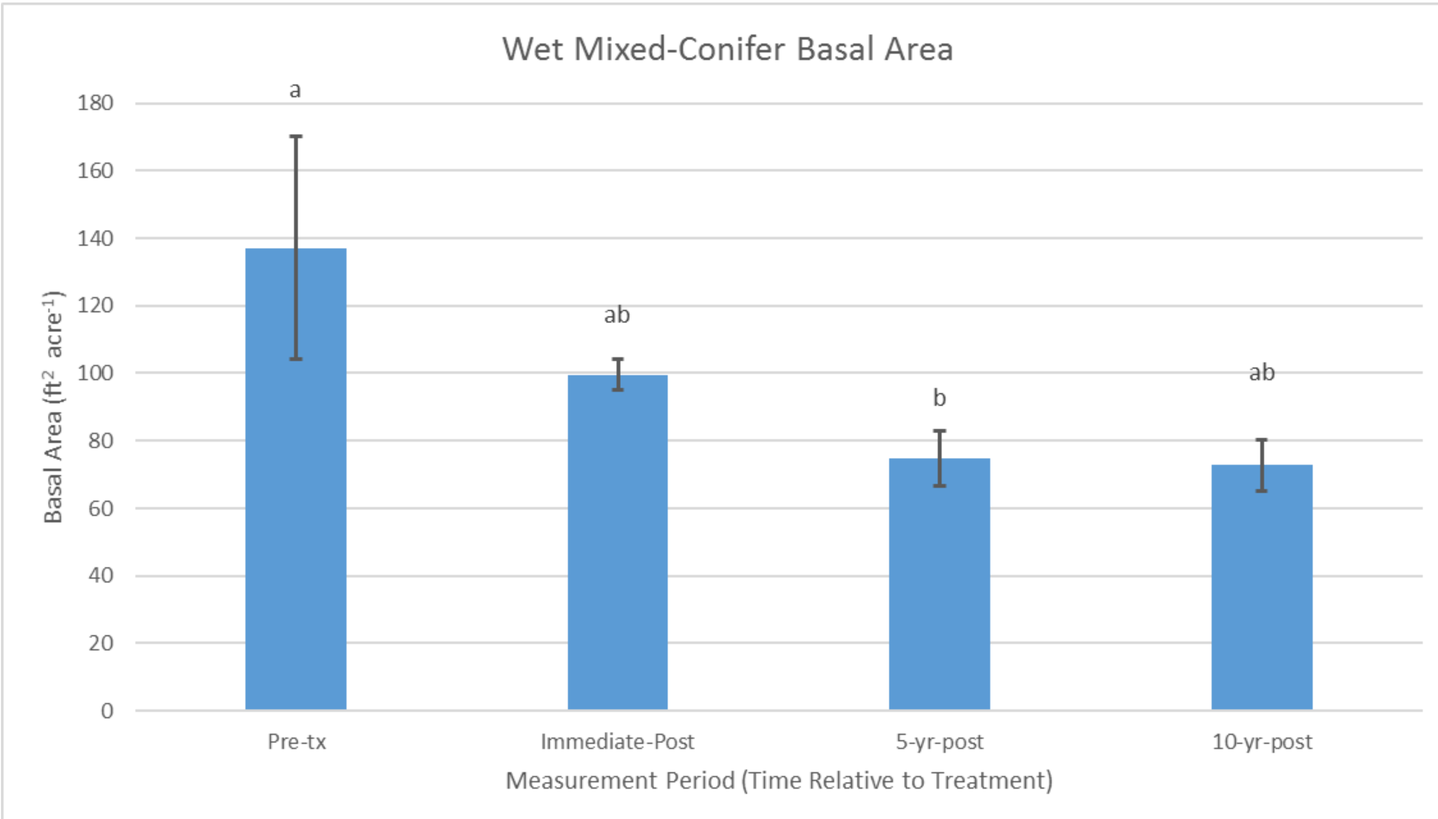

Figure III.1 Basal area per acre in wet mixed-conifer. Data displayed are means (± standard error of the mean) for each measurement period. Means marked with the same letter do not differ significantly ($\alpha = 0.05$) according to Tukey's Honest Significant Difference multiple pairwise comparison.

Table III.3 Analysis of Variance (ANOVA) Results for Dry Mixed-Conifer. The table is from a one-way ANOVA for an unbalanced design.

Metric		Sum of Squares	df	Mean Square	F	Sig.
Trees per Acre	Treatment	312312.039	3	104104.013	5.274	.013
	Error	256610.700	13	19739.285		
	Total	568922.739	16			
Basal Area per Acre	Treatment	20121.219	3	6707.073	9.244	.001
	Error	10158.041	14	725.574		
	Total	30279.259	17			
QMD for all Live Trees (in)	Treatment	31.184	3	10.395	7.751	.003
	Error	17.433	13	1.341		
	Total	48.618	16			
Average Height of Live Trees (ft)	Treatment	238.869	3	79.623	3.859	.041
	Error	226.975	11	20.634		
	Total	465.844	14			
Average Live Crown Base Height (ft)	Treatment	122.607	3	40.869	3.601	.043
	Error	147.533	13	11.349		
	Total	270.140	16			
Live Saplings per Acre	Treatment	238326.214	3	79442.071	.656	.593
	Error	1573813.542	13	121062.580		
	Total	1812139.755	16			
Live Seedlings per Acre (trees)	Treatment	789523.439	3	263174.480	.085	.967
	Error	46420505.298	15	3094700.353		
	Total	47210028.737	18			
Shrubs per Acre	Treatment	169979949.759	3	56659983.253	2.051	.165
	Error	303810165.770	11	27619105.979		
	Total	473790115.529	14			
Sick Tees per Acre	Treatment	676.188	3	225.396	.969	.442
	Error	2557.376	11	232.489		
	Total	3233.564	14			
Snags per Acre	Treatment	6341.460	3	2113.820	2.118	.147
	Error	12975.775	13	998.137		
	Total	19317.235	16			
Overstory Canopy Cover (%)	Treatment	4380.007	3	1460.002	6.543	.005
	Error	3346.940	15	223.129		
	Total	7726.947	18			
Total Surface Fuels (tons per acre)	Treatment	2416.899	3	805.633	3.118	.058
	Error	3875.114	15	258.341		
	Total	6292.013	18			
1000-hour fuels (tons per acre)	Treatment	418.029	3	139.343	2.052	.156
	Error	882.865	13	67.913		
	Total	1300.894	16			

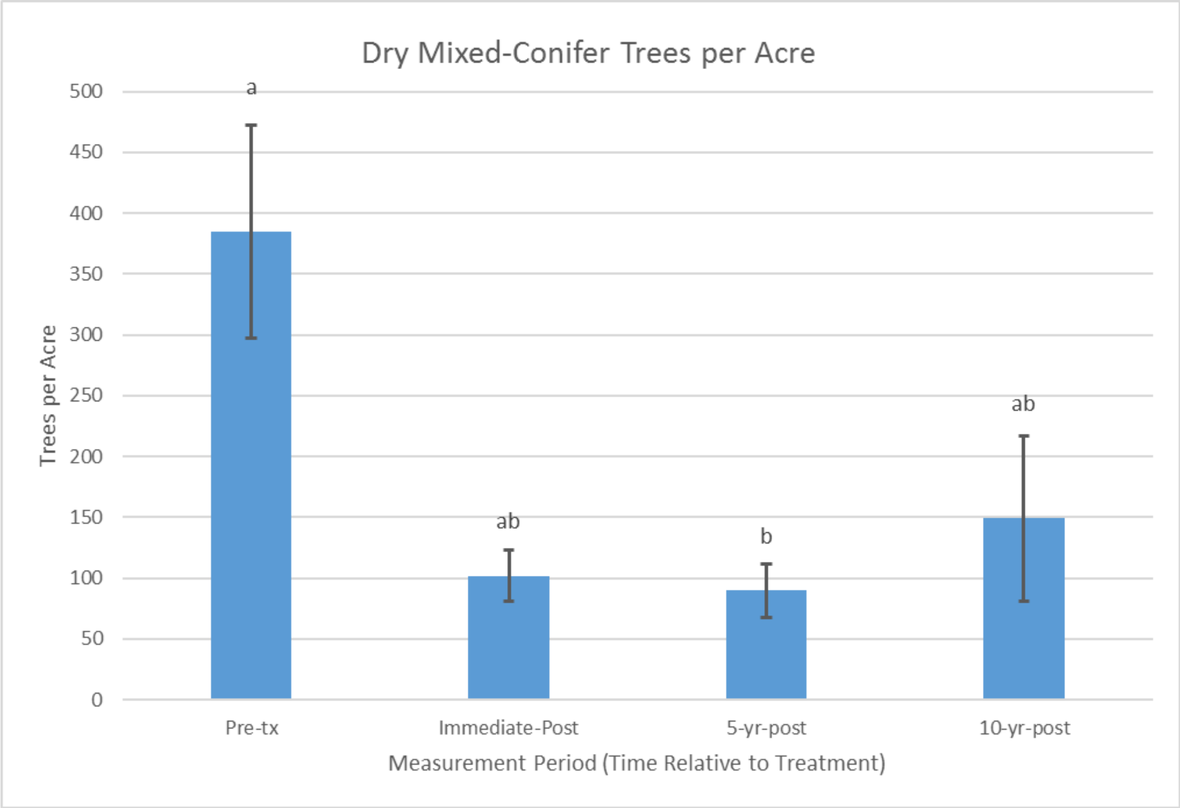

Figure III.2 Analysis of Variance (ANOVA) Results for Dry Mixed-Conifer Trees per Acre. Data displayed are means (± standard error of the mean) for each measurement period. Means marked with the same letter do not differ significantly (α = 0.05) according to Tukey's Honest Significant Difference multiple pairwise comparison.

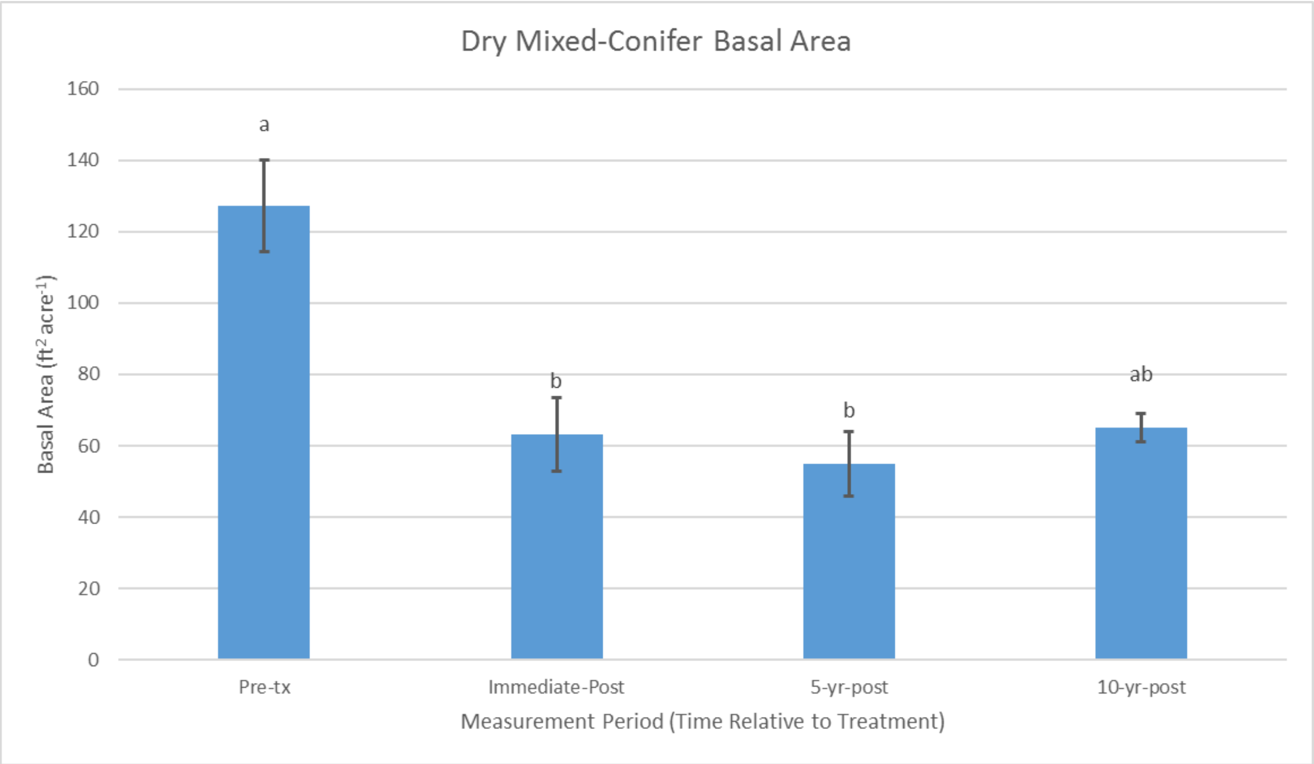

Figure III.3 Analysis of Variance (ANOVA) Results for Dry Mixed-Conifer Basal Area. Data displayed are means (± standard error of the mean) for each measurement period. Means marked with the same letter do not differ significantly ($\alpha = 0.05$) according to Tukey's Honest Significant Difference multiple pairwise comparison.

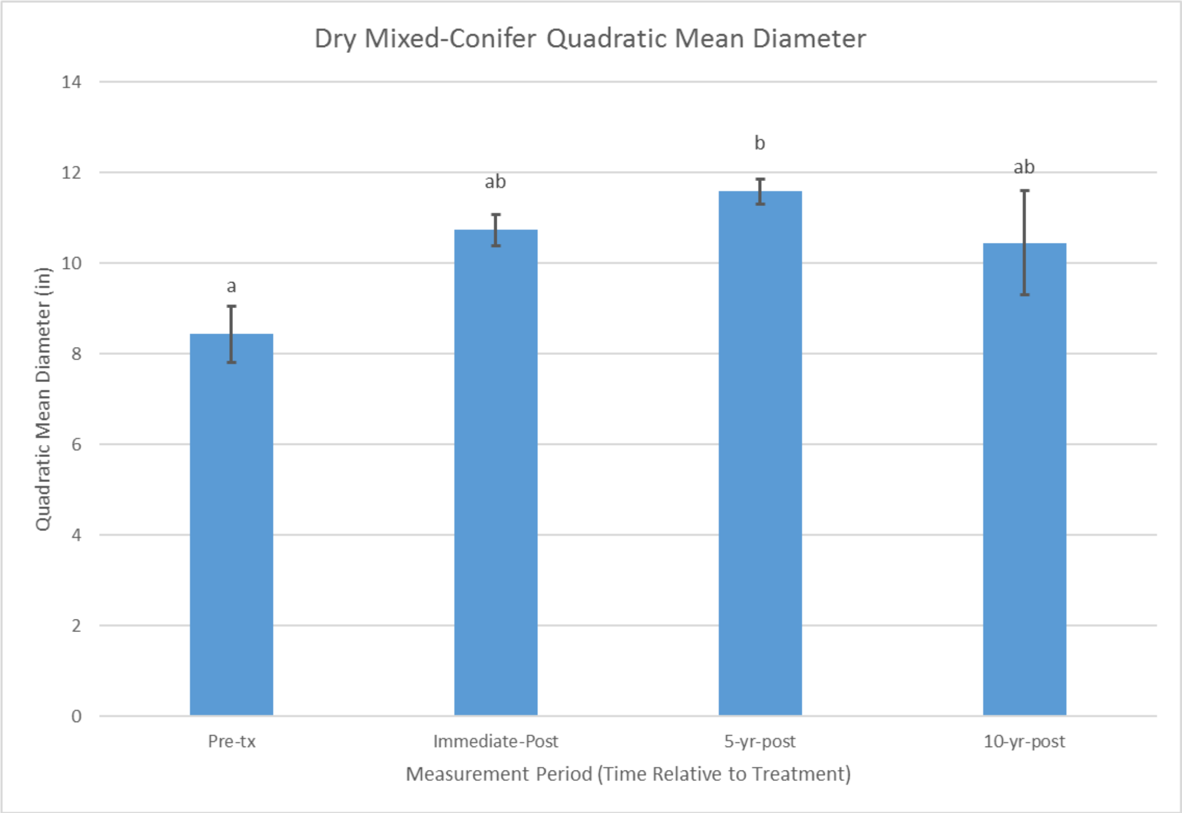

Figure III.4 Analysis of Variance (ANOVA) Results for Dry Mixed-Conifer Quadratic Mean Diameter. Data displayed are means (± standard error of the mean) for each measurement period. Means marked with the same letter do not differ significantly ($\alpha = 0.05$) according to Tukey's Honest Significant Difference multiple pairwise comparison.

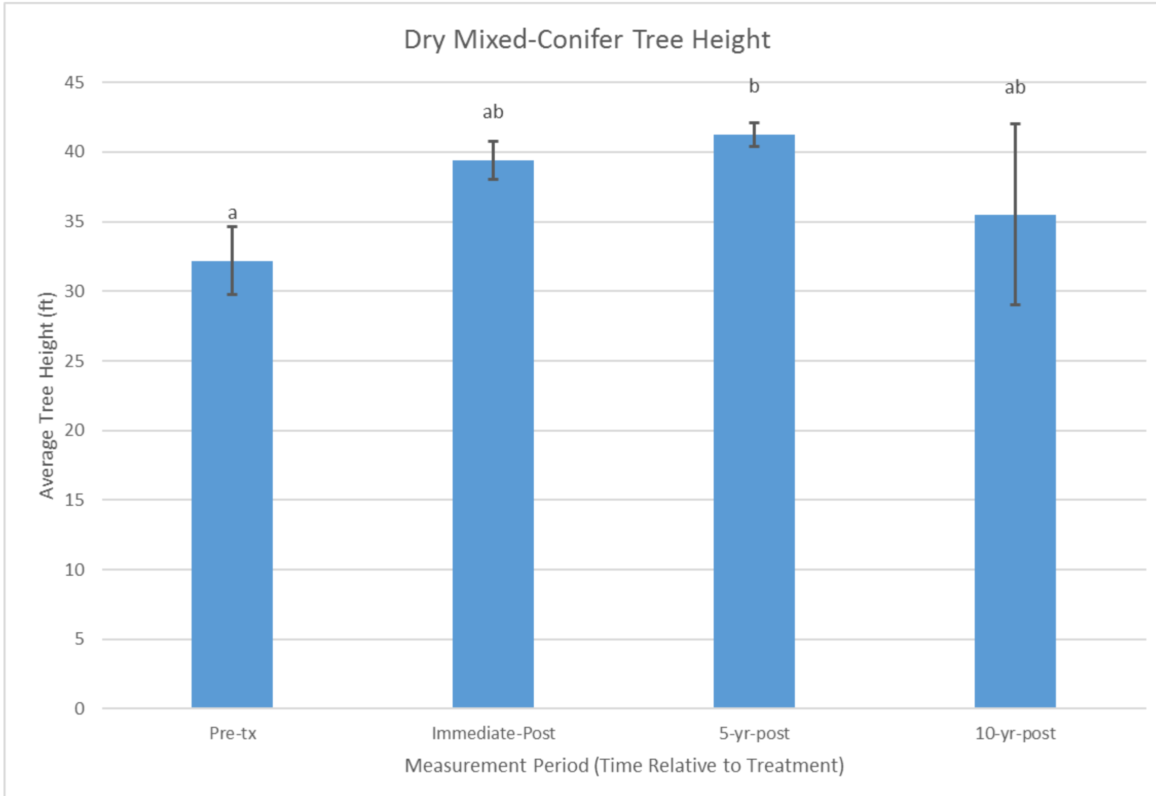

Figure III.5 Analysis of Variance (ANOVA) Results for Dry Mixed-Conifer Tree Height. Data displayed are means (± standard error of the mean) for each measurement period. Means marked with the same letter do not differ significantly ($\alpha = 0.05$) according to Tukey's Honest Significant Difference multiple pairwise comparison.

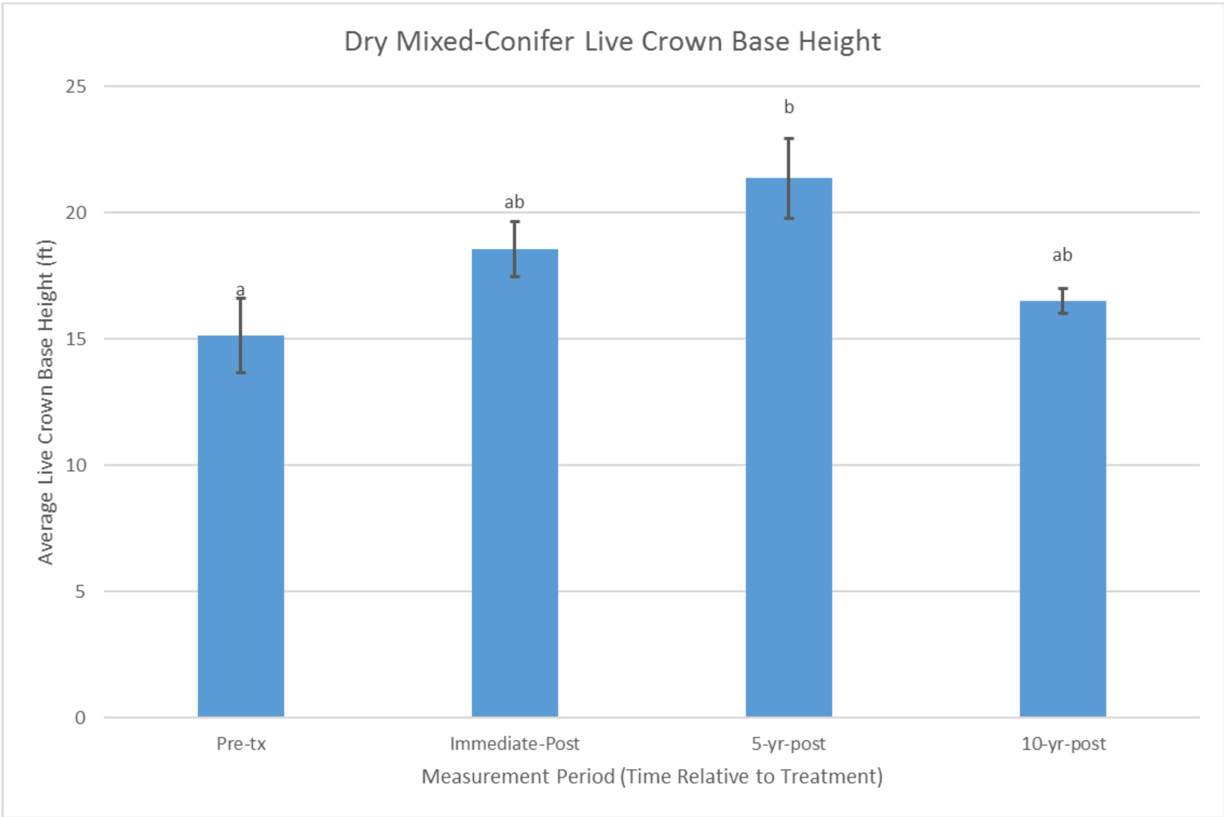

Figure III.6 Analysis of Variance (ANOVA) Results for Dry Mixed-Conifer Live Crown Base Height. Data displayed are means (± standard error of the mean) for each measurement period. Means marked with the same letter do not differ significantly (α = 0.05) according to Tukey's Honest Significant Difference multiple pairwise comparison.

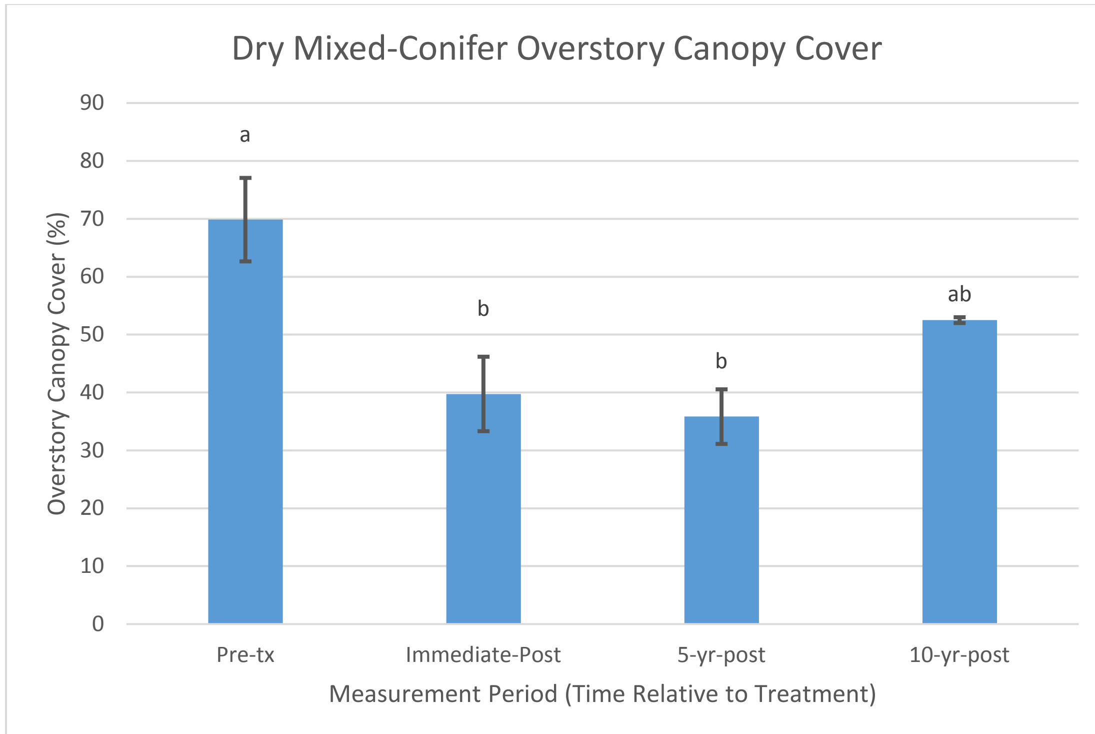

Figure III.7 Analysis of Variance (ANOVA) Results for Dry Mixed-Conifer Overstory Canopy Cover. Data displayed are means (± standard error of the mean) for each measurement period. Means marked with the same letter do not differ significantly ($\alpha = 0.05$) according to Tukey's Honest Significant Difference multiple pairwise comparison.

Table III.4 Analysis of Variance (ANOVA) results for Ponderosa Pine.The table is from a one-way ANOVA for an unbalanced design.

Metric		Sum of Squares	df	Mean Square	F	Sig.
Trees per Acre	Treatment	252065.761	3	84021.920	5.754	.001
	Error	1007509.548	69	14601.588		
	Total	1259575.309	72			
Basal Area per Acre	Treatment	29249.036	3	9749.679	12.139	.000
	Error	45779.955	57	803.157		
	Total	75028.991	60			
QMD for all Live Trees (in)	Treatment	53.166	3	17.722	1.609	.195
	Error	748.968	68	11.014		
	Total	802.133	71			
Average Height of Live Trees (ft)	Treatment	3052.253	3	1017.418	5.995	.001
	Error	8145.810	48	169.704		
	Total	11198.063	51			
Average Live Crown Base Height (ft)	Treatment	266.838	3	88.946	1.994	.125
	Error	2497.865	56	44.605		
	Total	2764.702	59			
Live Saplings per Acre	Treatment	159938.696	3	53312.899	4.246	.009
	Error	765865.248	61	12555.168		
	Total	925803.944	64			
Live Seedlings per Acre (trees)	Treatment	246095048.597	3	82031682.866	4.725	.005
	Error	1111211557.138	64	17362680.580		
	Total	1357306605.735	67			
Shrubs per Acre	Treatment	76338.761	3	25446.254	.885	.457
	Error	1236528.012	43	28756.465		
	Total	1312866.773	46			
Sick Tees per Acre	Treatment	510.170	3	170.057	1.184	.326
	Error	6896.366	48	143.674		
	Total	7406.535	51			
Snags per Acre	Treatment	578.272	3	192.757	.488	.691
	Error	26442.399	67	394.663		
	Total	27020.671	70			
Overstory Canopy Cover (%)	Treatment	2901.160	3	967.053	3.884	.014
	Error	13942.379	56	248.971		
	Total	16843.539	59			
Total Surface Fuels (tons per acre)	Treatment	348.108	3	116.036	1.355	.266
	Error	4708.244	55	85.604		
	Total	5056.352	58			
1000-hour fuels (tons per acre)	Treatment	425.446	3	141.815	5.146	.004
	Error	1322.803	48	27.558		
	Total	1748.249	51			

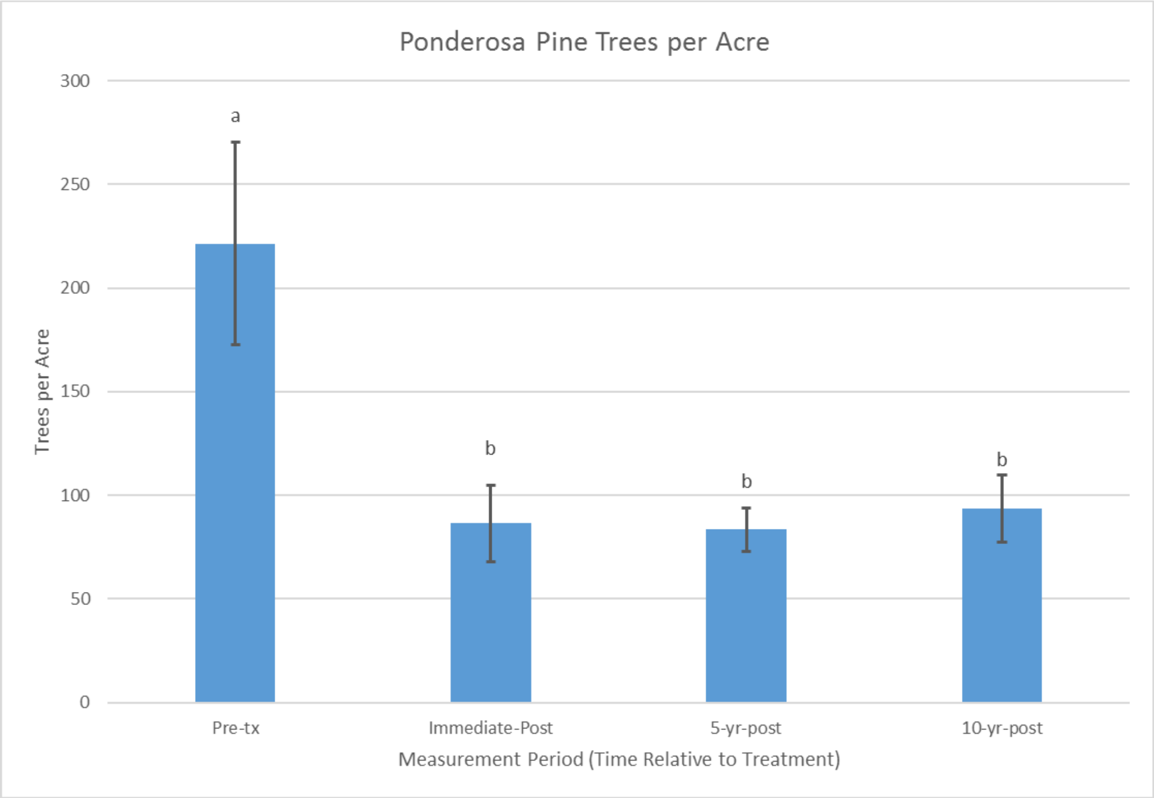

Figure III.8 Analysis of Variance (ANOVA) Results for Ponderosa Pine Trees per Acre. Data displayed are means (± standard error of the mean) for each measurement period. Means marked with the same letter do not differ significantly (α = 0.05) according to Tukey's Honest Significant Difference multiple pairwise comparison.

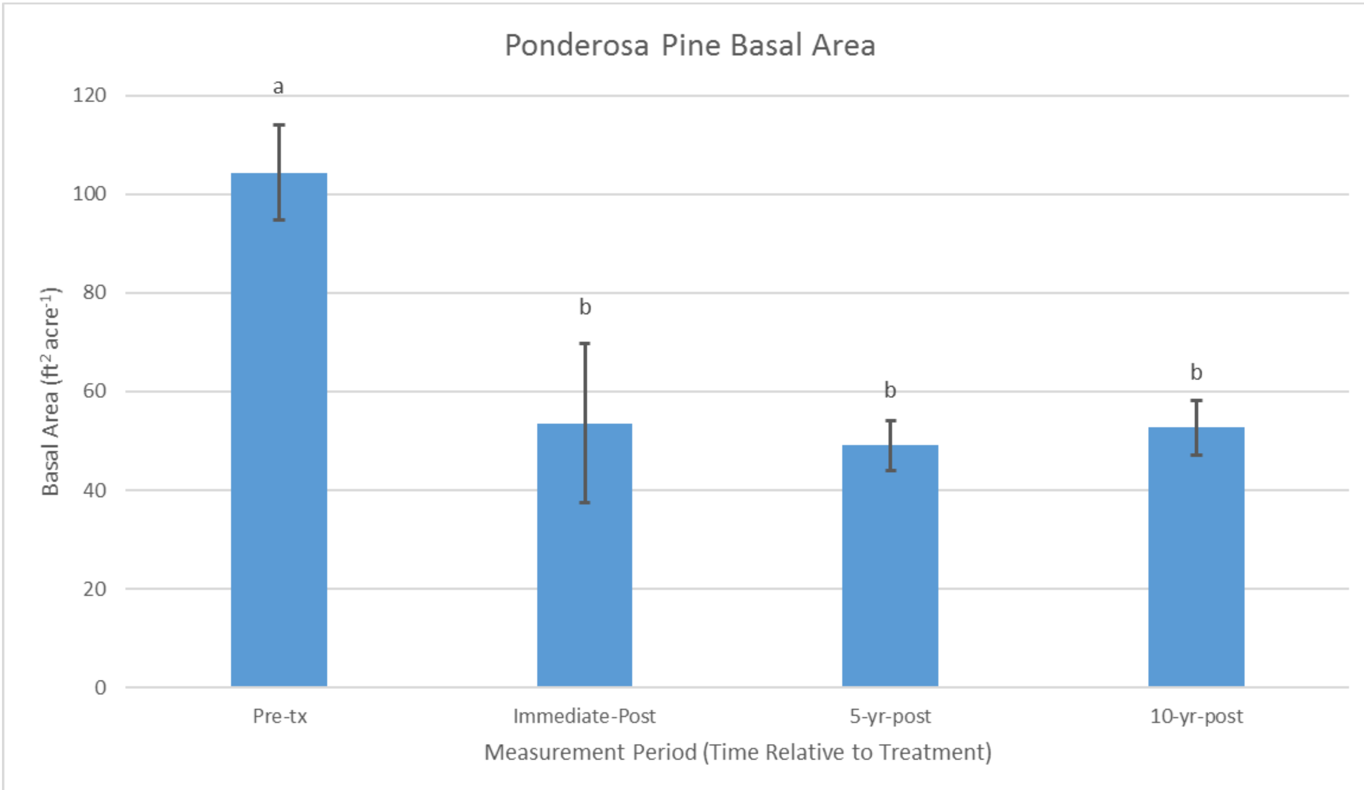

Figure III.9 Analysis of Variance (ANOVA) Results for Ponderosa Pine Basal Area. Data displayed are means (± standard error of the mean) for each measurement period. Means marked with the same letter do not differ significantly (α = 0.05) according to Tukey's Honest Significant Difference multiple pairwise comparison.

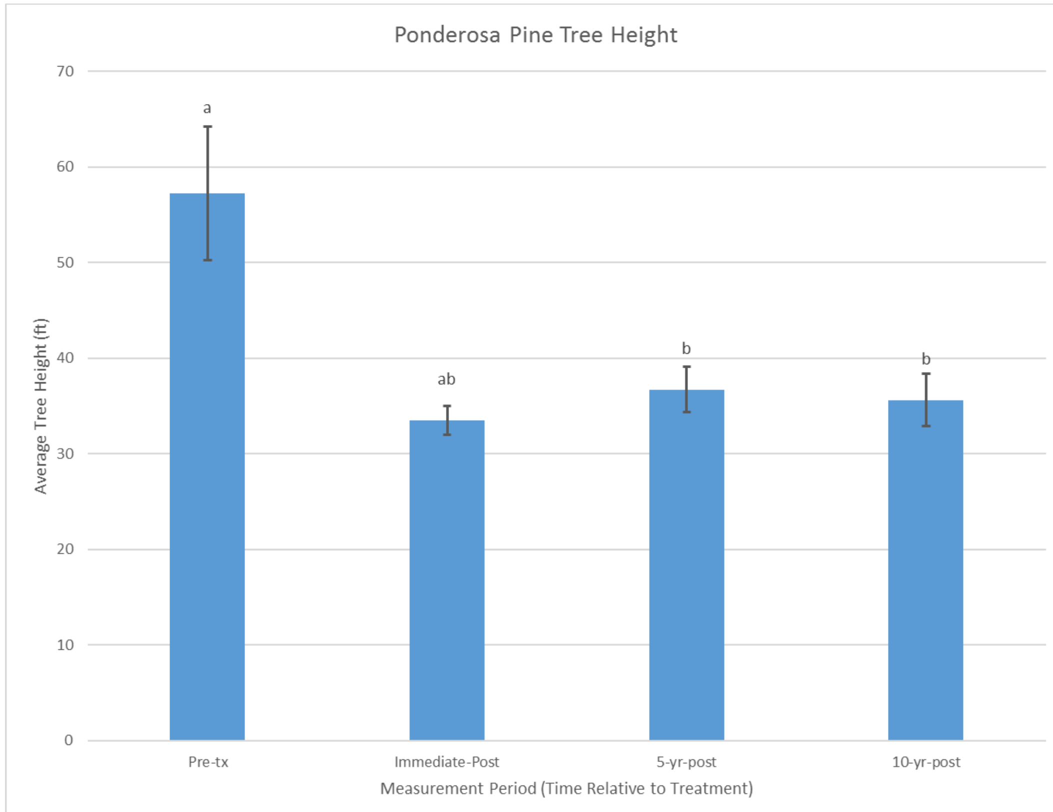

Figure III.10 Analysis of Variance (ANOVA) Results for Ponderosa Pine Tree Height. Data displayed are means (± standard error of the mean) for each measurement period. Means marked with the same letter do not differ significantly ($\alpha = 0.05$) according to Tukey's Honest Significant Difference multiple pairwise comparison.

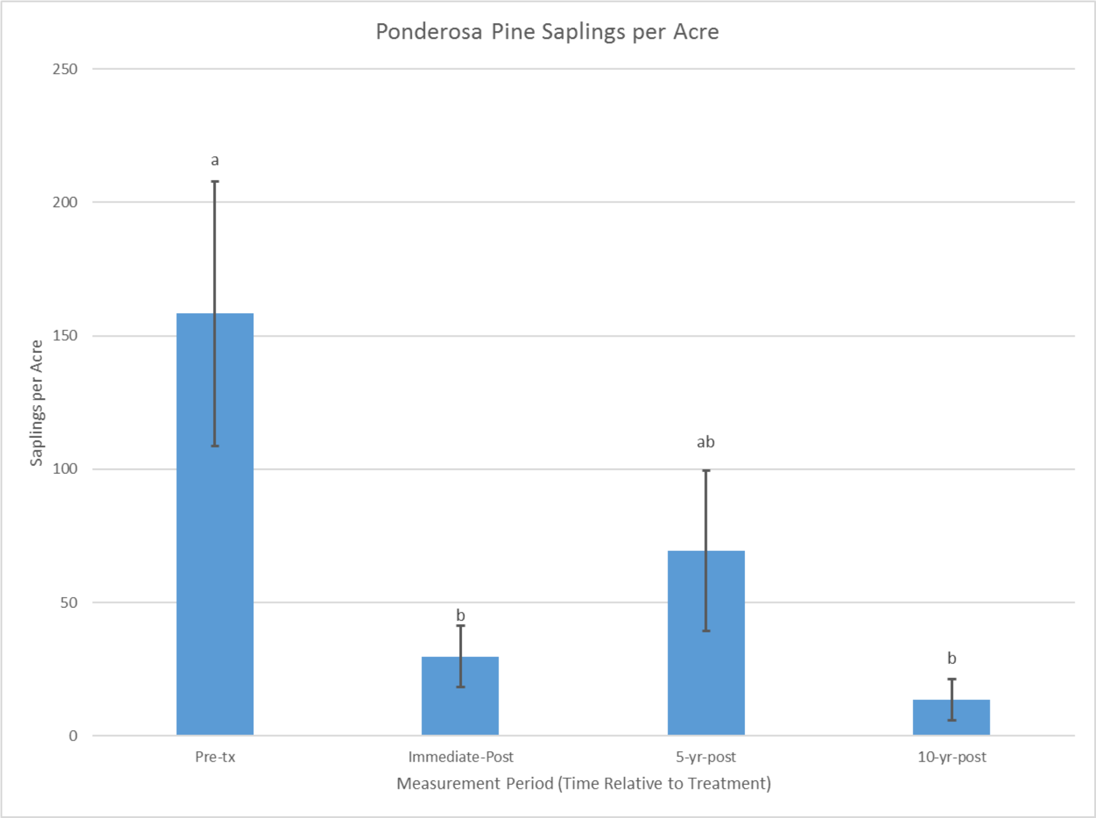

Figure III.11 Analysis of Variance (ANOVA) Results for Ponderosa Pine Saplings per Acre. Data displayed are means (± standard error of the mean) for each measurement period. Means marked with the same letter do not differ significantly ($\alpha = 0.05$) according to Tukey's Honest Significant Difference multiple pairwise comparison.

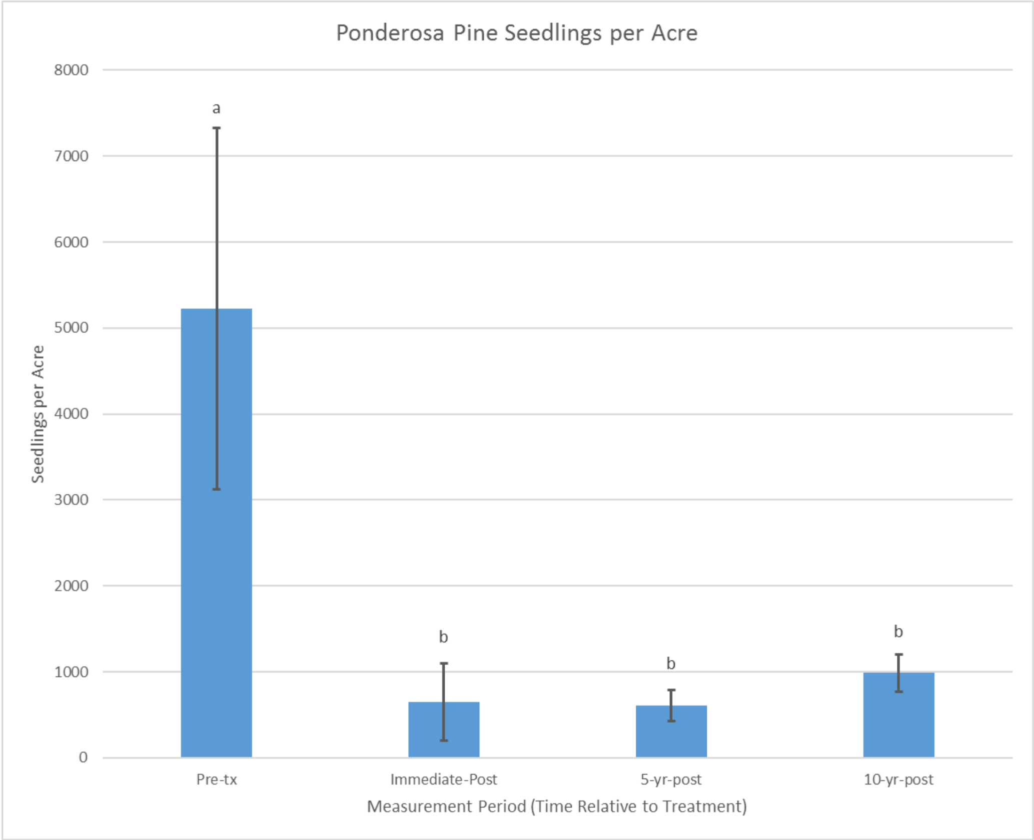

Figure III.12 Analysis of Variance (ANOVA) Results for Ponderosa Pine Seedlings per Acre. Data displayed are means (± standard error of the mean) for each measurement period. Means marked with the same letter do not differ significantly ($\alpha = 0.05$) according to Tukey's Honest Significant Difference multiple pairwise comparison.

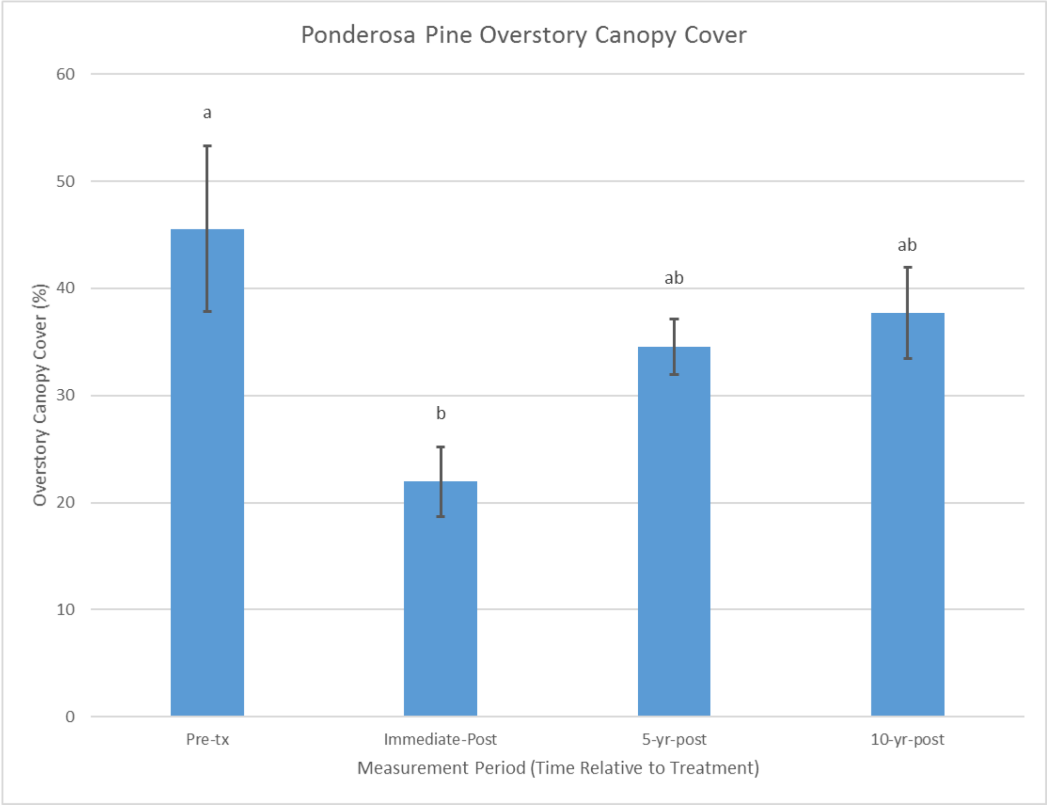

Figure III.13 Analysis of Variance (ANOVA) Results for Ponderosa Pine Seedlings per Acre. Data displayed are means (± standard error of the mean) for each measurement period. Means marked with the same letter do not differ significantly (α = 0.05) according to Tukey's Honest Significant Difference multiple pairwise comparison.

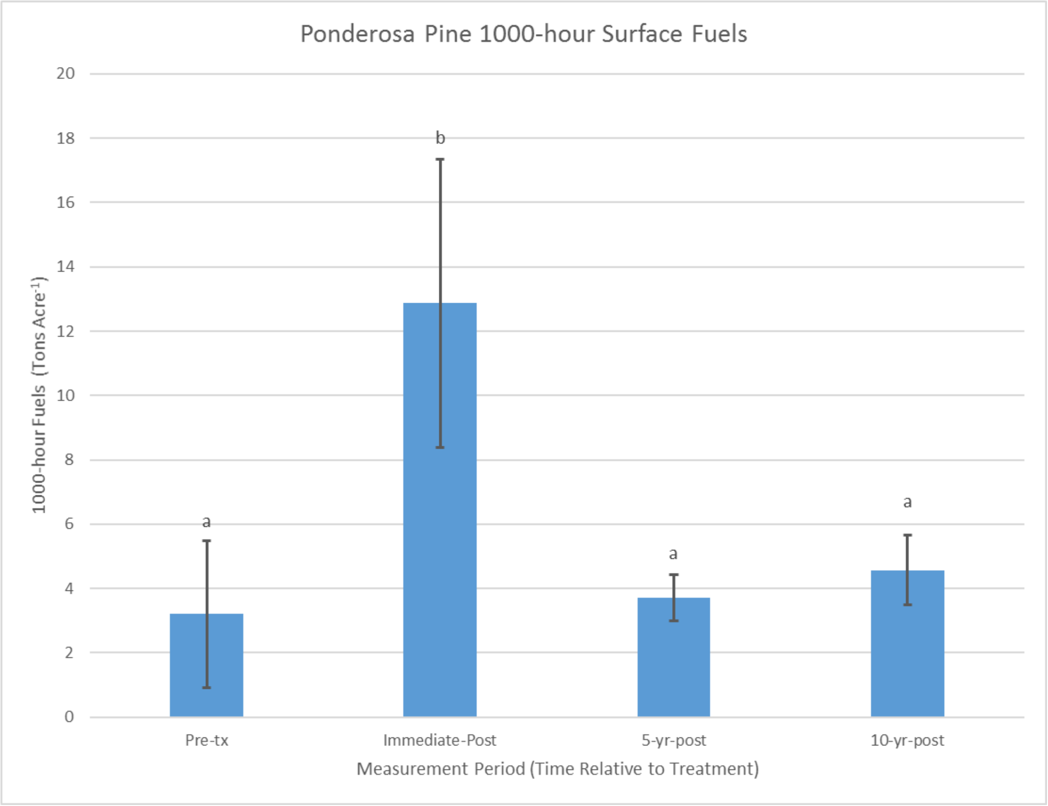

Figure III.14 Analysis of Variance (ANOVA) Results for Ponderosa Pine 1000-hour Surface Fuels. Data displayed are means (± standard error of the mean) for each measurement period. Means marked with the same letter do not differ significantly (α = 0.05) according to Tukey's Honest Significant Difference multiple pairwise comparison.

Table III.5 Analysis of Variance (ANOVA) Results for Piñon-Juniper.

Metric		Sum of Squares	df	Mean Square	F	Sig.
Trees per Acre	Treatment	160233.125	3	53411.042	4.301	.009
	Error	608552.189	49	12419.432		
	Total	768785.313	52			
Basal Area per Acre	Treatment	32573.806	3	10857.935	20.754	.000
	Error	15172.056	29	523.174		
	Total	47745.862	32			
QMD for all Live Trees (in)	Treatment	329.235	3	109.745	3.769	.019
	Error	989.936	34	29.116		
	Total	1319.171	37			
Average Height of Live Trees (ft)	Treatment	.001	1	.001	.000	.987
	Error	115.313	25	4.613		
	Total	115.314	26			
Average Live Crown Base Height (ft)	Treatment	.854	3	.285	.301	.825
	Error	23.672	25	.947		
	Total	24.526	28			
Live Saplings per Acre	Treatment	76828.841	3	25609.614	10.159	.000
	Error	83187.391	33	2520.830		
	Total	160016.232	36			
Live Seedlings per Acre (trees)	Treatment	4611332.489	3	1537110.830	2.726	.055
	Error	26500934.559	47	563849.671		
	Total	31112267.048	50			
Shrubs per Acre	Treatment	14857343.448	3	4952447.816	3.264	.047
	Error	25796922.219	17	1517466.013		
	Total	40654265.667	20			
Sick Tees per Acre	Treatment	17.286	1	17.286	5.519	.027
	Error	81.429	26	3.132		
	Total	98.714	27			
Snags per Acre	Treatment	29275.684	3	9758.561	7.831	.000
	Error	61062.529	49	1246.174		
	Total	90338.212	52			
Overstory Canopy Cover (%)	Treatment	2156.381	3	718.794	6.252	.002
	Error	4023.803	35	114.966		
	Total	6180.184	38			
Total Surface Fuels (tons per acre)	Treatment	109.383	3	36.461	1.413	.256
	Error	851.488	33	25.803		
	Total	960.871	36			
1000-hour fuels (tons per acre)	Treatment	21.607	3	7.202	1.248	.311
	Error	167.393	29	5.772		
	Total	189.000	32			

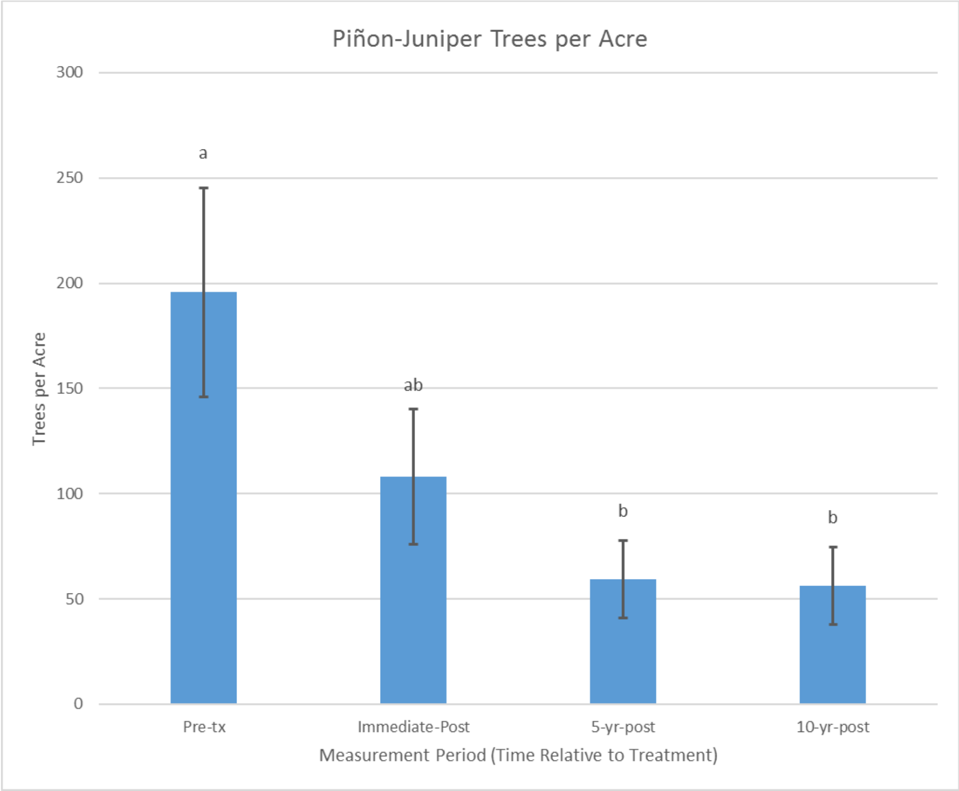

Figure III.15 Analysis of Variance (ANOVA) Results for Piñon-Juniper Trees per Acre. Data displayed are means (± standard error of the mean) for each measurement period. Means marked with the same letter do not differ significantly (α = 0.05) according to Tukey's Honest Significant Difference multiple pairwise comparison.

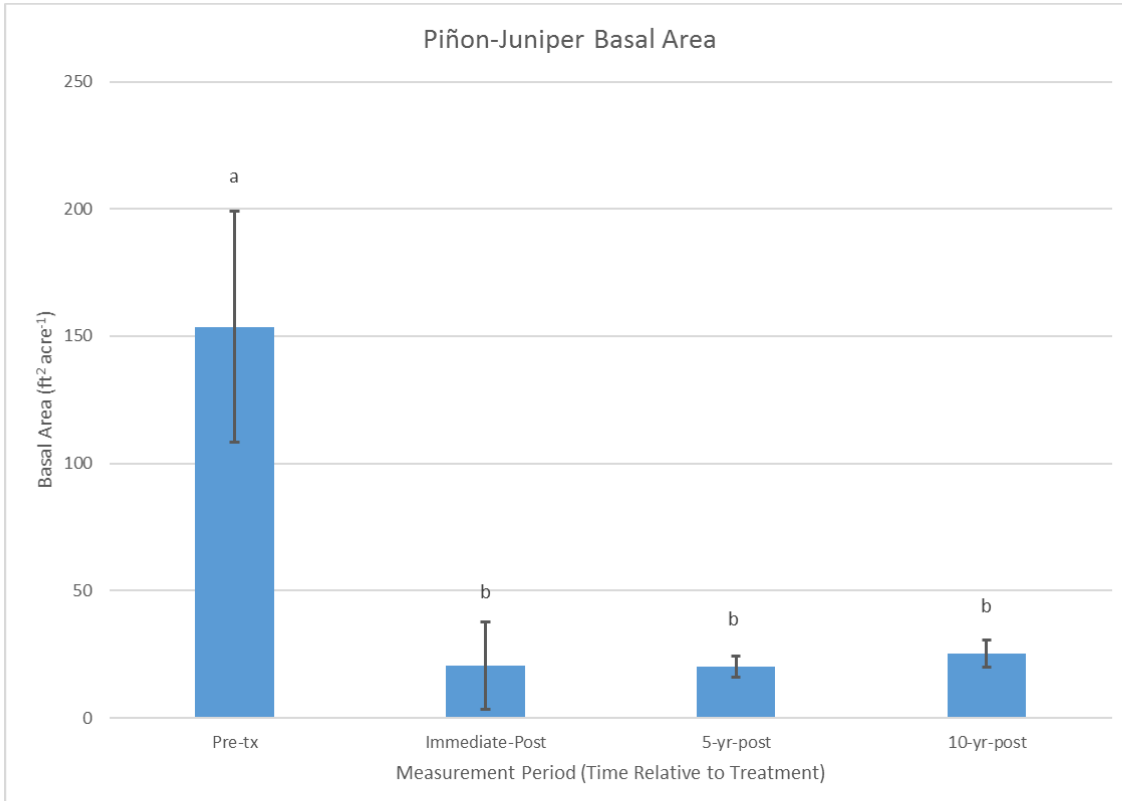

Figure III.16 Analysis of Variance (ANOVA) Results for Piñon-Juniper Basal Area. Data displayed are means (± standard error of the mean) for each measurement period. Means marked with the same letter do not differ significantly ($\alpha = 0.05$) according to Tukey's Honest Significant Difference multiple pairwise comparison.

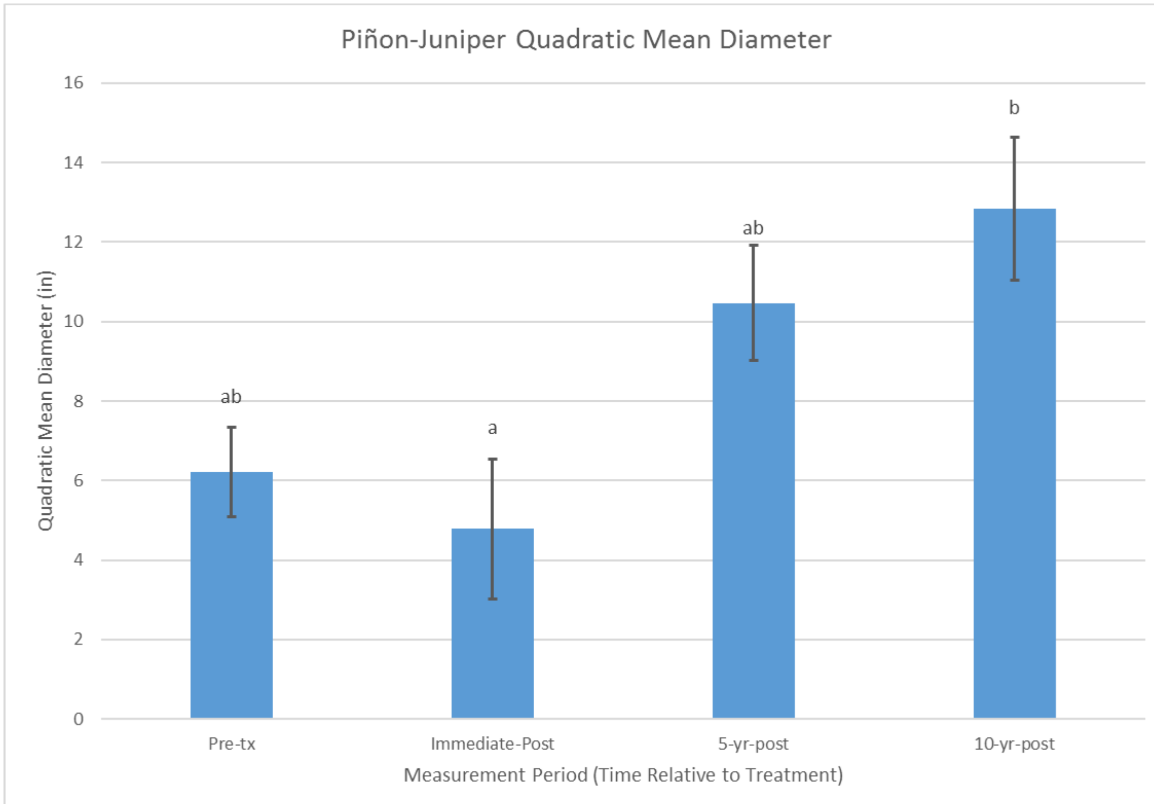

Figure III.17 Analysis of Variance (ANOVA) Results for Piñon-Juniper Quadratic Mean Diameter. Data displayed are means (± standard error of the mean) for each measurement period. Means marked with the same letter do not differ significantly ($\alpha = 0.05$) according to Tukey's Honest Significant Difference multiple pairwise comparison.

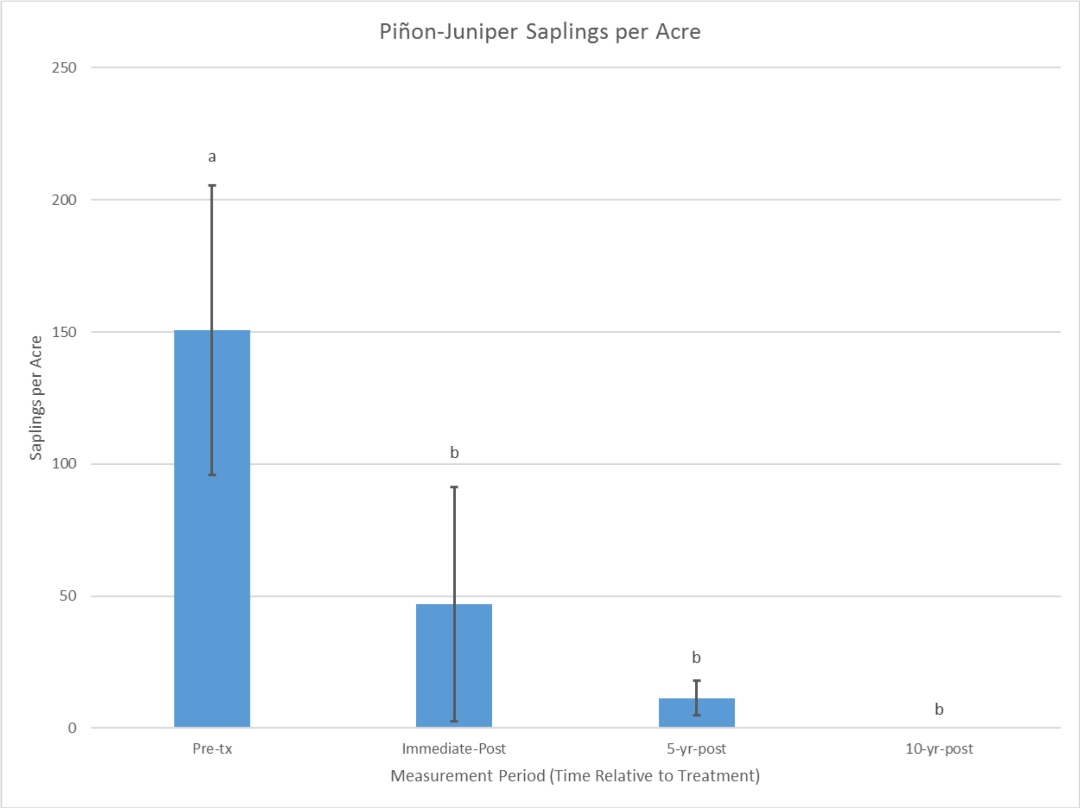

Figure III.18 Analysis of Variance (ANOVA) Results for Piñon-Juniper Saplings per Acre. Data displayed are means (± standard error of the mean) for each measurement period. Means marked with the same letter do not differ significantly ($\alpha = 0.05$) according to Tukey's Honest Significant Difference multiple pairwise comparison.

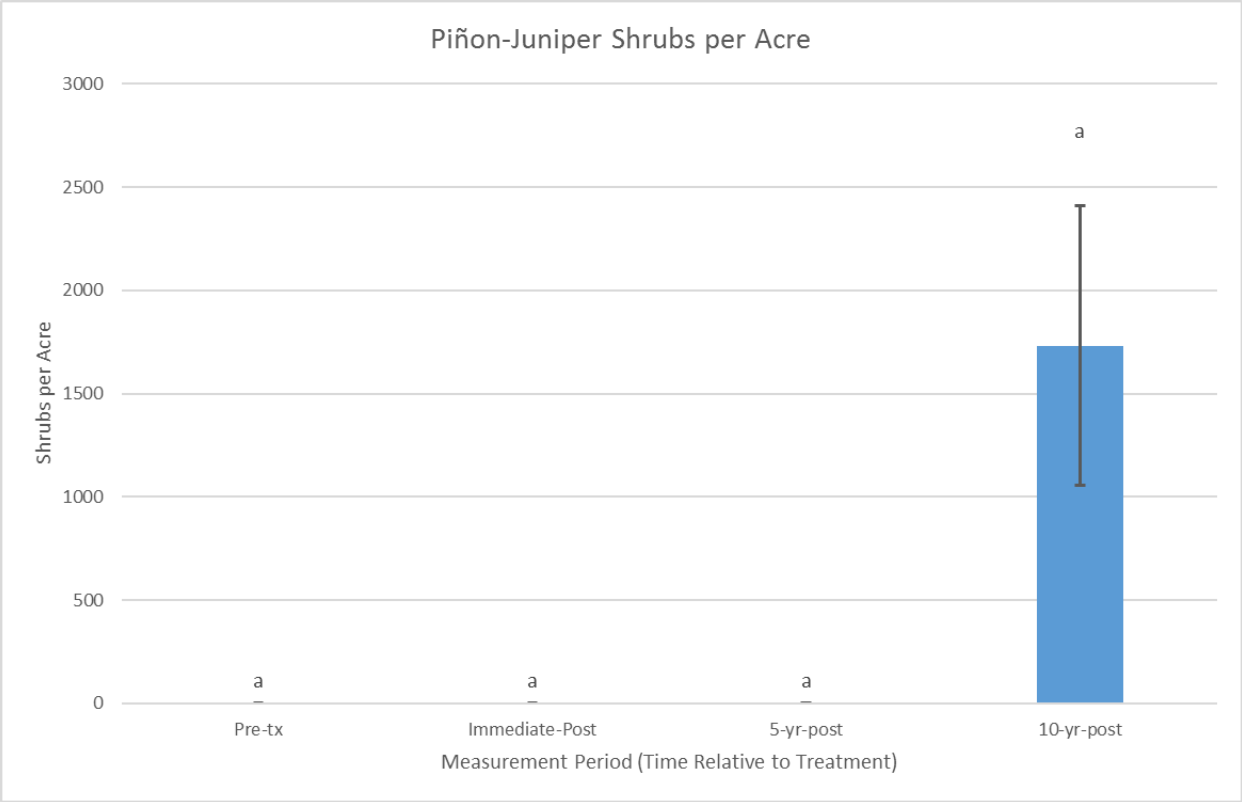

Figure III.19 Analysis of Variance (ANOVA) Results for Piñon-Juniper Shrubs per Acre. Data displayed are means (± standard error of the mean) for each measurement period. Means marked with the same letter do not differ significantly (α = 0.05) according to Tukey's Honest Significant Difference multiple pairwise comparison.

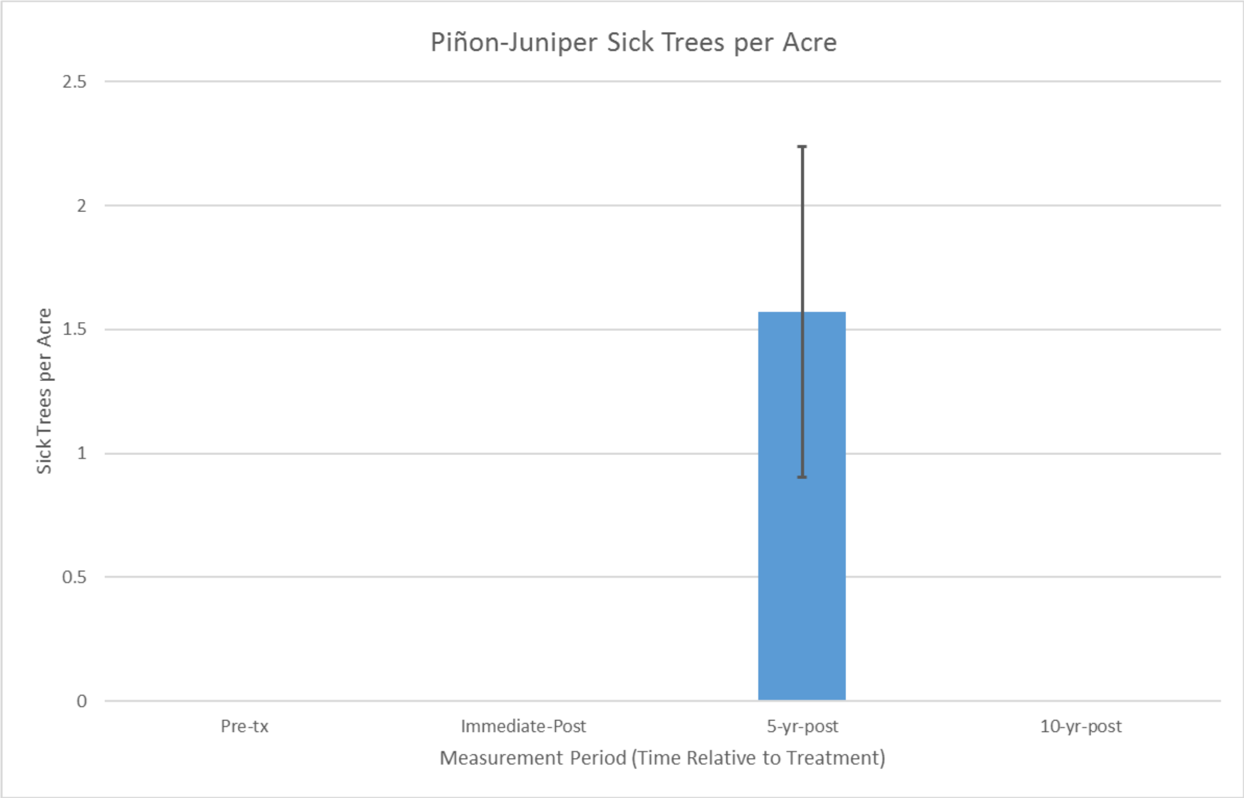

Figure III.20 Analysis of Variance (ANOVA) Results for Piñon-Juniper Sick Trees per Acre. Data displayed are means (± standard error of the mean) for each measurement period..

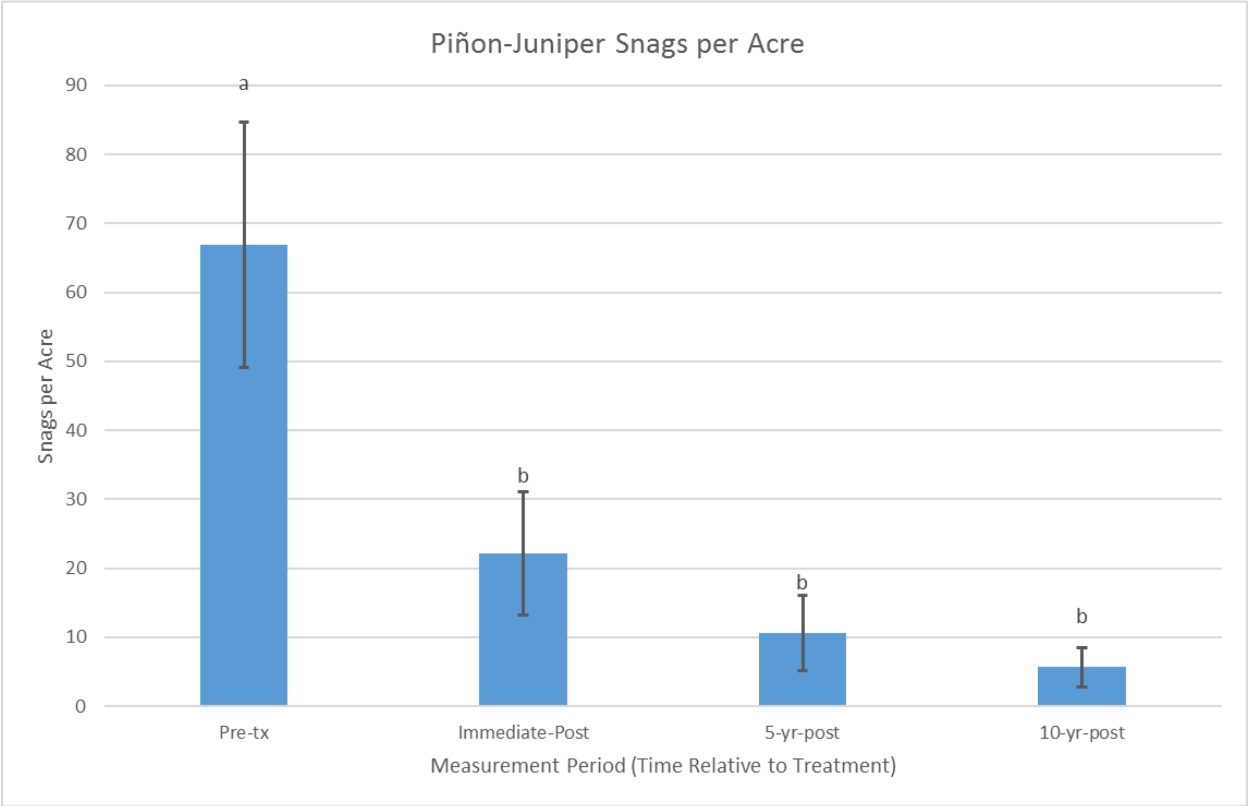

Figure III.21 Analysis of Variance (ANOVA) Results for Piñon-Juniper Snags per Acre. Data displayed are means (± standard error of the mean) for each measurement period. Means marked with the same letter do not differ significantly (α = 0.05) according to Tukey's Honest Significant Difference multiple pairwise comparison.

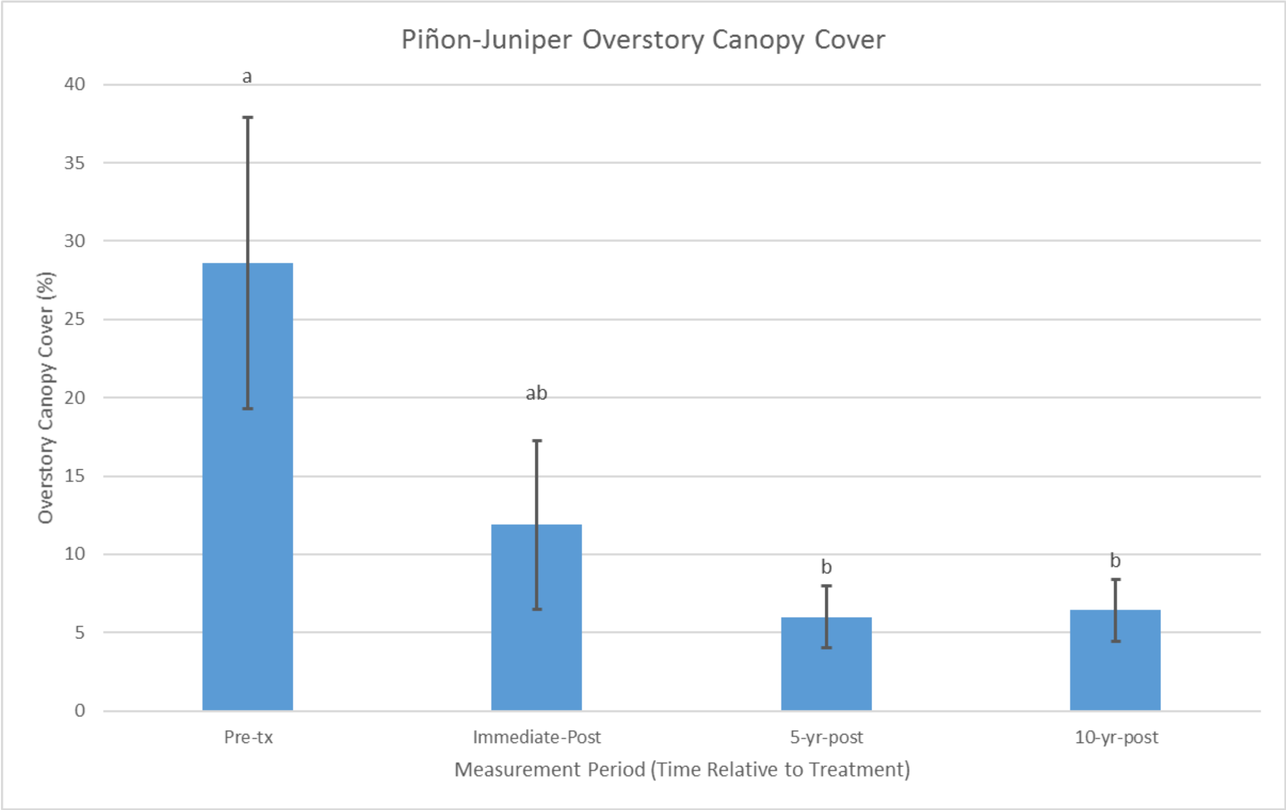

Figure III.22 Analysis of Variance (ANOVA) Results for Piñon-Juniper Overstory Canopy Cover. Data displayed are means (± standard error of the mean) for each measurement period. Means marked with the same letter do not differ significantly ($\alpha = 0.05$) according to Tukey's Honest Significant Difference multiple pairwise comparison.

IV. – Discussion

Wet Mixed-Conifer

In wet mixed-conifer, no significant differences were found between measurement periods (pre-treatment, post-treatment, 5 year post-treatment, 10 year post-treatment), with the exception of basal area. This is most likely because the wet mixed-conifer forest type had a small sample size, so a substantial amount of random noise was present in the results. It may also be because treatments on wet mixed-conifer sites were not sufficient to create detectable differences using the available monitoring methods and data. Figure III.1 on page 42 shows the trends (percent change from pre-treatment) for the only wet mixed-conifer metric with significant differences between one or more pairs of treatment means.

The difference in basal area was between pre-treatment and the 5 year and 10 year measurement periods; pre-treatment means were significantly higher. This result, shown in Figure IV.1 on page 78, could be consistent with removal of material during treatment and additional mortality in the stand post-treatment. Table IV.1 on page 82 graphs the duration of significant changes found in this forest type.

The lack of significant differences in metrics suggests the possiblity of minimal or no impact of treatments in this forest type. Meaningful conclusions about CFRP success in wet mixed-conifer will require more data.

Dry Mixed-Conifer

Figure IV.3, page 80, shows trends (percent change from pre-treatment) for all dry mixed-conifer metrics with significant differences between one or more pairs of treatment means.

In dry mixed-conifer, a significant difference was found between trees per acre pre-treatment and 5 years post-treatment; pre-treatment means were higher. Pre-treatment means had a large standard deviation due to a small sample size and variable ecological conditions of projects prior to treatment. However, this difference could suggest that additional mortality or harvesting (e.g., fuelwood) occurred between the immediate post-treatment and 5 year post-treatment visits, and that regeneration (seedlings/saplings) grew enough to be classified as "trees" between the 5 year post-treatment and 10 year post-treatment visits. Ten year post-treatment means were not significantly different from pre-treatment means.

A significant difference was found between basal area pre-treatment and immediately post-treatment, as well as between basal area pre-treatment and 5 years post-treatment. Pre-treatment means were higher. This is consistent with the expected impact of restoration treatments (removal of trees). Because pre-treatment was not significantly different from 10 years post-treatment, this may suggest that sufficient regeneration occurred by 10 years post-treatment to negate the impact of treatment on basal area.

Quadratic mean diameter pre-treatment was significantly different from 5 years post-treatment; pre-treatment means were lower. This is consistent with the expected impact of restoration treatments (removal of small diameter material). The fact that the significant difference was found at 5 years post-treatment rather than immediately post-treatment could be explained by additional mortality of small diameter trees, and/or release of suppressed trees, between immediate post-treatment and 5 years post-treatment. The lack of difference between pre-treatment means and 10 year post-treatment means may indicate that sufficient regeneration occurred by 10 years post-treatment to decrease the average DBH, and/or there was mortality of larger trees.

Height of live trees pre-treatment was significantly different from 5 years post-treatment; pre-treatment means were lower. This is consistent with the expected impact of restoration treatments (removal of smaller trees). Much as with quadratic mean diameter, the fact that the significant difference was found at 5 years post-treatment rather than immediately post-treatment could be explained by additional mortality of smaller trees, and/or release of suppressed trees, between immediate post-treatment and 5 years post-treatment. The lack of difference between pre-treatment means and 10 year post-treatment means may indicate that sufficient regeneration occurred by 10 years post-treatment to decrease the average height, and/or there was mortality of larger trees (e.g., due to disease, windthrow, etc.).

Live crown base height showed the same pattern as height of live trees. In this forest type, it is likely that restoration treatments removed smaller trees and firs, which have lower live crown base heights than ponderosa pine, thereby raising the live crown base height mean. The significant difference was found at 5 years post-treatment rather than immediately post-treatment. This could be explained by additional mortality of smaller trees, and/or release of suppressed ponderosa, between immediate post-treatment and 5 years post-treatment. Any prescribed fire that occurred between the two measurements could also increase the mean live crown base height. The lack of difference between pre-treatment means and 10 year post-treatment means may indicate that sufficient regeneration (of ponderosa and/or firs) occurred by 10 years post-treatment to decrease the average height. Mortality of larger ponderosa pines may also have occurred.

A significant difference was found between percent overstory canopy cover pre-treatment and immediately post-treatment, as well as between percent overstory canopy cover pre-treatment and 5 years post-treatment. Pre-treatment means were higher. This is consistent with the expected impact of restoration treatment (removal of trees). Because pre-treatment was not significantly different from 10 years post-treatment, this may suggest that regeneration occurred by 10 years post-treatment. Figure IV.3 on page 80 graphs the duration of significant changes found in this forest type.

The RMRS-GTR-310 provides historical reference ranges for dry mixed-conifer and ponderosa pine forest types (Reynolds et al., 2013, pp. 18-20, 28). Table IV.1 on page 82 compares available data using 95% confidence intervals for the means for CFRP projects. Dark grey cells indicate the confidence interval does not include any of the reference range, which indicates the forest type mean is not within the historic range of variability. White cells show either a partial or complete overlap, which suggests that the true mean could fall within the historic range of variability for the forest type.

Taken together, these results suggest that some of the impacts of CFRP treatments in dry mixed-conifer may not be detectable as significant changes until five years post-treatment, when natural processes such as growth and mortality have occurred. However, no measure in dry mixed-conifer was significantly different from its pre-treatment mean at the 10 year mark. It was possible that several means fell within historical reference ranges, but the confidence interval ranges were large. Pre-treatment canopy cover and trees per acre values were not within reference range, nor was canopy cover by five years post-treatment. In this forest type, 10 years may be too long for effects of a treatment to remain significant on the landscape. Additional data is needed.

Ponderosa Pine

Figure IV.5 on page 83 shows trends (percent change from pre-treatment) for all ponderosa pine metrics with significant differences between one or more pairs of treatment means. Note that in this figure, 1000-hour fuels are plotted on the right axis while all other metrics are plotted on the left.

In ponderosa pine forest types, trees per acre pre-treatment was significantly different than trees per acre immediately post-treatment, 5 years post-treatment, and 10 years post-treatment. The pre-treatment mean was higher. This is the expected result of treatments (removal of trees). Basal area per acre followed the same pattern, which could also be explained by the effect of the restoration treatment (removal of trees).

Average height of live trees, however, had a pre-treatment mean that was significantly different from both the 5 year post-treatment mean and the 10 year post-treatment mean. Interestingly, the pre-treatment mean was higher. This could be explained by treatment prescriptions that included removal of tall trees followed by post-treatment mortality of remaining tall trees and/or regeneration sufficient to lower the mean height.

The pre-treatment mean for live saplings per acre was significantly different from the immediate post-treatment and 10 year post-treatment means but not from the 5 year post-treatment mean. The pre-treatment mean was higher. This change could be explained by removal or mortality of saplings during treatment, followed by a recovery. The number of saplings per acre at five years may have recovered to pre-treatment levels, and individuals could have self-thinned or grown into the “tree” category by the 10 year re-measurement.

Density of seedlings per acre pre-treatment was significantly different than seedlings per acre immediately post-treatment, 5 years post-treatment, and 10 years post-treatment. The pre-treatment mean was higher. High seedling mortality during treatment is a logical explanation.

The percent overstory canopy cover was significantly different pre-treatment than it was immediately post-treatment, but was not significantly different from cover 5 years or 10 years post-treatment. This suggests a decrease in canopy cover following the restoration treatment, with recovery to pre-treatment levels by the 5 year mark.

While the total tons per acre of surface fuels was not significantly different between categories, mean tons per acre of 1000-hour fuels (logs over three inches in diameter) was significantly higher immediately post-treatment than pre-treatment. This difference could be attributed to material left on the ground or mortality (e.g. windthrow) following treatment. Fuelwood harvesting and/or prescribed fire (especially pile burning) between the immediate post-treatment and 5 years post-treatment measurement periods would account for the lack of difference between pre-treatment, 5 year post-treatment, and 10 year post-treatment means. Figure IV.6 on page 84 graphs the duration of significant changes found in this forest type.

The RMRS-GTR-310 provides ranges of values for historical structure of dry mixed-conifer and ponderosa pine forest types (Reynolds et al., 2013, pp. 18-20, 28). Table IV.1, page 82, compares available data using 95% confidence intervals for the means for CFRP projects. Dark grey cells indicate the confidence interval does not include any of the reference range, which indicates the forest type mean is not within the historic range of variability. White cells show either a partial or complete overlap, which suggests that the true mean could fall within the historic range of variability for the forest type.

When considered together, the ponderosa pine results show impacts of treatment in the immediate post-treatment measures. The time it takes for the projects to no longer be detectably different from their pre-treatment states is variable, ranging from no difference (e.g. average live crown base height) to greater than 10 years (e.g. trees per acre and basal area). Projects have the highest number of metrics within historical reference ranges immediately post-treatment. Snags were not within reference ranges by by five years post-treatment.

Piñon-Juniper

Figure IV.7 on page 86 shows trends (percent change from pre-treatment) for all piñon-juniper metrics with significant differences between one or more pairs of treatment means.

There was a significant difference between trees per acre pre-treatment when compared to 5 years and 10 years post-treatment, but not when compared to immediate post-treatment measures. The pre-treatment mean was higher. This is the expected result of treatments (removal of trees), and may indicate that additional mortality or harvesting (e.g. fuelwood) occurred between the immediate post-treatment and 5 year post-treatment visits.

Basal area per acre pre-treatment was significantly different than basal area per acre immediately post-treatment, 5 years post-treatment, and 10 years post-treatment. The pre-treatment mean was higher. This is the expected result of treatment (removal of trees).

Quadratic mean diameter was significantly different in the immediate post-treatment and 10 year post-treatment measurement periods; QMD immediately post-treatment was lower. This pattern does not clearly show the impact of restoration treatments, but suggests that trees grew larger over time without sufficient regeneration to lower the average diameter. The continued increase in QMD combined with the continued decrease in basal area may indicate ongoing fuelwood harvesting or other removal of smaller diameter materials.

Density of live saplings per acre pre-treatment was significantly different than saplings per acre immediately post-treatment, 5 years post-treatment, and 10 years post-treatment. The pre-treatment mean was higher, suggesting that restoration treatments removed or killed saplings, and this size class was not replaced in the stand within 10 years.

Snags per acre pre-treatment was significantly different than snags per acre immediately post-treatment, 5 years post-treatment, and 10 years post-treatment. The pre-treatment mean was higher, suggesting that restoration retreatment or associated activities (e.g. fuelwood harvesting) removed snags.

There was a significant difference between the percent overstory canopy cover pre-treatment when compared to 5 years and 10 years post-treatment, but not when compared to immediate post-treatment cover. The pre-treatment mean was higher. This is the expected result of treatment (removal of trees), but the lack of difference immediately post-treatment may indicate that additional mortality or harvesting (e.g. fuelwood) occurred between the immediate post-treatment and 5 year post-treatment visits. Figure IV.8 on page 87 graphs the duration of significant changes found in this forest type.

Taken together, the piñon-juniper metrics show the impacts of restoration treatments, but not always immediately. There is not much evidence of regeneration in this forest type in these metrics, but this could be impacted by grazing or other human activity. More information is needed.

Overall

To evaluate the success of the program by its own metrics, results will be compared to the expected directions of changes (see for reference Table II.2, page 26). In all tables referenced in the following paragraphs, green cells represent a change in the expected direction for restoration success, white cells represent no change, and red cells indicate a change in the opposite direction.

Wildfire threat reduction (Table IV.3, page 88) seems to have been somewhat successful, achieving the expected responses in six out of 12 metrics in dry mixed-conifer and piñon-juniper forest types. While the dry mixed-conifer responses were no longer significantly different from pre-treatment conditions at the 10 year re-measurement, the piñon-juniper metrics were. Little change was observed in the wet mixed-conifer forest type, and ponderosa pine had mixed results, including a trend toward lower tree heights and higher 1000-hour fuel loads immediately post-treatment.

Ecosystem restoration (Table IV.4, page 90) similarly had some success in dry mixed-conifer, piñon-juniper, and ponderosa pine forest types. Reforestation had only two key metrics: live trees and regeneration (seedlings/saplings). These responses did not support program-wide success in meeting this objective (Table IV.5, page 92).

The final program objective that can be evaluated with the current dataset is preservation of old/large trees (see Table IV.6, page 93). Results were also mixed here, with either increases or no change in QMD, and a decrease in post-treatment tree height in ponderosa pine.

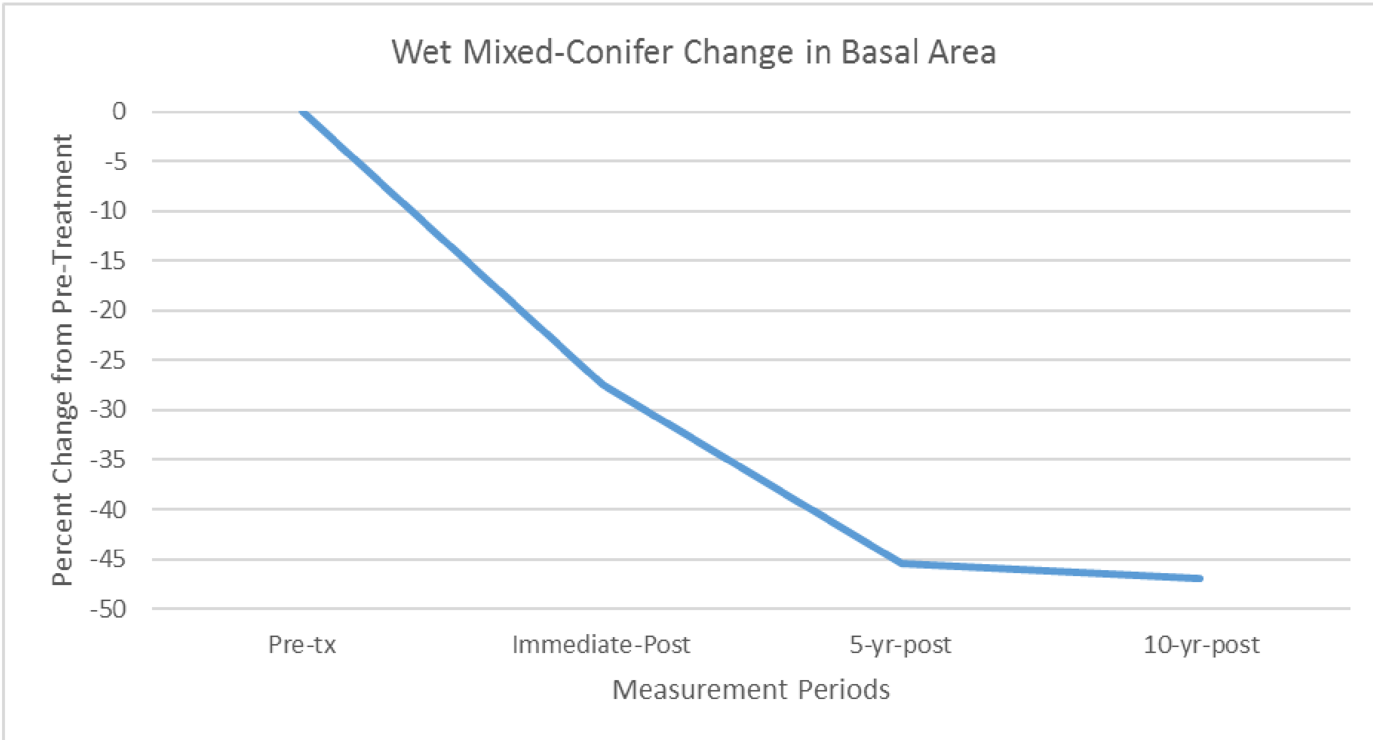

Figure IV.1 Wet Mixed Conifer Change in Basal Area. A significant change was detected between pre-treatment and the 5 year and 10 year measurement periods; pre-treatment means were significantly higher. The continued decrease in basal area after treatment may be due to additional mortality in the stand, for instance, due to windthrow.

Wet Mixed Conifer	Time Relative to Treatment												
Metric	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
	pretx		impost			5yrpost					10yrpost		
Trees per Acre		CFRP treatment											
Basal Area per Acre						decrease from pretreatment							
Quadratic Mean Diameter													
Tree Height													
Live Crown Base Height													
Saplings per Acre													
Seedlings per Acre													
Shrubs per Acre													
Sick Trees per Acre													
Snags per Acre													
Overstory Canopy Cover													
Total Surface Fuels													
1000-hour Surface Fuels													

Figure IV.2. Duration of changes in the wet mixed-conifer forest type. Dark grey cells indicate the confidence interval does not include any of the reference range, which indicates the forest type mean is not within the historic range of variability. White cells show either a partial or complete overlap, which suggests that the true mean could fall within the historic range of variability for the forest type.

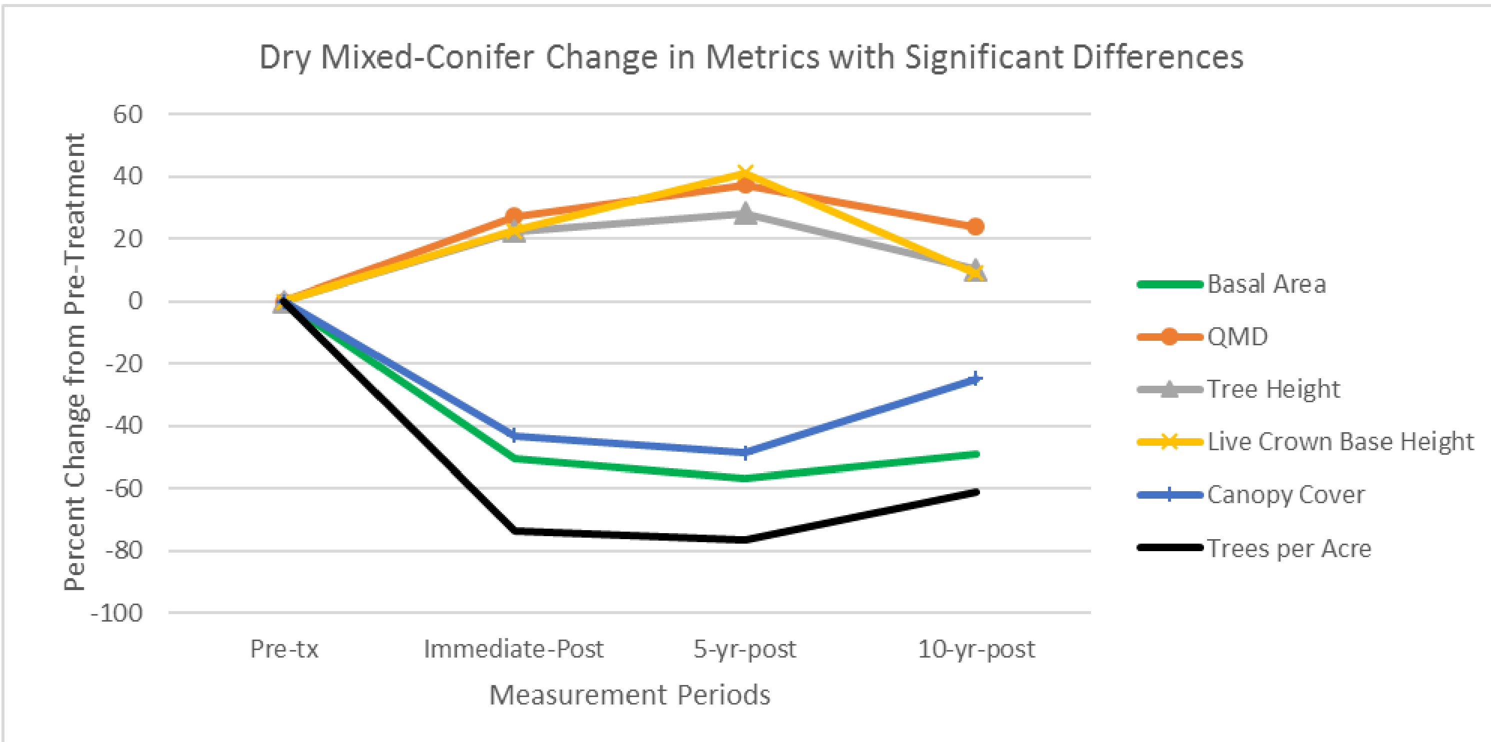

Figure IV.3 Dry Mixed-Conifer Change in Metrics with Significant Differences. These are the trends (percent change from pre-treatment) for all dry mixed-conifer metrics with significant differences between one or more pairs of treatment means.

Dry Mixed Conifer	Time Relative to Treatment												
Metric	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
	pretx		impost			5yrpost				10yrpost			
Trees per Acre		CFRP treatment	decrease from pretx										
Basal Area per Acre			decrease from pretreatment										
Quadratic Mean Diameter				increase from pretreatment									
Tree Height				increase from pretreatment									
Live Crown Base Height						increase from pretreatment							
Saplings per Acre													
Seedlings per Acre													
Shrubs per Acre													
Sick Trees per Acre													
Snags per Acre													
Overstory Canopy Cover			decrease from pretreatment										
Total Surface Fuels													
1000-hour Surface Fuels													

Figure IV.4. Duration of changes in dry mixed-conifer. Dark grey cells indicate the confidence interval does not include any of the reference range, which indicates the forest type mean is not within the historic range of variability. White cells show either a partial or complete overlap, which suggests that the true mean could fall within the historic range of variability for the forest type.

Table IV.1. Comparison of CFRP means to dry mixed-conifer reference ranges. Dark grey cells indicate the confidence interval does not include any of the reference range, which indicates the forest type mean is not within the historic range of variability. White cells show either a partial or complete overlap, which suggests that the true mean could fall within the historic range of variability for the forest type.

Metric	**Dry mixed-conifer historical value ranges from GTR 310**	**CFRP pre-treatment**	**CFRP immediate post-treatment**	**CFRP 5 year post-treatment**	**CFRP 10 year post-treatment**
Trees per acre	20.9-99.4	160 ≤ μ ≤ 610	11 ≤ μ ≤ 193	33 ≤ μ ≤ 146	-715 ≤ μ ≤ 1013
Basal area per acre	39.6-124	95 ≤ μ ≤ 156	19 ≤ μ ≤ 108	32 ≤ μ ≤ 78	14 ≤ μ ≤ 116
Openness (inverse of canopy cover)	78.5-87.1 or 79-87, depending on aggregation	12 ≤ μ ≤ 48	40 ≤ μ ≤ 81	52 ≤ μ ≤ 76	41 ≤ μ ≤ 54
Snags per acre	≥ Ponderosa forests (1-10)	19 ≤ μ ≤ 106	-9 ≤ μ ≤ 31	1 ≤ μ ≤ 56	-242 ≤ μ ≤ 307

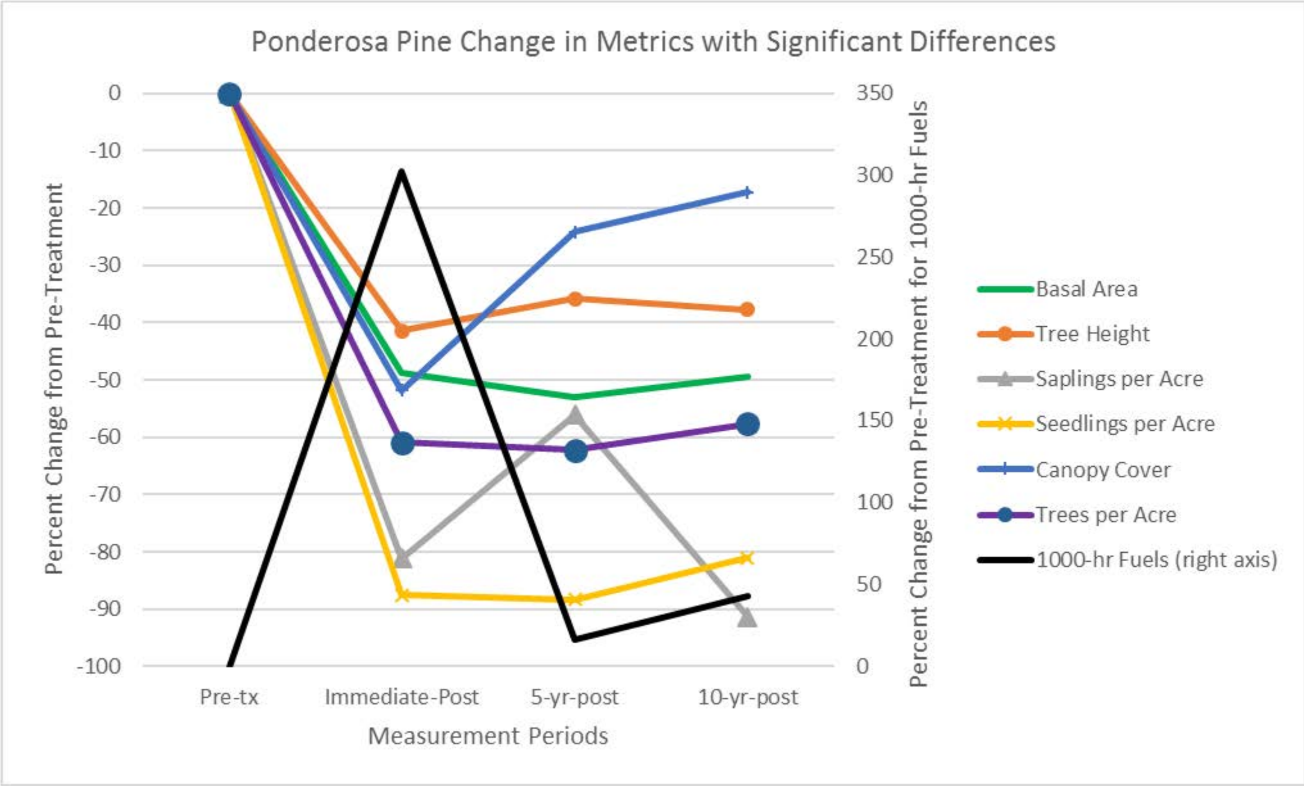

Figure IV.5 Ponderosa Pine Change in Metrics with Significant Differences. The graph shows trends (percent change from pre-treatment) for all ponderosa pine metrics with significant differences between one or more pairs of treatment means. Note that in this figure, 1000-hour fuels are plotted on the right axis while all other metrics are plotted on the left.

Ponderosa Pine	Time Relative to Treatment												
Metric	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
	pretx		impost			5yrpost				10yrpost			
Trees per Acre		CFRP treatment	decrease from pretreatment										
Basal Area per Acre			decrease from pretreatment										
Quadratic Mean Diameter													
Tree Height						decrease from pretreatment							
Live Crown Base Height													
Saplings per Acre			decrease from pretx								decrease from pretx		
Seedlings per Acre			decrease from pretreatment										
Shrubs per Acre													
Sick Trees per Acre													
Snags per Acre													
Overstory Canopy Cover			decrease from pretx										
Total Surface Fuels													
1000-hour Surface Fuels			increase from pretx			decrease from immediate posttx							

Figure IV.6. Duration of changes in ponderosa pine. Dark grey cells indicate the confidence interval does not include any of the reference range, which indicates the forest type mean is not within the historic range of variability. White cells show either a partial or complete overlap, which suggests that the true mean could fall within the historic range of variability for the forest type.

Table IV.2. Comparison of CFRP means to ponderosa pine reference ranges. Dark grey cells indicate the confidence interval does not include any of the reference range, which indicates the forest type mean is not within the historic range of variability. White cells show either a partial or complete overlap, which suggests that the true mean could fall within the historic range of variability for the forest type.

Metric	Ponderosa pine historical value ranges from GTR 310	CFRP pre-treatment	CFRP immediate post-treatment	CFRP 5 year post-treatment	CFRP 10 year post-treatment
Trees per acre	11.7-124	$119 \leq \mu \leq 324$	$46 \leq \mu \leq 127$	$62 \leq \mu \leq 105$	$59 \leq \mu \leq 128$
Basal area per acre	22.1-89.3	$83 \leq \mu \leq 125$	$12 \leq \mu \leq 95$	$39 \leq \mu \leq 59$	$41 \leq \mu \leq 64$
Openness (inverse of canopy cover)	52-90 or 70-90 depending on aggregation	$36 \leq \mu \leq 73$	$71 \leq \mu \leq 85$	$60 \leq \mu \leq 71$	$53 \leq \mu \leq 71$
Snags per acre	1-10	$7 \leq \mu \leq 29$	$1 \leq \mu \leq 22$	$10 \leq \mu \leq 28$	$10 \leq \mu \leq 29$

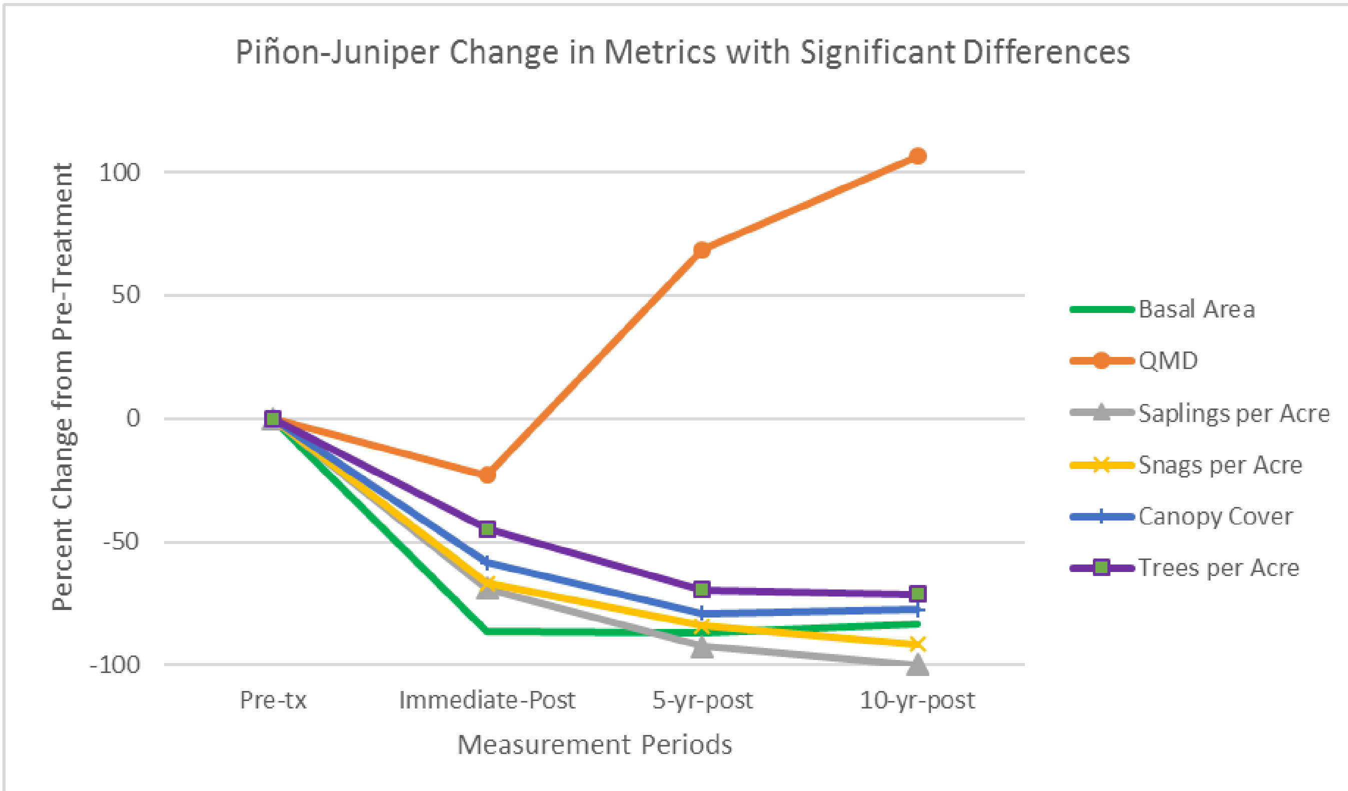

Figure IV.7 Piñon-Juniper Change in Metrics with Significant Differences. These are trends (percent change from pre-treatment) for all piñon-juniper metrics with significant differences between one or more pairs of treatment means.

Piñon-Juniper	Time Relative to Treatment												
Metric	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
	pretx		impost			5yrpost					10yrpost		
Trees per Acre		CFRP treatment				decrease from pretreatment							
Basal Area per Acre			decrease from pretreatment										
Quadratic Mean Diameter											increase from impost		
Tree Height													
Live Crown Base Height													
Saplings per Acre			decrease from pretreatment										
Seedlings per Acre													
Shrubs per Acre													
Sick Trees per Acre													
Snags per Acre			decrease from pretreatment										
Overstory Canopy Cover						decrease from pretreatment							
Total Surface Fuels													
1000-hour Surface Fuels													

Figure IV.8. Duration of changes in piñon-juniper. Dark grey cells indicate the confidence interval does not include any of the reference range, which indicates the forest type mean is not within the historic range of variability. White cells show either a partial or complete overlap, which suggests that the true mean could fall within the historic range of variability for the forest type.

Table IV.3. Wildfire threat reduction success evaluation. Green cells represent a change in the expected direction for restoration success, white cells represent no change, and red cells indicate a change in the opposite direction.

	Live trees per acre	Snags per acre	Sick trees per acre	Canopy Cover	Basal Area per Acre	Tree Size (QMD)
Wildfire Threat Reduction (part one)	**decrease or no change**	**generally decrease**	**decrease**	**decrease or no change**	**decrease**	**increase**
Wet Mixed Conifer	no significant change	no significant change	no significant change	no significant change	decrease between pretx and 5yrpost, 10yrpost	no significant change
Dry Mixed Conifer	decrease between pretx and immediate post	no significant change	no significant change	decrease between pretx and immediate post, 5yrpost	decrease between pretx and immediate post, 5yrpost	increase between pretx and 5yrpost
Ponderosa Pine	decrease between pretx and immediate post, 5yrpost, 10yrpost	no significant change	no significant change	decrease between pretx and immediate post	decrease between pretx and immediate post, 5yrpost, 10yrpost	no significant change
Piñon-Juniper	decrease between pretx and 5yr post, 10 yr post	decrease between pretx and immediate post, 5yrpost, 10yrpost	no pretx data	decrease between pretx and 5 yrpost, 10 yrpost	decrease between pretx and immediate post, 5yrpost, 10yrpost	increase between immediate post and 10 yr post

Table IV.3 (continued). Wildfire threat reduction success evaluation. Green cells represent a change in the expected direction for restoration success, white cells represent no change, and red cells indicate a change in the opposite direction.

	Tree Height	**Live Crown Base**	**Seedlings/ Saplings per Acre**	**Shrubs per Acre**	**Surface Fuels**	**1000-hr fuels**
Wildfire Threat Reduction (part two)	**generally increase**	**increase**	**decrease**	**generally decrease**	**decrease**	**decrease**
Wet Mixed Conifer	no significant change	no significant change	no significant change	no significant change	no significant change	no significant change
Dry Mixed Conifer	increase between pretx and 5yrpost	increase between pretx and 5yrpost	no significant change	no significant change	no significant change	no significant change
Ponderosa Pine	decrease between pretx and 5yrpost, 10yrpost	no significant change	decrease between pretx and 5yr post, 10 yr post	no significant change	no significant change	increase between pretx and immediate post decrease between immediate post and 5yrpost, 10 yrpost
Piñon-Juniper	no significant change	no significant change	decrease between pretx and 5yr post, 10 yr post	no significant change	no significant change	no significant change

Table IV.4. Ecosystem restoration success evaluation. Green cells represent a change in the expected direction for restoration success, white cells represent no change, and red cells indicate a change in the opposite direction.

	Snags per Acre	**Sick trees per Acre**	**Canopy Cover**	**Basal area per Acre**	**Tree Size (QMD)**
Ecosystem Restoration (part one)	**increase or decrease**	**possible initial increase then decrease**	**decrease or no change**	**decrease**	**increase**
Wet Mixed Conifer	no significant change	no significant change	no significant change	decrease between pretx and 5yrpost, 10yrpost	no significant change
Dry Mixed Conifer	no significant change	no significant change	decrease between pretx and immediate post, 5yrpost	decrease between pretx and immediate post, 5yrpost	increase between pretx and 5yrpost
Ponderosa Pine	no significant change	no significant change	decrease between pretx and immediate post	decrease between pretx and immediate post, 5yrpost, 10yrpost	no significant change
Piñon-Juniper	decrease between pretx and immediate post, 5yrpost, 10yrpost	no pretx data	decrease between pretx and 5 yrpost, 10 yrpost	decrease between pretx and immediate post, 5yrpost, 10yrpost	increase between immediate post and 10 yr post

Table IV.4 (continued): Ecosystem restoration success evaluation. Green cells represent a change in the expected direction for restoration success, white cells represent no change, and red cells indicate a change in the opposite direction.

	Tree Height	**Seedlings/Saplings per Acre**	**Shrubs per Acre**	**1000-hr fuels**
Ecosystem Restoration (part two)	**generally increase**	**decrease**	**decrease or increase**	**decrease**
Wet Mixed Conifer	no significant change	no significant change	no significant change	no significant change
Dry Mixed Conifer	increase between pretx and 5yrpost	no significant change	no significant change	no significant change
Ponderosa Pine	decrease between pretx and 5yrpost, 10yrpost	decrease between pretx and 5yr post, 10 yr post	no significant change	increase between pretx and immediate post decrease between immediate post and 5yrpost, 10 yrpost
Piñon-Juniper	no significant change	decrease between pretx and 5yr post, 10 yr post	no significant change	no significant change

Table IV.5. Reforestation success evaluation. Green cells represent a change in the expected direction for restoration success, white cells represent no change, and red cells indicate a change in the opposite direction.

	Live Trees per Acre	Seedlings/Saplings per Acre
Reforestation	increase or no change	increase
Wet Mixed Conifer	no significant change	no significant change
Dry Mixed Conifer	decrease between pretx and immediate post	no significant change
Ponderosa Pine	decrease between pretx and immediate post, 5yrpost, 10yrpost	decrease between pretx and 5yr post, 10 yr post
Piñon-Juniper	decrease between pretx and 5yr post, 10 yr post	decrease between pretx and 5yr post, 10 yr post

Table IV.6. Preservation of old/large trees success evaluation. Green cells represent a change in the expected direction for restoration success, white cells represent no change, and red cells indicate a change in the opposite direction.

	Sick Trees per Acre	**Tree Size (QMD)**	**Tree Height**
Preservation of old/large trees	**decrease**	**increase**	**generally increase**
Wet Mixed Conifer	no significant change	no significant change	no significant change
Dry Mixed Conifer	no significant change	increase between pretx and 5yrpost	increase between pretx and 5yrpost
Ponderosa Pine	no significant change	no significant change	decrease between pretx and 5yrpost, 10yrpost
Piñon-Juniper	no pretx data	increase between immediate post and 10 yr post	no significant change

V. - Conclusions

Letter and Spirit of the Law

The law creating the Collaborative Forest Restoration Program (CFRP) cites fire suppression, logging, and livestock grazing as causes for forest lands with an "unnaturally high number of small diameter trees." These forests, according to Section 602 of the Community Forest Restoration Act, are susceptible to catastrophic wildfires and provide fewer ecosystem services. Therefore the purpose of the law is to promote watershed health and reduce fire risk, decrease the number of small diameter trees and encourage their commercial use, to improve communication and collaborative partnerships, and to "develop, demonstrate and evaluate ecologically sound forest restoration techniques."

The law explains that multiparty monitoring and assessment will identify desired conditions, report upon effectiveness of the project, and assess short- and long-term *ecological* impacts for a minimum of 15 years. Further, for a new proposed project to be eligible to receive funding, it must "incorporate current scientific forest restoration information." The law does require an initial 5-year report from the Secretary to the Committee on Energy and Natural Resources, but otherwise does not specify exactly what is to be done with the monitoring data, short- and long-term, collected from these projects. It would seem in keeping with the spirit of the law, however, that the information that could be learned by comparing the collected monitoring data to a project's desired conditions/goals should be treated as part of the "current scientific forest restoration information" that future proposals are obligated to incorporate.

In other words, the ecological monitoring information generated as part of this project was not intended to sit in shelved reports somewhere, but rather to be part of an adaptive management framework designed to improve not only the CFRP but Southwest forest management overall.

Adaptive Management

Adaptive management is, most simply, learning from experience. Less simply, it is a decision-making process providing a structure that, when implemented by resource managers, should result in more informed management decisions and ecological responses that more closely match the desired and predicted outcomes. There are a myriad of definitions in literature, but the process is commonly visualized as an iterative feedback loop, such as Figure V.1 on page 101.

In theory, resource management should improve as more and more information (experience) becomes available. However, the Department of Interior's Adaptive Management Technical Guide (Williams & Brown, 2012) acknowledges that although adaptive management is frequently referenced by managers and management plans, it is in fact "infrequently implemented" (p. 1). Instead, processes such as trial-and-error are more common. It is this gap in the ecological data from CFRP projects that this thesis seeks to fill, with the recommendation that future re-evaluations as more data becomes available should be standard practice. One of the goals the Forest Service itself set in 2009 was to develop feedback loops using monitoring data (USDA Forest Service, 2009, p. 28). This research can provide a basis for adaptive management in both monitoring design and project implementation and follow-through for future CFRP projects, including more information on the interval needed for project maintenance and/or re-entry. For instance, preliminary field crew observations suggest that some projects are "escaping" around the 10 year mark, which program-wide analysis also suggest may be occurring at least in dry mixed-conifer.

Summary of Results and Implications

This thesis has explored the question of whether the CFRP program has so far met its ecological restoration objectives, as defined in the Community Forest Restoration Act (PL 106-393), the law which created it, and has found that results are mixed among forest types and objectives. Wet mixed-conifer projects generally do not show significant changes post-treatment. Dry mixed-conifer projects show clear impacts of treatment, but these are not significant by the 10 year re-measurement. Ponderosa pine projects have some longer-lasting impacts, while all piñon-juniper metrics that showed a significant difference still showed a significant difference at the 10 year re-measurement. Program-wide success was mixed for the objectives of wildfire threat reduction, ecosystem restoration, and preservation of old/large trees. Program success for the reforestation objective was not supported by this data, which is concerning as climate change impacts on forests are expected to worsen in the coming years. In keeping with the spirit of the law, these results would be most helpful if included as part of an adaptive management feedback loop, wherein results of a project make it back to the managers and decision-makers, and hopefully influence future decisions made as part of the program.

The results of this project would be relevant to managers because of implications not only for the CFRP program, but also for other restoration forestry efforts.

Program Recommendations

Several program-wide recommendations were made in previous publications that are supported by the findings of this project, such as monitoring assistance for grantees to standardize protocols and provide improved quality control. It would appear that tree condition data (e.g. healthy, unhealthy, mistletoe presence, etc.) is inconsistently collected. It would be valuable to collect slightly more detail than just "live" or "dead" for a tree, and mistletoe identification is within the skill set of most community members familiar with their forests.

Gaining access to data remains a major hurdle in conducting program-wide analysis. Ideas for a central data repository have been previously discussed, and should include not only final reports but also photographs, shapefiles, and information on project maintenance or re-entries. There is at present inconsistent enforcement of CFRP reporting and little incentive to follow through with timely analysis and publication of data. If that were to change, this data could be available for use in adaptive management decisions, particularly within the CFRP or CFLRP. In addition, a simple and timely reporting system would greatly reduce the stress that Forest CFRP Coordinators may feel when asked for data that has been filed away, unused, for many years, thereby improving communication and responsiveness. Finally, because results varied by forest types, it would be helpful for CFRP to adopt or define scientifically-based criteria for the clear identification of the Southwest forest types.

Finally, based on results, the biggest "weak spots" of existing treatments appear to be overall project success in the wet mixed-conifer forest type, project maintenance in the dry mixed-conifer forest type, and sufficient regeneration in ponderosa pine and piñon-juniper. An examination of grazing practices, actual implementation of prescribed fire, and other anthropogenic influences in project areas could help clarify how treatments could change to better achieve all program objectives.

Possibilities for Further Research

Further research is included in the requirements of the law which created the program. The law (Community Forest Restoration Act (Public Law 106-393 114 Stat 1625), 2000) requires the Secretary to "establish a multiparty monitoring and evaluation process in order to assess the cumulative accomplishments or adverse impacts of the Collaborative Forest Restoration Program….[and] assess the short- and long-term ecological effects of the restoration treatments, if any, for a minimum of 15 years."

Given more time, possibilities to expand this analysis include:

1. Try to collect or gain access to more data, especially in the mixed-conifer forest types.
2. Refine the piñon-juniper classification.
3. Spend more time investigating the differences in outliers, particularly when an entire project registers as outliers with most variables.
4. Consider analyzing species composition and forest structure (e.g. diameter classes) to look at compositional responses to treatment across age and size classes, e.g. what species are dominant in the snags classes, large trees, and regeneration.
5. Investigate the appropriateness of additional statistical analyses such as nonparametric analysis.

Beyond the 15-year monitoring mandate, continuation of this work is in NMFWRI's FY19 Federal Workplan which offers support for an additional year of analyses. By the end of that time, a summary report will be made available to interested stakeholders. Final publication of the results will be disseminated to interested parties including USFS CFRP Coordinators with the Carson, Cibola, Lincoln, Santa Fe, and Gila National Forests via email and posting on the NMFWRI CFRP webpage. Executive summaries will be published in NMFWRI's annual report. There will also be a request to present these results at the next CFRP Annual Workshop. Attendees at this workshop typically include USFS employees as well as grantees, interested applicants, the New Mexico Forest Industry Association, and others working in local forest products and forest management. It is hoped that additional questions, possibly access to data, and opportunities for continued research may arise from these meetings and in response to this publication.

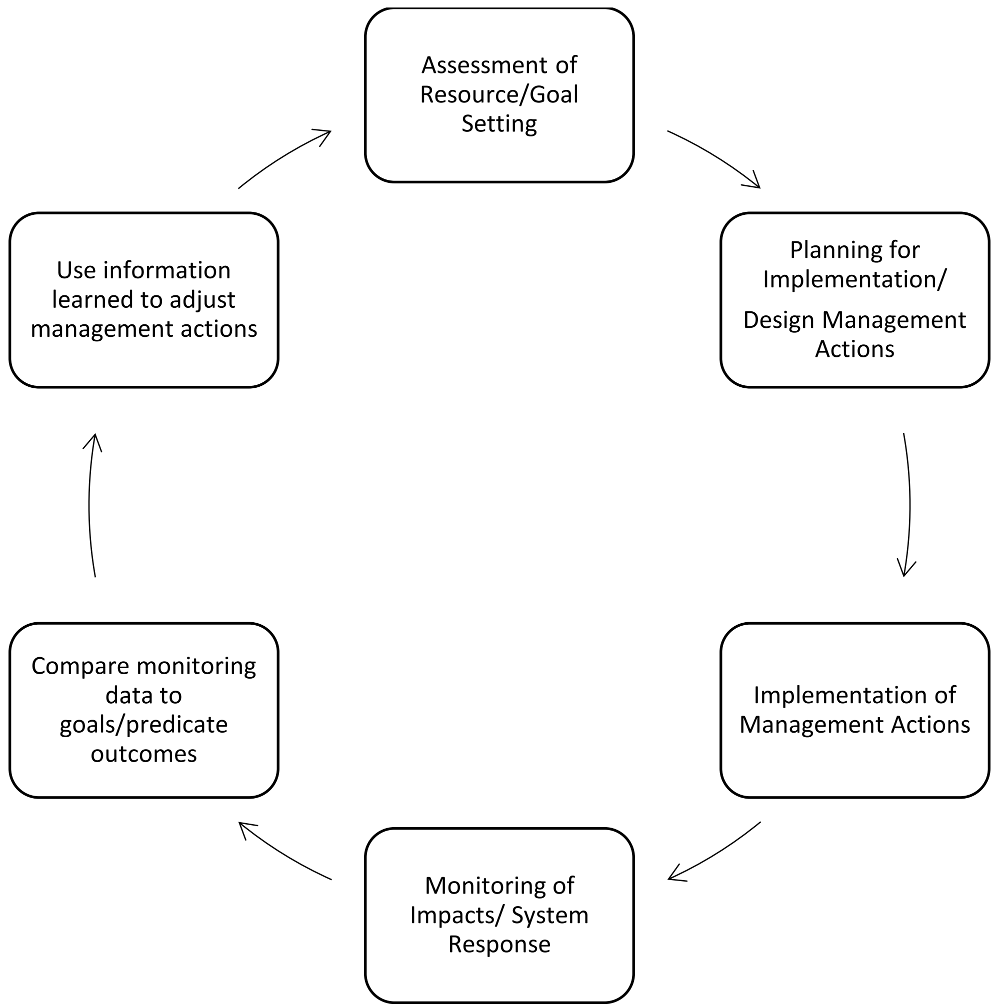

Figure V.1. Example Adaptive Management Loop

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Appendix A: List of Projects

The following is a list of CFRP projects with at least one measurement included in this analysis. A more detailed list can be obtained by contacting the author.

Wet Mixed-conifer Projects

Proposal ID	Project Title (in database; may not match full proposal title)	Forest/Agency
03-01	La Jicarita - Corrales Unit (plots 1, 4, 5)	Santa Fe
03-01	La Jicarita - Encinal Unit (plots 16, 22, 27 thru 38)	Santa Fe
03-01	La Jicarita - Walker Flats Unit (plots 6 thru 11, 13, 14, 15, 17 thru 21, and 24, 25, 26)	Santa Fe
06-10	Black Lake	NM SLO
21-12	Calf Canyon CFRP	Santa Fe
22-04	Gallinas TyM - Area 2 & 3 (plots 14 to 31)	Santa Fe
22-07	Barela Timber/Johnson Mesa	Santa Fe
28-05	Ensenada CFRP - Mixed conifer 1 (plots 10 to 13)	Carson
28-12	Black Lake Prescribed Fire	NM SLO

Dry Mixed-conifer Projects

Proposal ID	Project Title (in database; may not match full proposal title)	Forest/Agency
03-01	Walker Flats	Santa Fe
09-08	Black Lake II	NM SLO
Unknown	Griego/Las Dispensas Unit 1 (plots 1_05, 1_06, 1_09)	Santa Fe
Unknown	Griego/Las Dispensas Unit 2 (plots 2_01, 2_02, 2_03, 2_04, 2_08)	Santa Fe
Unknown	Griego/Las Dispensas Unit 3	Santa Fe
Unknown	Griego/Las Dispensas Unit 4/5/6	Santa Fe
16-12	Upper Mora - Walker Flats	Santa Fe
22-04	Gallinas T y M - Area 1 (plots 1 thru 13)	Santa Fe

Ponderosa Pine Projects

Proposal ID	Project Title (in database; may not match full proposal title)	Forest/Agency
01-05	Bluewater CFRP - Ponderosa Twin Springs	Cibola
01-05	Bluewater CFRP - Rice Park	Cibola
01-05	Bluewater CFRP - Upland Meadow	Cibola
01-05	Bluewater CFRP - Ponderosa Twin Springs	Cibola
02-05	P & M Thunderbird Unit 2 (South)	Cibola
02-05	P&M Thunderbird Unit 1 (North)	Cibola
03-09	Bluewater Utilization (PO Flats)	Cibola
06-10	Black Lake	NM SLO
07-09	Red Canyon	Cibola
11-01	Monument Canyon	Santa Fe
13-07	Ruidoso Schools	Lincoln
16-07	Santa Cruz/Embudo - Truchas Land Grant PP	Carson
21-04	Black Range CFRP (Sierra SWCD) aka Continental 1-c	Gila
21-04	Black Range CFRP (Sierra SWCD) aka Continental 1-t	Gila
21-04	Black Range CFRP (Sierra SWCD) aka Continental 2-c	Gila
21-04	Black Range CFRP (Sierra SWCD) aka Continental 2-t	Gila
21-04	Black Range CFRP (Sierra SWCD) aka Continental 3-c	Gila
21-04	Black Range CFRP (Sierra SWCD) aka Continental 3-t	Gila
28-05	Ensenada CFRP - Aspen 1 (plots 6 thru 9)	Carson
28-05	Ensenada CFRP - Meadow 2 (plots 17-19)	Carson
28-05	Ensenada CFRP - Ponderosa 2 (plots 14 to 16)	Carson
28-05	Ensenada CFRP - Ponderosa 3 (plots 1 to 5)	Carson
29-07	Ocate State Lands (Ocate A)	NM SLO
29-07	Ocate State Lands (Ocate B)	NM SLO
36-04	Turkey Springs (Ruidoso Downs) - USFS (red, plots 1 thru 7, excluding 6)	Lincoln
39-05	Cedar Creek	Lincoln
39-09	Rowe Mesa	Santa Fe

Piñon-Juniper Projects

Proposal ID	**Project Title** **(in database; may not match full proposal title)**	**Forest/Agency**
01-05	Bluewater CFRP - Phase I Savannah	Cibola
01-05	Bluewater CFRP - Phase II Savannah (Salitre Mesa)	Cibola
05-07	Unit 18	Tribal
05-07	Unit 19	Tribal
05-07	Unit 29	Tribal
05-07	Unit 40	Tribal
05-07	Unit 41	Tribal
05-07	Unit 46	Tribal
16-07	Santa Cruz/Embudo - BLM Boy Scout	Carson
16-07	Santa Cruz/Embudo - Cejita Mesa	Carson
16-07	Santa Cruz/Embudo - Truchas Land Grant PJ	Carson
27-04	Santa Fe CFRP WUI - tx 1	Santa Fe
27-04	Santa Fe CFRP WUI - tx 2	Santa Fe
27-04	Santa Fe CFRP WUI - tx 3	Santa Fe
27-04	Santa Fe CFRP WUI - tx 4	Santa Fe
27-04	Santa Fe CFRP WUI - tx 5	Santa Fe
27-04	Santa Fe CFRP WUI - tx 6	Santa Fe
36-04	Turkey Springs (Ruidoso Downs) - Turkey Creek (purple, 8 to 11)	Lincoln

Appendix B: Monitoring Protocols Used by FWRI on CFRP Projects

NMFWRI FFI/CSE-Based Sample Protocols

In use in current form since 2016

For questions or comments, contact: Kathryn R Mahan, Ecological Monitoring Specialist, NMFWRI

Office: 505.426.2147 Email: krmahan@nmhu.edu

Crews, Navigation & Plot Setup

Plots are most efficiently accomplished with a **3-person crew** but can also be taken with 2 people. More detailed plots, presented here as options, are most efficient with a 4- to 5-person crew. All crews need basic knowledge of monitoring methods and rationale, equipment, plant species and common tree pests and diseases.

Plots are established using a random point location with project-specific boundaries e.g. stand boundaries, treatment areas, vegetation types, etc. In our office, maps and plot locations are generated with ArcGIS utilities and are loaded onto a Trimble and Garmin GPS units. Unit maps, driving maps and driving directions are created and sent with the field crew. Once in the project area, navigation to a plot is typically accomplished through paper maps and the Garmin GPS units. Paper maps can be easily marked with Sharpies to indicate sequence of plot collection, dates, and teams at work; this information can be stored with the datasheets and may help answer questions that arise later. We use Garmin GPS units because they are user-friendly and can run on AA batteries which are easily replaced in the field. We use the Trimble unit to more accurately determine plot location and collect updated plot location coordinates which can later be post-processed for greater location accuracy with GPS Pathfinder Software. Plots must be moved one chain (66 ft) at a random azimuth from their original, intended location if they are within 75 feet of a road.

A marker (we typically use a 1-foot piece of ½ inch rebar with a mushroom cap) is installed at plot center. Where plots are being re-visited, a good metal detector may be of use to locate the center stake. Copies of the previous plot photos can also be useful.

Plots are set up using 8 pin flags in addition to the center stake. Crew members walk cardinal azimuths (N, E, S, W) from plot center and place pin flags at 11.78ft (11’ 9”) and 37.24ft (37’ 3”) to give visual aids for the two plots (1/10th ac and 1/100th ac) whose purposes are described below.

Photographs, Witness Trees & Other Plot data

Seven **photographs** are taken per plot. If more than one Brown’s transect is collected, additional photographs are taken in the same format. Typically, a white board with marker is used to tag each photo. The first photo taken at each plot is of the white board on the ground at plot center (“PC”). This ensures the data technicians are able to read the plot name and number and correctly identify the photos that follow. It is helpful if the camera used can record GPS coordinates.

Additional photos include:

- "C," taken from 75 feet along the North azimuth looking at a crew member holding the white board at plot center
- Brown's transect photo, "B_*degrees*" taken from the 75-foot mark of each fuels azimuth looking towards a crew member holding the white board at plot center
- "N," "E," "S," and "W" photos taken from plot center facing a crew member holding the white board 37.2' at each of the four cardinal azimuth flags. Additional photographs may be taken, but we recommend these be taken after the mandatory seven plot photos, and noted on the data sheets, so that there is no confusion for the data technicians.

A **witness tree** or trees should be near plot center to assist with finding plot center and ideally should be expected to survive any future thinning, fire, or other disturbance. For example, mature yellow-bark pines near plot center are easy to find and not likely to be thinned. Any healthy tree will work. The tree should be flagged, noted in the overstory data, and described on the Plot Description datasheet.

Photo order, hill slope, dominant aspect, coordinates, elevation, date, and **time** are recorded for each plot. **Comment fields** are available on all datasheets and we encourage all observations, including species, land use impacts, fire history, challenges in taking plot, etc. to be documented here.

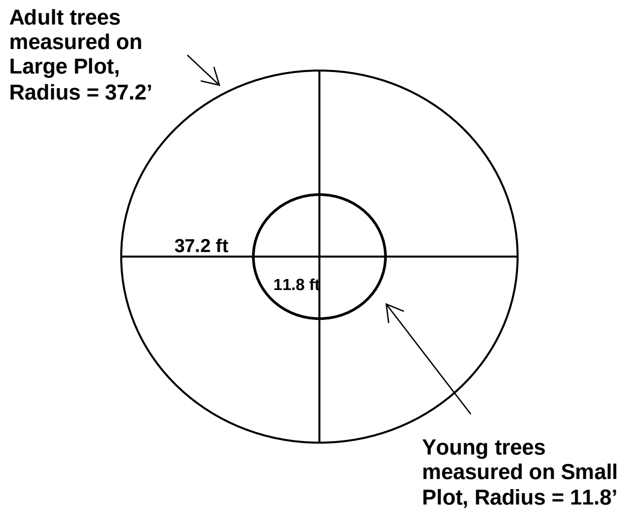
Overstory

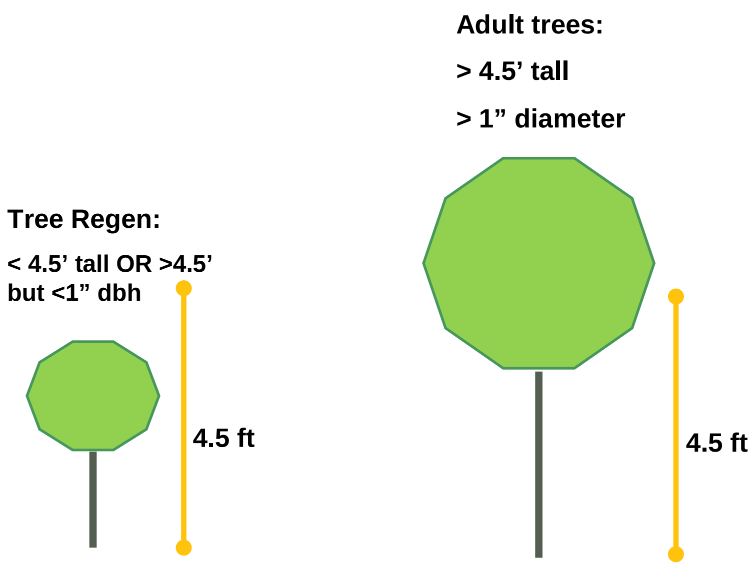
All **trees and snags** are measured within the 1/10th acre plot (37.24 ft. radius) circular, fixed area sample plot. We typically define a tree as ≥ 4.5 ft. and > 1.0 in dbh or drc, although other cutoffs may be used depending on objectives. Species, condition, dbh or drc, number of stems, total height, and live crown base height are recorded for each tree located within the plot. Most trees are measured at dbh with exception of those multi-stem species with more than two stems at dbh (i.e. *Quercus* spp., *Juniperus* spp.). Be aware that other trees/large shrubs with multiple stems, such as mountain mahogany or chokecherry, cannot be processed if they are measured at drc since their conversion formulas are unavailable. Depending upon the project, other information may be collected including damage and severity, scorch height, snag decay class, crown ratio, and crown class. Trees are recorded starting from the north azimuth line and moving clockwise, like spokes of a wheel from plot center. In dense stands, we find it helpful to flag the first tree measured to keep the crew oriented. If appropriate, this first tree may also serve as the **witness tree**. Do not forget to flag and record your witness tree.

Tree regeneration is measured on the nested 1/100th acre circular plot (11.78 ft. radius) and species, condition, and height class (>0-0.5 ft; >0.5-1.5ft; >1.5-2.5ft; >2.5-3.5ft.; >3.5-4.5ft) are recorded for each **seedling** or sprout. **Saplings** (>4.5ft but <1.0in dbh/drc) are also recorded in this way. **Shrubs** are measured on the same nested subplot and species, condition and height/diameter class are recorded for each stem just as with tree species; we typically record cacti in this category as well. Other cutoffs may be used for height and diameter classes depending upon objectives.

Trees and shrubs are typically recorded using their **USDA PLANTS code**, which is commonly a four letter code defined by the first two letters of the genus and first two letters of the species name (e.g. PIPO, ABCO, PIFL, PIED, JUDE, JUSC, QUGA, etc). Note that upon entry into a database, it is common for these codes to be followed by various numbers in order to differentiate between other species whose names would create the same code. These symbols can be found on the USDA PLANTS website, https://plants.usda.gov/

Canopy cover (density) is an average of four measurements from a spherical densiometer. These four measurements are taken facing out at the four small-plot pin flags along the perimeter of the nested subplot. In this way, each reading is spaced 90 degrees apart.

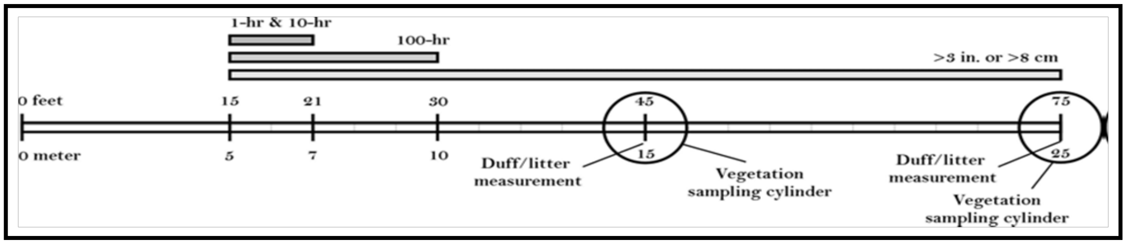




Fuels (Brown's)

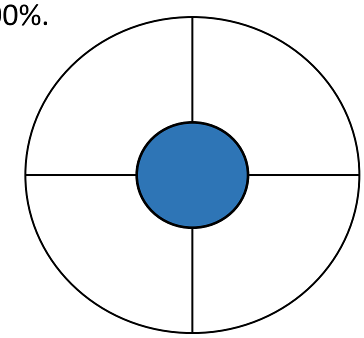
Dead woody biomass and forest floor depth are measured using a planar Brown's transect or transects. These transects may be at fixed or random azimuths. To select a random azimuth, one crew member spins a compass and another decides when to stop. Typically in our protocol, a fiberglass tape is run from the plot center stake out 75 feet and fuels are measured from 15 to 75 feet to account for the expected foot traffic disturbance around plot center. Parameters measured include **1, 10, 100, and 1,000 hour fuels** ("time-lag fuels"). Other lengths of transects, including variable lengths for each fuel size, may be used. For more information, see Brown 1974 and subsequent guidelines. Note that in our protocol, a piece of coarse woody debris (CWD) must be >3" in diameter and at least 3 feet long to count as a 1000-hour fuel; if it is >3" in diameter, but under 3 feet long, we count it as a 100-hour fuel. Decay class (1 to 5) and sometimes length is collected for each 1000-hour fuel.

Percent cover and height of **herbaceous live and dead material**, percentage cover and height (up to 6 ft.) of **woody live (excluding boles of trees) and dead** material are estimated using 6-foot diameter cylinders per Brown's planar intersect method at 45 and 75 ft (Brown 1974). **Litter and duff depths** are measured at 45 and 75 ft. The location, offset, and frequency of these measurements is flexible.



Understory

Vegetation and ground cover are estimated within the nested 1/100th acre plot; some project managers may request these measurements are conducted across the entire 1/10th acre area. Vegetation measurements include **aerial percent cover** of seedling/saplings, shrubs (including cacti), graminoids, and forbs, and may not necessarily total 100%. Depending upon objectives, aerial percent cover may be further stratified by individual species greater than 1% cover. **Ground cover measurements** include percent cover of plant basal area (including cacti), boles, litter, bare soil, rock, and gravel, and must total 100%.



Data processing and reporting

At this time, we use **FFI software**, as well as Excel spreadsheets, to enter and analyze our data. FFI is able to export to FVS and FuelCalc. FFI software and User Guides are available for download here: https://www.frames.gov/partner-sites/ffi/software-and-manuals/

In order to process individual piñons, junipers and oaks with more than 2 stems or whose branch structure made access difficult and were therefore measured at root collar (DRC) instead of breast height (DBH), we use the **equations developed by Chojnacky and Roger** (1999).

All our results are typically reported to two significant digits, with exceptions for those metrics we know were measured with either more or less precision.

Sample reports can be found on our website: http://nmfwri.org/resources/restoration-information/cfrp/cfrp-long-term-monitoring/cfrp-long-term-monitoring

SAMPLE DATASHEETS – BASIC PLOT

Plot Description

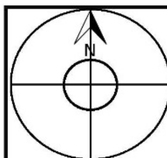
Observer:	______________________________
Recorder:	______________________________
Latitude (dd.dddddd):	____________________
Longitude (ddd.dddddd):	____________________
Elevation:	____________________

Administrative Unit:	__________________
Project Unit:	__________________
Macroplot:	__________________
Date (MM/DD/YYYY):	__________________
Time:	__________________

Photo Azimuths: ORDER TAKEN:	(1) of whiteboard at PC. (1) from 75 feet N looking south to PC (4) from PC in all four cardinal directions; (1) from each Brown's transect looking toward PC. ____________________

Hill Slope (% where steepest):	____________%
Aspect (circle one):	N E S W
Aspect azimuth (degrees):	____________°
Mag Declination:	____________°

Comments:



Describe Witness Tree(s):

Draw location of tree on plot

Color of Flagging/Marker Used: ______________________________

Aerial cover (%) (1/100th acre plot)			
Tree regen.	Shrubs	Graminoids	Forbs

Macroplot Sizes		
Size (Acres)	1/100	1/10
Radius (Feet, Decimal Feet)	11.78	37.24
Radius (Feet, Inches)	11' 9"	37' 3"

Tree Canopy (%)

Ground cover (%) (1/100th acre plot) (total 100 %)						
Plant basal	Bole	Litter	Bare soil	Rock (>2.5in)	Gravel (< 2.5 in)	Total (%)

Species	Condition (Live, Dead, Sick)	Small Plot—Tree Regen & Shrubs: Height classes—Seedlings (<4.5', <1" dbh/drc) > 0 - 0.5	> 0.5—1.5'	> 1.5' - 2.5'	>2.5 - 3.5	>3.5 - 4.5

Species	Condition (Live, Dead, Sick)	Small Plot—Tree Regen & Shrubs: Saplings >4.5', < 1"

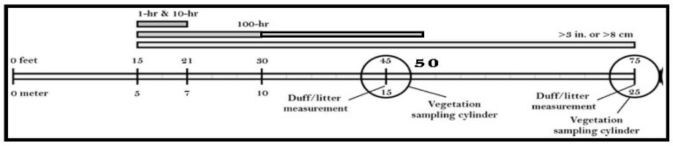
Surface Fuels

Sheet 1 of 2: Fine Woody Debris—Coarse Woody Debris

Observer	______________________
Recorder	______________________
Number of Transects	______

Administrative Unit:	____________
Project Unit:	____________
Macroplot:	____________
Date (DD/MM/YYYY):	____________
Time:	____________

1-hour Transect Length - 6′   10-hour Transect Length - 6′   100-hour Transect Length - 35′   1000-hour Transect Length - 60′



	Class	Diameter (in)
FWD	1-hr 10-hr 100-hr	0 to 0.25 0.25 to 1.0 1.0 to 3.0
CWD	1000-hr and greater	3.0 and greater

Fine Woody Debris (1, 10, 100 hr fuels)

Transect	Azimuth	Slope	1 - Hr Count	10 - Hr Count	100 - Hr Count	Comment
1	* Random for CFRP or (0°)					
2	135°					
3	270°					

Coarse Woody Debris (1000 hr fuels)

Transect	Slope	Log No.	Log Diameter	Decay Class	Comment

Precisions: Diameter: ±0.5 in ; decay class ±1 class ; Slope ±5 percent

Decay Class Description

1 All bark is intact. All but the smallest twigs are present. Old needles probably still present. Hard when kicked
2 Some bark is missing, as are many of the smaller branches. No old needles still on branches. Hard when kicked
3 Most of the bark is missing and most of the branches less than 1 in. in diameter also missing. Still hard when kicked
4. Looks like a class 3 log but the sapwood is rotten. Sounds hollow when kicked and you can probably remove wood from the outside with your boot. Pronounced sagging if suspended for even moderate distances
5 Entire log is in contact with the ground. Easy to kick apart but most of the piece is above the general level of the adjacent ground. If the central axis of the piece lies in or below the duff layer then it should not be included in the CWD sampling as these pieces act more like duff than wood when burned.

Surface Fuels

Sheet 2 of 2: Duff, Litter, and Vegetation

Observer	______________________
Recorder	______________________
Number of Transects	______
Transect Length: 75 ‘	

Administrative Unit:	____________
Project Unit:	____________
Macroplot:	____________
Date (DD/MM/YYYY):	____________
Time:	____________

Transect	Sample Location	Litter Depth	Duff Depth	Veg Item	% Veg Cover	Veg Hgt (d.d’)
1	45’			HD		
				HL		
				SD		
				SL		
1	75’			HD		
				HL		
				SD		
				SL		
2	45’			HD		
				HL		
				SD		
				SL		
2	75’			HD		
				HL		
				SD		
				SL		
3	45’			HD		
				HL		
				SD		
				SL		
3	75’			HD		
				HL		
				SD		
				SL		

Surface Fuels-Vegetation Item Code and Description

HD dead non-woody vegetation
HL Live non-woody vegetation
SD Dead woody vegetation
SL Live woody vegetation

% Veg cover

Code	Cover
0	No cover
0.5	>0-1 % cover
3	>1-5 % cover
10	>5-15 % cover
20	>15-25 % cover
30	>25-35 % cover
40	>35-45 % cover
50	>45-55 % cover
60	>55-65 % cover
70	>65-75 % cover
80	>75-85 % cover
90	>85-95 % cover

Comments:

Plot Number________________ **Page_____of______**

Observer/Recorder: ____________ Project/Site/Plot___________________ Date________________

	1/10th acre plot (37' 3'' radius)								
Tree #	Species	Tree cond.	DBH	DRC	No. stems	Total Tree Ht	LiCrBHt	Mistletoe (%)	Comments damage/disease, witness tree, etc.

SAMPLE DATASHEETS – DETAILED CSE PLOT

CSE Plot Description

Observer: ______________________________

Recorder: ______________________________

Latitude (dd.dddddd): ____________________

Longitude (ddd.ddddd): ____________________

Elevation (ft): ____________________

Administrative Unit: _________________

Project Unit: _________________

Macroplot: _________________

Date (DD/MM/YYYY): _________________

Time: _________________

Macroplot Sizes		
Size (Acres)	1/100	1/10
Radius (Feet, Decimal Feet)	11.78	37.24
Radius (Feet, Inches)	11' 9"	37' 3"

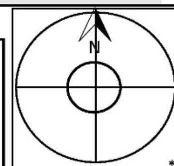
Hill Slope (where steepest): __________%

Aspect (circle one): N E S W

Aspect azimuth: __________°

Mag Declination: __________°

Describe Witness Tree(s):



Draw location of tree on plot

Color of Flagging Used: _______________

Photo Azimuths: (1) of whiteboard at PC. (1) from 75 feet N looking south to PC (4) from PC in all four cardinal directions; (1) from each Brown's transect looking toward PC.

ORDER TAKEN: ________________________

Comments/Description of Plot:

List by Species	AERIAL COVER (%) (ENTIRE 1/10th acre plot) Estimate Aerial Cover % for Species by Lifeform				
	Tree	Shrub	Forb/herb	Gramanoid	Cactus
TOTALS					

Tree Canopy Cover (%) (densiometer)

GROUND COVER (%) (ENTIRE 1/10th acre plot) (must total 100 %)						
Plant basal	Bole	Litter	Bare soil	Rock (>2.5in)	Gravel (< 2.5 in)	Total (%)

FOR CSE, SMALL PLOT INCLUDES ALL SEEDLINGS OR SAPLINGS <5 INCHES DBH/DRC.

Species	Condition (Live, Dead, Sick)	Small Plot (1/100th Acre only) - Tree Regen, Shrubs & Cacti Height classes—Seedlings (feet)				
		> 0 - 0.5'	> 0.5—1.5'	> 1.5' - 2.5'	>2.5' - 3.5'	>3.5' - 4.5'

Species	Condition (Live, Dead, Sick)	Small Plot (1/100th Acre only) - Tree Regen, Shrubs & Cacti Diameter classes—Saplings (inches)				
		> 0 - 1"	>1-2"	>2-3"	>3-4"	>4-5"

Precisions:
Slope: ±5 percent
Vegetation cover : ±1 class estimation or ±10%

CSE Surface Fuels

Observer	____________________
Recorder	____________________

Macroplot:	____________
Date (DD/MM/YYYY):	____________
Time:	____________

CSE Brown's Transects are 50 feet long, starting at PC.

Class	Count From	Total Length
1-hr, 10 –hr	44' to 50'	6
100-hr	38' to 50'	12
1000-hr	0' to 50'	50

Class		Diameter (in)
FWD	1-hr 10-hr 100-hr	0 to 0.25 0.25 to 1.0 1.0 to 3.0
CWD	1000-hr and greater	3.0 and greater

Decay Class Description

1 All bark is intact. All but the smallest twigs are present. Old needles probably still present. Hard when kicked

2 Some bark is missing, as are many of the smaller branches. No old needles still on branches. Hard when kicked

3 Most of the bark is missing and most of the branches less than 1 in. in diameter also missing. Still hard when kicked

4. Looks like a class 3 log but the sapwood is rotten. Sounds hollow when kicked and you can probably remove wood from the outside with your boot. Pronounced sagging if suspended for even moderate distances

5 Entire log is in contact with the ground. Easy to kick apart but most of the piece is above the general level of the adjacent ground. If the central axis of the piece lies in or below the duff layer then it should not be included in the CWD sampling as these pieces act more like duff than wood when burned.

Fine Woody Debris (1, 10, 100 hr fuels)	Transect	Azimuth	Slope	1 - Hr Count	10 - Hr Count	100 - Hr Count	Comment
	1	0°					
	2	180°					

Coarse Woody Debris (1000 hr fuels)	Transect	Log No.	Log Diameter	Decay Class	Length (feet)	Comment

Litter & Duff	Transect 1	15 '	30'	38 '	44'	45'
	Litter Depth (in)			N/a	N/a	
	Duff Depth (in)	N/a	N/a			N/a
	Transect 2	15 '	30'	38 '	44'	45'
	Litter Depth (in)			N/a	N/a	
	Duff Depth (in)	N/a	N/a			N/a

Precisions: Diameter: ±0.5 in ; decay class ±1 class ; Slope ±5 percent

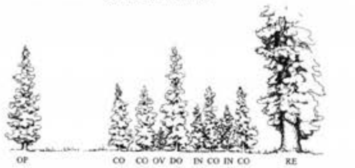
CSE Tree Data

Plot Number: ______________ Date: ____________________ Observer/Recorder:____________________ **Page ___ of _____**

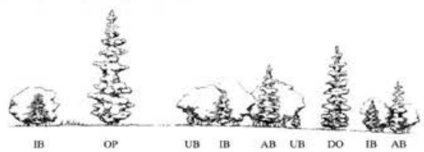
Tree #	Cond	Species	DBH	DRC	Number Stems	Total Tree Ht	LiCrBHt	Crown Ratio	Crown Class	Damage/Disease	Decay Class	Comment

CSE Tree Sheet Column	Description	Examples	Warnings
Tree #	Order of trees in plot, starting clockwise from N line, moving around plot like spokes of a wheel	1, 2, 3	Stay in order!
Condition	Condition of tree	L, D, S	If sick, identify why; If dead, record decay class of snag
Species	Species of tree, recorded using USDA PLANTS code	PIED, PIPO, JUSC, POTR	
DBH (in)	Diameter at breast height (4.5 feet); used for single-stem species	10.1, 4.2	CSE Plots only record trees over 4.5 ft, with DBH ≥5 inches, if tree would be measured at DBH
DRC (in)	Diameter at root crown (close to ground); use only on PIED, JUXX, or QUXX with <2 stems	7.4, 5.5	CSE Plots only record trees over 4.5 ft, with DRC ≥5 inches, if tree would be measured at DRC
Number of stems	Order of the stems measured	1, 2, 3, 4	
Total Tree Ht (ft)	Height of tree from ground to top of tree (whether top is live or dead); use rangefinder or clinometer	70, 15, 5	
LiCrBHt, Live Crown Base Ht (ft)	Height from ground to base of live crown (not necessarily on bole of tree)	6, 21, 50	Live trees only
Crown Ratio	Length of live crown divided by the total tree height	50%, 65%	Live trees only
Crown Class	Two-letter code that describes the relative position of the tree crown with respect to the competing vegetation	CO, DO, OP	See Reference Sheet for Classes
Damage/Disease	Recorded using categories in reference sheet in the following format: **Category/Agent/Tree Part/Severity**	10/000/BO/1	See Reference Sheet for Categories
Decay Class	A number between 1 and 5, similar to the decay classes used for CWD	Class 2, Class 3	Snags only; See Reference Sheet for Decay Classes
Comment	Otherwise observation about the tree, including whether or not it is a witness tree	*Nest in tree*	Note if this is your witness tree

Crown Class Illustration

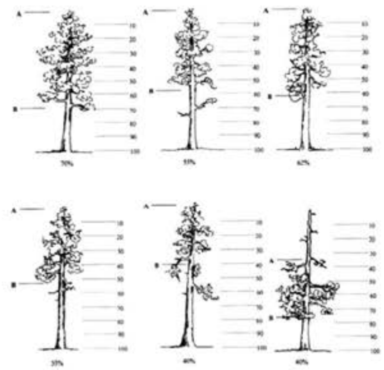


Brush Cover Crown Class Illustration



Code	Name	Description
OP	Open-grown or Isolated	Tree crowns receive full light from above and from all sides. In even-aged stands, these trees have their crowns well above the general canopy.
DO	Dominant	Tree crowns receive full light from above and partly from the sides. Crowns extend above the general level of the crown cover of others of the same stratum and are not physically restricted from above, although possibly somewhat crowded by other trees on the sides. In even-aged stands, dominant trees rise somewhat above the general canopy.
CO	Codominant	Tree crowns receive full light from above, but comparatively little from the sides. Crowns form a general level of crown stratum, are not physically restricted from above and are crowded by other trees from the sides. In even-aged stands, codominants form the general canopy level.
IN	Intermediate	Tree crowns occupy a definitely subordinate position and are subject to strong lateral competition from crowns of dominants and codominants. They receive little direct light from above through small holes in the canopy, but no light from the sides.
OV	Overtopped	Tree crowns receive no direct light from above or from the sides and are entirely below the general level of dominant and codominant trees.
RE	Remnant	Trees that remain from a previous management activity or catastrophic event. The tree is significantly older than the surrounding vegetation. Remnant trees do not form a canopy layer and are usually isolated individuals or small clumps. This definition is from the Region 6 Inventory and Monitoring System field procedures for the Current Vegetation Survey.
AB	Leader Above Brush	The terminal leader of the tree is above the surrounding brush while the middle or lower crown may be within the brush canopy.
IB	Leader Within Brush	The terminal leader and upper crown of the tree is within the brush canopy.

Code	Name	Description
UB	Leader Overtopped by Brush	The crown of the tree is completely overtopped by the surrounding brush. Brush cover crown classes only apply to isolated or dominant trees with brush competition; therefore, brush cover crown class codes are used as modifiers for open-grown or dominant trees. Competition from adjacent trees is more important than competition from shrubs if they both occur. Generally, brush cover crown codes are used in stands where overstory tree competition is absent.



Crown Ratio →

Snag Decay

Code	Bark	Heartwood Decay	Sapwood Decay	Limbs	Top Breakage	Bole Form	Time Since Death
1*	Tight, intact	Minor	None to incipient	Mostly Present	May be present	Intact	≤5 years
2	50% loose or missing	None to advanced	None to incipient	Small limbs missing	May be present	Intact	>5 years
3	75% missing	Incipient to advanced	None to 25%	Few remain	Approx. 1/3	Mostly intact	>5 years
4	75% missing	Incipient to advanced	25%+	Few remain	Approx. 1/3 to ½	Losing form, soft	>5 years
5	75%+ missing	Advanced to crumbly	50%+ advanced	Absent	Approx. ½+	Form mostly lost	>5 years

**Implies recent mortality, within the last 5 years.*

Snag Decay Classes