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Joint Fire Science Program

I. Abstract

Pinyon-juniper woodlands are a dominant vegetation type throughout the Interior West on lands managed by the U.S. Forest Service and the USDI Bureau of Land Management. The woodlands have traditionally been viewed as having a low risk of wildfires because of the lack of a continuous and dense ground cover and low tree stand densities. However, stand densities are often high and are increasing in many areas and wildfires, often resulting in loss of lives and property, will occur under conditions of low humidity, high temperatures and wind speeds, and an ignition source. Woodlands commonly surround or are adjacent to many towns in the region; however, in recent years, people have moved into the woodlands to construct individual homes and housing developments. In this decade, the ecology and fire risk in pinyon-juniper woodlands have changed dramatically because of the continuing drought and the region-wide infestation of the pinyon engraver beetle, *Ips confusus*, which have resulted in high pinyon mortality, increased fuel loadings, and risks of severe wildfires. Managers are attempting to reduce fire hazards and create defensible spaces in the wildland-urban-interface (W.U.I.). They have commonly used hand thinning-piling-burning prescriptions in the W.U.I. but have recently turned to mechanical mastication to accomplish stand reduction goals, especially where slope and soil surface conditions permit the safe operation of heavy equipment. In most situations the goal is to create a mosaic of open and wooded conditions on the landscape. These has advantages of maintaining wildlife habitats, tree and shrub growth, an esthetic landscape, and increasing herbaceous production while improving fire suppression opportunities and reducing fire hazards. However, managers do not know the consequences of mastication on soil nutrient and microbiological populations and on the residual tree, shrub, and herbaceous vegetation. While the number of research studies of the effects mastication on ecosystem components has increased recently, there still are many questions.

II. Background and Purpose

In September 2003, the Dolores Public Lands Office-Service Center of the San Juan National Forest in southwestern Colorado approached the Rocky Mountain Research Station concerning research needs pertaining to mastication in pinyon-juniper woodlands. The literature contained few references to research relevant to mastication, with none referenced for pinyon-juniper ecosystems. The Service Center at that time was using hydro-mow equipment (Figure 1.) to masticate small diameter (live and dead) standing pinyon and juniper, along with downed woody fuels in the W.U.I. Between 800 to 1,200 hectares of pinyon-juniper woodlands was annually targeted for treatment. Both land managers and the public voiced concerns regarding the treatment consequences of mastication residue additions on woodland ecosystem soils and vegetation resources. Of special concern was the potential for increased non-native invasive species, such as cheatgrass (*Anisanthia tectorum*) and musk thistle (*Carduus nutans*). The Center also utilized thinning-piling-burn prescriptions around sensitive areas such as archeological sites, oil and gas developments, and recreational and administrative areas.

The specific objectives of this study were to: 1) measure vegetative response (composition, cover, frequency, regeneration) of both overstory and understory, 2) describe changes to fuel loadings, and 3) determine total carbon (C) and nitrogen (N) pool sizes and associated microbial population in the soil in *Ips* killed pinyon-juniper woodlands of southwest Colorado region following mastication, thinning-piling-burning, and untreated plots.

Figure 1. Hydro-mower working in the School Area near Egnar, Colorado in the fall of 2005.

III. Study Description and Location

Three pinyon-juniper sites (Figure 2.) previously scheduled for mastication were selected for the study. The pinyon species in this area is *Pinus edulis* with Utah juniper (*Juniperus osteosperma*) the most common juniper species and a small component of Rocky Mountain junipers (*J. scopulorum*). Gambel oak (*Quercus gambelii)* was common but in its shrub form. All three areas were scheduled for treatment in the fall of 2005.

The long-term annual mean precipitation at Mesa Verde National Park, just south of the study areas, was 47 cm. The sites and some characteristics are:

1) School (BLM; NE of Egnar, Colorado; 2,318 ± 13 m; Sandstone Parent Material).

2) Summit (BLM; N of Mesa Verde National Park, Colorado; 2,115 ± 25 m, Mancos Shale, Sandstone Parent Materials).
3) May Canyon (FS; N of Dolores, Colorado; 2,209 ± 14 m; Sandstone, Shale Parent Materials).

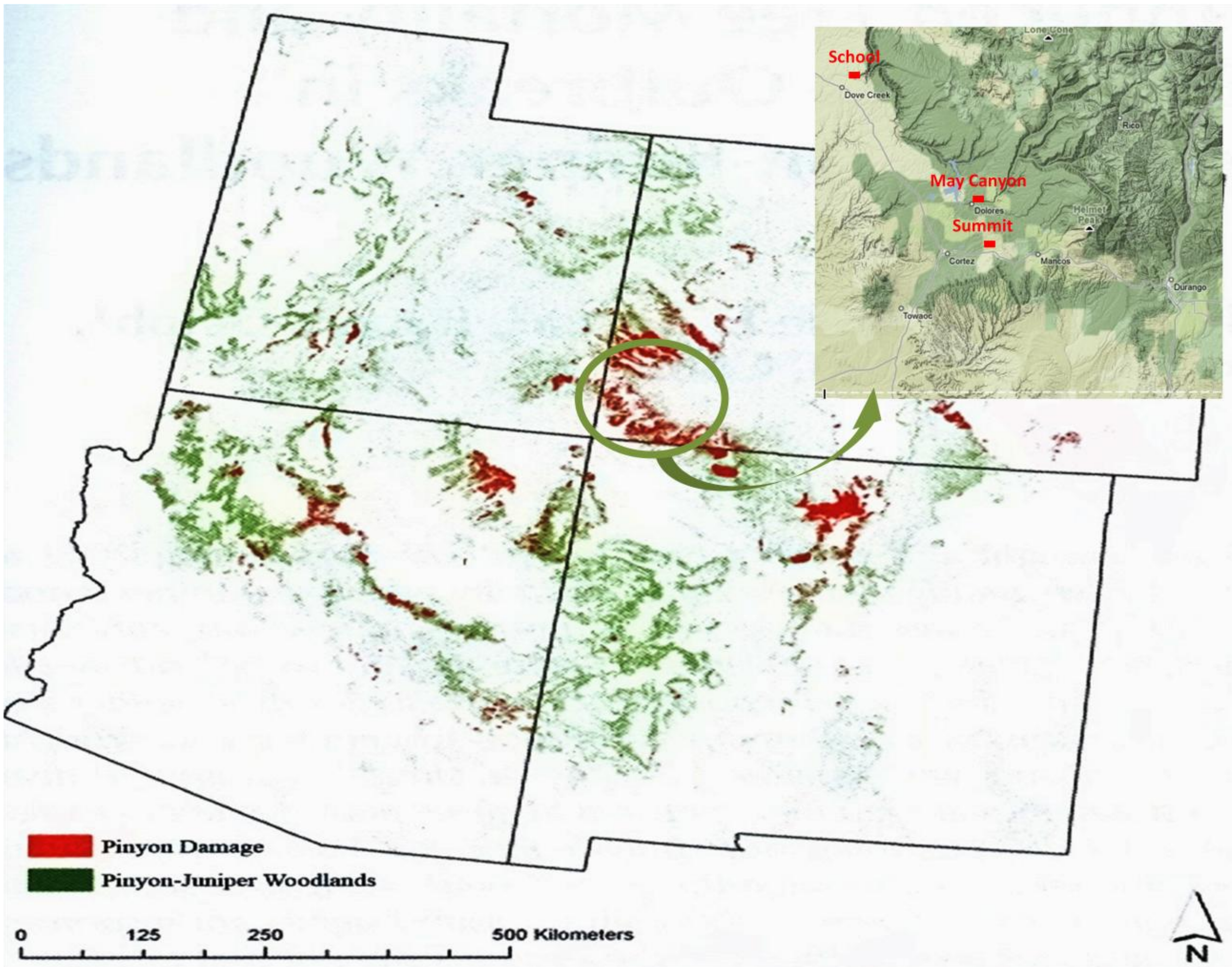

Figure 2. Regional pinyon mortality (2000-2005; Forest Health Protection, USFS, USDA). Inset shows the location of the three study sites in southwest Colorado.

Three 10.5-ha square plots were established in each treatment area. Each plot contained 36 randomly located sampling points. Points were located by GPS, then marked using a spike with a steel washer attached driven to ground level. One of the three treatments-mastication, thinning-piling-burning, or control was randomly assigned to each plot, totaling to nine treatment plots. Pre-treatment sampling of overstory and understory vegetation, dead and down woody material, and soils was conducted in the fall of 2005 just prior to treatments being applied. Post- treatment measurements of overstory, tree regeneration, and dead and down material were made in 2006 and 2007, with understory vegetation and soils were being conducted in 2006, 2007, and 2008. Available mineral soil nitrogen (N) was measured on a continuous basis post-treatment for the complete study, with replacement probes being swapped in July and November of each year.

The San Juan National Forest and the Dolores Service Center prepared and administered the contracts and treatments. Mastication was accomplished using a large hydraulic lawnmower mounted on a rubber tired front-end loader (Figure 1). Mowing was conducted in the fall and winter of 2005-2006 while *Ips* activity is low to avoid further attraction to the sites. Our plots are nested within the greater scheduled mastication areas. The general mastication guidelines were to: create a random mosaic of small openings and strips 0.5 to 3.0 acres in size; reduce density of trees 2.5 to 25 cm d.b.h.; treat 80% of the woody material so that it is less than 2.5 cm in diameter and 15 cm long; cut 50% of the brush canopy, and protect live pinyon trees and designated snags.

The thinning-piling treatments were conducted under contract with a private company. The thinning guidelines were: thin between 40 to 60% of the canopy cover; target dead pinyon and dense pockets of live trees; leave good trees greater than 20 cm d.b.h. and good saplings; leave tree clumps of 0.10 to 0.80 ha in size; cut 50% of the brush canopy. The the piles were covered with kraft paper and burned in early 2006. The thinning treatment cost was $2,500 to $5,000 per ha relative to $920 per ha for mastication.

The overstory was measured to determine pre- and post-treatment conditions using 0.02 ha fixed circular plots. Overstory measurements include species, diameter at root collar, insect or disease conditions, and plant condition (including mortality). A subset of the trees on a plot also was measured for height and crown diameter. All standing recently dead trees were measured for d.r.c. A subset of dead trees, which still exhibited full crown characteristics, was measured. Height-diameter regressions were developed and tree volumes calculated using equations developed by Chojnacky (1985).

Dead and down material was measured using a modified Brown's Technique (Brown 1974) with a 15-m tape centered on the plot center point. It was difficult to reestablish the exact centers for every plots after treatment. New point centers were re-established, yet a shift of 15 cm could produce a different plot. The 2005 and the subsequent inventories should be viewed as independent samples, not as repeat samples. The Brown transects were reoriented in following surveys, even in the controls, because of disturbances to the original line locations.

The herbaceous community and ground cover were measured at every other plot (18 out of 36 plots per treatment) using Rooted Nested Frequency (RNF) frames 50 cm x 50 cm along a 30.5 m transect. One RNF frame was measured every 3 m, starting at 1.5 m, for a total of five frames. Only species rooted within the frame were recorded.

Shrub composition and canopy cover were measured at every other plot where herbaceous community was measured (9 plots per treatment) using the line intercept method. Shrubs also were measured along the entire length of the 30.5 m transect where RNF data was recorded. Shrubs were recorded by three classes: dead (the entire shrub is dead), live (any part of the shrub is live), and dead within live (there is a major dead branch or section within a live shrub).

Information on the RNF protocol, including rules for describing ground cover, is described in the Nested Frequency Methodology Technical Guide on the NRIS-TERRA website under Rangeland Protocols at: www.fsweb.sandy.wo.fs.fed.us/terra/national_protocol_teams/index.shtml . This web site also contains information on the Line Intercept Protocol that can be found in the Line Intercept Technical Guide. Both protocols also are described in USDA Forest Service, Region 2 Rangeland Monitoring and Analysis Handbook (USDA Forest Service 1996).

Surface organic horizon and mineral soil samples (0-5 cm and 5-15 cm depth) were collected and measured for total mass, C, and N. Total C and N were determined by thermal conductivity detection after combustion at temperatures up to 1200^{o}C on a commercially available elemental analyzer (ThermoQuest EA Flash 1112, Milan, Italy). Soil pH measurements were made with a combination pH electrode using a 1:1 soil: water slurry (McLean 1982).

In-situ available nitrogen (N) was collected within a 1-m zone surrounding the perimeter of the vegetation plot by utilizing Plant Root Simulators (http://www.westernag.ca/innov/) post-treatment. In-situ probes were exchanged twice a year to provide a continuous index of available N mineralized within each treatment. After collection, these probes were returned to the Flagstaff laboratory, processed, and sent to WesternAg Laboratories, Inc. to be analyzed for ammonium and nitrate following extraction with 2M KCl.

Mineral soil samples (0-5 cm) for soil microbial structural assessments (PLFA) were collected at the same location as the PRS probes, then composited by transect. All cell membranes contain phospholipid fatty acids (PLFA). These molecules can serve as general, as well as specific, biomarkers for different taxonomic groups; such as fungi, actinobacter, gram-negative and gram-positive bacteria. PLFA profiles have been shown to be an effective method for distinguishing microbial communities from soil that differ in management practices (Klug and Tiedje 1993). We used multivariate methods (multi-response permutation procedure) to assess treatment effects on microbial community structure as well as other statistical approaches (Biondi et al., 1988; McCune and Grace, 2002).

IV. Key Findings

Overstory

An average of 90% of the pinyon trees at the School Site were alive, while only 41% of the pinyon trees at Summit. The May Canyon Site was intermediate with 66% alive. Junipers were more common at Summit making up an average of 32% of the overstory and least common at School with 17% of the stand density. The stand measurements indicate that May Canyon represented a middle position between the other two sites. Almost twice as much basal area and three times as much volume were removed by thinning relative to mastication. Sixty-one percent of the plots at School, the flattest area with slopes of 3 to 4%, were at least 50% masticated. The number dropped to 42% at Summit and 31% at May Canyon, with more than 40% of the plots at Summit and May Canyon either not treated or lightly treated.

An objective following treatments was to maintain tree cover. To maintain tree cover regeneration would be crucial. The number of pinyon and juniper trees varied from 492 trees per ha at the School mastication plot to 1,221 trees per ha in the May Canyon thinning plot. Authorities vary on what is adequate regeneration for pinyon-juniper woodlands, but a value of 494 trees per ha is often suggested. If that value is accepted, all nine site-treatment combinations contain adequate regeneration.

Understory Vegetation and Shrubs

Neither mastication nor thinning-piling-burning altered the community of herbaceous plants significantly, but of concern was a significant increase in musk thistle and cheatgrass with thinning and burning. These non-natives are nitrophilic, so we see considerable density increases around the edge of the pile burns due to ammonium deposition following prescribed burning. Tree cover was significantly decreased by hand thinning and burning, while mastication reduced live shrub and tree cover but not significantly. Mastication appears to be more effective at reducing shrub cover than hand thinning. Gambel oak, a sprouter, has almost regained pre-treatment levels of cover, while Utah Serviceberry has remained similar to the initial reduction following treatments. At issue with respect to shrub cover is shading and competition for resources by Gambel oak and the affect it may have on pinyon regeneration and vigor of the seedlings.

Dead and Down Analyses

Woody fuel loading in megagrams per ha fluctuated throughout the three years. Initial values were very large at Summit which had the highest stand density, greatest amount of *Ips* mortality and a relatively large number of old and declining juniper trees. The values for all three plots at Summit exceeds an average value of about 11.4 ± 7.4 megagrams per ha measured in eight similar stands along the New Mexico-Colorado border (Ottmar et al. 2000). These authors reported a range of from 9.0 to 42.1 megagrams per ha. The controls and thinning-piling-burning plots on all three sites indicate a decline between 2005 and 2006 and then a slight increase between 2006 and 2007. The mastication plots indicate, with the exception of Summit, an increase over time. Increases in 2007 are related to dead pinyon trees continuing to fall. In general, the amount of fuel in the 7.6 cm and larger class declined while the amounts in the smaller classes increased.

Soils

Available N mineralized over the three years of post-treatment was not statistically significant, even though there is a trend toward lower N supply rates with mastication. Surface organic horizon C:N ratios significantly increased over time with mastication, but not in the mineral soil. Cooperators at two of our sites have also shown very low decomposition rates of the masticated material, especially when compared with other ecosystems such as ponderosa pine and lodgepole pine (Mike Battaglia, RMRS, USFS, Ft. Collins, CO; personal communications). We hope to address these issues in the future with continued monitoring and additional research that specifically focuses on these issues.

Microbial populations were sensitive to treatments, both mastication and thinning-piling-burning. A useful indicator of microbial structural changes in soil is the ratio of fungi to bacteria (Bardgett et al. 1996; Grayston and Prescott 2005). Altered fungal to bacterial ratios are indicative of changes in organic matter inputs. Fungi are favored with organic matter inputs of greater C:N ratios. This differed from our anticipated results as F:B ratios decreased with mastication. We utilized specific biomarkers for fungi, gram-positive bacteria, gram-negative bacteria, and actinobacter to determine which group was driving the change in F:B ratios. Both gram-negative and gram-positive bacteria increased in the masticated plots relative to controls, while fungi and actinobacter were not significantly altered by treatments. Utilizing some of the soil physical measures from a companion study (Mike Battaglia, RMRS, USFS, Ft. Collins, CO; personal communications), provided clues to why the bacteria increased under mastication. Soil temperatures were cooler during the summer, warmer during the winter, and soil moisture was higher during the summer with mastication, Our anticipation originally was that the wide C:N ratios of the masticated surface material would favor fungi, which in turn would draw on the total N pool in the surface mineral soil to assist with decomposition of this surface organic material. Two issues did not go as anticipated, first decomposition of this surface material was almost non-existent as fungi did not appear to be able to utilize this material, and second the total N pool in the surface mineral soil was unaffected.

V. Management Implications

- Mastication provides a effective low-cost, low-risk alternative for fuel treatments in pinyon-juniper woodlands.
- Mastication does not negatively impact the short-term regeneration of pinyon and juniper.

- Shrub cover can be significantly reduced by mastication in the short-term, yet recovery by sprouting shrubs can be quit fast and may negatively impact tree regeneration in the long-term.
- Mastication favors stoloniferous plants, such as Canadian thistle, while thinning-piling-burning strongly favors cheatgrass and musk thistle. When non-native invasive plants are present prior to fuels treatment, mitigating the potential increase prior to treatment is preferable.
- Slow decomposition of masticated residues and increasing C:N ratios of these residues poses the potential to reduce nitrogen mineralization or begin to immobilize nitrogen in the mineral soil over the long-term.
- Bacteria are favored under masticated material due to attenuation of soil temperature and moisture extremes. Fungi are needed for decomposition of recalcitrant organic residues, yet it appears their potential to respond to additional inputs with wide C:N ratios is limited in pinyon-juniper woodlands.

VI. Relationship to Other Recent Findings and Ongoing Work on this Topic

The mortality created by drought and *Ips* outbreak created wildfire conditions in pinyon-juniper woodlands that previously were of little concern to fire management. The literature on pinyon-juniper management concentrates on hand thinning using different silivicultural prescriptions to alter stand densities primarily for improved livestock grazing, yet none that address mastication as an alternative for either fuel or stand reductions. Residue management following hand thinning has been to pile and burn or to lop and scatter. Our aim was to contrast the typical pile and burn technique to mastication. As with other studies, our findings suggest that there may be some long-term effects that require further monitoring, but that tree regeneration appears to be adequate to create fully stocked woodlands.

As with our project a major concern has been the increase in invasive species. Other research has looked at invasive species increases due to degradation of pinyon-juniper woodlands from overgrazing by domestic livestock or following stand reductions by hand thinning. We contrasted the differences between the typical mechanical treatment (hand thinning) to mastication. Our results show that there is an increase in frequency of invasives following mastication, but not to the extent seen with thinning-piling and burning. Mastication also favors stoloniferous and sprouting plants compared to plant that disperse large quantity of seeds, such as cheatgrass and musk thistle.

Fuels managers are concerned with the residues left following mastication. Our values were higher that recorded in other studies, but are of a different nature. Mastication creates a fuelbeds of higher densities than typically seen and with much smaller fuel size classifications. These are outside the parameters that currently exist in fuel management models.

Previous research on microbial populations have shown increased fungal to bacterial ratios with increasing recalcitrant surface organic residues (wider C:N ratios), yet we did not find this to be the case in our study. Masticated materials altered physical parameters in the mineral soil to favor increased bacterial populations, by why fungi did not increase needs further investigation. This change in microbial populations did not alter N availability, yet the pattern with time suggests that over time immobilization may begin to reduce N availability.

VII. Future Work Needed

- Continued monitoring of tree regeneration and spatial qualities of stand regeneration to determine long-term outcome following mastication.
- Continued monitoring to determine if surface organic matter C:N ratios widen even further and the implications for decomposition of this surface mastication residue. Alter size of masticated organic residues in an in-situ decomposition analysis.
- Determine if short-term increases in bacterial communities in the mineral soil will alter nutrient availability for plants.
- Implement a prescribed burn into the masticated areas to determine fire behavior of these treated areas. Monitor ecosystem processes (decomposition, N mineralization, etc.) post-fire.
- Study alternative invasive plant mitigation treatments that can be used prior to site mastication to reduce the increase in non-native plants following fuels treatments.

VIII. Deliverables Crosswalk

Proposed	**Delivered**	**Status**
Regional Workshops with NF, NP, and BLM personnel	1) First year post-treatment field trip, status of research results. 2) Technology transfer of knowledge gained from mastication study. PI's presented talks and invited additional speakers with expertise in cheatgrass control and mycorrhizal surveys.	Completed Sept. 2006 Completed Sept. 24, 2009
Presentations	Three oral presentations, one poster present at professional society symposia. See citation database.	Completed
Referred and tech transfer publications of study results	Three manuscripts in preparation. See citation database.	In progress (Will post completed manuscripts on JFSP website).

IX. Literature cited

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X. Additional Reporting (Appendices and othe inputs to JFSP)

A. Input into Findings Database (available from www.firescience.gov)
B. Digital Photo Library (JFSP database, www.firescience.gov)
C. Completed Deliverables (JFSP citation database, www.firescience.gov)

Final Report

Gottfried, G.J., and Overby, S.T. 2009. Effects of fuel/fire risk reduction treatments using hydro-mow or thinning on pinyon-juniper ecosystem components within the wildland-urban interface. Final Project Report (Project # 05-2-1-98). November 20, 2009. Flagstaff, AZ.

Knowledge Transfer Workshops and Advisory Meetings

Gottfried, G. J.; Overby, S. T. 2009. Overstory and fuel loading changes following mastication or thinning of southwestern pinyon-juniper stands. Workshop with land managers from the southwestern Colorado region. September 28, 2009. Dolores, CO.

Overby, S.T.; Gottfried, G.J. 2009. Soil, understory and shrub responses to fuel reduction treatments in pinyon-juniper woodlands of southwest Colorado. Workshop with land managers from the southwestern Colorado region. September 28, 2009. Dolores, CO.

Professional Presentations (oral)

Gottfried, G, J.; Overby, S. T. 2009. Overstory and fuel loading changes following mechanical mastication or thinning of southwestern pinyon-juniper stands. Seventh North American Forest Ecology Workshop 2009. Logan, UT: 25.

Overby, S.T.; Gottfried, G. J. 2009. Does mastication residue alter soil nitrogen dynamics in woodlands of southwest Colorado? Seventh North American Forest Ecology Workshop 2009. Logan, UT: 44.

Overby, S.T.; Gottfried, G.J. 2009. Soil nitrogen and microbial responses to fuel reduction treatments in pinyon-juniper woodlands of southwestern Colorado. Annual Soil Science Society of America Proceedings. 2009 November 1-4. Pittsburgh, PA.

Professional Presentations (poster)

Gottfried, G, J.; Overby, S. T. 2009. Overstory, fuel loading, and soil nitrogen changes following mechanical mastication or thinning pinyon-juniper stands in southwestern Colorado. Association for Fire Ecology Congress; Savannah, Georgia. December, 2009.

Manuscripts in progress:

Nitrogen and soil microbial dynamics following fuel reduction treatments in Pinyon-Juniper ecosystems. Submission to Soil Science Society of America Journal.

Herbaceous and shrub response to fuel reduction treatments in southwest Colorado Pinyon-Juniper ecosystems. Submission to Rangeland Ecology and Management.

Changes in pinyon-juniper stand and fuel loading characteristics following mastication or thinning. Submission to the Western Journal of Applied Forestry.