Restoring Conservancy Lands Following the Angora Fire – a Preliminary Assessment

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January 2012

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Acknowledgements

This report is a collaborative effort between the California Tahoe Conservancy and the University of California Cooperative Extension, and was made possible only through the assistance of many willing cooperators. The post-fire treatments were coordinated by Christy Daugherty, CalFIRE Registered Professional Forester (retired), with field work by the California Conservation Corps. The United States Army Corps of Engineers provided funding for restoration and monitoring. Individual Conservancy Staff were critical to the effort, especially Judy Clot - Associate Environmental Planner, who orchestrated post-fire treatments and aided in early monitoring efforts; Tina Carlsen - Natural Resources Program Manager who assisted with data analysis and interpretation; Scott Carroll - Associate Environmental Planner, who headed up stream profile monitoring; Adam Lewandowski - Associate Environmental Planner, who coordinated invasive weed monitoring; and the Tahoe Resource Conservation District Forest Habitat Enhancement crew, which built monitoring silt fence structures. University of California Cooperative Extension specialists Gary Nakamura - Area Forestry Specialist (retired) and Richard Harris – Extension Forestry Specialist, provided critical insight on monitoring goals and methods. Mike De Lasaux - Natural Resources Advisor, provided help in the field. David Fournier, Assistant Vegetation Management Officer with the USDA Forest Service Lake Tahoe Basin Management Unit, was critical to coordination with Forest Service partners throughout the permitting process.

Executive Summary

This report presents preliminary monitoring results for restoration activities conducted by the California Tahoe Conservancy (Conservancy) after the June 2007 Angora Fire near South Lake Tahoe, California. Of the 90 acres owned by the Conservancy in the burn area, 40 were in larger parcels that experienced high intensity fire in which nearly 100% of trees were killed. Conservancy goals for these areas, including the 30-acre Mule Deer and the 10 acre Expressway parcels, were to re-establish a native forest quickly and to reduce hazards posed by dead trees and fuel accumulation

These areas were treated with an "active" restoration approach involving removal of dead trees. Large dead trees, over ten inches in diameter, were cut and skidded to a landing where they were processed, loaded on log trucks, and sent to a nearby mill. Small trees were masticated (ground up) and left on site to control erosion and to suppress competing vegetation. Additional measures were installed to minimize the risk of soil erosion and sedimentation to Lake Tahoe. After mastication was completed, one to two year-old tree seedlings were planted.

Monitoring reported on here evaluates the effectiveness of this approach in the severely-burned areas of the Angora fire. Areas treated with the active approach are compared with adjacent USDA Forest Service (Forest Service) land not treated during the duration of this monitoring effort.

Conclusions

We conclude that the "active" restoration approach used by the Conservancy was effective at reaching the goals of re-establishing a native forest while minimizing water quality impacts and fire risk. Planted seedlings are growing quickly and becoming young trees. We estimate that this approach will expedite the return to a forested condition in the area by about 60 years. In the adjacent untreated area, the few naturally sprouting tree seedlings are unlikely to thrive due to competition from vigorously growing brush.

We also found that tree removal using heavy equipment did not compact the soil and that erosion control measures were effective, although the mild winter experienced immediately after the fire was critical in reducing soil erosion risk.

The woody mulch left on site was effective at suppressing brush and minimizing soil erosion that could impair Lake Tahoe's clarity. However, it forms a layer of surface fuel that carries some fire risk. The relative fire risk posed by the woody mulch as compared to the risk from rapidly growing brush and falling dead trees on the untreated site is difficult to assess. We hope to learn more about the effects of tree removal and mulching through additional monitoring of fuel, vegetation, and seedling data in the future.

Methodology

Data was collected immediately after the Angora Fire on Conservancy land and on nearby Forest Service land using the Before-After-Control-Impact approach. Monitored Conservancy lands were treated while Forest Service lands were used as untreated control areas. The majority of data collection took place within permanent forest inventory plots. Pre-treatment data collection occurred on all plots in summer and fall 2007. Timing of post-treatment data collection differed according to parameter but continued from 2008 to 2010. This report summarizes the data and analysis conducted through 2010, with the exception of seedling data collected in 2011. Treatment occurred on Forest Service lands in 2011, but comparing current conditions is beyond the scope of this project. The report provides evaluation of treatment success in the first three to four years post-fire.

Key Findings

Forest Stand Development: A new forest has been established on Conservancy lands with about 130 planted tree seedlings per acre.

- Very few mature trees survived the fire in the studied area and so there is little natural tree seed source remaining. No naturally-occurring seedlings were found on monitoring plots in treated and untreated areas.
- Based on data and observations of other burned areas in similar forest types, we estimate that the treatment accelerated the development of a new forest by about 60 years.

Native Vegetation Recovery: Growth of native vegetation including brush and herbaceous species was greater in untreated areas than in the treated area. This appears to be a result of leaving wood mulch on the treated area to suppress brush and favor conifers. At least 55% of the ground area was covered by vegetation by 2010 where no treatment was done, while only 30% of the treated area was covered.

- Greater cover in the untreated area is accounted for by a small number of brush species, which out-compete most tree seedlings and so inhibit re-establishment of a forest stand.
- Lesser brush cover in the treated area has allowed a greater total number of native species to return (22) compared with the untreated site (18).

Invasive Weeds*:* Invasive species took advantage of post-fire conditions to spread in the Angora burn area.

- Invasive species found in the treated area include ox-eyed daisy (*Chrysanthemum leucanthemum*), yellow toadflax (*Linaria vulgaris*), Dalmation toadflax (*Linaria genistifolia ssp. Dalmatica*), perennial pepperweed (*Lepidium latifolium*), and yellow starthistle (*Centaurea solstitialis*).
- Aggressive detection and treatment appears to have curbed weed growth, with the notable exception of Bull thistle, which has spread widely in the burn area.
- Comparison of weed spread in treated versus untreated areas was outside the scope of this project.

Soil Quality and Erosion*:* Erosion control measures taken to avoid movement of soil off the treated Conservancy site appear to have been effective, although the occurrence of two mild winters after the fire means these measures were not tested by any severe precipitation event.

- The small, intermittent channel on site has remained stable and supports vigorous vegetation growth, suggesting it will remain stable in the near future.
- Monitoring silt fences erected within the channel collected half a ton of sediment the first winter and another third of a ton the second winter. This leads to a total sediment yield of less than 0.02 tons per acre for the first two years. This is drastically lower than for other post-fire erosion studies we are aware of.
- Comparison of sediment yield in treated versus untreated areas was outside the scope of this project.
- No detectable increase in soil compaction was created by tree harvesting operations. Monitoring showed no apparent effect on soil strength on the treatment site.

Fuels and Fire Hazard: Although the masticated material left on site was effective at minimizing soil erosion and suppressing brush competing for growing space with conifer seedlings, it does form a layer of surface fuel that carries some level of wildfire risk.

- Mastication more than tripled the amount of woody mulch material on the treated site. Fuel totaled 86 tons per acre in the treated area, nearly nine times greater than on the untreated site. Of this, 35 tons per acre are in the smallest, most ignitable size.
- Though the fire risk cannot be calculated at this time as computer models do not accurately predict wildfire behavior in masticated fuels, it is generally accepted that masticated fuels burn with lower flame lengths than natural fuels and are more difficult to ignite because compaction impedes the fire's access to oxygen.
- Wildfire risk is becoming significant on the untreated site, where abundant brush and falling dead trees create an increasingly large fuel load. It is unclear how this risk compares to that on the treated site presently, but it is clear that the risk will increase on the untreated site while it decreases on the treated site.

Introduction

This report presents preliminary monitoring results for restoration activities conducted by the California Tahoe Conservancy (Conservancy) after the June 2007 Angora Fire. The fire burned 3,100 acres in and near South Lake Tahoe, California including 177 Conservancy-owned urban parcels, totaling 90 acres (*Figure 1*).

Figure 1. Conservancy-owned parcel where the Angora fire caused 100% tree mortality, August 2007.

The California Tahoe Conservancy is an independent State agency established to develop and implement programs through acquisitions and environmental improvement projects to improve water quality in Lake Tahoe, preserve and enhance the scenic beauty and recreational opportunities of the region, provide public access, preserve wildlife habitat areas, and manage and restore lands to protect the natural environment.

Of the 3,100 acres burned by the Angora Fire, 34% burned with high severity and 42% burned with moderate severity (Weaver et al 2007). Mapping conducted by the US Forest Service Burned Area Emergency Response (BAER) team immediately following the fire is displayed in Figure 2. Following containment of the Angora Fire, the Conservancy deployed resource assessment teams for a rapid, initial analysis of post-fire conditions on Conservancy properties. The Conservancy burn severity assessment is displayed in Figure 3. Restoration goals developed based on this information prioritized removal of dead, dying and hazardous trees and installation of erosion control measures. This approach was driven, in part, by the location of the Conservancy's parcels. Dead falling trees were a major concern within the residential neighborhood, as they could be dangerous to residents rebuilding homes and would create a fire hazard. Also, these parcels are located within the drainage of Angora Creek, a tributary of the Upper Truckee River that flows into Lake Tahoe. The lake is a water resource of international stature famed for its clarity and many local efforts are focused on reducing and preventing sediment transport to Lake Tahoe.

Treatments were intended to establish a native conifer forest as quickly as possible, reduce hazards posed by dead trees falling, and reduce the risk of soil compaction, soil erosion, and sedimentation to Lake Tahoe. An emergency contract was put into place with Sierra Pacific Industries for salvage harvest operations on the Conservancy's two larger ownerships and designated urban lots within the burn area. Approximately 1.2 million board feet of timber was removed from the site and sent to Sierra Pacific Industries' mill in Camino (see Figure 4 and

Figure 5). Un-merchantable material was masticated (see Figure 5) and left on site to provide cover of exposed soil to reduce erosion. Revenue generated from tree removal was used to offset the cost of mastication and erosion control treatments. Tree removal was completed by October 2007.

This monitoring project was developed to track the effectiveness of the treatments described. It was designed in a short time frame since initial treatments began within two months of the fire. Extension specialists from the University of California were crucial to the design, as were University of California faculty and Pacific Southwest Research Station scientists consulted on methods. Monitoring was carried out by staff from the California Tahoe Conservancy and University of California Cooperative Extension.

Monitoring methods used in this analysis are detailed in the *Angora Fire Restoration Monitoring Protocol for the California Tahoe Conservancy* (Wade and Kocher 2011). This monitoring protocol was developed and implemented beginning in August 2007 and was revised as necessary. The protocol includes details about study design and data collection methods used to determine effectiveness of treatments.

This report presents preliminary answers to monitoring questions proposed at the beginning of the effort. Data and analysis described here pertain mostly to the Conservancy's Mule Deer parcel, a 30 acre area that was burned severely with nearly 100% tree mortality. We expect that some of the initial answers to monitoring questions may change as time passes and the burned area evolves and re-vegetates.

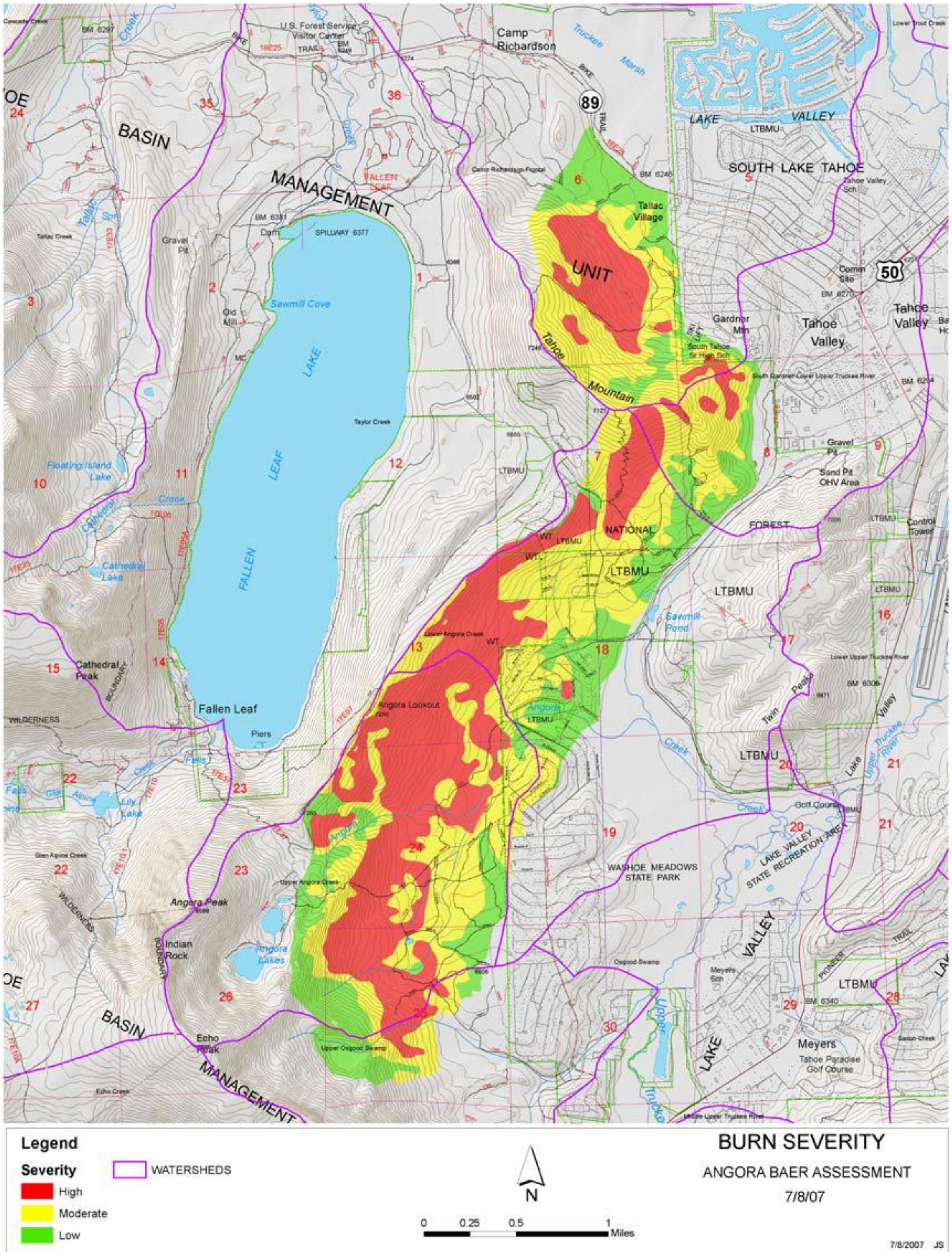

Figure 2. Map of burn severity as assessed by the Forest Service BAER team, July 2007.

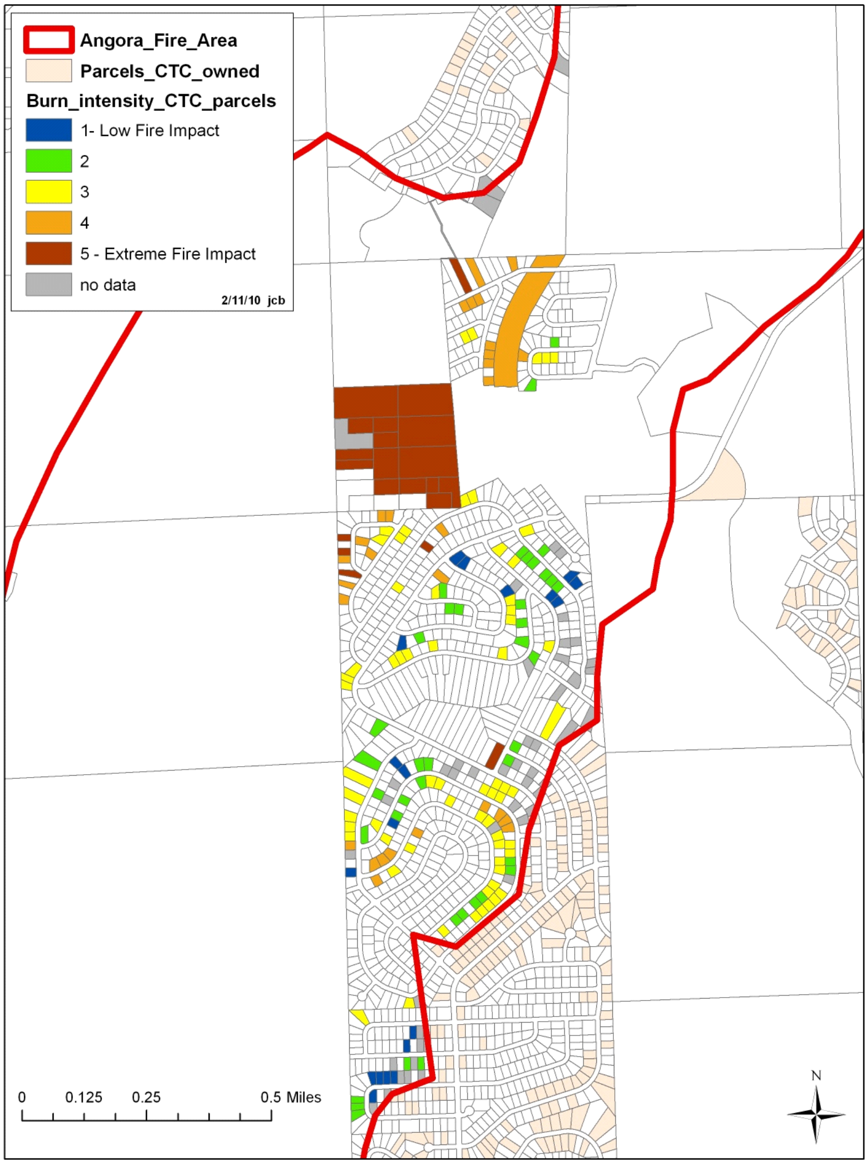

Figure 3. Severity of burn effects on Conservancy parcels by the Angora Fire, June 2007.

Figure 4. Fire-killed trees were skidded to a landing and taken to a lumber mill by Sierra Pacific Industries, September 2007.

Figure 5. Limbs and small trees (10 inches in diameter and smaller) were masticated and left on site.

Study Design, Monitoring Questions and Effectiveness Criteria

The general study design used for this monitoring effort is a Before-After-Control-Impact approach (Stewart-Oaten et al. 1986, Smith 1998). The exception was for channel monitoring, where there was no control channel available for comparison to the channel in the treated area. Data collected immediately after the Angora Fire in Summer and Fall 2007 constitutes the pre-treatment data set. Post-treatment data was collected at different times depending on the type of treatment and parameter measured. In most cases, control areas were also sampled during the same time intervals. Data collection has been focused on 39 permanent forest inventory plots installed across Conservancy properties (Figure 6). Plots were established to capture the range of vegetation types in the burned area (lodgepole pine, Jeffrey pine, and mixed conifer) and burn severity (severe, moderate, and light to unburned). Seven plots were established on the severely-burned, 30-acre Mule Deer parcel. 10 plots were established on the 10-acre, moderate-severely burned Expressway parcel. Seven plots were established on smaller lots within the neighborhood, which burned with varying severity. In addition, 12 control plots were established on nearby Forest Service lands where no treatments occurred until late 2011. Figure 7 displays the inventory plot layout. Plots included in this analysis are the Mule Deer plots, the Expressway plots, and a selection of the 12 control plots on Forest Service property.

The goal of the monitoring effort is to assess the effectiveness of the Conservancy post-fire restoration approach including reforestation, erosion control and the avoidance of impacts to soil from the tree removal process. Specific monitoring questions, parameters measured, timing, effectiveness criteria and field methods are summarized in Table 1. Additional monitoring to determine how post-fire restoration treatments affected wildlife populations was conducted by Dr. Pat Manley, Forest Service Pacific Southwest Research Station, and was reported on separately (Manley 2008).

Figure 6. Location of monitoring plots on Conservancy and Forest Service land.

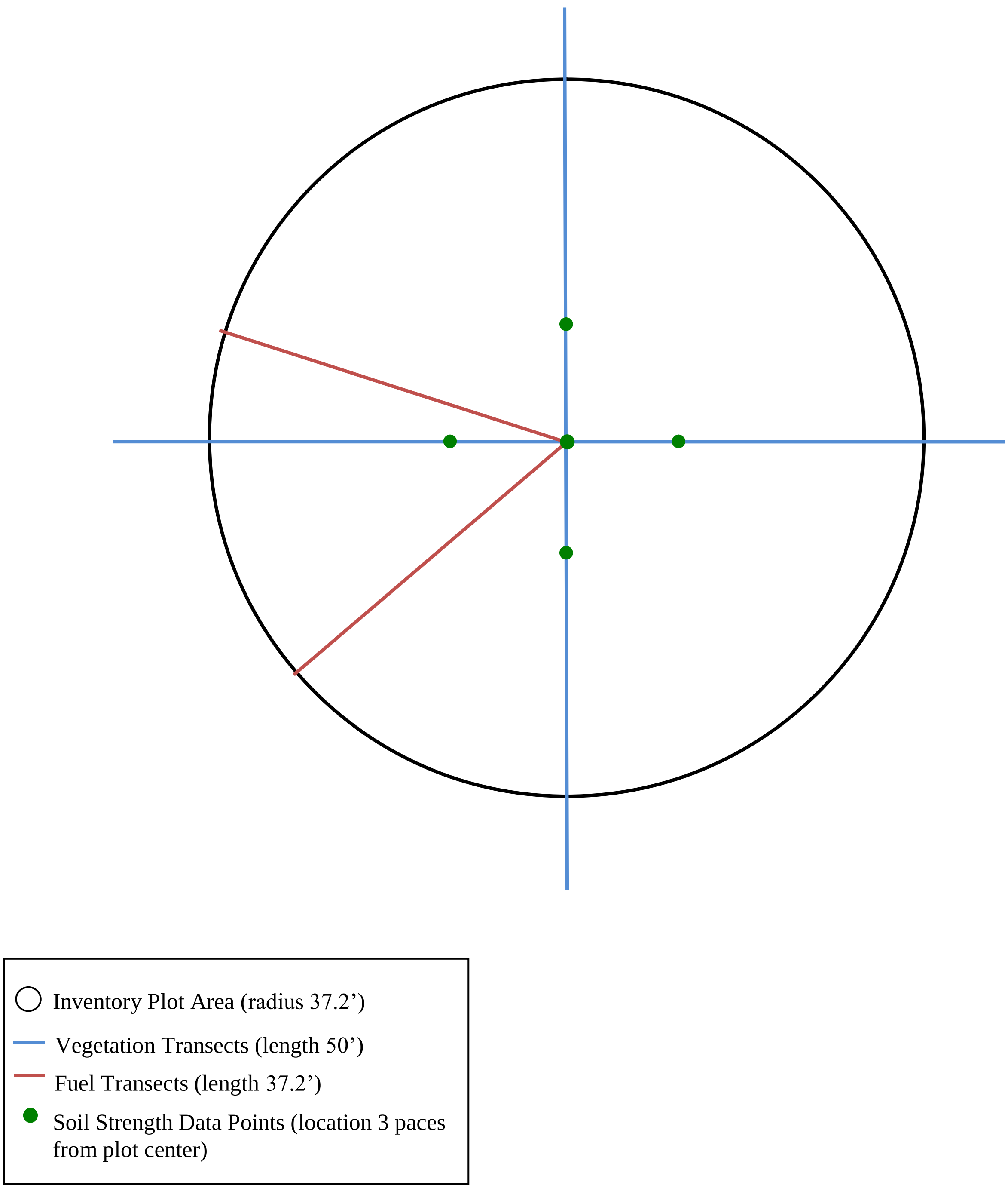

Figure 7. Location of monitoring transects and points within forest inventory plots.

Table 1. Summary of Monitoring Methods

Monitoring Question	Parameters	Timing	Effectiveness Criteria	Field Methods
Did treatments accelerate forest stand development?	Number and size of trees	Pre-treatment, immediately post treatment, every five years thereafter - 2007, 2008, 2009, 2010	More rapid modeled and observed recovery of forest conditions	Inventory plots and seedling surveys
Did planted seedlings survive at an acceptable rate?	Percent survival	Fall 2008 (following fall 2007 and spring 2008 planting) spring 2010	80% survival of planted seedlings	Seedling surveys
Did tree removal and mastication promote desired species?	Native species richness, cover by nativity and life form	Late summer for three years - 2008, 2009, 2010	Increased native species richness and reduced brush cover on treated sites	Cover/frequency transects
Did application of native seed mix promote increased cover of native species and higher native species richness in the burned area?	Native species richness, cover by nativity and life form	Late summer for three years – 2008, 2009, 2010	Greater % cover and number of native species where seeded compared to not seeded	Cover/frequency transects
Were invasive species populations promoted by the fire?	Incidence and cover of invasive species	Annually following the fire as funding allows – 2008, 2009, 2010	Identification and treatment of invasive species in the fire area	Weed surveys and treatments
Did treatments reduce ground fuels accumulation and associated fire risk on forested parcels?	Tons per acre of fuel by size class, predicted potential fire behavior	Pre-treatment, immediately post treatment, every five years thereafter – 2007, 2008, and 2009	Fuels will be reduced by treatments and treated areas will have lower modeled potential flame lengths and rate of spread than untreated areas	Line intercept transects, hybrid fuel method used where fuels are masticated
Did post fire salvage logging impact soil quality?	Soil strength	Pre-treatment, immediately post-treatment, spring and fall through 2009	No significant increase in soil strength on treated parcels compared with control	Cone penetrometer sampling and measurement of soil moisture
Did erosion control practices minimize soil erosion from burned areas?	Channel profile, soil volume leaving site	Immediately post-treatment and post-winter season for 2 years – 2008 and 2009	Lower captured sediment volume over predicted (no control available), unmitigated sediment flux following fire, no significant change in channel profile	Channel longitudinal profile, monitoring silt fences

DATA AND RESULTS

FOREST STAND DEVELOPMENT

Tree Establishment

Monitoring Question: Did post fire treatments accelerate forest stand development?

Effectiveness Criteria: The treated area will recover a forested condition more rapidly than untreated (control) areas based on observations and modeling results.

Treatment and Background: Tree removal and mastication eliminated most of the standing dead trees on the Mule Deer parcel, leaving an average of six snags per acre for wildlife habitat. Most trees were felled by hand and skidded to landings for removal from the site. A masticator was used to grind up smaller trees and logging slash. Jeffrey pine (*Pinus jeffreyi*), sugar pine (*Pinus lambertiana*), and incense cedar (*Calocedrus decurrens*) seedlings were planted on the Mule Deer parcel in 2007, 2008 and 2010. As of 2010, no trees had been removed from the Forest Service control plots. No seedlings had been planted on Forest Service control plots by 2010. No naturally occurring seedlings were found in treatment or control plots.

Monitoring Methods:

Tree Data

Measurements including height, diameter, health status, and live crown ratio were collected on all standing trees within the forest inventory plots. The detailed method is described in Wade and Kocher (2011). Analysis presented here includes data from seven treated plots on the Conservancy Mule Deer parcel, and nine on the untreated Forest Service parcel, all severely burned. Plots were installed and measured before treatments occurred in August 2007. A first round of post-treatment data collection began in late Summer 2007 and continued through Summer 2008. In 2009 and 2010, plots were re-visited to record any newly fallen snags and natural seedling regeneration. If resources are available, tree data will be continually collected over time, and the effectiveness of the treatment in restoring a forested condition will be assessed compared with the untreated site.

Seedling Surveys

Seedling surveys were used to determine the need for continued planting and to more accurately predict forest stand development. Seedlings were surveyed across the Mule Deer parcel in the Fall of 2008 and 2010. Surveys from 2008 provided survival data, as only one planting had been performed at that point and dead seedlings were still visible. Seedling survival surveys were not conducted on the control site because no seedlings were planted and no naturally-occurring seedlings were observed there. For information on the sampling design and field method used, see Wade and Kocher (2011).

Modeling

Forest development must be tracked over many years in order to assess the true effectiveness of treatments. In the meantime, computerized forest growth modeling can be used to make predictions about future stand development. Forest Vegetation Simulator (FVS) is a computer model which uses tree and seedling data and user-input management actions to project growth and decay of trees and snags at user-specified intervals into the future. Natural regeneration must be input by the user. Shrub presence and growth is not simulated by the model, so the user must take expected shrub presence into account when estimating establishment and growth of seedlings, both planted and natural.

Forest development was modeled for both the treated and untreated parcels. Inputs to the model representing predicted future stand development in the burn area are summarized in Table 2. For the treated parcel, inputs were based on post-treatment tree data, planted seedling information based on surveys, and the expected timing, abundance, and composition of natural seedling regeneration. To represent actual stand conditions as best as possible, we told the model to plant 130 seedlings per acre in 2012, based upon 2012 seedling stocking surveys. Survival estimates for these seedlings are taken from a combination of 2008 survival surveys and observed survival to date. Survival is assumed to be higher than that seen in 2008 because many of the trees are now well established. Survival is estimated at 90% for Jeffrey pine, and 50% for both sugar pine and incense cedar. Low survival is estimated for sugar pine and incense cedar because the site is south-facing, dry and exposed. We introduced approximately 650 naturally occurring seedlings per acre on the treated site in 2067.

For the untreated parcel, the model was supplied with post-fire tree data and expected timing, abundance, and composition of natural seedling regeneration. We introduced 450 naturally growing seedlings per acre there in 2067.

Natural seedling occurrence was initiated in the model on both sites in the year 2060. We estimated at least 50 years would pass between the fire and establishment of natural tree seedlings because there are few nearby living trees to provide seed and there is vigorous brush competition. This estimate is supported by a study using aerial photos showing little to no natural tree regeneration 50 years after an 1890s fire on Angora Ridge (Russell et al.1998).

The model predicts that in 2067, the treated site will contain a mature pine/cedar stand (Figure 8, Figure 10) with few openings and little brush. The model predicts no mature trees on the untreated site by 2067 (Figure 9, Figure 10) and nearly complete brush cover.

Table 2. Summary of Inputs to Forest Vegetation Simulator

Site	***Source of Seedling Data***	***Seedlings per acre-2010***	***% Survival***	***Natural Regeneration-2060***
Treated	2010 Seedling	Jeffrey Pine - 100	90	650 seedlings/acre

	Surveys and 2010 Plantings	Sugar Pine - 20	50	
		Incense Cedar - 10	50	
Untreated	2010 Inventory	None	N/A	450 seedlings/acre

It should be noted that these predictions assume that fire will not return to the site prior to 2067. If another fire does occur, forest development will be slowed further.

Data Summary and Analysis:

Tree and Seedling Data

Seedling surveys show that the treated site contains very few standing dead trees and an abundance of live seedlings. The untreated site contains about an abundance of snags and no live seedlings (Table 3).

Table 3. Summary of Tree and Snag Data on Treated and Untreated Sites, Post-treatment

Study Area	Snags Per Acre	Live Seedlings Per Acre
Conservancy Mule Deer (treated)	6	130
Forest Service (untreated)	300	0

Modeled Future Stand Conditions

Table 4 shows a projection of live trees per acre by diameter class on the two sites in 2017 and in 2067, following a flush of natural regeneration introduced at both sites in 2060. In 2017, the treated site contains 98 seedlings (those planted in 2007-2010 and expected to survive), while the untreated site contains none. In 2067, the treated site contains mature trees with diameters between 12 and 30 inches, grown from planted seedlings, plus naturally occurring seedlings, while the untreated site contains only the naturally occurring seedlings introduced in 2060.

Table 4. Live Trees per Acre by Diameter Class on Treated and Untreated Sites

		Live Trees per Acre by Diameter Class						
	Year	<2”	2-6”	6-12”	12-18”	18-24”	24-30”	**Total**
Treated	2017	105	0	0	0	0	0	**105**
	2067	325	0	0	34	62	7	**428**
Untreated	2017	0	0	0	0	0	0	**0**
	2067	225	0	0	0	0	0	**225**

Figure 8 shows FVS-predicted live trees by size class and species on the treated site in 2067. Figure 9 shows the same for the untreated site. Figure 10 shows FVS-generated pictures of stand development over time for both sites.

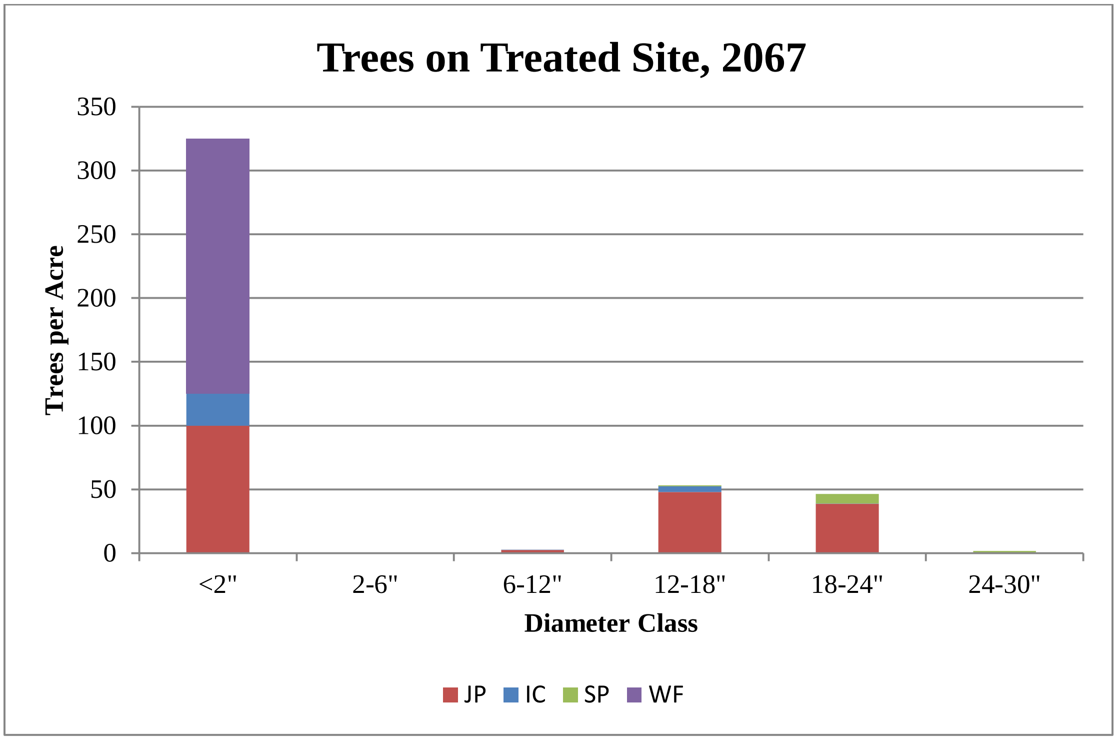

Figure 8. Modeled live trees on the treated site, 2067.

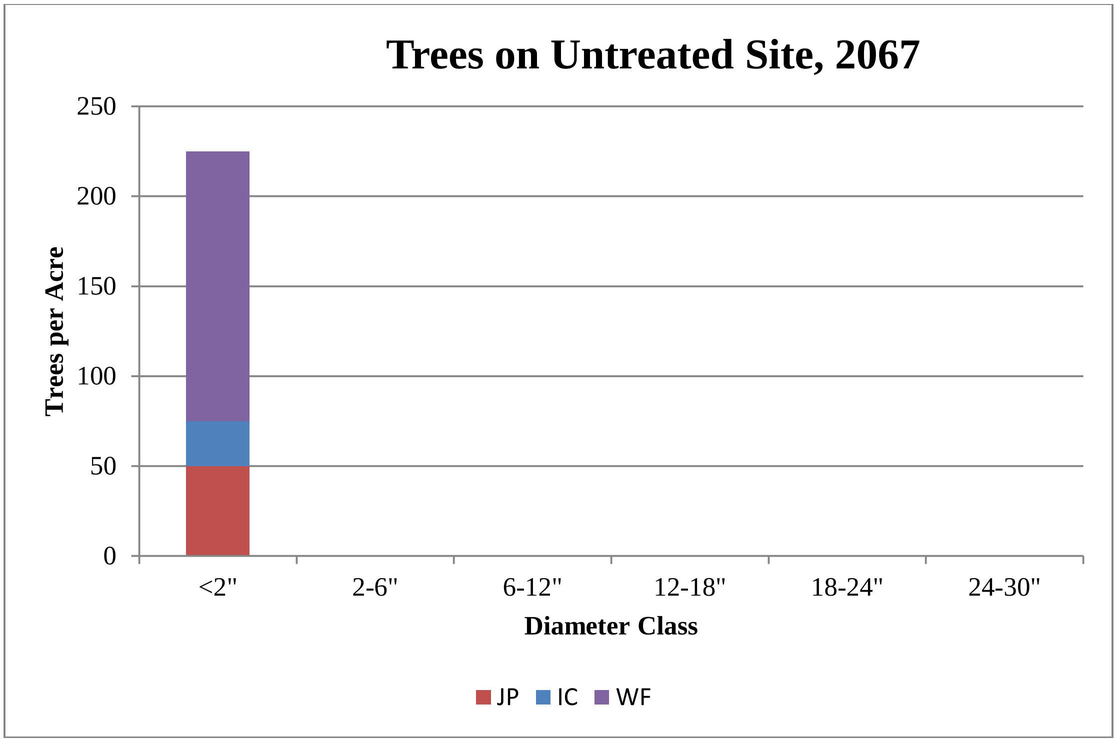

Figure 9. Modeled live trees on the untreated site, 2067.

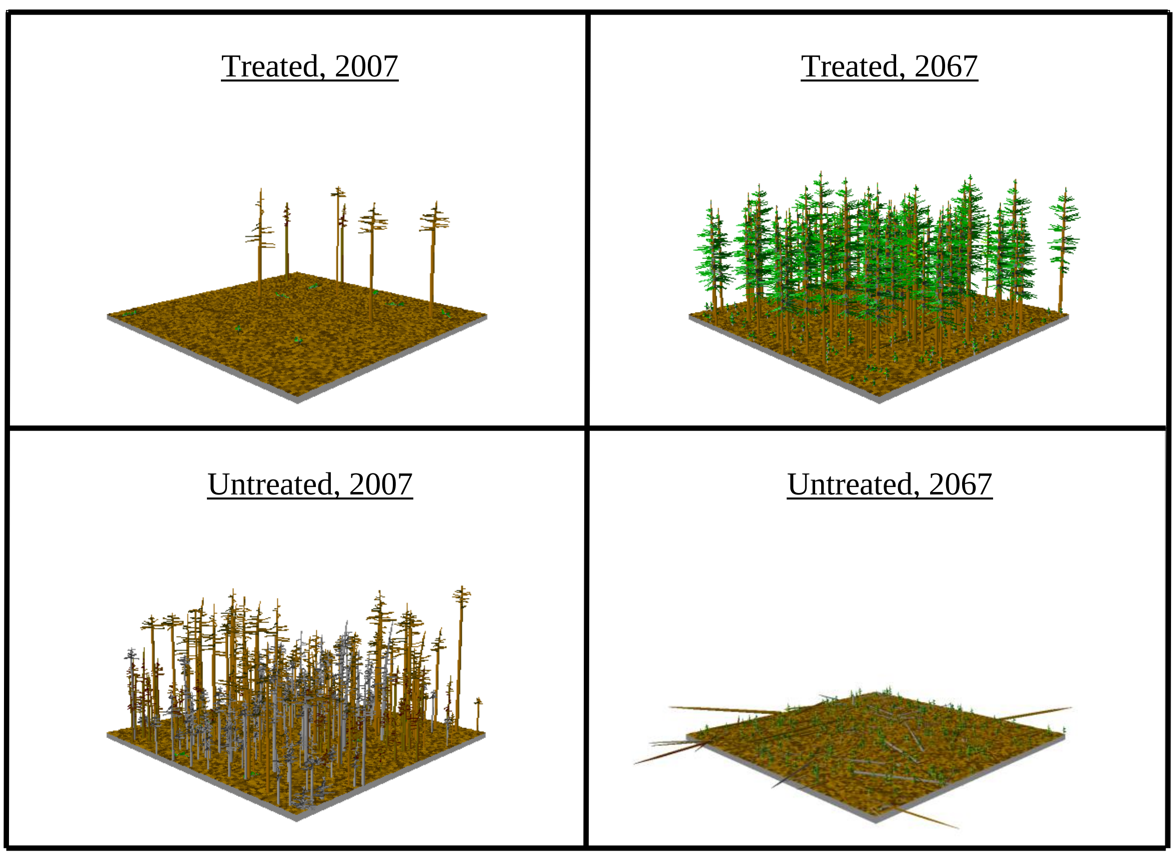

Figure 10. Modeled representations of treated and untreated forest stands based on observed conditions (2007) and predicted conditions (2067).

Preliminary Answer to Monitoring Question:

Did post fire treatments accelerate forest stand development?
Yes, to date, post fire treatments have accelerated forest stand development on the Conservancy Mule Deer parcel. The healthiest planted trees are now two to three feet tall (Figure 11). Treatments have suppressed competition from shrub growth, which should allow for high survival and growth rates among the planted seedlings. On the untreated control plots, vigorous shrub re-growth in addition to distance from seed sources appears to be preventing re-establishment of a new forest. Forest recovery, however, is a long-term process. Final conclusions concerning how treatments have accelerated development cannot be made at this time. Continued monitoring of forest development would provide more solid conclusions regarding treatment effectiveness.

Next steps: We recommend that full inventory plot data be collected every five years, and that updated predictions be made using current data.

Figure 11. Jeffrey pine trees planted in Fall 2007 where almost three feet tall and vigorous, August 2010.

Seedling Survival

Monitoring Question: Did planted seedlings survive at an acceptable rate?

Effectiveness Criteria: Seedlings will survive at a rate of 80% or greater.

Figure 12. Seedling planted Fall 2007.

Treatment and Background: The greatest planting effort following the fire focused on the Mule Deer parcel. Planting began in the fall of 2007 and continued through spring 2011. The majority of seedlings planted were Jeffrey pine (*Pinus jeffreyi*). Also planted were sugar pine (*Pinus lambertiana*) and incence cedar (*Calocedrus decurrens*).

Monitoring Methods: Seedling survival was assessed in Fall 2008, following plantings in Fall 2007 and Spring 2008. A grid of 74 1/10th acre plots was laid out across the property, within which all seedlings were tallied by species and status (live, dead or unhealthy). The detailed survey method can be found in Wade and Kocher (2011).

Data Summary and Analysis: Table 5 provides a summary of seedling survival data to date. Overall survival was 71 percent. The spring of 2008 was extremely dry and drought stress no doubt contributed to seedling mortality.

Table 5. Summary of 2008 Seedling Survival Data

Acres Planted	Plots in Analysis	Total Trees Planted in Plots	# Alive	# Dead	Survival (%)
25	74	79	56	23	71

Preliminary Answer to Monitoring Question:

Did planted seedlings survive at an acceptable rate?
No, seedling survival on the Mule Deer parcel fell short of the target 80% in September 2008. Information collected in this survey was used to inform additional planting that occurred in 2009 and 2010. The seedling survival rate of subsequent plantings is not known. It was

infeasible to estimate survival of these plantings since the planting date of each seedling was not obvious. Instead, surveys identified the number of live seedlings per acre. Current stocking is 130 trees per acre which meets the target goal.

Next Steps: Seedling survival monitoring was a short-term effort to assess the success of planting efforts carried out in 2007-2008. No further monitoring will be conducted.

SURFACE VEGETATION RECOVERY

Establishment of Desired Native Species

Monitoring Question: Did tree removal and mastication treatments promote desired native species?

Effectiveness Criteria: Treated site will have greater cover of native, non-brush species compared to the control site.

Treatment and Background: On the Conservancy Mule Deer site, nearly all merchantable trees were removed, and small trees and slash were masticated, leaving a layer of woody material on the ground. The thickness of this layer varies across the site, likely attributed to the amount of time spent by the masticator in each location. The minimum depth measured in any one location was zero and the maximum 10.2 inches. The lowest plot-wide average depth is 2/3 inch and the highest is 4.2 inches. Surface treatment on the Forest Service control plots consisted of the application of a thin layer of hydro-mulch applied by aircraft immediately post-burn. This layer was intended to break down after the first winter. No trees were removed and no further surface treatments were applied. No seeding was done on either the treatment or control plots included in this analysis in order to isolate the effects of tree removal and mastication on surface vegetation.

Monitoring Methods: Surface vegetation was sampled in late summer 2008, 2009 and 2010 using the Cover-Frequency method within the Feat/Firemon Integrated (FFI) program. Four 45-foot transects were sampled on each inventory plot (one in each cardinal direction). Cover, height and nested rooted frequency of each plant species was sampled within five 20-inch squares (quadrats) per transect, for a total of 20 quadrat samples per plot. Details can be found in Wade and Kocher (2011). In 2009, five measurements of fuel depth (including masticated material and pine needles) were taken within each quadrat.

Data Summary and Analysis: Surface vegetation on six of seven Mule Deer plots (one plot was excluded because it is within a wet area and thus has different vegetation growth conditions) was compared with that on the nine Forest Service plots where all trees were killed by the fire.

Based on field data, we used the FFI program to create a report of average cover by species on each plot. For each plot, cover by species was summed within three categories: native, non-native, and nativity unknown (for plants not identified to species). Then these plot-level values were averaged to determine percent cover of native and non-native species on the treated and untreated sites. These data are displayed in Figure 13. Native species richness (the number of native species present) was calculated for each site and is displayed in Figure 14. Cover by life form was calculated in the same manner as nativity, within the following categories: shrub, herb/forb and grass-like, displayed in Figure 15.

Total vegetative cover and native cover were both considerably higher on the untreated site than on the treated site in all study years. However, species richness was higher on the treated site than the untreated site in all years. Native cover on the untreated site is dominated by shrubs (Figure 15) which accounts for the lower species richness. In all survey years, shrubs comprised over ninety percent of the native cover on the untreated site. The greater cover of native species on the untreated site can be completely accounted for by the abundance of shrubs. By contrast, over 50% of the native vegetative cover on the treated site was herbaceous in all years. Cover by native herbaceous species was higher on the treated site than the untreated site in 2009 and 2010.

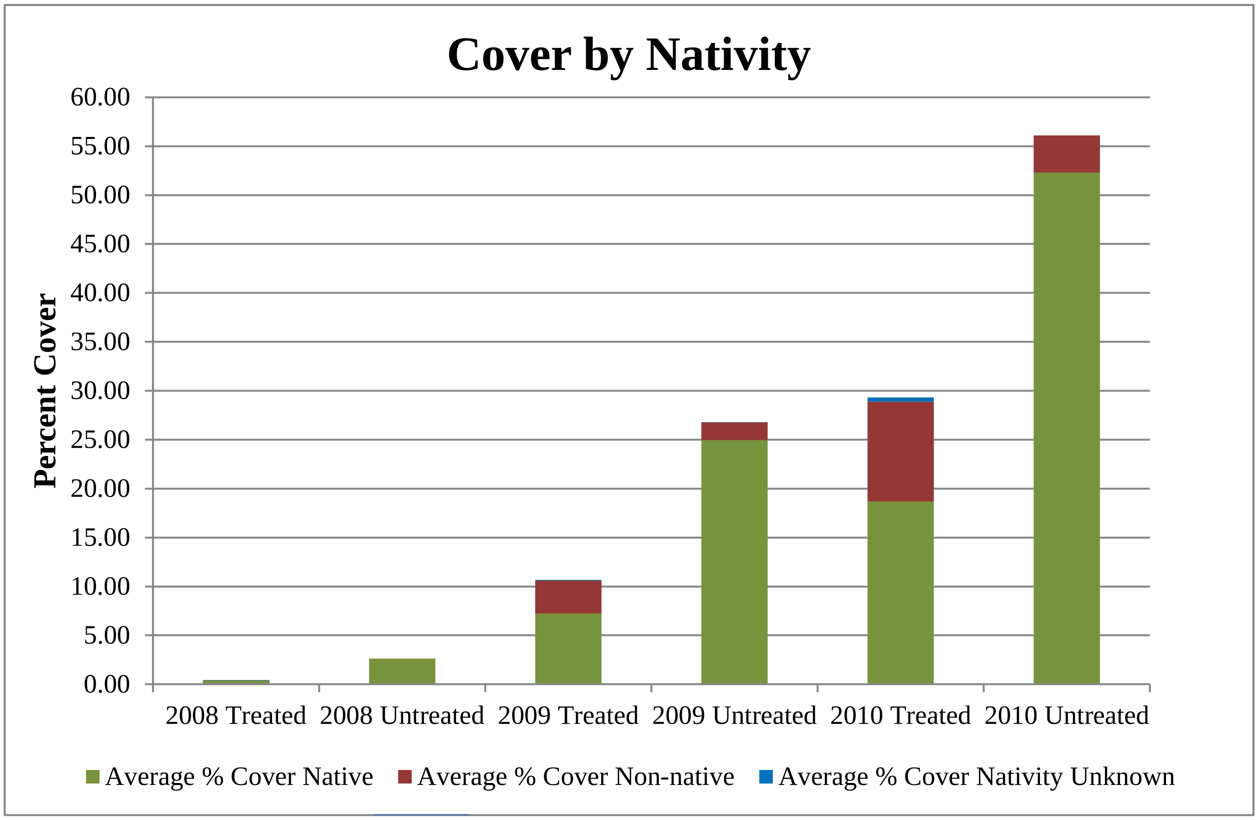

Figure 13. Cover by nativity on treated and untreated sites, 2008 to 2010.

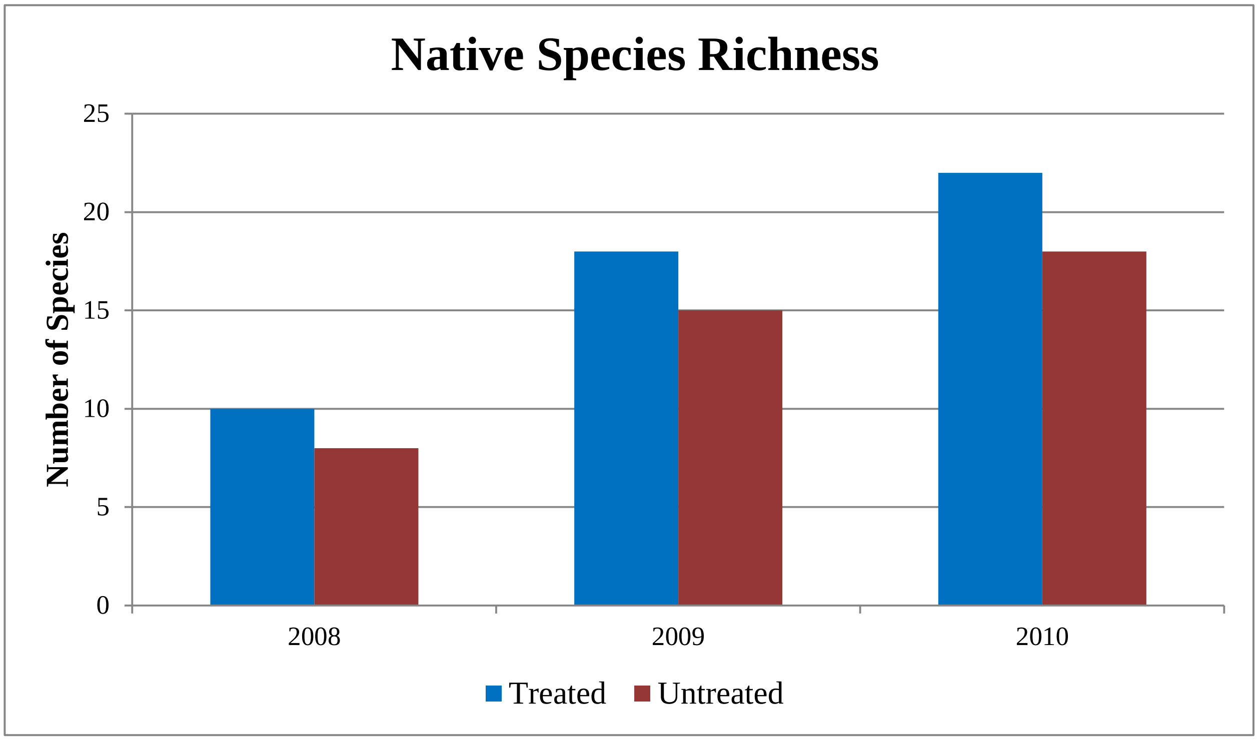

Figure 14. Species richness on treated and untreated sites, 2008 to 2010.

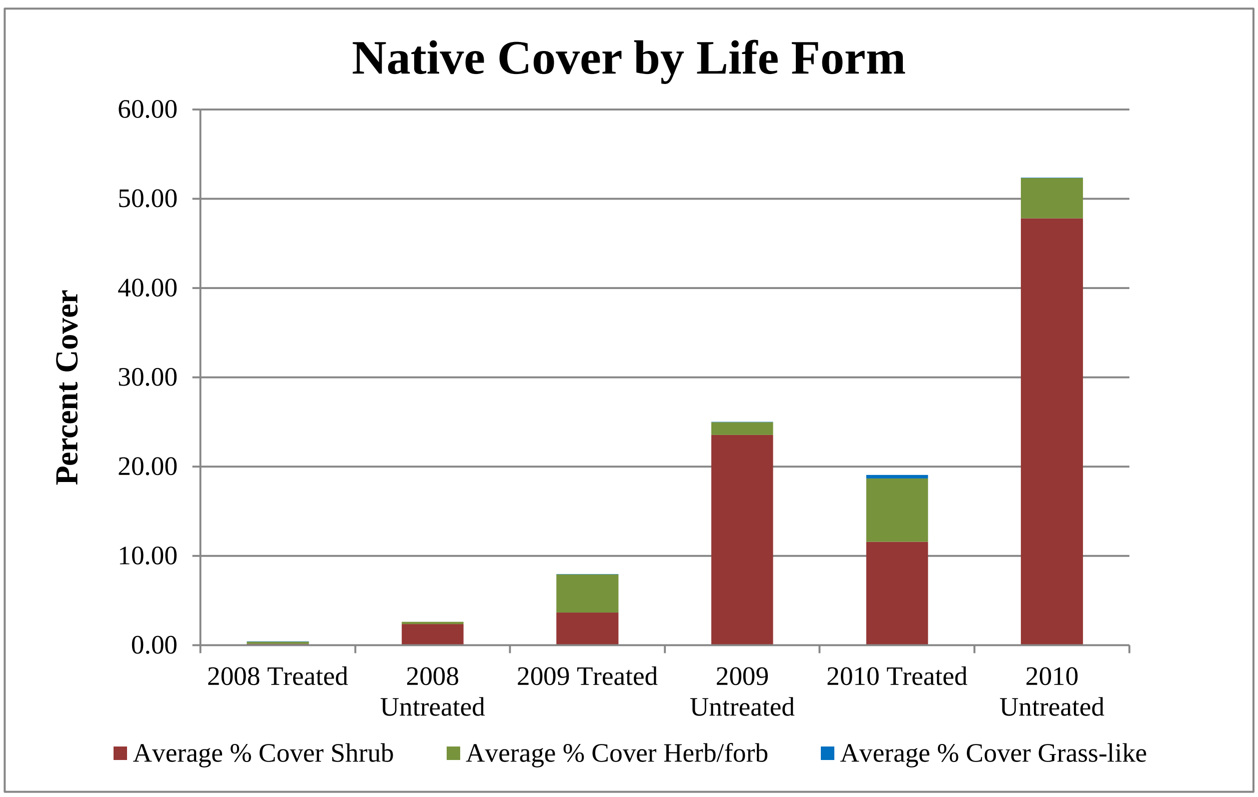

Figure 15. Native cover by life form on treated and untreated sites, 2008-2010.

Differences in the level and type of vegetative cover between treatments can be seen clearly in photos of the two sites. Figure 16 shows 2007 photos (prior to any treatment) and 2010 photos (after treatment on the Mule Deer parcel) on three different plots: an untreated plot, a treated plot with light masticated cover and a treated plot with heavy masticated cover. The untreated site shows vigorous re-sprouting of shrubs, dominated by whitethorn (*Ceanothus cordulatus*) two years after the fire. On the treated plot where masticated material cover is light, we see little shrub growth and abundant herbaceous growth. On the treated plot where masticated material is heavy, it appears that masticated material has almost entirely suppressed brush growth, allowing for greater abundance and variety of herbaceous vegetation (Figure 17).

Preliminary Answer to Monitoring Question:

Did surface treatments, including tree removal and mastication, promote desired native species?
The untreated site has greater cover of native species than the treated site. However, this native vegetation is largely brush. Though it is a natural part of the post-fire community, brush competes fiercely with planted seedlings and therefore is not considered desirable on the treated site where the primary goal is reforestation. Native herbs and forbs are more abundant on the treated site than the untreated site. Monitoring shows that tree removal and mastication has promoted desired species in this area. Further analysis could be used to determine whether these values are statistically significant.

Next steps: We recommend that further analysis include tests of statistical significance on differences in native cover, species richness, and cover by life form at the two sites. It appears that the depth of woody material has an influence on vegetative cover, and this relationship may be explored using 2009 and 2010 woody cover depth data.

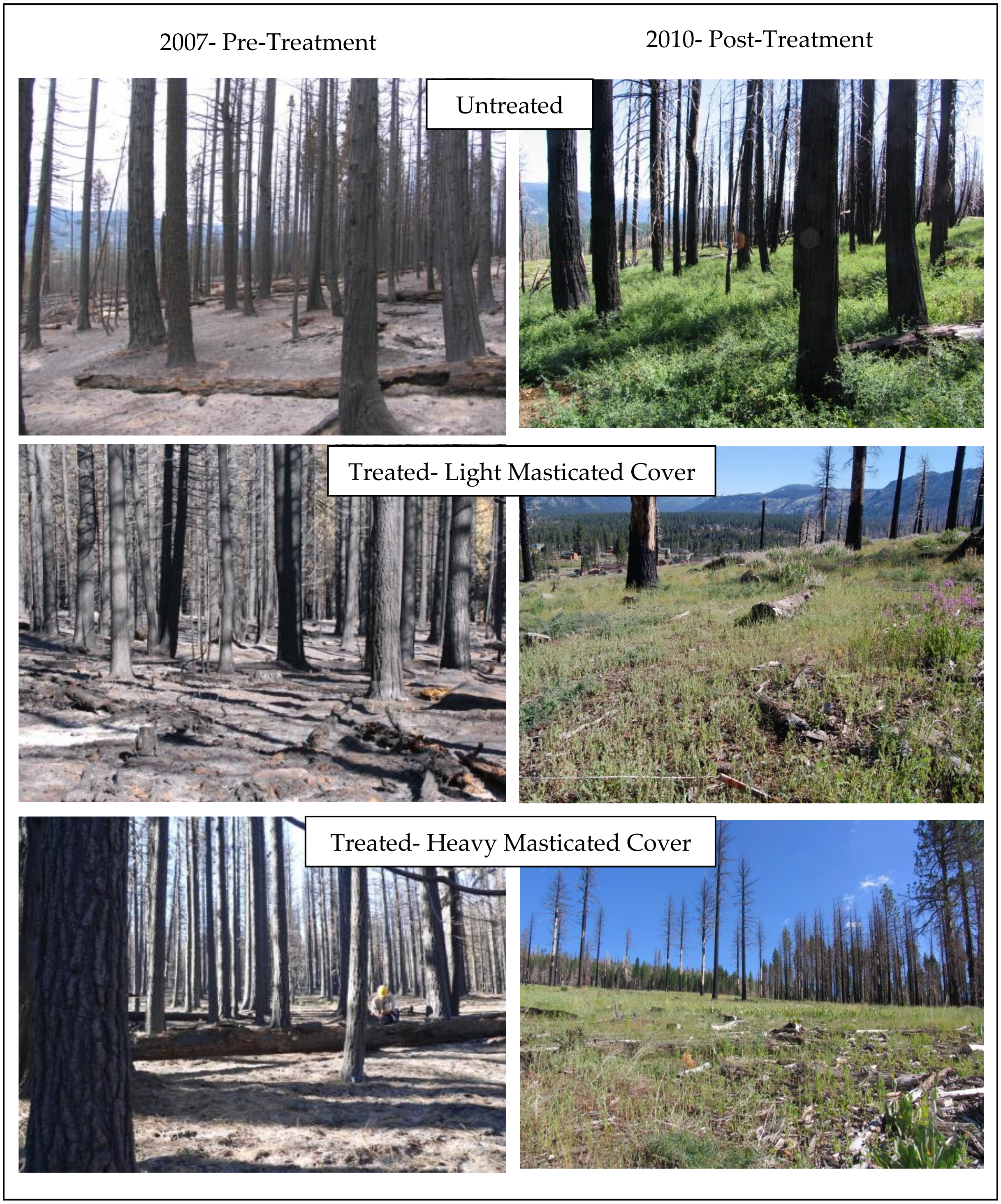

Figure 16. Vegetation in three locations with varying depth of ground cover in 2007 (on left) and in 2010 (on right).

Figure 17. Herbaceous growth on treated Mule Deer parcel, Summer 2010.

Seeding for Re-vegetation

Monitoring Question: Did reseeding promote increased cover of native species in the burned area?

Effectiveness Criteria: Seeded areas will have greater cover and richness of native species compared to unseeded areas.

Treatment and Background: A variety of restoration treatments were applied to the Conservancy's fire-affected parcels. In many cases, restoration included the application of a native seed mix in order to encourage the re-establishment of ground cover to stabilize and build soils and to restore ecological function to the site. On the ten-acre Conservancy Expressway parcel, half of the ten plots were seeded, and half were not, so that an assessment of the vegetation recovery following seeding versus natural regeneration alone could be made.

Figure 18. Scattering native seed mix on severely-burned Conservancy land.

Data Collected: Surface vegetation was sampled within 20 quadrats, laid out along four transects per plot. Cover and height of each species was measured, along with the nested rooted frequency within four sub-quadrat areas. See Wade and Kocher (2011) for complete sampling design and field method descriptions. Vegetation sampling was conducted in late Summer 2008, 2009, and 2010. In 2009 and 2010, five measurements of fuel depth (including masticated material and pine needles) were taken inside each quadrat.

Data Summary and Analysis: Based on field data, the FFI program was used to create a report of average cover by species on each plot. For each plot, cover by species was summed within three categories: native, non-native, and nativity unknown (for plants not identified to species). Then these plot-level values were averaged to determine percent cover of native and non-native species on the treated and untreated sites. Figure 19 shows the cover of native, non-native and unknown vegetation on the seeded and unseeded sites in 2008, 2009 and 2010.

As expected, total cover increased significantly in both conditions from year to year. There does not appear to be a significant difference in native cover between treated and untreated areas in any year. In 2008 there was 1.6 percent more native cover in the unseeded plots than the seeded plots. In 2009, the difference in nativity between the two conditions is slight, but there is greater cover (about 4%) of unknown species in the seeded area. If these are in fact native species, then the native cover in the seeded areas would be somewhat greater than in the unseeded area in 2009. Overall, in 2010, there appears to be little difference between the two sites.

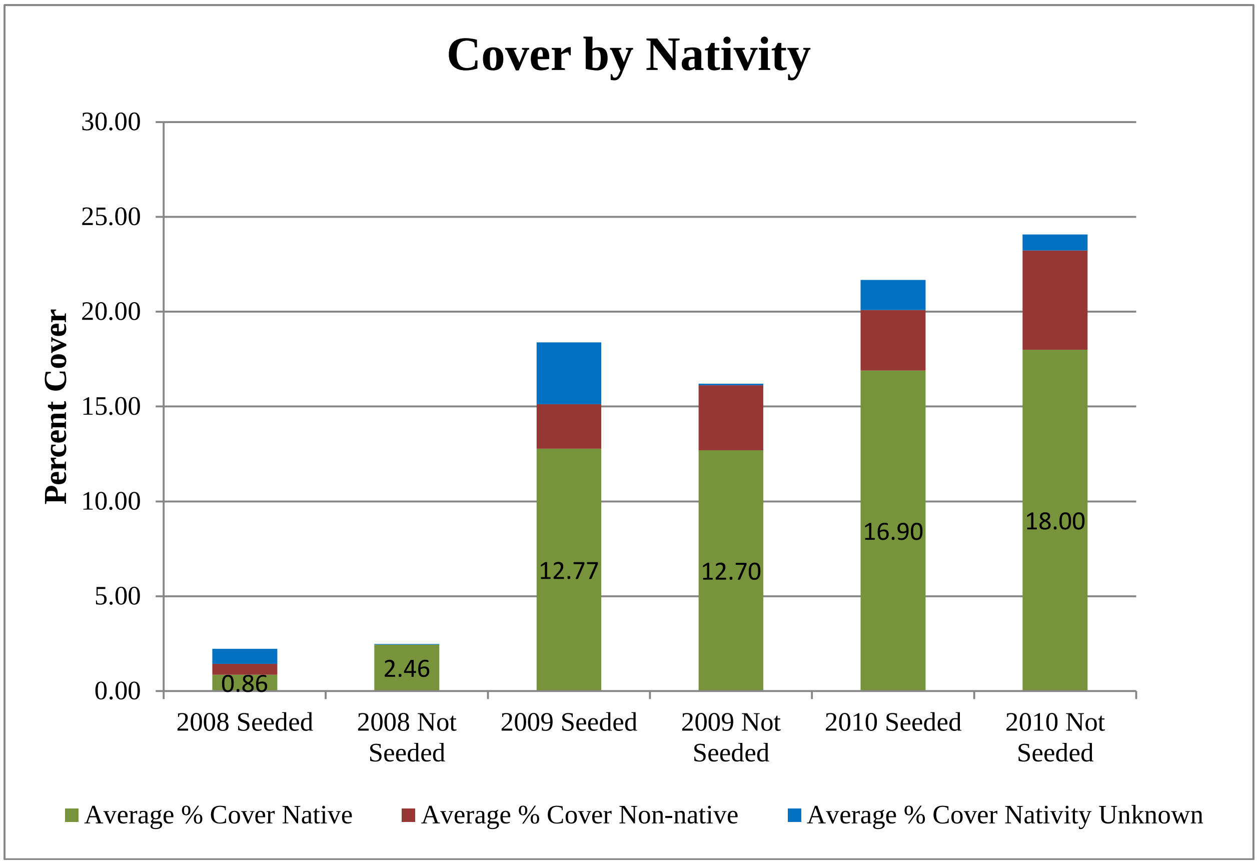

Figure 19. Cover by nativity on seeded and unseeded plots, 2008-2010.

Species richness (the number of native species present) was calculated for each site and is displayed in Figure 20. Species richness was calculated to be higher on the unseeded plots in all study years.

Preliminary Answer to Monitoring Question:

Did reseeding promote increased cover of native species in the burned area?
No, the cover of native vegetation does not appear to have been increased by seeding. There does not appear to be a significant difference between the cover of native vegetation on the two sites. Seeding also did not increase the number of native species, which is higher (though may not be statistically significant) on the unseeded site. There is a fair amount of variability in factors such as fuel depth and burn severity across the plots, which may have had an effect on native species cover and abundance. Further analysis would be needed to determine whether this is the case.

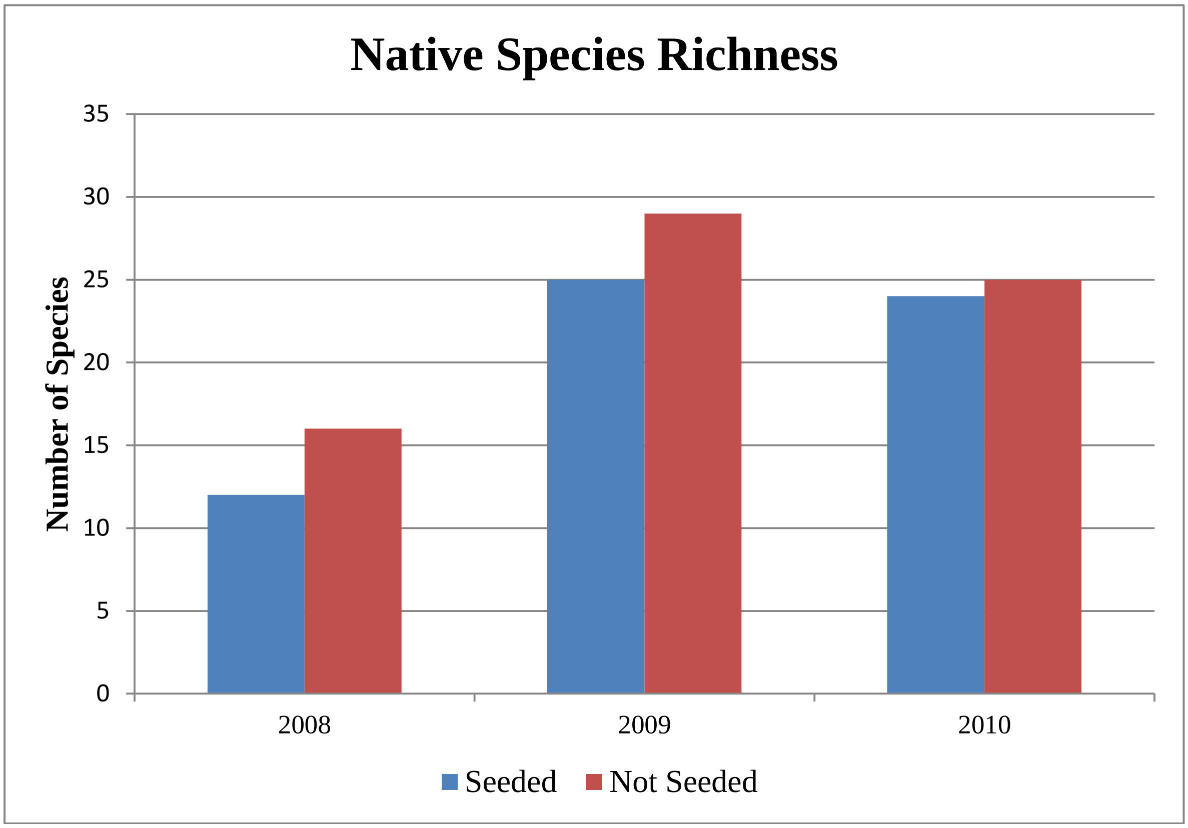

Figure 20. Species richness on the seeded and unseeded plots in 2008, 2009 and 2010.

Next steps: Additional analysis could be done to determine whether differences in cover between the sites are statistically significant. As mentioned above, variability in several factors on the plots may be contributing to variability in vegetative cover. Classifying plots based on fuel depth and burn severity would aid in better understanding of factors contributing to these results. Woody cover depth is likely to be a significant factor as there is considerable variation in fuel type and depth across these plots. Fuel depth measurements made in 2009 and 2010 could be used to address this question.

Invasive Weeds

Monitoring Question: Were invasive species populations promoted by the fire?

Effectiveness Criteria: The incidence and cover of invasive weeds should not increase over time.

Treatment: Data collection and treatment of invasive weeds occurred simultaneously. All Conservancy parcels were surveyed in early June 2008 to identify and treat weeds that may have been introduced onto Conservancy properties during firefighting efforts or during the subsequent clean up and rebuilding of the neighborhood burned by the Angora Fire. Surveys continued in 2009 and treatment continued in 2010.

Monitoring Method: A total of 231 Conservancy parcels, encompassing 103.2 acres, were surveyed for the presence of 23 invasive weeds by the Forester's Co-Op (FCO). FCO crews used methods consistent with El Dorado County Department of Agriculture standard procedures. Crews walked lines in a logical direction spaced approximately 10-feet apart. Covering a single parcel usually required two passes (up and back). Larger parcels often required many hours and multiple passes to fully cover the area. Weeds were identified using the University of Nevada Cooperative Extension booklet *Invasive Weeds of the Lake Tahoe Basin*, and DiTomaso and Healy's 2006 *Weeds of California and Other Western States*. When necessary, plant samples were sent into the UC Davis Herbarium for identification. Surveys were done in early June and late July. Plants are still in early growth stages in June, making identification more difficult but allowing for treatment before flowers and seeds can spread. The second pass done in July captures plants in more mature growth stages and allows for treatment of later season plants before they have bloomed and seeded. Only known weed infestation sites were revisited in 2010.

Data Summary and Analysis: Populations of Dalmatian toadflax (*Linaria genistifolia ssp. Dalmatica*) yellow toadflax (*Linaria vulgaris*,) bull thistle (*Cirsium vulgare*) tall whitetop (*Lepidium latifolium*) ox-eyed daisy (*Chrysanthemum leucanthemum*) and yellow starthistle (*Centaurea solstitialis*) were identified and treated in 2008 and 2009 (Table 6). Invasives were treated or removed when found. On early passes, bull thistle was removed by hand or with a shovel since soils were saturated with water and entire plants with roots could be easily removed. Herbicides used on other species were applied as foliar spot spray on the individual weed. Five occurrences of Dalmatian Toadflax (*Linaria Dalmatica*) were treated in summer 2010 (see *Figure 22*).

Table 6. Invasive Weeds Found and Treated After the Angora Fire, 2008 and 2009

Weed Scientific Name	Weed Common Name	2008 Survey & Treated Occurrences		2009 Survey & Treated Occurrences	
		June 2008	July 2008	June 2009	July 2009
Cirsium vulgare	Bull thistle	13	42	37 (12 new)	40
Chrysanthemum	Ox-eyed daisy	2	2	1	1

Weed Scientific Name	Weed Common Name	2008 Survey & Treated Occurrences		2009 Survey & Treated Occurrences	
leucanthemum					
Linaria vulgaris	Yellow toadflax	3	9	0	0
Linaria genistifolia ssp. Dalmatica	Dalmatian toadflax	4	4	1 (2 untreated)	7
Lepidium latifolium	Perennial pepperweed/tall whitetop	1	2	0	0
Centaurea solstitialis	Yellow starthistle	0	0	0	1
	TOTAL	23	59	41	49

Due to the efforts of the Lake Tahoe Basin Weed Coordinating Group, most incidences of invasive weed establishment are staying constant or decreasing within the Angora burn area. While several incidences of yellow toadflax or tall whitetop were found in 2008, detection and treatment appeared to be effective and no incidences were found in 2009. A new infestation of yellow starthistle was found in 2009, which appears from its timing to not have been spread by post-fire treatments. The invasive species that has been most difficult to prevent the spread of is bull thistle, due to its resemblance to native thistles, difficulty of control, and prolific seeding.

Figure 21. Dalmatian toadflax in the Angora burn area, 2010.

Preliminary Answer to Monitoring Question:

Were invasive species populations promoted by the fire?

Yes, invasive species took advantage of post-fire conditions to spread in the Angora burn area. However, detection and immediate treatment appear to be containing any site advantage that may promote their growth. Bull thistle is one notable exception that may require additional efforts to contain as recommended by the Lake Tahoe Basin Weed Coordinating Group.

Next steps: Additional analysis may be done when reports of the monitoring and treatment of known weed sites that occurred in Summer 2011 becomes available. No effort has been made to compare post fire treatment areas and types with outbreaks of invasive weeds in this report but such an analysis may be done in the future.

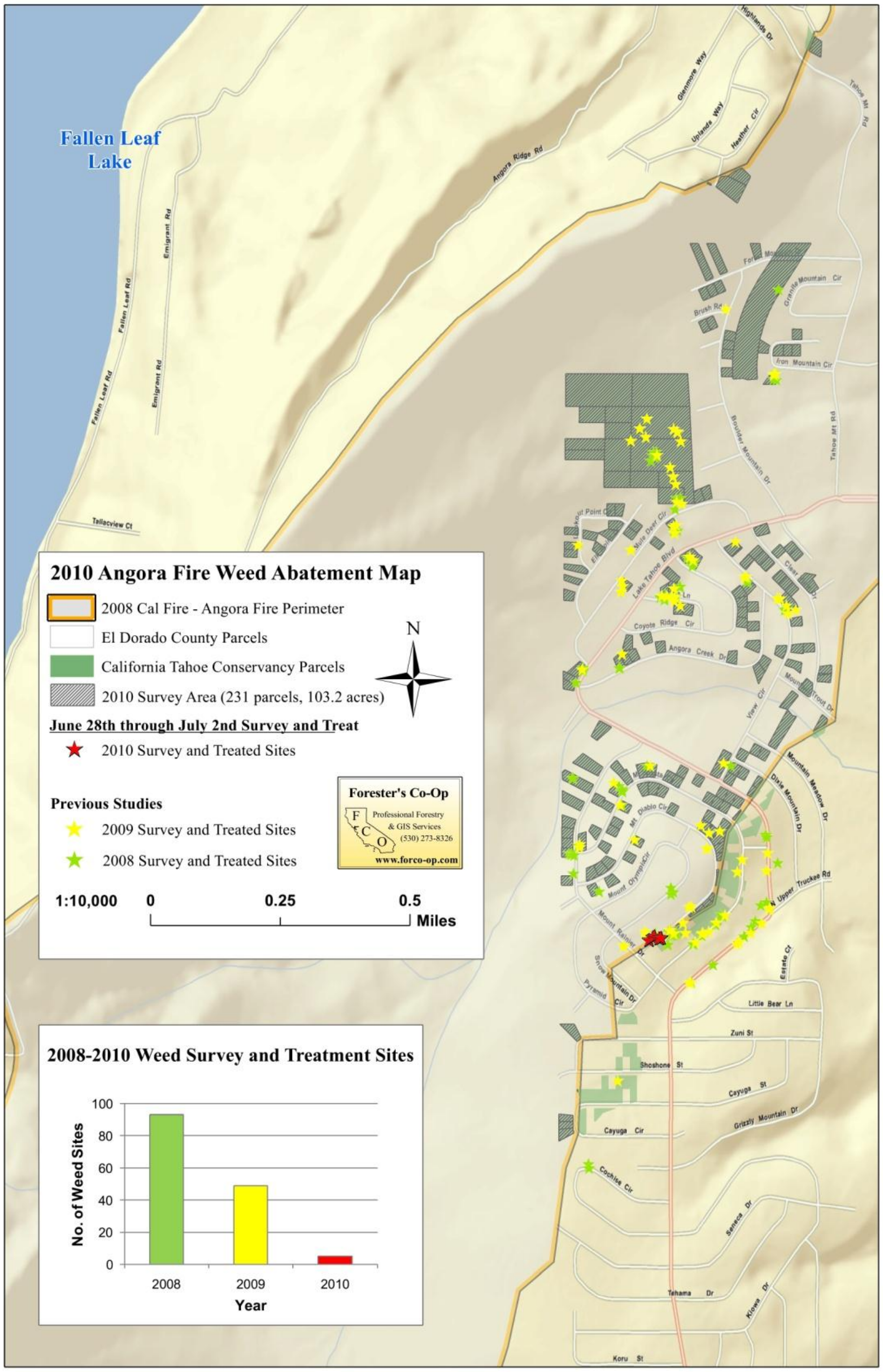

Figure 22. Post-Angora Fire invasive weed species and locations, 2010.

Fuels Accumulation and Fire Risk

Monitoring Question: Did treatments reduce fuels accumulation and associated fire risk on forested parcels?

Effectiveness Criteria: Fuels will be reduced by treatments and modeled fire behavior in treated areas will be characterized by lower potential flame length and rate of spread than that in untreated areas.

Treatment and Background: Very different ground fuels conditions were created by treatments on Conservancy and Forest Service lands. The entire Conservancy Mule Deer parcel experienced complete tree mortality and the stems of trees with diameters larger than 10 inches were removed, while the limbs and small trees were masticated and left on site (see Figure 23). Much of the Forest Service site experienced complete mortality, with a smaller portion being lightly or moderately burned. No trees were removed from the Forest Service plots, so no fuels were added to the site as a result of treatment[1]. In severely burned areas, a layer of aerially deposited hydro-mulch was deposited for erosion control for the first winter season, but decomposed within the first year (see Figure 24). Moderately burned areas typically had a layer of wood straw applied to reduce erosion.

Figure 23. Typical condition of ground fuels following tree removal and mastication on Conservancy lots, 2008.

[1] Data collection and analysis reported here was completed before the Forest Service began treatment of the Angora Fire area in Fall 2011. A number of control plots were treated in Fall and Winter 2011. Thus, control plot measurements are no longer accurate.

Figure 24. Typical slope on the Forest Service untreated site, covered with an aerially-applied layer of hydro-mulch.

Monitoring Methods: Fuels data were collected for the Conservancy and Forest Service plots using two different methods depending on the type of fuel bed found. The Planar-Intercept method (Brown, 1974) was used where fuels were not masticated. Two 37.2 foot transects were sampled per inventory plot. This includes pre-treatment fuels data on all plots and 2008 (post-treatment period) fuels data on untreated plots. A modified method was used for measuring treated plots. Masticated fuels are often numerous and would be extremely time-consuming and difficult to quantify using the Planar-Intercept method. Kane et al. (2009) reports that the Planar-Intercept method is inaccurate for quantifying masticated fuels in the 1-hour and 10-hour size classes (0-0.24″ and 0.25-1″ in diameter respectively) and suggests a modified method for measuring such fuels. Using this method, masticated material was collected within a 400 square-inch frame laid along a basic Brown's transect. It was sorted into size classes, dried and weighed to yield a measurement of fuel mass per unit area, then extrapolated to an estimate of tons per acre. 100-hr (1-3″) and 1000-hr (>3″) fuels were quantified as per the Planar-Intercept method. For detailed methods, see the *Angora Fire Restoration Monitoring Protocol*, Wade and Kocher (2011).

Post-treatment fuel data were collected on four masticated plots on the Conservancy Mule Deer parcel in 2008. Fuels on all untreated Forest Service plots were re-measured in 2008 using the planar-intercept method, but only those plots (n=9) that experienced 100% tree mortality similar to the treated plots are included in the analysis here.

In order to represent the entire fuel profile of each condition, standing dead fuel loads were quantified using tree data from inventory plots. The forest growth model FVS was used to create a standing fuel load report for the treated and the untreated sites.

Data Summary and Analysis:

All fuel load data collected using the Planar-Intercept method was entered into the FEAT/Firemon Integrated (FFI) program for storage and analysis. FFI was used to generate reports quantifying the weight of fuel on each plot in tons per acre by size class. Where the hybrid method was used, the dry weight of 1-hour and 10-hour fuels collected within the 400 square-inch frame was translated into tons per acre of fuel within each size class. For each plot, fuel loads from the two transects were averaged to calculate fuel load values in the 1-hour and 10-hour size classes.

Surface Fuel Loads

On the treated site, surface fuel loads increased threefold from pre- to post-treatment because masticated material was left on the surface. *Figure 25* shows the pre-treatment (2007) and post-treatment (2008) fuel loads on the Conservancy Mule Deer site compared with the untreated surface fuel load measured in 2008.

The untreated site had 9.4 tons per acre of fuel that following the Angora fire, almost all in the largest size category of three inches or higher in diameter (1000-hour) which is the most resistant to ignition. The treated site had more than three times that much survive the fire, 28.5 tons per acre, also almost all in the largest size class.

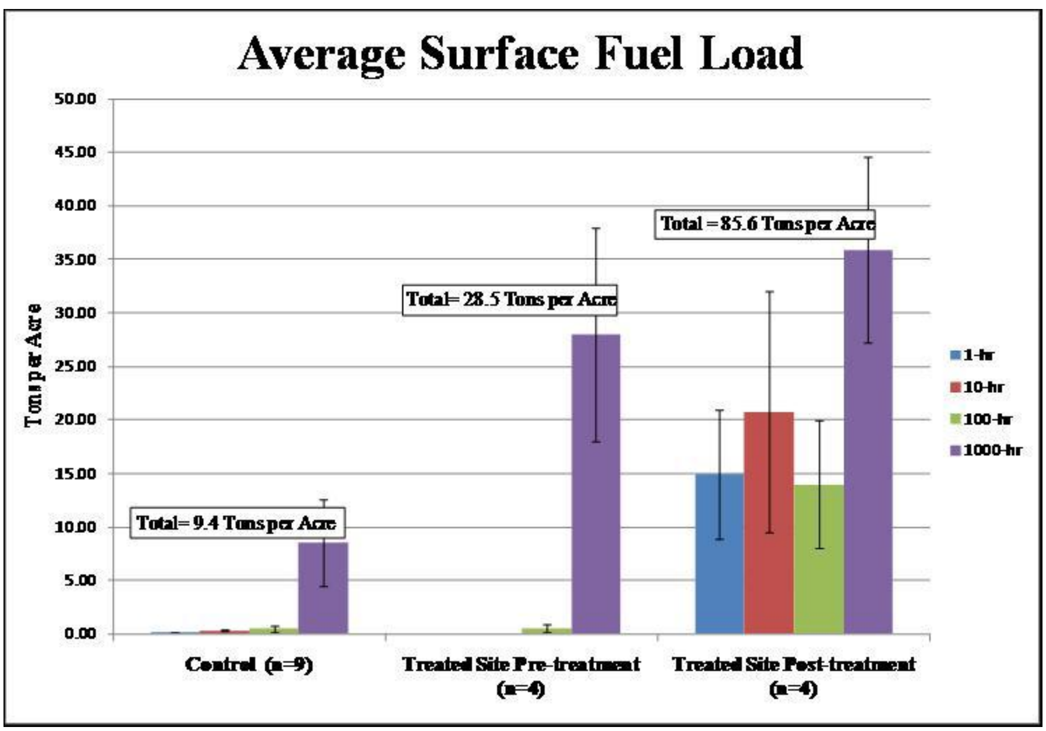

Figure 25. Surface fuel loads by size class on the treated and untreated parcels (error bars represent standard error).

Mastication of tree limbs and small trees left a total of 85.6 tons per acre on site, of which 15 tons were in the smallest, most ignitable size class of less than a quarter inch in diameter (1-hour fuel). Another 20 tons per acre were a quarter to an inch in diameter, 14 tons per acre were one to three inches in diameter and over 36 tons were over three inches in diameter.

Standing Fuel Loads

Standing dead fuel loads on each site are reported here in terms of average number of dead trees per acre by size class. Figure 26, Figure 27, and Figure 28 display data for the untreated site in 2008, and for the treated site before and after treatment. The standing dead fuel load on the treated site was lower than the untreated site before treatment, and is much lower following treatment, containing an average of 7.5 snags per acre compared with the nearly 300 snags per acre still standing on the untreated site.

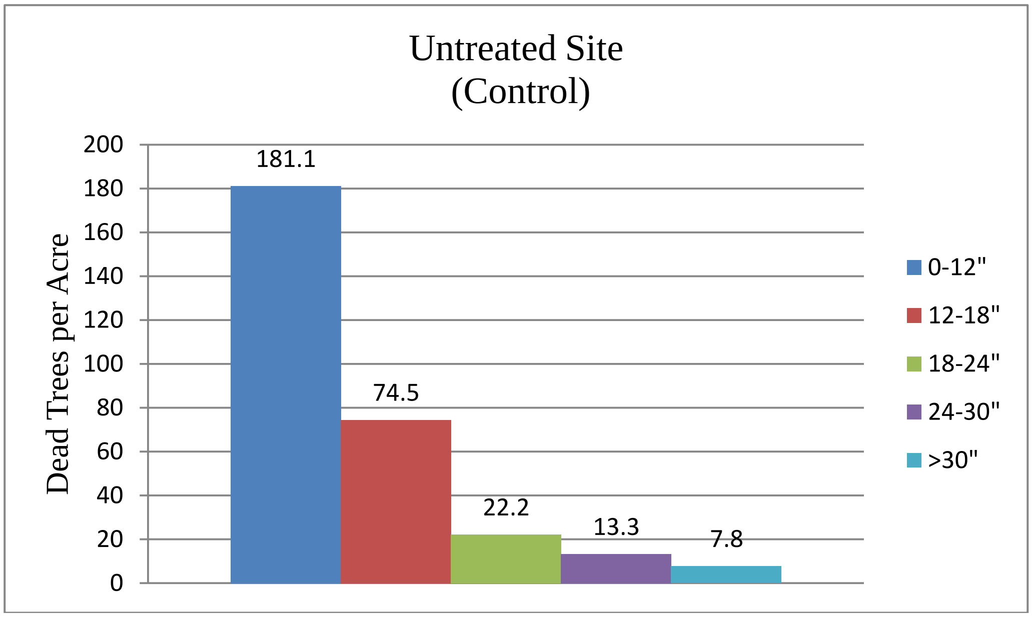

Figure 26. Standing dead fuel loads by diameter class on the untreated site, 2008.

The data show that surface fuel load is currently much higher where tree removal and mastication occurred, whereas standing fuel load is much higher where no treatments occurred. Over the next couple of decades, many of the dead trees left on untreated areas will fall to the ground, creating a surface fuel load that surpasses that on the treated site, where fuels will have partially decomposed. The rate of surface fuels accumulation on the untreated parcel can be modeled using FVS, but such modeling is not appropriate for the treated site. As Kane et al. (2009) say, "actual fire behavior in masticated fuel beds differs substantially from outputs of fire behavior models". Masticated fuelbeds are known to burn at a slower rate than natural fuels due to the size and arrangement of fuels. According to Glitzenstein et al. (2006) mastication may reduce the threat of wildfires and smoke near the wildland-urban interface.

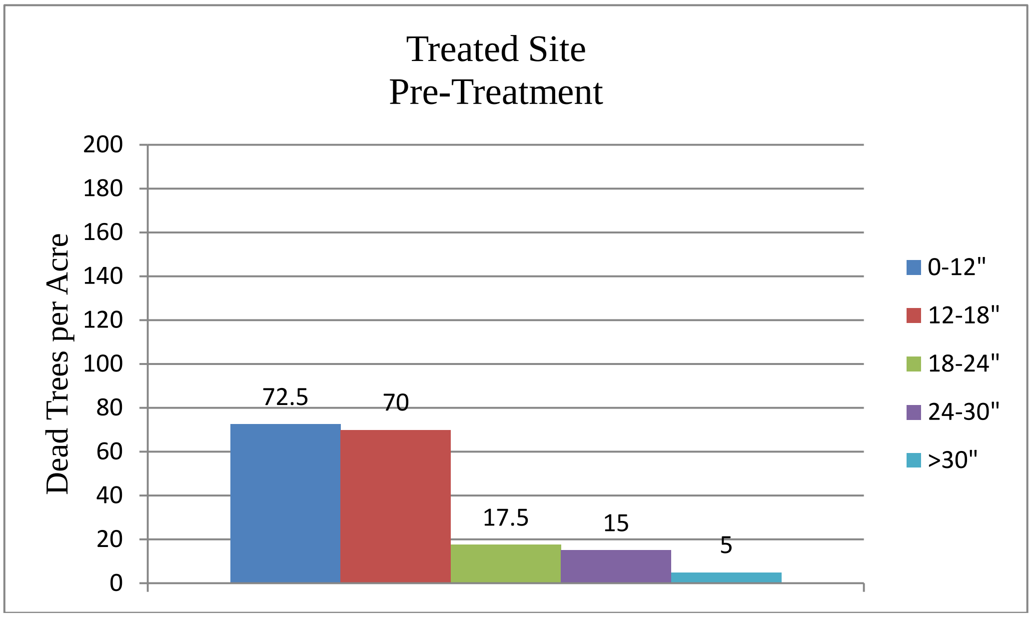

Figure 27. Standing dead fuel loads by diameter class on the treated site, 2007.

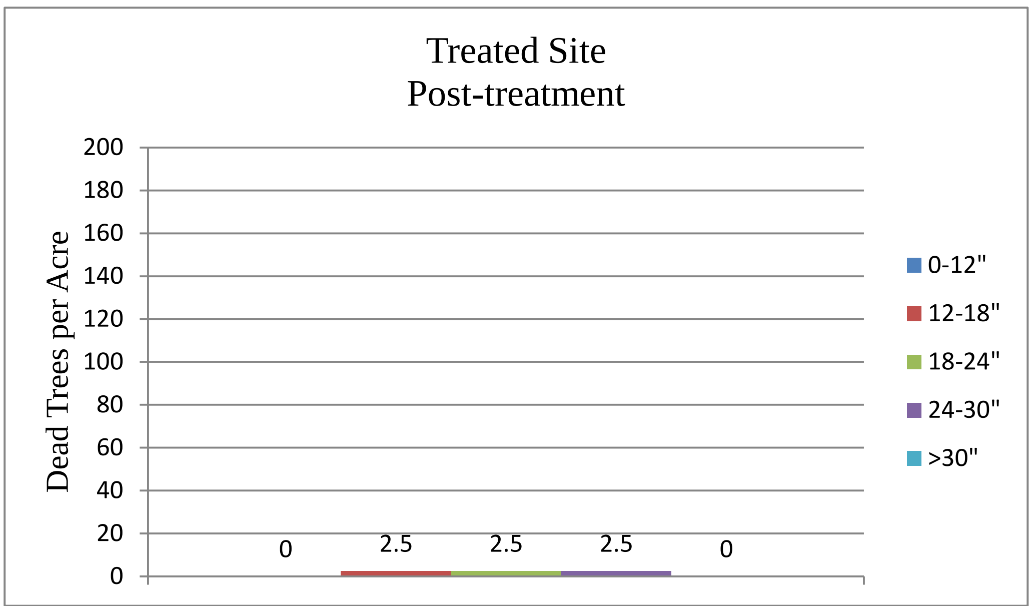

Figure 28. Standing dead fuel loads by diameter class on the treated site, 2008.

Potential Fire Behavior

Quantitative analysis of current and future potential fire behavior are often made through computer modeling. However, currently available models do not sufficiently account for the decomposition rates or fire behavior of masticated fuels. In addition, fire behavior as predicted by the FVS model does not account for the brush layer, which is increasing in depth on the untreated site (Figure 16). Due to these limitations, relative potential fire behavior between the two sites cannot be accurately simulated at this time.

A layer of masticated surface fuel covers much of the Mule Deer parcel while untreated areas have very little woody surface fuel. However, there is a significant and growing shrub layer on the untreated site and an abundance of standing dead fuel that will soon become surface fuel. In addition, masticated fuel beds do not burn as readily as natural fuels, including brush. Relative potential fire behavior on the two sites based on current fuel loads is difficult to asses due to differences in fuel type.

Fuel loads on the treated site will decrease over time. Masticated wood fiber will decompose more quickly than larger natural fuels since it is in a smaller size class with more surface area. When standing dead trees fall, they will create a significant surface fuel load. A study by Russell et al. (2006) found that snags from similar pine species would mostly have fallen within 15 years of the fire that created them. Heavy brush cover combined with accumulation of abundant woody fuels is likely to create severe potential fire behavior where no treatment is done. It is clear that fuel loads will decrease on treated sites while increasing on untreated sites, but the rate at which this will happen is unclear.

Preliminary Answer to Monitoring Question:

Did treatments reduce fuels accumulation and associated fire risk on forested parcels?
This question cannot be answered definitively at this time. It is not possible to accurately model potential fire behavior on the masticated site, making it difficult to assess the relative fire risk on the two parcels.

What is known is that standing dead trees and brush dominate the fuel load in untreated areas, while masticated fuels dominate on the treated site. All fuels on the treated site are masticated, and it is generally accepted that masticated fuels burn with lower flame lengths than natural fuels and are more difficult to ignite because compaction impedes the fire's access to oxygen. Therefore, it is difficult to assess on which site fire behavior would be more severe today. As time progresses, standing dead trees in untreated areas will fall, creating high surface fuel loads, while masticated fuels on the treated site decompose, further increasing fire risk on the untreated site compared to the treated site.

Continued monitoring of both surface and standing fuel loads would provide better insight into the developing fuel profiles of the two sites, and therefore future fire potential. As modeling capabilities improve, simulations of current and future potential fire behavior may be possible.

Next steps: We recommend that surface fuel and standing fuel load data be collected every five years as possible. We also recommend that the development of models that accurately predict fire behavior of masticated fuels be monitored, and used once available.

SOIL QUALITY AND EROSION

Soil Strength

Monitoring Question: Did post-fire mechanical treatments impact soil quality?

Effectiveness Criteria: No significant increase in soil strength on treated parcels compared with control.

Treatment and Background: Treatments on the 30-acre Mule Deer parcel involved the use of a skidder to pull logs to landings, and a masticator to grind up small trees and logging slash. The masticator moved across the entire parcel. Concern over the use of heavy equipment in forestry treatments is common, and is focused on fine textured soils and on operations that take place under moist soil conditions. However, post–Angora fire treatments occurred in the late Summer 2007 when soils were dry. Also, the soils within the study area are of the Tallac series (http://websoilsurvey.nrcs.usda.gov/) a coarse sandy loam which is less vulnerable to compaction. Therefore, little soil impact was expected. No heavy equipment was used on the adjacent Forest Service land, which serves as a control.

Monitoring Methods: Soil strength was measured in order to evaluate any impacts from heavy equipment. Soil strength is a measurement of resistance to penetration and mimics the experience of plant roots pushing through soil. Pre-treatment soil strength was measured using a Rimik CP20 Recording Soil Penetrometer, and post-treatment soil strength was measured using a Rimik CP40II Recording Soil Penetrometer (Figure 30). Fifteen insertions were made within each forest inventory plot. Soil strength increases when soil has low moisture content, so care was taken to record strength measurements during similar moisture conditions so that results from different visits would be comparable. A soil sample was taken on each plot to measure the soil moisture at each visit (Figure 29). Soil samples were weighed immediately after collection, then dried and weighed again to determine the percent moisture content of the original sample.

Pre-treatment soil strength measurements were taken during the week of August 9, 2007, under dry soil conditions. Post-treatment measurements were taken twice annually (under moist and dry soil conditions) in 2008 and 2009. 2008 measurements were taken in May and September, and 2009 measurements were taken in July (due to a wet spring) and September. (For detailed methods, see the Angora Fire Restoration Monitoring Protocol, Wade and Kocher, 2011).

Data collected during the dry seasons from five Forest Service control plots and six of the seven Mule Deer plots are included in this analysis.

Figure 29. Using a slide hammer to obtain a soil sample.

Figure 30. Measuring soil strength with a recording soil penetrometer.

Data Summary and Analysis:

Soil Moisture

Differences in soil moisture were 1% or less between the treatment and control sites during each visit. On both the treatment and control sites, no greater than 3% difference was found between 2007, 2008, and 2009 measurements. Therefore, we conclude that differences in soil strength between sites and between visits cannot be attributed to soil moisture differences, which were negligible.

Soil Strength

Fifteen soil strength measurements were averaged by depth for each plot. The plot-level averages were then averaged for each treatment area, yielding a parcel-wide soil strength average for each depth. Outliers, defined as any number greater than two standard deviations from the mean, were identified and removed from the average. Standard error was calculated for each depth using the standard deviation of the mean.

Figure 31 shows the average soil strength by depth under dry conditions on the untreated site in 2007, 2008 and 2009. Figure 32 shows the same for the untreated site. Soil strength values ranged from 500 kilopascals (72 pounds per square inch (psi)) to 2800 kp (406 psi) on the treated sites and from 350 (51 psi) to 3100 (450 psi) on the control site.

Data show that soil strength actually decreased at most depths from 2007 and 2008 on the treated site, while there is no apparent change on the untreated site. A significant decrease in soil strength resulting from treatment seems unlikely, though mastication may cause some break up of surface soil layers through its digging of masticated material into the soil. Statistical analysis would be needed to determine whether there is any significant difference from year to year.

Preliminary Answer to Monitoring Question:

Did post-fire mechanical treatments impact soil quality?
No, no increase in soil strength was detected. Therefore, we can conclude that mechanical treatments did not significantly impact soil quality.

Next Steps: Data collection is complete for this portion of the monitoring plan. Analysis may continue to assess the statistical significance of the change in soil strength from year to year.

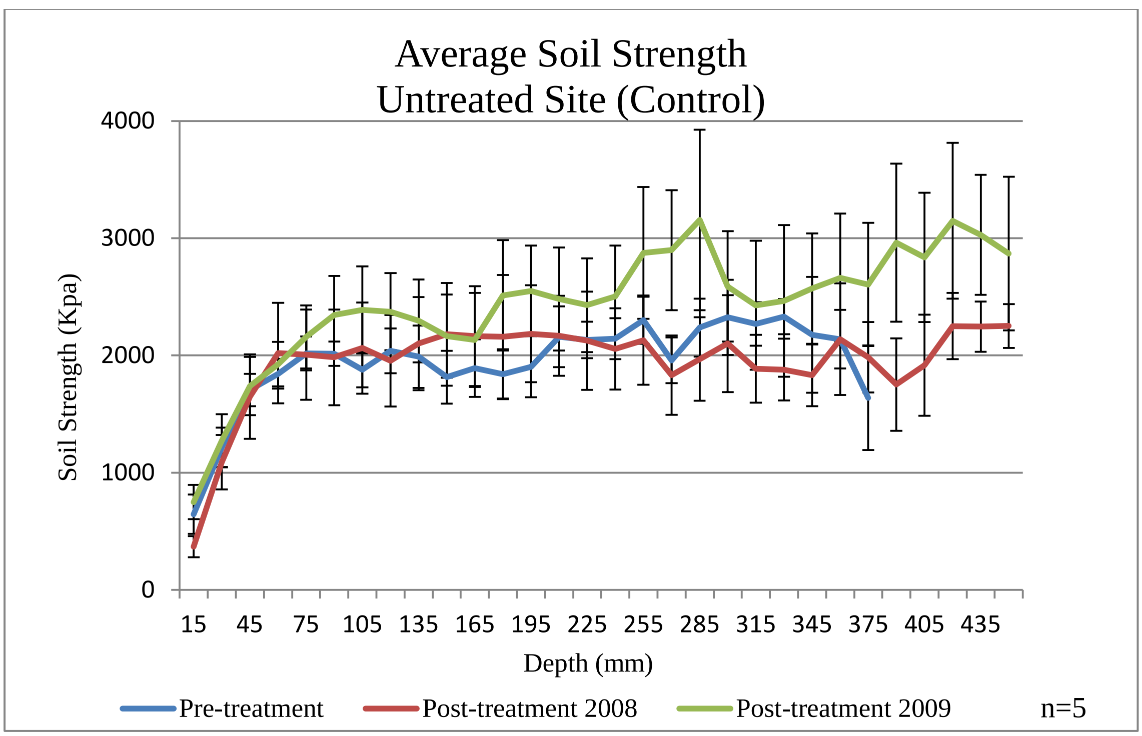

Figure 31. Average soil strength by depth on the untreated site.

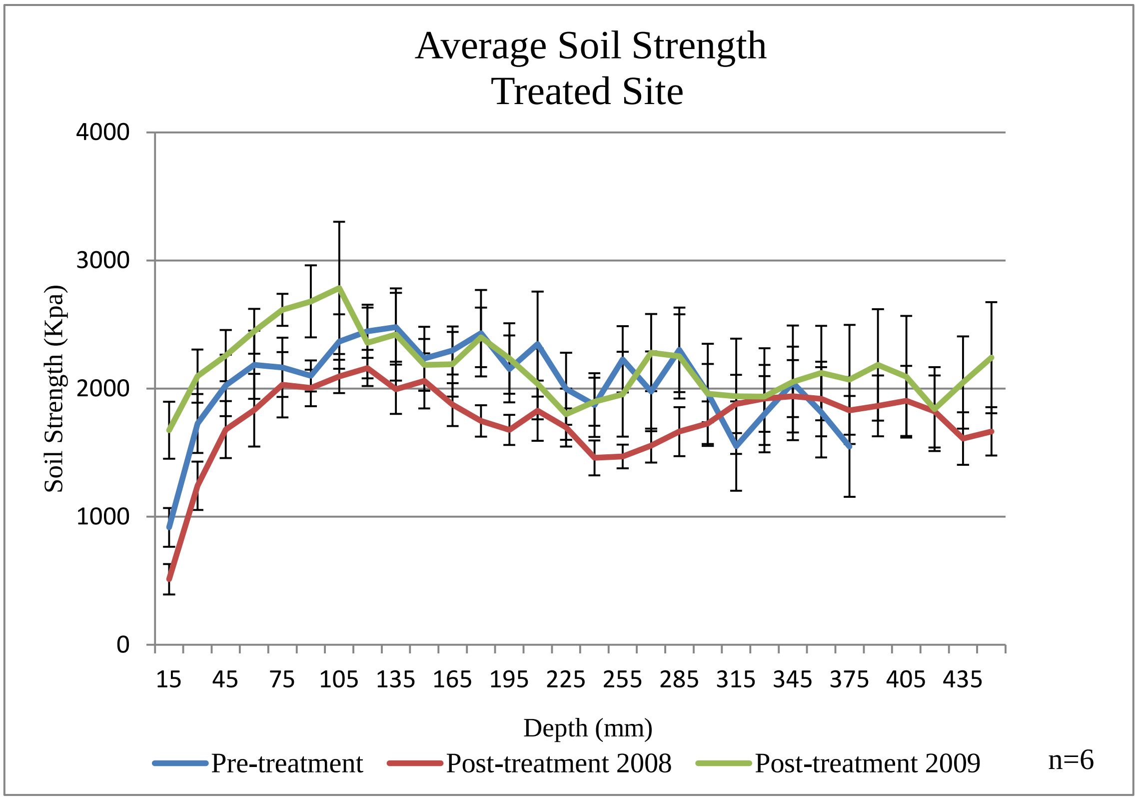

Figure 32. Average soil strength by depth on the treated site.

Streambank Stability

Monitoring Question: How was the stability of the stream channel affected by the fire and post-fire treatments?

Effectiveness Criteria: No significant stream channel incision or avulsion (presence of active headcuts or rills and gullies).

Figure 33. Placing a coir log in stream channel on the Mule Deer parcel, 2007.

Treatment and Background: A small, first order recurring stream runs down the center of the Conservancy-owned Mule Deer parcel. During the Summer and Fall of 2007, following the Angora Fire, several measures were taken to stabilize this drainage. Masticated material was kept out of the Stream Environment Zone (SEZ) surrounding this drainage, but pine needles were spread within the area to minimize bare ground. Coir logs (made of coconut fiber) and tree logs were dug in to the channels themselves to slow the momentum of running water and to catch sediment that would otherwise be delivered from the channel (Figure 33). Following the period of Spring 2008 runoff, sediment began to build up behind the coir logs and contour logs within the larger SEZ. This sediment was dug out, and the coir logs were armored with large rocks and logs to increase their sediment capture potential and avoid sediment overtopping these features. Also, additional pine needles were spread within the SEZ in order to further decrease the proportion of bare ground.

During the winters directly following the fire, precipitation was below average and fell primarily as snow, reducing the erosion potential of the site. Oliver et al. (2011) found that the total precipitation in water year 2008 and 2009 was 31 and 41 inches respectively, which is less than the 26 year average of 46 inches per year. In 2008 most came during the winter as snow, while in 2009, there were more late spring rains.

Monitoring Methods: Stream channel longitudinal profiles were done in Fall 2007 and 2008. The channel's elevation was surveyed for 1000 feet – along the entire project reach. One benchmark was established at the uppermost point of the channel along with several more throughout the channel. Benchmark elevations were recorded to the nearest hundredth foot. A total station survey instrument was located to minimize the number of times repositioning was needed. One surveyor extended a measuring tape down the deepest part of the channel (the thalweg) while holding a stadia rod to allow the other to measure the elevation in hundredths of feet and horizontal distance within the nearest tenth of a foot at regular intervals (see **Error! Reference source not found.**).

Figure 34. Conducting the stream longitudinal profile survey. Fall 2007.

Measurements were also taken at important bed features including the position of coir logs and woody debris. Additional surveys planned in 2009 and 2010 were not done since very little change was detected.

Data Summary and Analysis: Longitudinal profile survey data from 2007 and 2008 were compared to determine the degree of scour and fill, and the net change in elevation along the stream profile. Elevation data were entered into a simple model that calculates net change.

The results indicated that the channel scoured 61 square feet of two dimensional area (channel length versus channel bed elevation) and filled 157 square feet of stream bed area after one season. This represents a net increase in area from 2007 to 2008 of 96 square feet. In the following section we calculate the wetted area of the channel to be 2,250 square feet. Therefore, 96 square feet of filling represents 4% of the wet channel area. The filling can be attributed to sediment deposition behind coir logs placed in the channel. These can be seen as slight changes in elevation in the 2008 profile (Figure 35).

These results and field observations indicate that there was no overall change in the vertical stability of the stream channel in the first year following the fire. Stream channel treatments most likely contributed to stability, though firm conclusions cannot be reached since no untreated comparison channel was monitored. It should also be noted that the winter of 2007-2008 was a below average precipitation year, with minimal fall rains and no significant rain-on-snow events.

Vegetative growth in the relatively wet stream area has been vigorous (See Figure 36) contributing to channel stability. The channel continues to appear stable as of January 2012, with very few rills on the side slopes entering the channel.

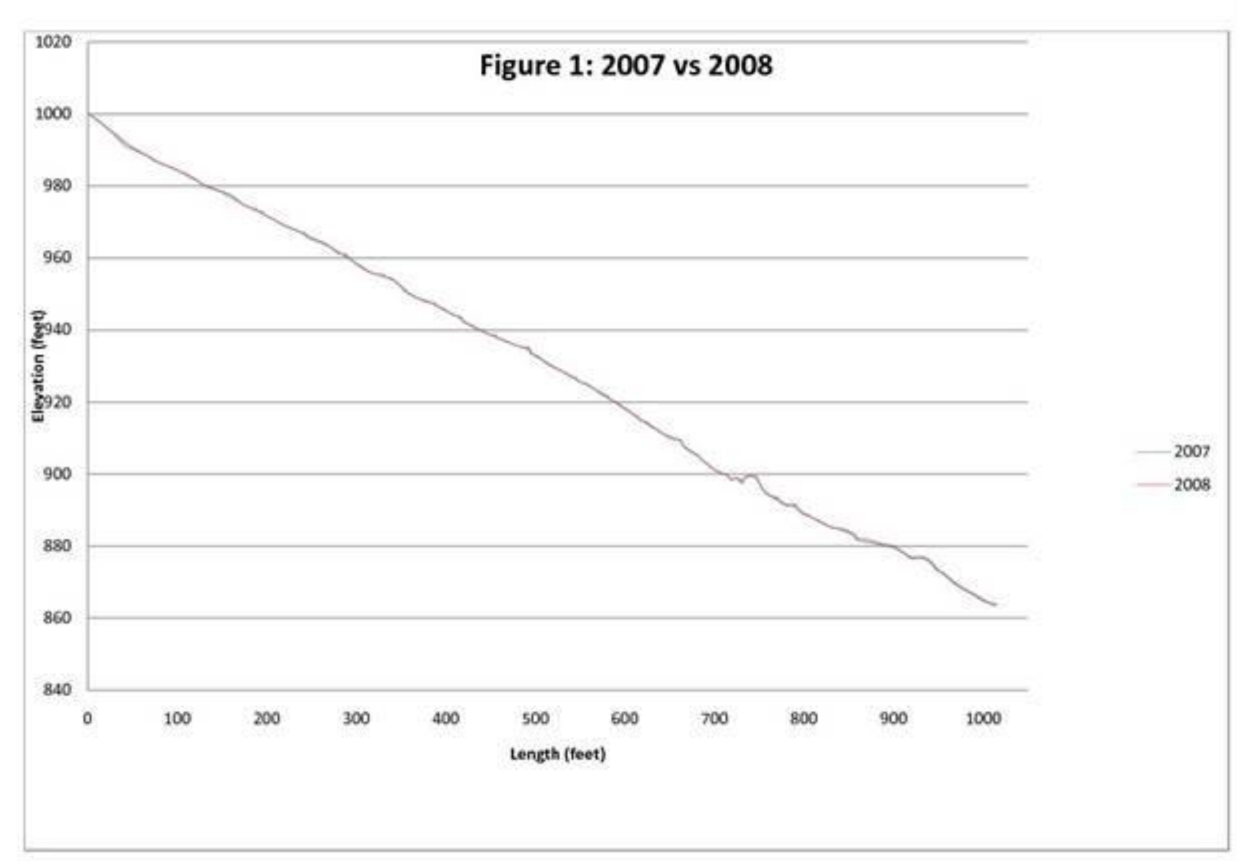

Figure 35. Longitudinal profile of the Mule Deer main channel in 2007 and 2008. Very little change can be seen.

Answer to Monitoring Question:

How was the stability of the stream channel affected by the fire and post-fire treatments?
The stream channel remained stable following the fire and restoration treatments.

Next steps: No repeat longitudinal profile surveys are planned since very little change has been detected.

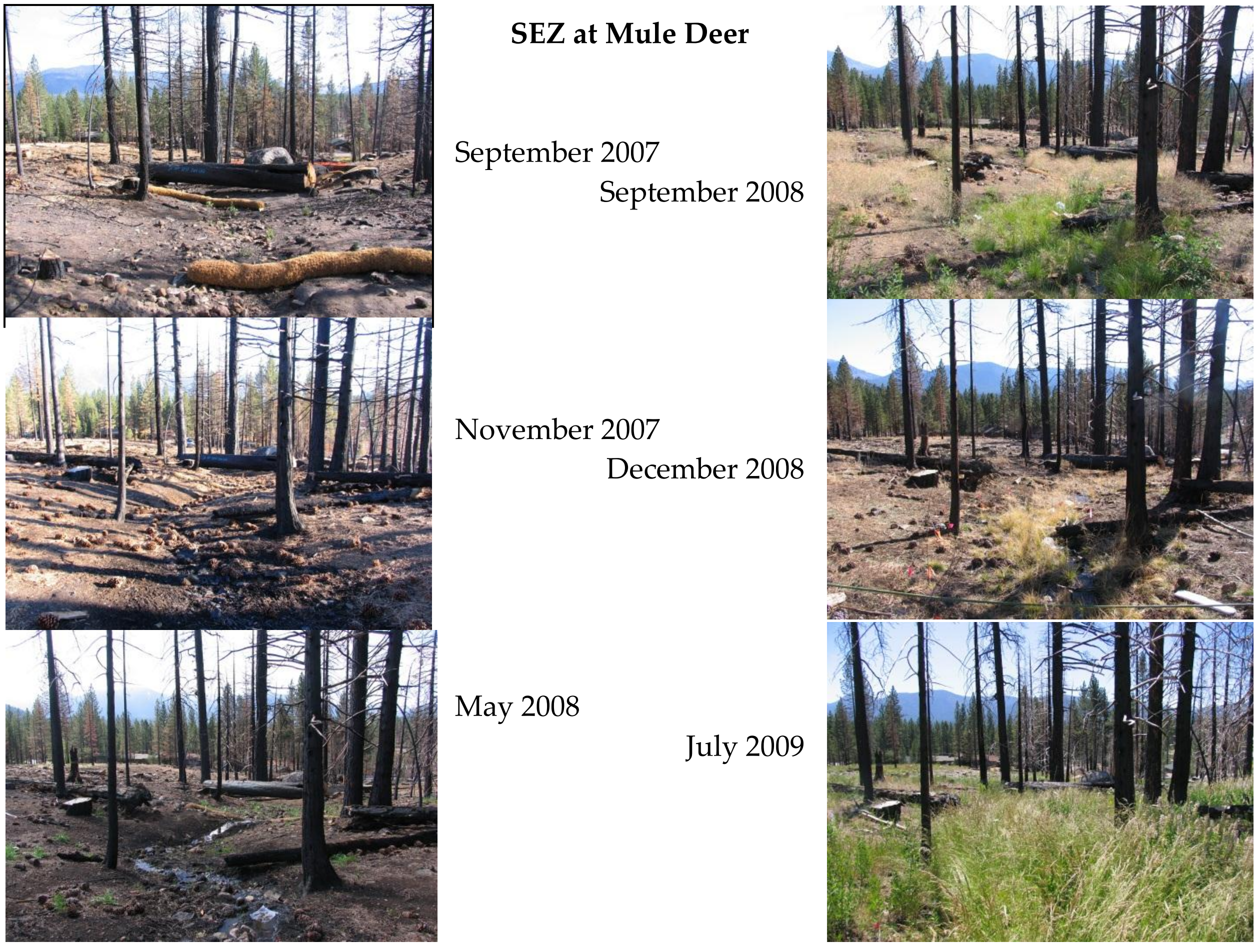

Figure 36. Photo series of one channel photo point at six different visits, September 2007 to July 2009.

Soil Erosion

Monitoring Question: Did erosion control practices minimize soil erosion from burned areas?

Effectiveness Criteria: There will be 50% less captured sediment volume than predicted from unmitigated sediment flux following fire.

Treatment and Background: During the Summer and Fall of 2007, following the Angora Fire, several erosion control measures were taken to minimize the amount of sediment delivery to Angora Creek via the first order, intermittent stream on the Conservancy-owned Mule Deer property. Across the property, dead standing trees were masticated and the resulting material was broadcast on the site to stabilize soils. Small trees were felled on contour to detain any sediment produced. Within the SEZ, pine needles were scattered and coir logs and dead trees were arranged to minimize erosion within the channel itself.

As described in the previous section, precipitation in 2008 and 2009 was below average and fell primarily as snow, reducing the erosion potential of the site.

Monitoring Methods: A series of sediment capturing silt fences was built across the main channel on the Mule Deer property. This channel bisects the lower part of the parcel and contains runoff in the spring months, remaining somewhat wet all year. Fences were located to capture the greatest possible proportion of sediment transported via the channel. The assumption was that the sediment captured by the fences evaded erosion control measures and would have otherwise been transported to Angora Creek and Lake Tahoe. In October 2007, five fences were installed near the base of the drainage, where two main channels merge into one before being directed through a culvert. Figure 37 shows the layout of these fences. For more details on construction, see Wade and Kocher (2011).

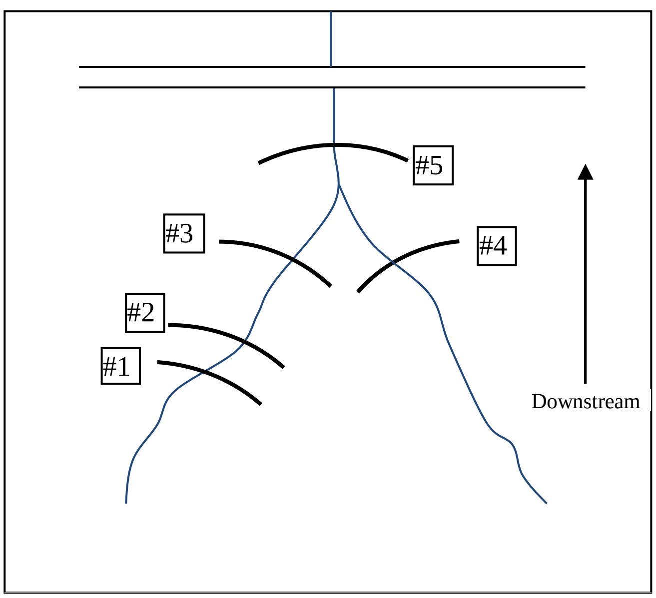

Figure 37. Monitoring silt fences installed in the main drainage, October 2007.

Sediment Volume

Sediment was removed from the silt fences each year in the spring or summer once the water had drained (Figure 38). Removal of sediment following each significant runoff event was not feasible due to retention of water following these events. Sediment was excavated using shovels and hand trowels, deposited in buckets, and weighed. Soil from each fence was mixed well and a sample was taken and weighed, then dried and weighed again to yield a ratio of dry to wet weight. This was used to calculate the dry weight of sediment captured by each fence.

Figure 38. Monitoring silt fences holding sediment and water, late Winter 2008.

Sediment was collected from the fences in spring 2008 to yield an estimate of sediment delivered during the 2007-2008 water year. Sediment was collected again between July and August 2009 once the channel and fences dried up after a particularly wet spring/early summer.

Contributing Area Delineation

The drainage area contributing to the channel was delineated in Spring 2008 by walking the perimeter with a GPS unit. The edges of the contributing area were estimated visually using topographic indicators of water and sediment flow patterns. GIS was then used to estimate the size of the contributing area (42 acres). The area of the channel was calculated by multiplying the length of the channel above the silt fences (750 feet) by the wetted width of the channel (3 feet) to yield an area of 2,250 square feet (0.05 acres). The streamside area around the channel that appeared to contribute sediment to it measured about 20 feet wide, which leads to a larger channel area estimation of 15,000 square feet (0.34 acres).

Ground Cover Assessment

The percentage of ground covered within the channel area was measured in Spring 2008. Two transects were established, running up the left and right sides of the drainage, 10 feet from the center of the channel. Each transect was 700 feet long, and a ground cover condition (bare, vegetative or woody cover) was assigned at a point every 20 feet, beginning at the top silt fence. Ground cover was measured as 65% in Spring 2008 and 82% in Fall 2008 after additional ground cover, mostly pine needle litter, was applied.

Data Summary and Analysis:

Captured Sediment Volume

Table 7 shows the corrected dry weight of sediment collected from each fence. Total weights of sediment are graphically displayed in

Figure *39*. A total of 932 pounds (0.47 tons) of sediment were collected after the first winter and 697 pounds (0.35 tons) were collected after the second winter following the fire.

Table 7. Summary of Sediment Collected from Silt Fences

	Dry Sediment Collected (lbs)		
	2008	***2009***	***Total***
Fence #1	531	243	774
Fence #2	296	360	656
Fence #3	71	57	128
Fence #4	0	28	28
Fence #5	34	9	43
Total (lbs)	***932***	***697***	***1629***
Total (tons)	***0.47***	***0.35***	***0.81***

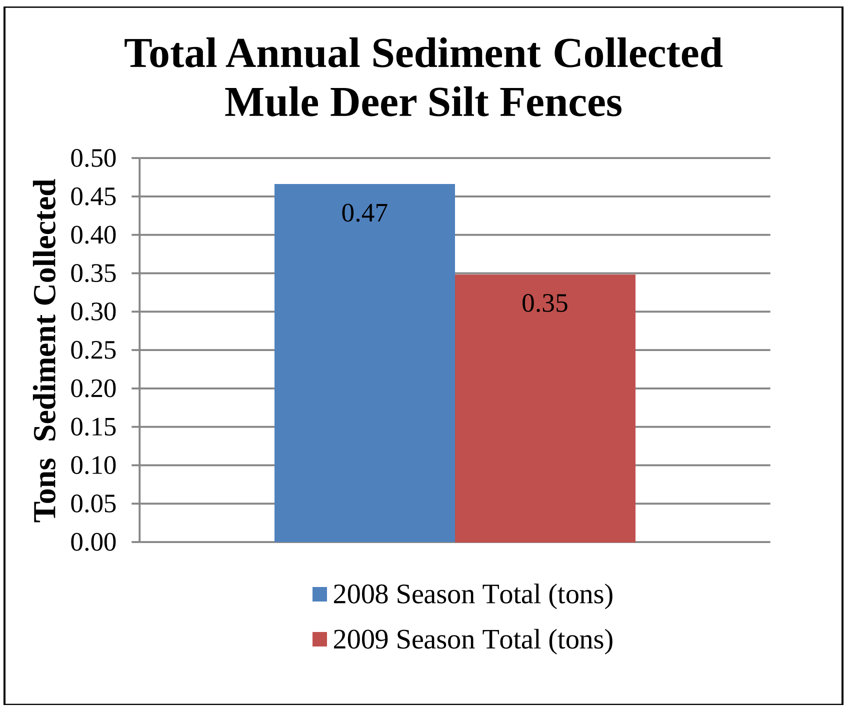

Figure 39. Graph of sediment collected from silt fences, 2008 and 2009.

Source of Sediment Delivered

Observations suggest that the dominant process of sediment transport in the study area was lateral channel erosion. There is some visual evidence of lateral migration and widening of the channel. Longitudinal profile measurements made at the site (see the Streambank Stability section) show little to no vertical incision within the channel. A very small amount of rilling was observed in 2008, and greater sheet wash is assumed to have occurred that year due to lower percent ground cover than the following year. Channel erosion may have been exacerbated by increased flows from the upper watershed resulting from complete removal of vegetation within the entire 42-acre contributing area, which extends up a steep slope to the top of a ridge.

In addition, sediment transported by the channel does not appear to be coming from above the channelized portion of the watershed. Observations revealed no evidence of overland flow in the area and relatively uniform cover would likely limit most sediment from being transported into the channel. At the top of the channel is a spring, suggesting that flow uphill of this point is largely underground.

This is consistent with results found by Moody and Martin (2009) who report that, across the western United States, about 75% of the coarse sediment yield after fires comes from channels, while only about 25% comes from hillslopes.

It is unclear how much sediment escaped through or over the silt fences, although the amount of sediment lost seems minimal. Inspections downstream of the fences did not show obvious areas of deposition. Similar fences evaluated in other studies have shown a trapping efficiency of over 90% for the first two years of use (Robichaud et al. 2001).

Sediment Yield

Sediment yield depends upon the area used to normalize the sediment collected, which is difficult to estimate and is influenced by many factors. Yield is calculated in Table 8 using three different contributing areas. Yield based on the total drainage area of 42 acres is very low, only 0.01 tons per acre in 2008, and 0.008 tons per acre in 2009. Yield based on the contributing area of the channel's wetted width is 9.1 tons and 6.8 tons per acre in 2008 and 2009 respectively. Yield based on the streamside area is 1.4 and 1.0 tons per streamside acre in 2008 and 2009.

Table 8. Sediment Yield from the Main Channel, 2008 and 2009

	Sediment Collected (tons)	
	2008	**2009**
Sediment collected from silt fences	0.47	0.35
Sediment Yield (tons per acre)		
Based on entire drainage (42 acres)	0.01	0.008
Based on streamside area (0.34 acre)	1.4	1.0
Based on channel wetted width (0.05 acre)	9.1	6.8

Since no comparable burned swale that did not receive erosion control treatments was available as a control, reference data from other post-fire research was used for comparison (see Table 9). Sediment yields measured using the same sediment fence methodology after the Pendola Fire in Yuba County ranged from 0.45 to 8.09 tons per acre (personal communication – Drew Coe, Central Valley Regional Water Quality Control Board 2009). Moody and Martin (2009) synthesized post-fire sediment yields within the first two years after wildfire throughout the western United States. The synthesis includes 25 studies using similar channel volume collection methodology to measure sediment yield within a similar rainfall regime. These studies found a range of post fire annual sediment yields of 0.06 to 1249 tons per acre in the first two years after the fire. Average and median yields were 125 and 23 tons per acre respectively.

Table 9. Sediment Yield Comparisons from Other Fires

Sediment Yield Comparisons from Other Fires (tons per acre)		
	Maximum	Minimum
Pendola Fire - Yuba County, California	8.09	0.45
Range from 25 similar studies in Western United States	1249	0.06

In any study, the actual area contributing sediment is unknown, but Moody and Martin (2009) assume in their synthesis that the contributing area for sediment volume measurements is the entire drainage area upstream from the measurement site. Coe (personal communication, 2009) also suggested that this conceptualization of contributing area is reasonable and commonly used. Therefore, assuming a 42-acre contributing area, sediment yields within the Mule Deer drainage are well below those measured in other studies. Furthermore, even if the channel area is used to calculate sediment yield, the maximum yield of 9.1 is well below the average and median yields reported by Moody and Martin (2009).

We conclude that the erosion control measures, which left a high percentage of the drainage and channel area covered, were effective at minimizing erosion. The extraordinary quality of the 2007-2008 winter, in which rainfall was below normal, there were no rain-on-snow events, and the melting period was slow and gradual, also contributed to the very low sediment yields measured compared to elsewhere.

This conclusion is consistent with intensive water quality monitoring that showed minimal water quality impacts from the Angora fire. Oliver et al. (2011) concluded that “erosion control efforts, below average annual precipitation and the timing of its arrival (absence of summer and fall rainstorms), and the existence of a wet meadow below the burned watershed likely reduced the negative impacts that would have been expected from such a severe wildfire.”

Preliminary Answer to Monitoring Question:

Did erosion control practices minimize soil erosion from burned areas?
Yes, it appears that erosion control measures were effective at mitigating the potential for increased sediment delivery within the studied channel. Though we are lacking a directly comparable, burned, unmitigated swale, the mass of sediment collected was considerably lower than sediment yields measured in other studies of burned swales. The low amount of sediment collected was probably also a product of the relatively mild years directly after the fire, especially the winter of 2007 during which very little rain fell.

Next steps: Data collection for this portion of the monitoring plan is concluded.

CONCLUSIONS AND SUMMARY

We conclude that the active restoration approach used by the Conservancy has expedited the return to a forested condition by about 60 years. Planting native conifer seedlings and suppressing competing brush by leaving masticated material on site spurred development of a new forest in an area where very little tree seed source remained.

Dead tree removal using heavy equipment does not appear to have significantly compacted the soil in the treated area. Erosion control measures were effective at maintaining the stability of the channel and reducing the amount of soil leaving the site, although the mild winter experienced immediately after the fire no doubt was critical in reducing any soil erosion impacts. It is unknown whether erosion control treatments would have been successful under more intense hydrological events.

Although the masticated material left on site was effective at minimizing soil erosion, it does form a layer of surface fuels that carry some level of elevated wildfire risk in the short term. The exact risk cannot be calculated at this time as computer models to not accurately predict wildfire behavior in masticated fuels. It is unclear whether fire behavior would be more severe on the treated site or on the untreated site, where brush and dead standing trees are abundant. It is generally accepted, though, that a wildfire is less likely to start and easier to contain in masticated fuel beds because compaction robs it of needed oxygen.

In addition, the high density of standing dead snags in the untreated area will eventually fall to the ground as surface fuel onto the robust understory of flammable brush. The amount of time it will take for fire risk on the treated parcel to decrease as the masticated material decomposes versus the amount of time it will take for the risk on the untreated land to increase is not known. Fuel loads may be monitored as they change over time, and as modeling capabilities improve, simulations of current and future potential fire behavior may become possible. We hope to learn more about the timing and tradeoffs that resulted from the mastication treatment through additional monitoring of ground vegetation and seedling data in the future.

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