Angora Fire Vegetation Monitoring
Annual Progress Report October 2009

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Introduction

The Angora fire burned approximately 3000 acres of Jeffrey pine and mixed conifer forest between June 24 and July 2, 2007. Much of the fire burned at a high severity due to strong winds, unseasonably dry fuels, and high forest fuel loadings. The Angora fire destroyed 254 homes, and final loss plus suppression costs totaling about $160,000,000 place it among the costliest wildfires in US history. The fire also burned 480 acres of fuels treatments intended to modify fire behavior, and protect public and private assets in the Angora Creek watershed. These fuel treatments were shown to have reduced fire severity in most treated stands (Safford et al., 2009). Notable exceptions to treatment effectiveness were two treatment units, where fuels were less effectively removed from the stand, due to treatment limitations on steep slopes, and residual slash piles. Treatments also provided a safe zone for firefighters and decreased smoke and heat production, increasing suppression efficiency and saving some homes (Murphy et al., 2008).

Although the Angora fuels treatments are a success story, much of the fire burned at very high severity, with about 53% of the fire experiencing >75% canopy mortality based on a remotely sensed index (Relative differenced Normalized Burn Ratio; Miller and Thode 2007). Because much of the fire is situated on steep slopes, and near trails and houses, the high severity has prompted concerns over the state of post-fire vegetation recovery, including concern about hazard trees, erosion, tree regeneration, stream sedimentation and future forest fuel loading, among other things. Managers from the USFS, California Tahoe Conservancy and private landowners have responded to these concerns using a variety of management tools (hazard tree removal, hydromulching, seeding, tree planting, streambank stabilization, sediment capture areas, etc.; see BAER report, 2007 and Angora Fire Restoration Project Proposal, 2009).

In 2008, researchers from the University of Montana established plots throughout the burn to document fire effects on vegetation, and to establish baseline information for long-term monitoring of vegetation regeneration, tree mortality, and fuel loading. Data collected in 2008 were used in Safford et al. (2009) which documented how fuels treatments affected fire behavior in the Angora fire. Vegetation data have also been shared with researchers studying wildlife diversity response to burn intensity and treatment history (Manley et al, 2008; SNPLMA proposal). A subset of the initial plots were revisited in 2009 to assess the efficacy of fuels treatments, wildfire effects on vegetation regeneration and mortality, and fire and management effects on stand carbon budgets.

In this document, we present initial summaries of data collected in 2008 and 2009, including information on: fire effects on trees and tree mortality, stocking levels and rates of conifer regeneration, post-fire surface covers, fuels, and plant diversity. Although results presented in this report are generally descriptive, they provide a snapshot of vegetation conditions two years after the Angora fire, and may prove useful to future management decisions. Note that this report does not focus on comparing forest stands that were treated for fuels before the fire versus untreated stands, as a fairly complete summary of those results was recently published in Safford et al. (2009). We plan to continue our monitoring in 2010, with further measurements expected in 2012 and 2017 (5 and 10 years after fire).

Methods

In the summers of 2008 and 2009, crews from the University of Montana surveyed eighty-two 1/5th acre plots on a 400m regular grid in and around the Angora burn area using USFS Region 5 common stand examination (CSE) protocol for fixed area plots. Unburned plots were not re-visited in 2009. Two-hundred thirty-three 1/70th acre (14.07 ft radius) "regeneration" plots were also established on a 200m grid, with each CSE plot having a co-located regeneration plot. Plot centers were found using a handheld Trimble GPS unit. The centers of CSE plots were marked with a rebar and orange cap, and by tagging "in" trees with aluminum tags (#1-1900). Yellow or orange Pin flags and yellow/black striped flagging were used to mark regeneration plots.

Common Stand Exams

At each CSE plot, we followed guidelines for Intensive level plot surveys, collecting information on: trees, species composition and cover, vegetation and ground cover, fuel loading, and treatment history. Plots had a fixed area of 1/5th acre, with a 52.7' radius, adjusted for slope. Complete information on CSE protocols can be accessed online (USDA, 2008), but will be briefly summarized here.

Tree data: Within each plot, we tagged and mapped all trees above 5" DBH for live trees, and 10" DBH for dead trees. For each tagged tree, we recorded diameter at breast height (DBH), species, damage, and mortality. For tagged trees surviving fire, we also recorded surviving crown ratio, percentage bole char, percent crown scorch/torch, height to live crown, and crown class. Trees marked as live in 2008 were revisited in 2009 and further damage or mortality was noted. A subset of tree heights were recorded at each plot, and over 200 trees were cored in 2009 for growth calibration of the Forest Vegetation Simulator for future research. Trees below the DBH threshold were counted and tallied by species, mortality status, and diameter (0-5" and 5-10"). In this document, we present tree information by stems per acre, and basal area (ft^2) per acre when possible, using an expansion factor of 5 (for 1/5th acre plot size).

Plot data: At each plot, we recorded the slope, azimuth, horizontal and vertical shape, hillslope position, fuel model, CalVeg type, and observed fire severity (see Table 1 for definitions). Remotely sensed burn severity and elevation values were assigned to each plot using ArcGIS. Photos were taken from 50'-60' south of plot center looking north.

Cover estimates: Ground surface covers were optically estimated, with cover of bare, rock, gravel, litter, wood, shrubs, forbs, and grasses adding up to 100% (see CSE protocols for complete list of possible covers). Mulch cover was estimated as a separate value. Trace covers were recorded as .5%. Covers of each lifeform (tree, shrub, graminoid, forb) were also made optically. In 2009, we separately estimated cover by mortality status for trees and shrubs. Covers were also estimated for each species present on the plot, and separately for live and dead covers of tree and shrub species.

Species composition: Each species occurring within the plot was recorded. Graminoid species were only identified to type (grass, reed or sedge) in most cases. Plant age and flowering status made identification to species difficult for some plants. In such cases, we either assigned a genus only (e.g. *Aster* or *Epilobium*) or recorded it as unknown. Identification of fire killed trees was sometimes difficult, most often when distinguishing between Red or White fir, and Sugar or Western White pine. Species codes were taken from the USDA PLANTS database (USDA, NRCS, 2009). Sampling began at the end of May, and finished mid-August both years.

Fuel Transects: Four 50' long Brown's fuel transects were established at each plot. Transects began at plot center, and ran in cardinal compass directions. Fuels were counted starting at the ends of transects away from plot center. One and ten hour fuels (0-0.25" and .25-1") were counted for 10' on each line, hundred hour fuels were counted for 25', and coarse woody debris (>3") was sampled for the entire length of each transect, recording piece diameter and decay class. Duff and litter depths were taken in cm at 25' and 50' on each transect. Fuel loadings for fine and coarse woody fuels were estimated following guidelines in Brown, 1974.

Plot History: At each plot, we compiled a list of histories as per CSE protocol. Common histories included natural tree regeneration, planted tree regeneration, recent thinning, past thinning/logging (as determined by stump rottenness and FACTS information), tree cutting (trees left), salvage cutting (trees taken), and roads/trails, etc. We tallied all visible thinned, salvaged, and older thin/log stumps by 5" increments. Hydromulch presence was recorded in 2008 and 2009– in areas where it was thinly applied, the mulch was much less noticeable by 2009

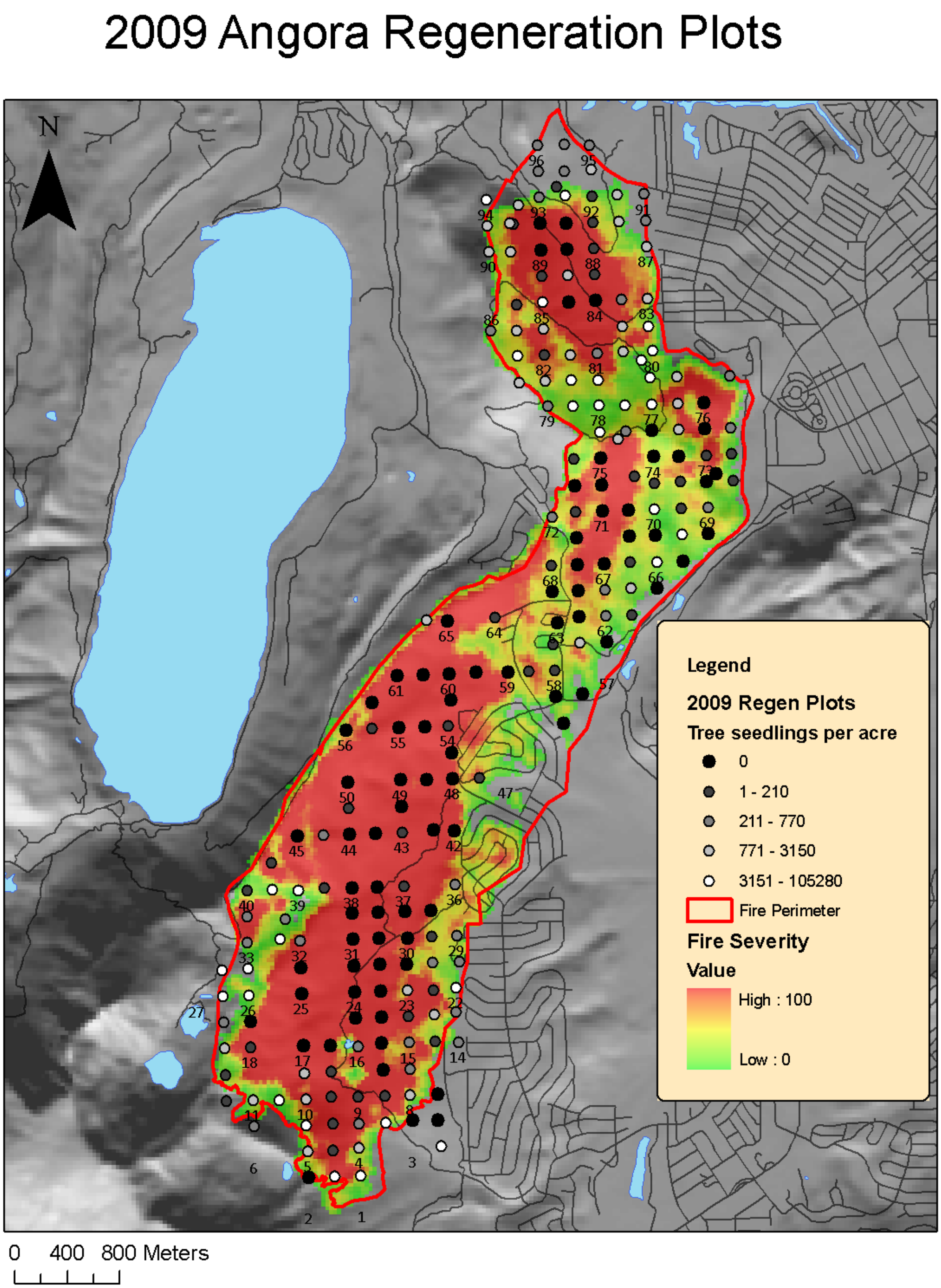
Regeneration plots

We used protocols developed in 2008 that are being used by the Forest Service as a standard to track post-fire regeneration patterns in the California National Forests. We visited 233 plots throughout the fire in 2009, 224 of which were also visited in 2008 (with some of these plots being outside the burn). Plots were 1/70th acre in size (14.07 ft radius). We recorded standard plot measurements including aspect, slope, vegetation type, fire severity, and plot treatment history (thin, old thin, salvage, tree planting, invasives). Stand basal area was estimated at each plot using a Relaskop with BAF of 20 to tally live and dead trees. We estimated covers of bare ground, litter, rock (>1" in size), coarse woody debris (>3"), vegetation, and shrub cover at each plot, as well as overhead live and overhead dead canopy cover percent. We recorded the species and diameter of trees surviving fire. For every shrub species within the plot, we estimated cover and modal height, and noted invasive species presence and cover. Post-fire tree seedlings were counted by species, and the height and age of the tallest individual recorded. If tree seedlings were not found in the plot, we searched within a 50' radius and recorded the species, distance and azimuth to the nearest (post-fire) tree seedling. We recorded the distance, azimuth, and species of the nearest seed source (some plots had no seed source visible and were assigned a value of 1000 ft). We also measured soil depth with a tile probe for most plots in 2008. Distance and azimuth measurements were generally taken with a True Pulse 360 Laser Rangefinder, and plot photos were taken from the southern plot edge facing north. We present tree regeneration rates on a per acre basis using an expansion factor of 70 (for a 1/70th acre plot).

Table 1. Definitions of observed fire severity

Severity rating	Description
0	**Unburned.**
1	**Low severity:** Patchy burning, <100% area burned. Minor overstory mortality, some understory shrubs and seedlings survived. Light charring of duff and litter.
2	**Light burn**: Isolated overstory mortality, most understory plants dead but not consumed.
3	**Moderate burn:** Mixed overstory mortality, understory plant dead and mostly consumed.
4	**High Intensity ground:** Most of overstory trees killed, but fire was not carried through crown. Some isolated and group torching possible. Dead needles and small branches remaining on most trees 1 year post fire. Understory plants killed and consumed.
5	**High intensity crown:** Most overstory trees killed by a sustained crown fire. Few needles remaining 1 year post fire, complete combustion of understory.

Figure 1: Map of Regeneration plots visited in 2009**.** Common Stand Exam plots are labeled by plot number, but not drawn.



RESULTS

Fire effects on trees: Mortality and survival

Based on 68 burned CSE plots, we estimate pre-fire median stem density as 195 stems per acre, and median basal area as 181.53 ft^2 per acre (red dashed lines, figure 2). These numbers are comparable to sampled control plots (blue dotted lines figure 2), and variable probability sampling (using a prism) estimates from regeneration plots (not shown). Except for plots in fire severity 1, the median basal area of all burned plots is similar, regardless of fire severity. However, there is a trend of increasing fire severity with higher stem densities (figure 2). The single most dense plot did not experience extreme fire behavior (plot 39), in part because it is located in a topographically shaded drainage at a high elevation.

Table 2: Count of CSE plots in burned area, and estimates of acres represented. *Because we did not establish plots there, we excluded the acreage in the burned neighborhood northeast of Mt. Rainier Circle to the bottom of Boulder Mtn. drive., an area of about 150 acres.

Observed Fire severity	Number of CSE plots	Est. % of burn area	Estimated number of acres
0	12	**NA**	**NA**
1	3	3 / 68 = 4.4%	120
2	16	23.5%	642
3	16	23.5%	642
4	13	19.1%	523
5	20	29.4%	803
Total:	80	100%	2780 (of 2930)*

One year after fire, stands which burned at a low severity had higher tree survival rates, and more surviving basal area per acre than more severely burned areas (Table 3). Surviving basal area per acre ranged from a mean of 151.4 ft^2 per acre in stands with low fire severity, to 25.08 ft^2 per acre in stands experiencing high mortality but no crown fire, and to less than 2 ft^2 per acre in the most severely burned stands (table 3).

Trees with a large diameter had the highest survival rates, with more than 40% of all stems over 20” surviving fire (Table 4). Before fire, the median diameter of all stems was 13.8”, but because larger trees survived at a higher rate, the median diameter of trees surviving fire was 14.5”. Second year mortality further increased the median stem diameter of live trees to 14.8”. Before fire, 15-20” trees had the highest basal area but because larger diameter stems had higher survival rates, trees between 20-25” had the highest basal area per acre after fire.

In 2009, we revisited all tagged live trees within the burned plots and checked for second year mortality and damage. Out of 564 tagged trees surviving the first year after fire on our plots, 11% (64 stems) died in the second year. White fir accounted for 44% of second year mortality, Jeffrey pine 36%, Sugar pine and Lodgepole pine 9.5% each, and only a single Incense cedar died in the second year. USFS Region 5 salvage marking guidelines (based on Hood et al., 2007) use percent crown length kill and cambium kill to predict delayed conifer mortality following fire. Hood et al. (2007) also found that diameter at breast height is also a significant predictor of post-fire mortality for most species. Although we did not sample cambium damage, we found a strong relationship between percent crown surviving, and second year mortality, but not between diameter and second year mortality (figure 3).

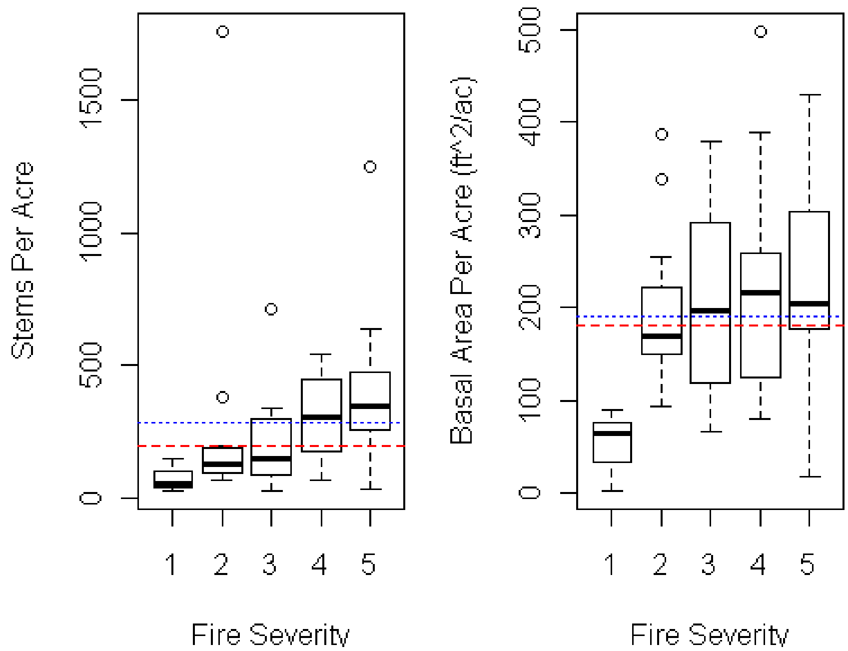


Figure 2: Summary of pre-fire basal area per acre, and stems per acre plotted by fire severity. All live and dead understory (>4.5 ft tall) and overstory trees are included in this summary. Red dashed and blue dotted lines represent median values from burned and control plots respectively.

Table 3: First year survival rates of stems and basal area by fire severity. We present survival rather than mortality rates because of difficulty identifying pre-fire snags in the more severe fire classes.

Fire Severity	Surviving stems/acre	Total Stems/acre	Fraction Stems Surviving	Surviving BA/acre	Total BA/acre	Fraction BA surviving
1	61.67	78.33	0.787	51.14	52.52	0.974
2	183.75	243.44	0.755	158.4	192.12	0.825
3	61.56	200	0.308	123.97	207.52	0.597
4	10.38	298.46	0.035	25.08	223.83	0.112
5	5.25	397.25	0.013	1.61	230.7	0.007

Table 4: First year survival rates of stems and basal area, by diameter class.

Diameter Class	Surviving stems/acre	Total stems/ acre	Fraction Stems Surviving	Surviving BA/acre	Total BA/acre	Fraction BA surviving
0-5"	21.40	108.26	0.20	0.72	3.76	0.19
5-10"	12.35	77.97	0.16	4.01	22.41	0.18
10-15"	10.07	43.70	0.23	8.28	36.31	0.23
15-20"	9.19	24.57	0.37	15.03	40.48	0.37
20-25"	5.74	12.75	0.45	15.42	34.43	0.45
25-30"	2.87	5.14	0.56	11.74	21.04	0.56
30-35"	1.03	2.10	0.49	5.85	12.06	0.48
35-40"	0.59	1.45	0.41	4.29	10.89	0.39
40" +	0.74	1.67	0.44	8.63	25.62	0.34

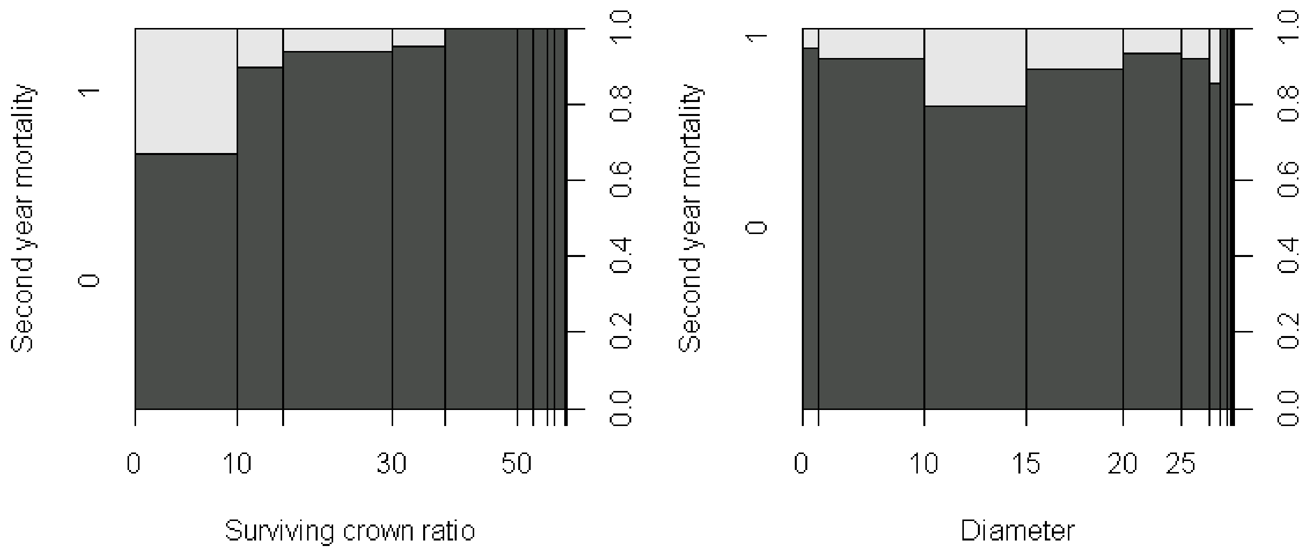


Figure 3: Second year mortality, plotted against surviving crown ratio, and diameter. On the y-axis, “1” and “0” indicate second year mortality and still surviving trees, respectively. Widths of columns along the x-axis are in proportion to the number of stems in that category.

REGENERATION

To grow into a mature tree, a seedling must first establish itself, requiring a seed source and proper conditions for germination (e.g. mineral soil, sufficient moisture, mycorrhizal presence). After establishing, a seedling must survive a number of potential mortality agents including herbivory, biotic (e.g. root competition) and abiotic stresses (high temperatures, water stress). After fire, conditions are favorable for conifer establishment as mortality of trees and shrubs reduces competition for light and water resources, and nutrients locked up in forest fuels are converted into forms available to plants. However, fire can also create conditions unfavorable to tree regeneration, when nearby seed sources are killed, or when canopy vegetation is killed, exposing seedlings to intense radiation. There is evidence that shrubs may facilitate the establishment of shade-tolerant White fir seedlings by reducing surface temperatures and evaporative demand (Oakley et al., 2006). However, this benefit is not extended to pine seedlings, which typically establish in drier microsites, and where more sunlight is available (Gray et al., 2005). Moisture has also been shown to play a strong role in seedling establishment and tree growth in the Sierras. Royce and Barbour (2001) found that Greenleaf Manzanita is more efficient than Jeffrey pine at extracting water from soils, potentially inhibiting establishment. Pulses of tree establishment have been shown to coincide with heavy precipitation years (North et al., 2005a).

There has been some concern over low rates of tree regeneration in the Angora fire, prompting proposals for widespread tree planting. In 2008, we found only 14 seedlings on 5 plots (for an average stocking rate of .07 seedlings per acre across the fire). The lack of first year regeneration may be partially due to the early burn date, when seeds had not yet matured in their cones, as well as the consumption of seedbeds in fire. However, we observed much higher rates of tree regeneration in 2009, finding fir (*Abies*) regeneration on 54% of plots, *Pinus* regeneration on 27% of plots, and either type on 62% of plots (Table 5; for this analysis, we lump regeneration by genus, due to identification difficulties described later in this section).

In 2009, we observed that mean seedling stocking rates (fraction of plots with seedlings) and seedling densities (per acre) decreased with increasing fire severity (table 5, figure 1). More than three-quarters of plots in lower intensity burns (severity 1-3) had seedlings present, and only one in ten plots did not have tree seedlings within 50' of plot center. In higher severity burns (severity 4-5), stocking rates dropped to 54%, with one in three plots having no seedlings within 50'. Lower severity burns averaged between 1000 and 2000 seedlings per acre, while the most intensely burned plots (severity 5) had an average of 106.67 seedlings per acre. The ratio of mean counts of *Abies* to *Pinus* seedlings was highest in lower severity burned areas, and the average distance to the nearest seed source increased with higher fire severity (table 5).

On each regeneration plot, we recorded any history of management activities (table 6). Although we have not yet analyzed how treatment history may have affected seedling establishment, it is notable that nineteen plots (8%) had been salvaged in 2007 or 2008, with another eight plots marked for salvage. Twenty-one plots (10%) had been outplanted with Jeffrey pine or Incense cedar seedlings. On planted plots, median stocking rates were 280 trees per acre.

Although we used a seedling identification guide (Franklin, 1961) to identify tree seedlings, some may have been misidentified due to their young age, and similar characteristics. We identified seedlings to species where possible, and genus when not. Young incense cedar seedlings were sometimes incorrectly identified as Fir or White fir seedlings, but we estimate that Incense cedar seedlings occurred on relatively few plots, and in small amounts. Throughout the summer, it became easier to distinguish between seedling species, and identification of all species should be possible in 2010.

Table 5: Summary of seedling stocking rates and densities on regeneration plots. Stocking density, number of regeneration plots, mean seedlings per acre, and mean distance to seed tree in 2009, grouped by fire severity. High mean values for *Abies* in fire severity 2 were partially driven by two very densely stocked plots)								
Fire severity	# of plots	Fraction plots w/out regen	Fraction w/out Regen in 50' radius	Mean *Abies* per acre	Mean *Pinus* per acre	*Pinus*: *Abies* ratio	Mean total regen per acre	Mean seed tree dist (ft)
0	19	.16	.05	1164.21	33.16	.028	1204.74	10.34
1	21	.33	.09	963.33	576.67	.598	1540.00	9.88
2	46	.13	.02	6458.26	447.39	.069	6905.65	7.50
3	45	.27	.09	1208.67	770.00	.641	1978.67	13.84
4	60	.50	.20	854.00	71.17	.083	925.17	167.13
5	42	.60	.35	101.67	5.00	.049	106.67	355.71
Total:	233							
Mean:		.33	.133	1996.31	335.61	.168	2331.92	120.87

Table 5b: Median seedling stocking rates by fire severity.					
Fire Severity	Number of plots	Median Total seedlings / acre	Median *Abies* / acre	Median *Pinus* / acre	Median seed tree dist (ft)
0	19	350	350	0	0.00
1	21	280	280	0	1.50
2	46	455	280	0	0.00
3	45	280	280	0	6.00
4	60	35	0	0	84.50
5	42	0	0	0	269.50
Overall median	233	140	70	0	15

Table 6: Counts of regen plots by plot history. Count column does not add up to 233 because 7 plots had three histories, and 20 plots had two histories	
Count:	History
46	Older thin or log (rotten cut stumps)
42	Recent Thin
40	Invasive (all prickly lettuce)
21	Tree planting
17	Salvage (trees removed)
8	Future Salvage
5	Various cutting (trees not removed)
129	No history

SURFACE AND SPECIES COVERS

Canopy and ground surface cover in a stand can affect multiple ecosystem processes, including erosion rates, surface temperatures and nutrient loss rates, factors which all may affect the type and amount of regenerating vegetation after fire. Sites with high amounts of bare soil, and steep slopes may be at risk for high erosion rates, threatening long-term site productivity, and Tahoe Basin water resources through sedimentation and nutrient runoff (BAER report, 2007). Johnson et. al (2009) found that fire results in annualized losses of nitrogen twice as large as any other factor, although the establishment of nitrogen fixing shrubs such as *Ceanothus* may replace lost nutrients due to fire within decades. Although sun and exposed mineral soil are generally considered helpful for Jeffrey and Sugar pine regeneration (when a seed source is present), the loss of canopy and surface covers with fire can also lead to higher surface temperatures and more negative water balances. Loss of canopy and surface covers may increase competition for limited water and nutrient resources, impacting the establishment, growth and survival of regenerating vegetation.

Two years after the fire (2009), more severely burned plots exhibited higher amounts of exposed bare ground and gravel cover, as well as lower litter cover (figure 4). Observations of high gravel cover were partially due to surface coarsening and soil erosion on steep, severely burned plots (see photo 3 in appendix 1).

Although severely burned plots tended to have less litter and more bare cover, they had similar shrub and forb covers as compared to more moderately burned plots (figure 5). This trend is partially driven by the location of a number of intensely burned plots near a water source where forb seedbeds were less impacted by burning, but also due to vigorous second-year growth by a few species of shrubs and forbs (photos 3 and 4, appendix 1). Many shrub species in the fire have adaptations allowing them to quickly re-establish after burning. Adaptations include heat-induced seed germination for the two most common species (*Ceanothus cordulatus* and *Arctostaphylos patula*), and vegetative re-sprouting for many other common shrub species including Huckleberry oak, and Bush chinquapin (Hauser, 2006; Reeves, 2007; USFS Fire Effects Information System). The approximate evenness of shrub cover across all burn severities two years after fire (figure 5) hides the fact that shrub cover in low severity plots (especially in areas which had prefire fuel treatment) is largely composed of resprouting shrubs, whereas shrub cover in high severity plots is primarily contributed by shrub seedlings which germinated after fire. Shrub cover due to seedling growth will probably result in high shrub cover values in many high fire severity areas in the coming years. Cover of other life forms (tree, graminoid, and forb) was lower in high severity plots than in low severity plots (figure 5). Although regrowth of any type of vegetation protects soil resources from erosion, a study conducted at the Teakettle Experimental Forest found that where shrubs were present, shade tolerant species (i.e. White fir) established more readily than drought-tolerant pines (Oakley et al.,2006).

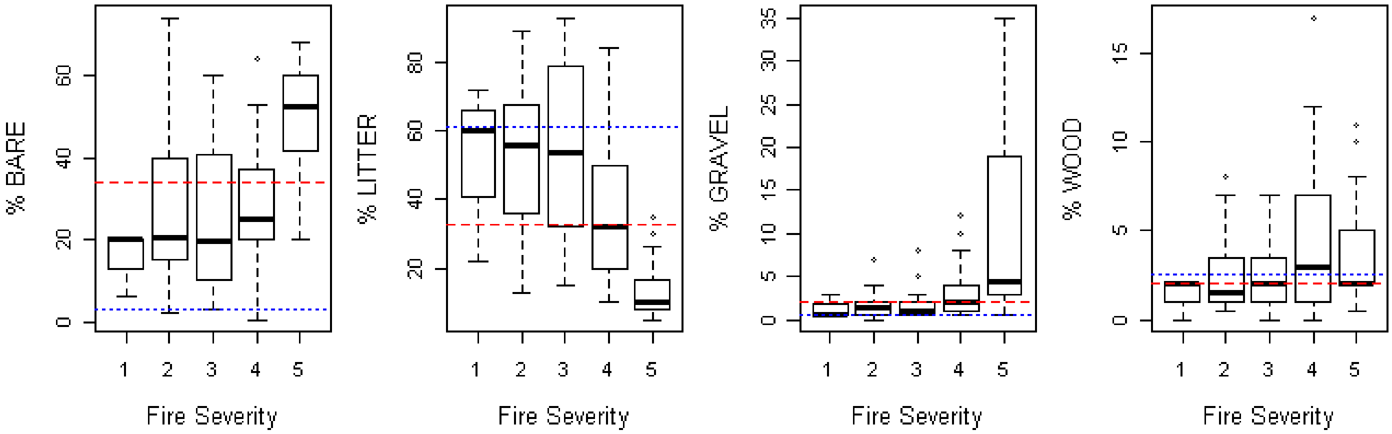


Figure 4. Percent cover of bare ground, litter, gravel, and wood on CSE plots in 2009, grouped by fire severity. Red (dashed) and blue (dotted) lines represent median values from burned and control plots respectively.

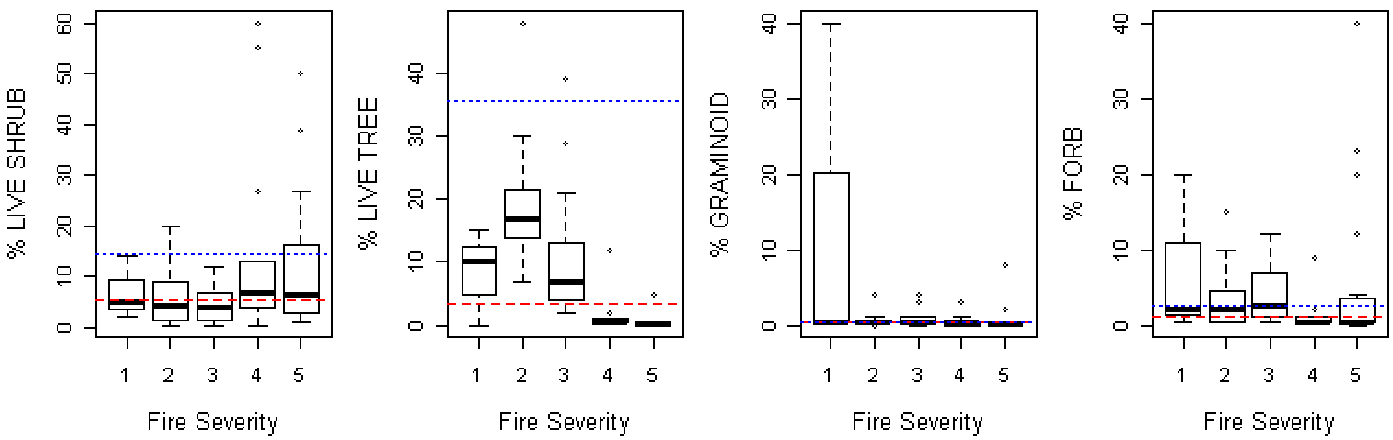


Figure 5. Percent cover of live shrubs, live trees, graminoids, and forbs on CSE plots in 2009, grouped by fire severity. Three of four outliers in forb cover values in burn severity 5 came from plots near streams in the southern portion of the fire (plots 30,37 and 48). Red (dashed) and blue (dotted) lines represent median values from burned and control plots respectively.

FUEL LOADING

Future fuel loads in the Angora fire area and their impact on potential flame lengths and suppression effectiveness are of great concern to managers. As of 2009, our results do not show strong trends in post-fire fuel loadings as related to fire severity. However, median loadings of 1 hour fuels are highest on plots assigned a fire severity rating of 4. These stands experienced high fire related mortality, but little consumption of canopy fuels. This type of stand may present a short term fuel hazard as fire killed trees drop twigs and branches to the ground, providing abundant small diameter fuels which are effective at carrying flame fronts. Eventually, smaller diameter litter will decompose, but tree fall will contribute to higher loadings of 100 hour and coarse woody debris, particularly in areas of high tree mortality. This is not likely to begin to occur for a number of years. We observed almost no treefall of dead trees in 2009, but subsequent monitoring will track treefall, and fuel loads over time.

In the Angora Fire Restoration Project proposal, managers identify 15 tons per acre (including logs) as the maximum desireable fuel load to maintain flame lengths of 4 feet or less in the event of a future fire (Angora Fire Restoration Project Proposal, 2009). The proposal outlines that activity fuels from proposed cutting would amount to up to 5 tons per acre, with additional fuels being removed via whole tree removal, chipping, mastication, and pile burning, leaving a maximum of 15 tons per acre on site. In 2009, we found that 23.5% of plots surveyed had estimated total fuel loads of at least 15 tons per acre, with 13% of plots having more than 30 tons per acre, although high fuel loading values were occasionally driven by a few large diameter logs. As such, the desired conditions stated in the Restoration proposal may be challenging to achieve in some areas, especially as trees fall and bring canopy fuels to the forest floor.

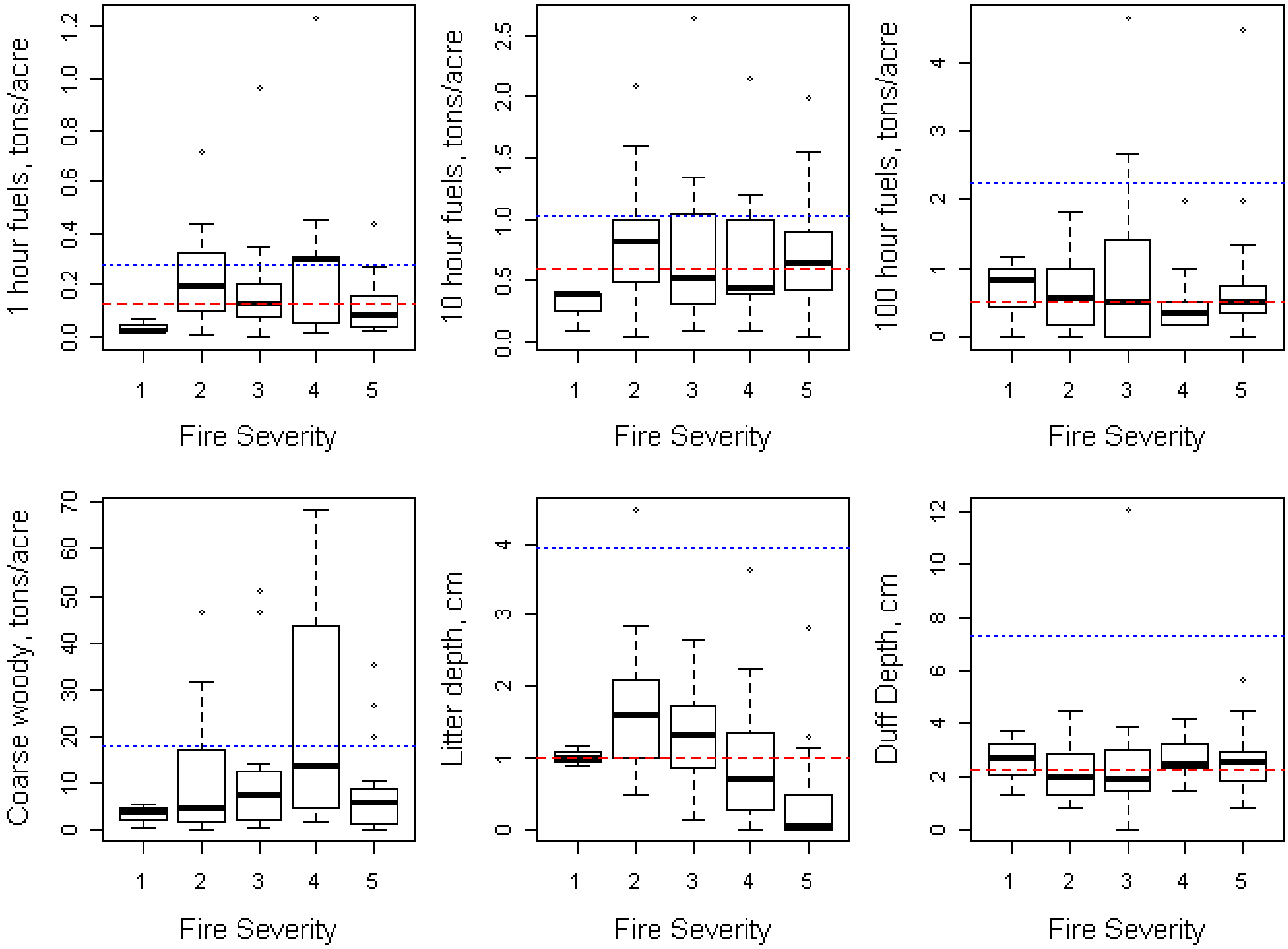


Figure 6: Fuel loadings (tons per acre) in 2009, litter, and duff depths on CSE plots, stratified by fire severity. Red (dashed) and blue (dotted) lines represent median values from burned and control plots respectively.

SPECIES DIVERSITY

Accross the 68 burned CSE plots, we identified over 170 different species. We identified 9 tree species, 28 shrub species, and 136 forb species (see Appendix 2 for a complete species list). In unburned Sierran forests, soil mositure, litter depth, and light conditions have been identified as having a strong influence on understory plant distribution, factors which are all significantly altered by the occurrence of fire (North et al, 2005b). Fire increases the amount of light reaching the forest floor, frees up water resources by killing vegetation, exposes bare soil, and results in temporarily elevated levels of nitrogen and phosphorous formerly locked up in forest litter. There is some evidence that thinning treatments followed by burning may enhance understory species richness and cover, but there has been speculation that heterogeneous burn patterns are more effective at promoting understory diversity because of the wider range of post-fire conditions (Wayman and North, 2007). Early season prescribed fire has been shown to create more heterogeneous burn patterns, due to high fuel moistures (Knapp and Keeley, 2007). Although the Angora fire had record low fuel moisture on the date of burn, and large swaths of the fire burned at uniform high severity, there are many locations where forb and shrub understory communities have benefited from fire effects, showing higher numbers of forb species as compared to control plots. Note that there is some indication from the Angora (including the fire severity transects reported on in Safford et al. 2009) and other eastern Sierra fires that prefire treatments may lead to higher burn heterogeneity and postfire plant diversity. We will report on three year-patterns in diversity in our 2010 summary.

Two years after fire, lower forb and graminoid diversity was observed in plots with higher fire severity ratings, although plots in every severity class were observed to have both low and high forb species counts (figure 7). Shrub diversity (like shrub cover) did not decline at higher fire severities.

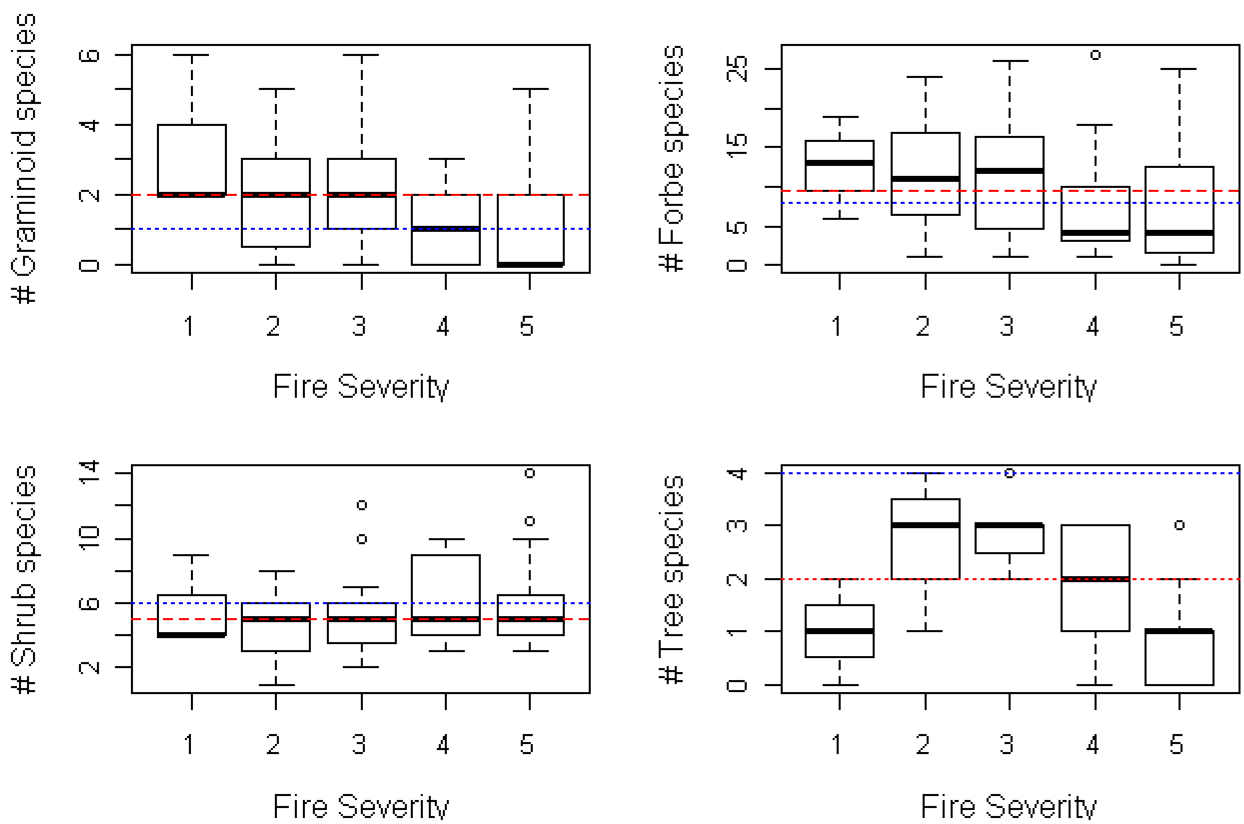


Figure 7 : Number of live species per CSE plot by lifeform and fire severity in 2009. Red (dashed) and blue (dotted) lines represent median values from burned and control plots respectively.

The most common tree was white fir, with live individuals (including first year seedlings) found on 70% of CSE plots within the burn area (see section on regeneration). Jeffrey pine was the second most common tree (58% of plots), and had an average cover of almost double that of white fir. Other trees observed were incense cedar (25% of plots), red fir (20% of plots), sugar pine (15% of plots), lodgepole pine (4 plots), quaking aspen (2 plots), Western white pine (1 plot). Mountain hemlock (*Tsuga mertensia*) was observed in minor quantities in cold drainages around the edge of the fire.

The most common shrub species was Mountain whitethorn (*Ceanothus cordulatus*) which occurred on 90% of burned CSE plots (and 70% of regen plots), with an average cover of 6%. In 14% of the CSE plots, Mountain whitethorn had greater than 10% cover. Greenleaf manzanita was the second most common shrub (70% of plots), followed by Creeping Snowberry, Mahala mat, Huckleberry oak, Snowbrush, Bush Chinquapin, Sierra gooseberry, Serviceberry and Bitterbrush. More than eighteen species of shrubs occurred on at least 10% of the plots, with plots north of Gardner Mountain showing particularly high shrub diversity and cover.

The most common forb species (spreading groundsmoke, *Gayophytum diffusum*) was found on 48% of plots, following findings by Wayman and North (2007), who observed large increases in the cover of another species of *Gayophytum*. The second most common species was the invasive prickly lettuce (*Lactuca serriola*) which was found on 44% of CSE plots, and 22% of burned regeneration plots. In 2008, prickly lettuce was only observed in a few scattered locations and along roads in the northern part of the fire. In the summer of 2009, some areas became dominated by tall (1-5 feet), infestations of prickly lettuce with covers up to 60%, particularly noticeable later in the unusually wet summer. Invasive bull-thistle (*Cirsium vulgare*) was observed in one regeneration plot in a south facing draw of Gardner Mountain, but was rarely seen in the burn area. Cheatgrass (*Bromus tectorum*) was observed in minor quantities near paved roads. Other common forb species include two rockcresses (*Arabis hoeblii* and *platysperma*; 32% and 25% of plots), Brewer's daisy (*Eriogeron breweri*; 29% of plots), three species of *Phacelia* (esp. *heterophylla*), and 25 other species present on at least 10% of CSE plots.

Conclusion

The Angora fire drastically altered many basic ecosystem properties across 3000 acres of forest within the wildland urban interface. The mortality and combustion of overstory and understory vegetation, fuels, and organic horizons have altered surface conditions in a variety of ways, many of which are related to fire severity. Increases in the amount of light, mineralization of nutrients, and removal of competing vegetation have altered conditions so that forbs, shrubs and trees have increased chances for establishment, potentially increasing diversity and landscape heterogeneity as compared to pre-fire conditions. However, the fire also altered portions of the landscape in ways that may inhibit the re-establishment of a forested condition, and may put the area at risk for future high severity fires. Large areas of high mortality, combined with shrub regeneration may limit the natural establishment of conifers in some areas. This may restore stands of chaparral on Angora ridge that have shrunk over the last 60 years due to tree invasion abetted by fire suppression (Nagel and Taylor, 2005), but it may also result in conversion of previous forest to shrublands for a period of many decades. Continued monitoring will better reveal patterns of post-fire vegetation recovery in the Angora drainage, and provide data to support future management decisions.

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Appendix 1: Photos

Photo 1 and 2: Photos of CSE plot 60 taken in June of 2008 (left) and 2009 (right). Live shrub cover increased from 8% in 2008 to 55% in 2009, driven by growth of *Ceanothus cordulatus* seedlings, and Creeping snowberry. Plot is located just west of salvaged California Tahoe Conservancy parcel, ~500 m west of Boulder Mtn. Drive. This plot was planted with Jeffrey pine and Incense cedar seedlings in 2009.

Photo 3: Example of erosion and surface coarsening in steep, severely burned location near CSE plot 39.

Photo 4: Aspen regeneration in a former conifer stand near Angora steam.

Appendix 2: Species list, species counts at 68 burned plots in 2009:

Lifeform	Scientific Name	Common Name	Species	# burned plots occurring
Tree	Abies concolor	white fir	ABCO	45
Tree	Pinus jeffreyi	Jeffrey pine	PIJE	40
Tree	Calocedrus decurrens	incense cedar	CADE27	16
Tree	Abies magnifica	California red fir	ABMA	14
Tree	Pinus lambertiana	sugar pine	PILA	10
Tree	Pinus contorta	lodgepole pine	PICO	4
Tree	Abies (seedling)	fir	ABIES	3
Tree	Populus tremuloides	quaking aspen	POTR5	2
Tree	Pinus monticola	western white pine	PIMO3	1
Tree	Tsuga mertensia	Mountain hemlock	TSME	0
Shrub	Ceanothus cordulatus	whitethorn ceanothus	CECO	62
Shrub	Arctostaphylos patula	greenleaf manzanita	ARPA6	48
Shrub	Symphoricarpos mollis	creeping snowberry	SYMO	28
Shrub	Ceanothus prostratus	prostrate ceanothus	CEPR	23
Shrub	Quercus vacciniifolia	huckleberry oak	QUVA	20
Shrub	Ceanothus velutinus	snowbrush ceanothus	CEVE	16
Shrub	Chrysolepis sempervirens	bush chinquapin	CHSE11	16
Shrub	Ribes roezlii	Sierra gooseberry	RIRO	16
Shrub	Amelanchier alnifolia	Saskatoon serviceberry	AMAL2	15
Shrub	Purshia tridentata	antelope bitterbrush	PUTR2	15
Shrub	Prunus emarginata	bitter cherry	PREM	12
Shrub	Ribes cereum	wax currant	RICE	11
Shrub	Ribes nevadense	Sierra currant	RINE	11
Shrub	Arctostaphylos nevadensis	pinemat manzanita	ARNE	10
Shrub	Rubus parviflorus	thimbleberry	RUPA	10
Shrub	Salix scouleriana	Scouler's willow	SASC	9
Shrub	Symphoricarpos rotundifolius	roundleaf snowberry	SYRO	9
Shrub	Salix	willow	SALIX	8
Shrub	Ribes viscosissimum	sticky currant	RIVI3	5
Shrub	Sambucus racemosa	red elderberry	SARA2	5
Shrub	Lonicera conjugialis	purpleflower honeysuckle	LOCO5	4
Shrub	Allophyllum integrifolium	white false gilyflower	ALIN3	3
Shrub	Artemisia tridentata	big sagebrush	ARTR2	3
Shrub	Rosa woodsii	Woods' rose	ROWO	2
Shrub	Acer glabrum	Rocky Mountain maple	ACGL	1
Shrub	Alnus incana ssp. tenuifolia	thinleaf alder	ALINT	1
Shrub	Chrysothamnus nauseosus var. albicaulis	Rabbitbrush	CHNAA7	1
Shrub	Lonicera involucrata	twinberry honeysuckle	LOIN5	1
Shrub	Valeriana californica	California valerian	VACA2	1
Graminoid	unk_Grass species		GRAM_SP	68
Graminoid	Carex	sedge	CAREX	36
Graminoid	Triticum	wheat	TRITI	3

Graminoid	Juncus	rush	JUNCU	2
Graminoid	**Bromus tectorum**	**cheatgrass**	**BRTE**	**1**
Graminoid	Iris	iris	IRIS	1
Forb	Gayophytum diffusum ssp. parviflorum	spreading groundsmoke	GADIP	38
Forb	**Lactuca serriola**	**prickly lettuce**	**LASE**	**30**
Forb	Arabis holboellii	Holboell's rockcress	ARHO2	22
Forb	Erigeron breweri	Brewer's fleabane	ERBR4	20
Forb	Phacelia heterophylla	varileaf phacelia	PHHE2	18
Forb	Arabis platysperma	pioneer rockcress	ARPL	17
Forb	Cryptantha	cryptantha	CRYPT	17
Forb	Senecio integerrimus	lambstongue ragwort	SEIN2	17
Forb	Stephanomeria lactucina	lettuce wirelettuce	STLA	17
Forb	Allium campanulatum	dusky onion	ALCA2	16
Forb	Apocynum androsaemifolium	spreading dogbane	APAN2	16
Forb	Collinsia parviflora	maiden blue eyed Mary	COPA3	13
Forb	Silene lemmonii	Lemmon's catchfly	SILE2	13
Forb	Wyethia mollis	woolly mule-ears	WYMO	13
Forb	Arnica parryi	Parry's arnica	ARPA13	12
Forb	Cistanthe umbellata	Mt. Hood pussypaws	CIUM	12
Forb	Cirsium andersonii	rose thistle	CIAN	11
Forb	Lupinus	lupine	LUPIN	10
Forb	Balsamorhiza sagittata	arrowleaf balsamroot	BASA3	9
Forb	Epilobium angustifolium ssp. circumvagum		EPANC	9
Forb	Lathyrus lanszwertii var. lanszwertii	Lanszwert's pea	LALAL2	9
Forb	Pteridium aquilinum	western brackenfern	PTAQ	9
Forb	Achillea millefolium	common yarrow	ACMI2	8
Forb	Collomia grandiflora	grand collomia	COGR4	8
Forb	Eriogonum nudum	naked buckwheat	ERNU3	8
Forb	Mentzelia dispersa	bushy blazingstar	MEDI	8
Forb	Phacelia hastata ssp. hastata		PHHAH2	8
Forb	Crepis acuminata	tapertip hawksbeard	CRAC2	7
Forb	Kelloggia galioides	milk kelloggia	KEGA	7
Forb	Tragopogon dubius	yellow salsify	TRDU	7
Forb	Claytonia rubra	redstem springbeauty	CLRU2	6
Forb	Descurainia incana	mountain tansymustard	DEIN5	6
Forb	Hackelia velutina	velvet stickseed	HAVE	6
Forb	Microseris nutans	nodding microseris	MINU	6
Forb	Monardella odoratissima	mountain monardella	MOOD	6
Forb	Phlox diffusa	spreading phlox	PHDI3	6
Forb	Trifolium	clover	TRIFO	6
Forb	Viola macloskeyi	small white violet	VIMA2	6
Forb	Epilobium	smooth willowherb	EPILOB_sp	5
Forb	Epilobium glaberrimum	glaucus willowherb	EPGL	5
Forb	Lotus nevadensis	Nevada bird's-foot trefoil	LONE4	5
Forb	Lupinus polyphyllus	bigleaf lupine	LUPO2	5
Forb	Paeonia brownii	Brown's peony	PABR	5
Forb	Polygonum douglasii	Douglas' knotweed	PODO4	5
Forb	Potentilla glandulosa	sticky cinquefoil	POGL9	5
Forb	Streptanthus tortuosus	shieldplant	STTO3	5
Forb	Unknown species, not Ided		unk_sp	5
Forb	Aster integrifolius		ASIN3	4

Forb	Castilleja applegatei	wavyleaf Indian paintbrush	CAAP4	4
Forb	Cordylanthus tenuis	slender bird's beak	COTE3	4
Forb	Erysimum	wallflower	ERYSI	4
Forb	Gilia capillaris		GICA4	4
Forb	Heracleum lanatum		HELA4	4
Forb	Lupinus argenteus	Tahoe Lupine	LUAR14	4
Forb	Orobanche fasciculata	clustered broomrape	ORFA	4
Forb	Phacelia hydrophylloides	waterleaf phacelia	PHHY	4
Forb	Pyrola picta	whiteveined wintergreen	PYPI2	4
Forb	Thalictrum fendleri	Fendler's meadow-rue	THFE	4
Forb	Aconitum columbianum	Columbian monkshood	ACCO4	3
Forb	Allium obtusum	red Sierra onion	ALOB	3
Forb	Antennaria rosea	rosy pussytoes	ANRO2	3
Forb	Brickellia grandiflora	tasselflower brickellbush	BRGR	3
Forb	Clarkia rhomboidea	diamond clarkia	CLRH	3
Forb	Cymopterus terebinthinus var. californicus		CYTEC2	3
Forb	Eriogonum wrightii	bastardsage	ERWR	3
Forb	Fragaria virginiana	Virginia strawberry	FRVI	3
Forb	Geranium richardsonii	Richardson's geranium	GERI	3
Forb	Hieracium albiflorum	white hawkweed	HIAL2	3
Forb	Horkelia fusca	pinewoods horkelia	HOFU	3
Forb	Lilium parvum	Sierra tiger lily	LIPA3	3
Forb	Madia glomerata	mountain tarweed	MAGL2	3
Forb	Malacothrix floccifera	woolly desertdandelion	MAFL	3
Forb	Mimulus guttatus	seep monkeyflower	MIGU	3
Forb	Penstemon speciosus	royal penstemon	PESP	3
Forb	Potentilla gracilis	slender cinquefoil	POGR9	3
Forb	purple tubular 5 parted flower, on angora ridge, photo 2771		unk_purp_spatulate	3
Forb	Veratrum californicum	California false hellebore	VECA2	3
Forb	Agoseris retrorsa	spearleaf agoseris	AGRE	2
Forb	Anaphalis margaritacea	western pearly everlasting	ANMA	2
Forb	Arabis	rockcress	ARABI2	2
Forb	Arnica latifolia	broadleaf arnica	ARLA8	2
Forb	Aster ascendens		ASAS5	2
Forb	Aster_sp	Asgter	ASTER	2
Forb	Crepis occidentalis	largeflower hawksbeard	CROC	2
Forb	Eriogonum umbellatum	sulphur-flower buckwheat	ERUM	2
Forb	Mimulus mephiticus	foul odor monkeyflower	MIME	2
Forb	Mitella breweri	Brewer's miterwort	MIBR6	2
Forb	Pedicularis semibarbata	pinewoods lousewort	PESE2	2
Forb	Penstemon rydbergii	Rydberg's penstemon	PERY	2
Forb	Phacelia	phacelia	PHACE	2
Forb	Phacelia mutabilis	changeable phacelia	PHMU2	2
Forb	Phacelia ramosissima	branching phacelia	PHRA2	2
Forb	Polygonum bistortoides	American bistort	POBI6	2
Forb	Ranunculus occidentalis	western buttercup	RAOC	2
Forb	Rumex	dock	RUMEX	2
Forb	Senecio triangularis	arrowleaf ragwort	SETR	2

Forb	Smilacina racemosa	False solomons seal	SMRA	2
Forb	Taraxacum officinale	common dandelion	TAOF	2
Forb	Agoseris glauca	pale agoseris	AGGL	1
Forb	Arabis drummondii	Drummond's rockcress	ARDR	1
Forb	Arenaria kingii	King's sandwort	ARKI	1
Forb	Aster occidentalis		ASOC	1
Forb	Calochortus leichtlinii	smokey mariposa	CALE3	1
Forb	Chaenactis douglasii	Douglas' dustymaiden	CHDO	1
Forb	Chenopodium	goosefoot	CHENO	1
Forb	Cirsium vulgare	bull thistle	CIVU	1
Forb	Crepis pleurocarpa	nakedstem hawksbeard	CRPL	1
Forb	Delphinium	larkspur	DELPH	1
Forb	Equisetum	horsetail	EQUIS	1
Forb	Ericameria suffruticosa	singlehead goldenbush	ERSU13	1
Forb	Eriogonum marifolium	marumleaf buckwheat	ERMA4	1
Forb	Eriogonum spergulinum	spurry buckwheat	ERSP6	1
Forb	Galium triflorum	fragrant bedstraw	GATR3	1
Forb	Gilia leptalea		GILE	1
Forb	Ipomopsis aggregata	scarlet gilia	IPAG	1
Forb	Lepidium densiflorum	common pepperweed	LEDE	1
Forb	Ligusticum grayi	Gray's licorice-root	LIGR	1
Forb	Linanthus ciliatus		LICI	1
Forb	Lomatium nevadense	Nevada biscuitroot	LONE	1
Forb	Lotus oblongifolius	streambank bird's-foot trefoil	LOOB2	1
Forb	Lupinus breweri	Brewer's lupine	LUBR3	1
Forb	Lupinus lepidus var. sellulus		LULES2	1
Forb	Nemophila spatulata	Sierra baby blue eyes	NESP	1
Forb	Osmorhiza chilensis		OSCH	1
Forb	Osmorhiza occidentalis	western sweetroot	OSOC	1
Forb	Perideridia parishii	Parish's yampah	PEPA21	1
Forb	Polemonium californicum	moving polemonium	POCA3	1
Forb	Prunella vulgaris	common selfheal	PRVU	1
Forb	Rorippa nasturtium-aquaticum		RONA2	1
Forb	Sarcodes sanguinea	snowplant	SASA5	1
Forb	Saxifraga oregana	Oregon saxifrage	SAOR2	1
Forb	Solanum xanti	chaparral nightshade	SOXA	1
Forb	Solidago canadensis	Canada goldenrod	SOCA6	1
Forb	Verbascum thapsus	common mullein	VETH	1
Forb	Viola adunca	hookedspur violet	VIAD	1
Forb	Viola glabella	pioneer violet	VIGL	1

Appendix 2 continued: Regeneration plot list of shrub species, occurrence rates, average cover, and average modal height (in cm) for 219 burned plots in 2009.

Species	Avg. Cover	Avg. modal height (cm)	# of Plots	Scientific Name	Common Name
CECO	5.49	27.77	161	Ceanothus cordulatus	whitethorn ceanothus
ARPA6	1.66	28.82	134	Arctostaphylos patula	greenleaf manzanita
CEPR	4.87	9.04	57	Ceanothus prostratus	prostrate ceanothus
SYMO	1.95	17.74	56	Symphoricarpos mollis	creeping snowberry
LASE	1.42	26.03	40	Lactuca serriola	prickly lettuce
QUVA	5.25	37.15	34	Quercus vacciniifolia	huckleberry oak
PUTR2	3.30	46.85	27	Purshia tridentata	antelope bitterbrush
CEVE	2.31	19.79	24	Ceanothus velutinus	snowbrush ceanothus
AMAL2	1.83	51.17	21	Amalanchier alnifolia	Serviceberry
RINE	1.33	37.30	20	Ribes nevadense	Sierra currant
CHSE11	1.67	30.17	18	Chrysolepis sempervirens	bush chinquapin
RIRO	1.26	26.65	17	Ribes roezlii	Sierra gooseberry
ARNE	10.39	12.93	14	Arctostaphylos nevadensis	pinemat manzanita
RIVI3	3.33	41.67	12	Ribes viscosissimum	sticky currant
RUPA	1.05	31.36	11	Rubus parviflorus	thimbleberry
PREM	0.56	30.56	9	Prunus emarginata	bitter cherry
SALIX	3.17	81.11	9	Salix	Willow (other than Scoulers)
ARTR2	3.50	56.67	6	Artemisia tridentata	big sagebrush
SASC	8.92	113.33	6	Salix scouleriana	Scouler's willow
PENE3	0.50	10.00	4	Penstemon newberryi	mountain pride
SARA2	1.50	61.25	4	Sambucus racemosa	red elderberry
ALINT	7.33	105.00	3	Alnus incana ssp. tenuifolia	thinleaf alder
SYRO	11.17	15.00	3	Symphoricarpos rotundifolius	roundleaf snowberry
ROWO	1.83	35.00	3	Rosa woodsii	Woods' rose
RIBES	0.50	6.00	3	Ribes	currant
RICE	0.83	28.33	3	Ribes cereum	wax currant
CIVU	0.50	3.00	1	Cirsium vulgare	Bull thistle
LOCO5	0.50	15.00	1	Lonicera conjugialis	purpleflower honeysuckle
ACGL	0.50	30.00	1	Acer glabrum	Rocky Mountain maple
LOIN5	1.50	15.00	1	Lonicera involucrata	twinberry honeysuckle