Angora Fire Vegetation Monitoring
Annual Progress Report October 2010

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INTRODUCTION

The Angora fire burned about 3000 acres of mixed conifer forest and suburban development in June 2007. Fueled by strong winds and high fuel loads, over half of the burn area experienced high rates of tree mortality and severe fire effects. In the summers of 2008-2010, researchers from the University of Montana established and monitored 68 permanent Common Stand Exam (CSE) plots within the burn area to track tree mortality, vegetation composition, and fuel loads. Researchers also surveyed 200+ regeneration plots within the burn area each summer to track tree regeneration and shrub recovery. This document summarizes progress and accomplishments over the last year, and provides a summary of forest vegetation conditions within the Angora fire over the monitoring period.

Data from monitoring the Angora monitoring plots collected between 2008-2009 have been used in a number of reports, papers, and ongoing research. Tree mortality data was used to demonstrate that pre-fire forest fuels treatments ameliorated fire severity (Safford et al., 2009). Vegetation and fuels data are being shared with USFS researchers studying how bird and small mammal diversity and recovery are influenced by fire severity and management treatments (Manley et al., 2008, SNPLMA proposal). Results were also presented at an Angora Fire focused oral session at the Tahoe Science Conference in March 2010 (Carlson et al., 2010). Further, information about regeneration rates were used in the proposal for the Angora Fire Reforestation Project (USDA, 2010). Finally, data from 2008-2010 are being used in research investigating how long-term forest carbon stocks in managed and unmanaged stands are sensitive to variable rates of mortality and regeneration, to be completed in 2011. This report marks the third consecutive year of monitoring, but plots will be re-visited again in 2012 and 2017 to better understand long term patterns of forest recovery, and vegetation response to pre-fire, and post-fire forest treatments. Data are stored in a Microsoft Access format and are available upon request.

In this report, we use data collected from 2008-2010 to summarize changing vegetation conditions in the fire. We present rates of tree mortality and snag breakage, changes in fuel loads from 2008-2010 and tree regeneration. We also describe how fire severity and management affect patterns of post-fire understory cover and species richness.

METHODS

In the summers of 2008-2010, crews from the University of Montana surveyed eighty-five 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, but were visited in 2010. In 2010, we also established an additional eight unburned 'control' plots outside the fire (data not presented here). We also established over two-hundred 1/70th acre (14.07 ft radius) "regeneration" plots throughout the fire 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 rebar and orange cap, and by tagging "in" trees with aluminum tags (#1-1900).

Common Stand Exams

At each CSE plot, we followed Region 5 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. We established 68 plots within the burn area (Table 2), and 9 plots each in nearby thinned, and unthinned forest. Five of the 68 CSE plots had been fully logged with most logs removed as of 2010. We surveyed 16 plots which had been treated for fuels before fire (based on observations and information from the FACTS database), 3 of which were logged after fire. We visited 27 plots within 400 meters of thinned areas that we classified as "unthinned" forest (after excluding plots with riparian or chaparral vegetation), 1 of which was logged after fire.

Tree data: Within each plot, we tagged and mapped all trees above 5" DBH for live trees, and 10" DBH for dead trees. Trees below breakpoint were counted and tallied by species, mortality status, and diameter (0-5", 5-10"). 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 2010, noting further damage or mortality. Common damage types include fire, insect attack, red turpentine beetle, partial girdling from fire, and mistletoe. In 2010, we took note of any snags that were broken or had fallen. Trees below the DBH threshold were counted and tallied by species, mortality status, and diameter (0-5" and 5-10") in 2009. 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 recorded a fire severity class in 2008 (see Table 1 for definitions of fire severity). 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 0.5%. Covers of each lifeform (tree, shrub, graminoid, forb) were also made optically. In 2009 and 2010, 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 each tree and shrub species.

Species composition: Each species occurring within the CSE plot was recorded. Graminoid species were only identified to type (graminoid, *Carex* or *Juncus*). Plant age and flowering status made identification to species difficult for some species. 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), and species were identified using *Plants of the Tahoe Basin* (Graf, 1999) and the California *Jepson Manual* (Jepson et al., 1993). Sampling began at the end of May, and finished mid-August all years.

Fuel Transects: Four 50' long Brown's fuel transects were surveyed at each plot. Transects began at plot center, and ran in cardinal directions (14.5^{o} E compass declination). 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. *In 2010, we made additional measurements on CWD.* We recorded diameter at small end, diameter at large end, log length, and percent consumption for each log >1 meter long, in addition to diameter at intersect and decay class (following Waddell, 2002). These additional measurements allow more robust estimates of coarse woody debris attributes. Duff and litter depths were taken in centimeters at 25' and 50' on each transect. Fuel loadings for fine fuels were estimated following guidelines in Brown, 1974. CWD attributes were estimated using procedures from Waddell, 2002.

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), invasive species, 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, but was rarely visible in 2010.

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 California National Forests. Over the course of three years, we visited 287 plots inside and outside the burn area. We present data on 200 plots in the fire that were visited in both 2009 and 2010.

On each plot, we recorded standard plot measurements including aspect, slope, vegetation type, fire severity, and plot treatment history (thin, old thin, postfire log, 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"), surface vegetation, and shrub cover at each plot (summing to 100%), as well as overhead live and overhead dead canopy cover percent. We also estimated the grass, forbe, and total shrub cover in 2010. 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 natural (post-fire) tree seedling. Planted trees were counted separately by species. 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). 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).

Data presentation

We generally use box and whisker plots to summarize data visually as many variables are highly non-normal. Our box plots can be interpreted such that the central line in the box represents the median, with boxes extending to the 1st and 3rd quartiles, and whiskers extending to 1.5 times the interquartile range. Outlier points are drawn separately. We report measurements in English units (i.e. ft^2 per acre), unless otherwise specified.

Table 1. Definitions of observed fire severity

Severity	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 may be 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, Understory plants killed and consumed.

Table 2: Count of CSE and Regen plots in burned area surveyed in 2010.
[a]: We do not report results from unburned plots
[b]: We lump fire severity 1 and 2 together as severity 2 for the purpose of this report.

Observed Fire severity	Number of CSE plots	Number of Regeneration Plots
0[a]	18	18
1[b]	3	19
2	17	43
3	13	42
4	15	54
5	20	42
Total:	86	218

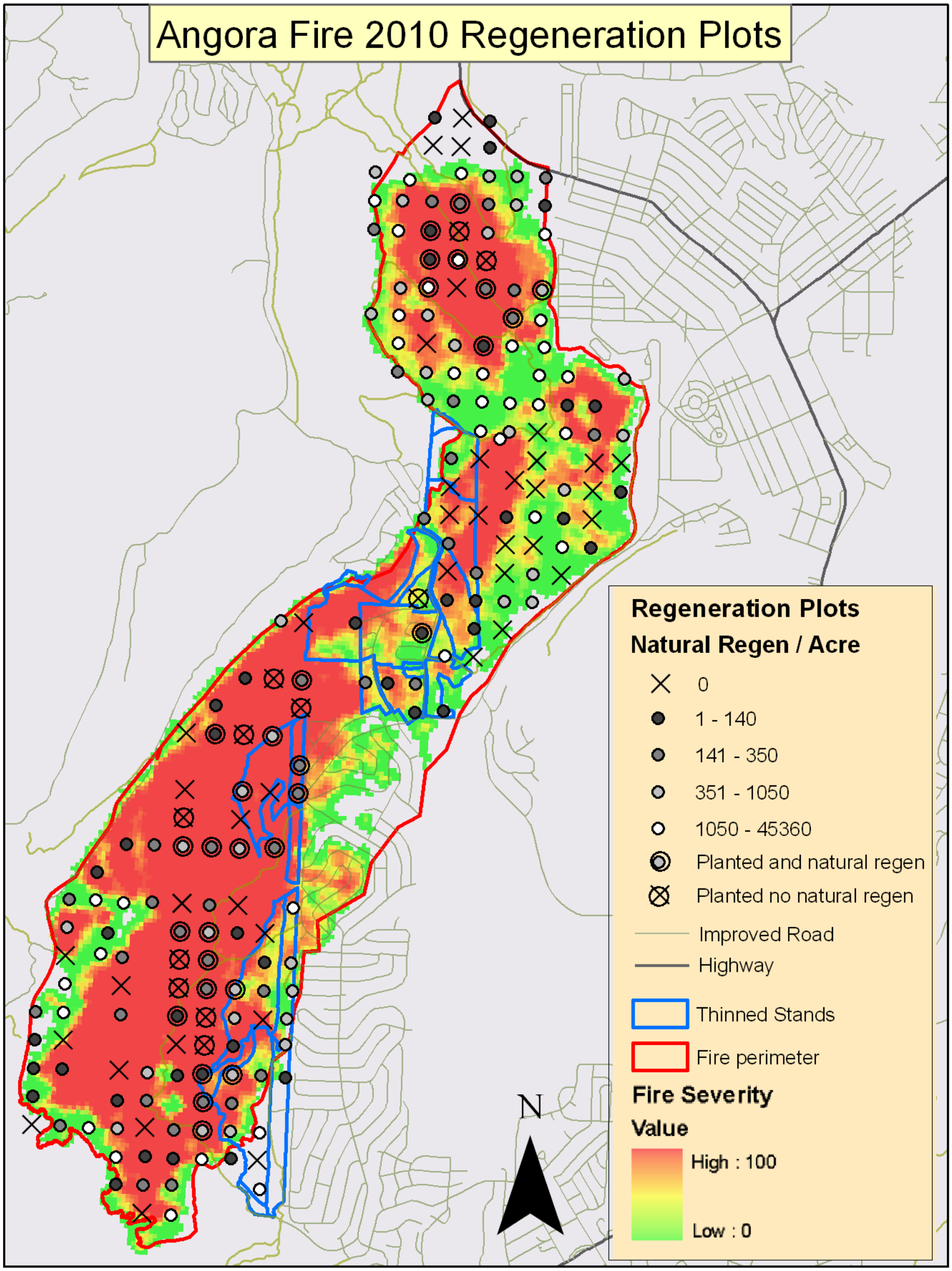

Figure 1. Map of regeneration plots surveyed in 2010. Plots are symbolized by an 'X' if no natural regeneration is present. Dark to light dots represent plots with low to high rates of natural regeneration, respectively. Plots with an extra circle were planted as of 2010.

RESULTS

Tree mortality and snag breakage

One year after fire, median basal area mortality rates ranged from 5-30% in low severity burns, to well over 90% in more severely burned areas, with an overall 58.5% basal area (BA) mortality rate across all severities (Figure 1b). Pre-fire live tree density (log normalized) was a significant predictor of basal area mortality rates one year after fire (p val < 0.001, Figure 1a), whereas pre-fire basal area was not significantly related to mortality rates. Post-fire mortality (2009-2010) contributed an additional 5.4% to the cumulative basal area mortality rate, bringing the overall mortality rate to 63.9% as of 2010 (Figure 1c-d). Ten-percent of our CSE plots experienced more than 19% of total fire related basal area mortality more than one year after fire.

Before the Angora fire, median live tree stem density and basal area within the burn area was 195 stems and 181.53 ft^2 per acre, respectively over all fire severities. As of 2010, overall median live stem density was 15 stems per acre, and basal area was 22.97 ft^2 per acre.

Rates of snag breakage were highest in stands experiencing intense ground or crown fire (severity 4-5), and for species of Fir. Breakage rates of snags >10" DBH averaged ~10% in low-moderate severities, and above 20% in more severely burned stands (Table 3). *Abies* snags had higher rates of breakage than other species, with breakage rates near 30%. *Pinus jeffreyi* had a breakage rate of 12% as of 2010 (Table 4).

As of 2010, five of our sixty-eight CSE plots had been fully logged. An additional five plots experienced selective tree cutting totaling at least 50 ft^2 per acre, some of that representing hazard cutting of large cat-faced snags during fire suppression. Three of the five logged plots were cut in 2008, immediately following fire. Two plots were logged between 2009 and 2010, as part of the hazard tree reduction efforts along system roads. We report regeneration and fuel loading separately for logged, and unlogged plots. Tree marking for the Angora Restoration Project began in the spring / summer of 2010. Although we recorded which trees had been marked for removal in some plots, we were unable to collect this information for all stands in which cutting is planned.

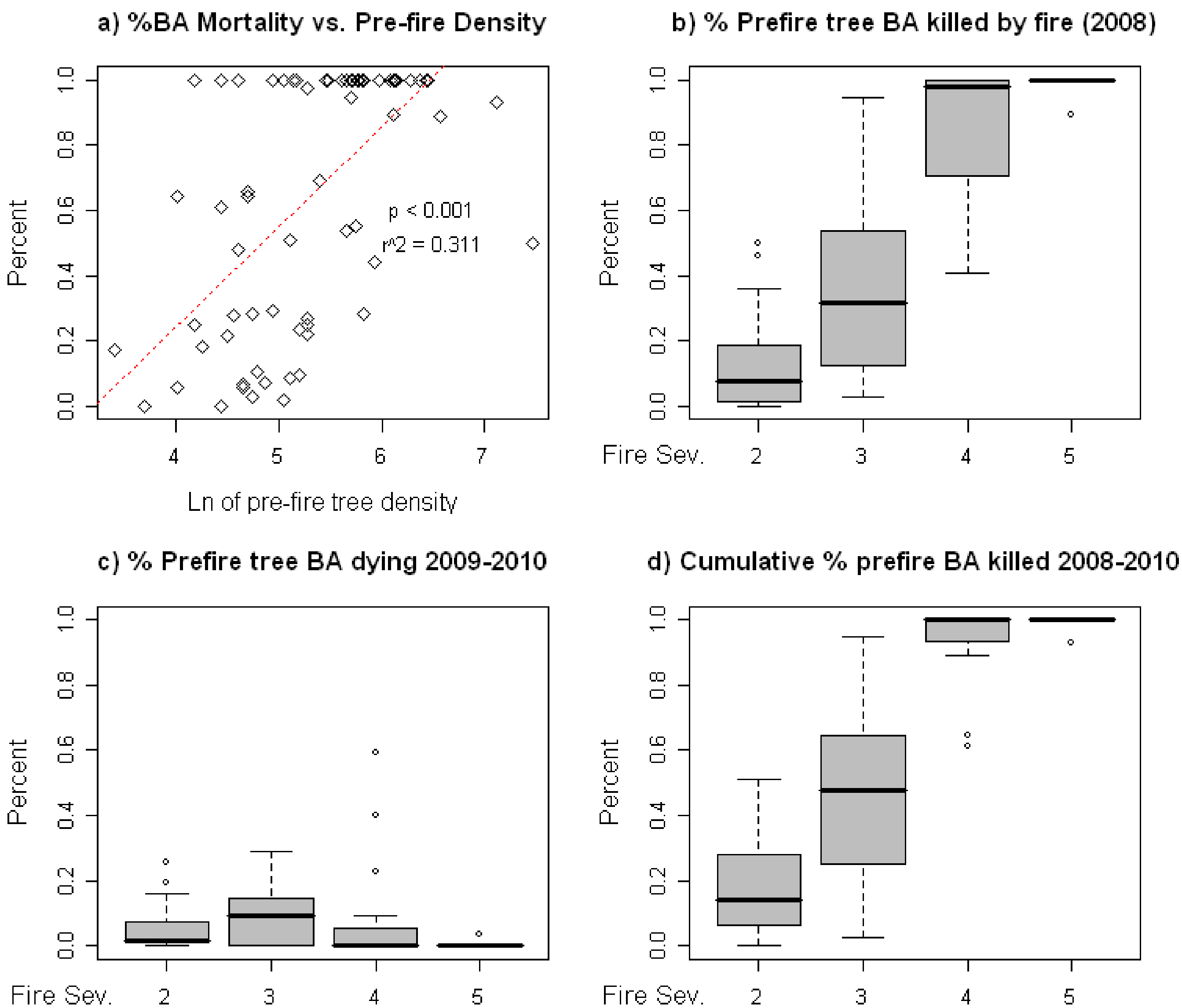

Figure 2. a) Relationship between the natural logarithm of pre-fire stem density and percent BA killed through 2010. **b)** Percent prefire tree basal area (ft^2 / acre) killed by fire; **c)** Percent prefire tree basal area observed to die 2009-2010; **d)** Cumulative percent prefire tree BA killed by fire and after fire;

Fire Severity	# Snags	# Broken	Percent broken	Avg. Diameter
2	67	7	10.45	17.38
3	107	10	9.35	16.37
4	256	62	24.22	17.03
5	434	71	16.36	15.84
Total	864	150	17.36	--

Table 3. Rates of snag breakage by fire severity

SPECIES	# Snags	# Broken	Percent broken	Avg. Diameter
ABCO	428	92	21.50	15.79
ABIES	45	14	31.11	13.71
ABMA	47	14	29.79	15.26
CADE	42	0	0.00	19.01
UNK	4	0	0.00	11.53
PICO	51	2	3.92	14.75
PIJE	214	26	12.15	17.17
PILA	21	2	9.52	25.61
PIMO	1	0	0.00	13.80
PINUS	11	0	0.00	21.34
Total	864	150	17.36	--

Table 4. Rates of snag breakage by tree species.

Tree regeneration

Natural regeneration of trees within the Angora fire was temporally and spatially variable. In the first summer after fire, there was almost a complete failure of natural regeneration within the burn area. We found only 14 seedlings on three of 196 regeneration plots in 2008. However, we observed much higher rates of natural tree regeneration in both 2009, and 2010. In 2009, *Abies concolor* and *Abies magnifica* had a bumper seedling crop. 55% of plots within the fire contained natural *Abies* regeneration, while 30% of burned plots had *Pinus* seedlings in 2009 (**Table 5**). In 2010, *Pinus jeffreyi* and *Pinus lambertiana* seedlings emerged in many plots, including many areas where few nearby seed sources were available due to fire (fire severities 4-5). In 2010, overall stocking rates of *Abies* had dropped to 50%, and stocking rates of *Pinus* rose from 30% to 60%. This widespread regeneration of *Pinus* seedlings caused median levels of *Pinus* regeneration to exceed 70 seedlings per acre across all fire severities. More than 75% of the fire had natural regeneration in 2010, but 35% of severely burned areas still lack natural regeneration.

Abies reproduction was nearly absent in 2010. Based on 186 plots where we relocated the plot center in 2010, mortality rates of *Abies concolor* and *Pinus jeffreyi* seedlings were 35-45% between 2009 and 2010.

We visited nineteen regeneration plots which had been logged by 2010 which were analyzed separately for 2010 data. Most logged plots had *Pinus* seedlings (79% of plots), but very few *Abies* seedlings (present on 10% of plots). Because fir seedlings established naturally before logging (2009) and pines established naturally after logging (2010), it is possible that tree removal operations may have resulted in widespread seedling mortality. 85% of logged plots had been planted, at a mean and median density of 210 planted seedlings per acre (**Table 5**).

Planted seedlings were found throughout the burn area. Seedlings were planted in 6%, 19% and 32% of plots in severities 3-5, respectively as of 2010. Jeffrey pine, Sugar pine and Incense cedar accounted for 55%, 25% and 19% of live planted seedlings, respectively in 2010. Plots which were planted had a mean of 245 and median of 280 planted seedlings per acre. Most planting was achieved under the Angora Fire Reforestation Project, which proposed planting 200-250 trees per acre. Our estimates of planting rates are similar to the upper proposed limit of planting densities.

Although we assigned a species to all regenerating trees, we report rates of regeneration by genus rather than species, for ease of analysis and because definitive identification of some seedlings to the species level was difficult, even 1 year after fire. *Abies concolor* and *Abies magnifica* were the most difficult to distinguish, looking particularly similar just after germinating, but it was easy to distinguish between seedlings belonging to *Abies* and those belonging to *Pinus*. *Pinus* species were individually identifiable based upon the number of cotyledons (Franklin, 1961). Regeneration rates were highly skewed, with a small number of plots having high amounts of regeneration. For example, in 2009-2010, 64% of all natural seedlings counted were contained on just 5% of the plots. As such, typical regeneration patterns in various fire severities are best represented by median rates and stocking rates.

Although rare, we also observed a number of Quaking aspen (*Populus tremuloides*) and Black cottonwood (*Populus balsamifera*) seedlings in the fire. Many of the Quaking aspen seedlings appeared to be non-vegetative, as they were singular and fire-killed aspen were not visible. We observed two cottonwood seedlings on the ridge above South Lake Tahoe High School.

2008		Nat. Regen /acre		Pinus / acre		Abies / acre		CADE / acre		Planted / acre		Dist. Seed Tree ft		% plots with regen				
Fire Sev.	# plots	Mean	Median	Mean	Median	Mean	Median	Mean	Median	Mean	Median	Mean	Median	Total Natural	Pinus	Abies	CADE	Planted
1	19	0	0	0	0	0	0	0	0	0	0	27.16	23.5	0.0	0.0	0.0	0.0	0.0
2	43	3.26	0	0	0	0	0	0	0	0	0	19.41	13	2.3	2.3	0.0	0.0	0.0
3	42	6.67	0	0	0	0	0	0	0	0	0	30.4	19.5	4.8	4.8	0.0	0.0	0.0
4	53	0	0	0	0	0	0	0	0	0	0	169.67	91	0.0	0.0	0.0	0.0	0.0
5	39	0	0	0	0	0	0	0	0	0	0	364.54	285	0.0	0.0	0.0	0.0	0.0
Total:	196	2.14	0	0	0	0	0	0	0	0	0	131.8	39.25	1.5	1.5	0.0	0.0	0.0

2009		Nat. Regen /acre		Pinus / acre		Abies / acre		CADE / acre		Planted / acre		Dist. Seed Tree ft		% plots with regen				
Fire Sev.	# plots	Mean	Median	Mean	Median	Mean	Median	Mean	Median	Mean	Median	Mean	Median	Total Natural	Pinus	Abies	CADE	Planted
1	19	980	280	40.5	0	936	280	3.68	0	0	0	18.71	15	68.4	15.8	63.2	5.3	0.0
2	43	7198	560	86.2	0	5382	280	1730	0	0	0	18.99	13.5	88.4	34.9	74.4	7	0.0
3	42	2115	525	340	0	1668	280	107	0	60	0	29	20	81.0	47.6	66.7	23.8	16.7
4	54	961	70	55.7	0	885	0	20.7	0	23.3	0	178.1	102.5	59.3	25.9	44.4	9.3	9.3
5	42	145	35	35	0	105	0	5	0	48.3	0	370.19	283	50.0	19.0	35.7	4.8	16.7
Total:	200	2375.1	210	116	0	1857	70	401	0	29.1	0	137.78	37.5	69.0	30.0	55.5	10.5	9.5

2010		Nat. Regen /acre		Pinus / acre		Abies / acre		CADE / acre		Planted / acre		Dist. Seed Tree ft		% plots with regen				
Fire Sev.	# plots	Mean	Median	Mean	Median	Mean	Median	Mean	Median	Mean	Median	Mean	Median	Total Natural	Pinus	Abies	CADE	Planted
1	18	583.33	420	163	140	401	70	19.4	0	0	0	17.79	10.39	83.3	61.1	61.1	11.1	0.0
2	42	2783.3	455	288	70	1653	70	842	0	0	0	17.66	13.12	78.6	61.9	59.5	14.3	0.0
3	35	2018	560	366	210	1082	140	600	0	22	0	44.82	20.99	88.6	77.1	62.9	31.4	5.7
4	57	722.11	280	179	70	511	0	31.9	0	44.2	0	158.76	91.84	68.4	56.1	43.9	21.1	19.3
5	37	160.81	70	88.9	70	58.7	0	13.2	0	77.6	0	466.6	297	64.9	51.4	29.7	8.1	32.4
Total:	189	1297	280	213	70	771	0	312	0	32.6	0	153.16	36.08	75.1	60.8	49.7	18	12.0
Salvaged:	19	276.32	210	251	210	14.7	0	11.1	0	206	210	264.25	133.5	84.2	78.9	10.5	5.5	84.2

Table 5. Summary of regeneration rates by year, fire severity, and type (natural, planted). In 2010, we analyze plots logged after fire separately. CADE = *Calocedrus decurrens* (Incense cedar).

Fuel Loading

Fuels data from 2008-2010 confirms that the Angora fire caused a reduction in surface fuels of all size classes as compared to nearby unburned forest, but that fuels accumulation is rapidly proceeding within the fire, particularly in areas of severe fire effects. One year after fire, stands which burned at a high severity had similar or fewer fine fuels than less severely burned stands, reflecting greater rates of fuel consumption in high intensity fire (**Figure 3**). Three years after fire this trend was reversed as severely burned stands (severity 4-5) had median fine fuel loads (<3” diameter) of ~2 tons/acre, nearly double that of less severely burned stands. The large increase in fine fuels 2008-2010 was driven by the surface accumulation of branches from fire killed trees, with most fuels belonging to the 100 hour size class (1 - 3“diameter). Rates of coarse woody debris (CWD, >3 inches diameter) loading was slightly higher in severely burned areas in 2010, and most burn severities experienced an increase in CWD loading over the three years of this study.

Fine fuel loads in logged areas within the fire are high (~4 tons/acre, n=5), mostly due to large loadings of 100 hour fuels. However, surveys show that mean CWD loadings (>3” diameter) in logged plots (4.3 tons/acre) are still much lower than unlogged control plots (30.2 tons/acre), and slightly higher than thinned control plots (3.4 tons/acre).

Even after being burned, pre-fire fuels treatments continue to be effective at protecting forests from fire through reduced fuel loading. In stands which were thinned before fire, fine and coarse woody fuel loads are lower than in nearby unthinned stands (**Figure 4**). The difference is largely due to lower mortality rates in thinned stands, and less accumulation of fuels from dead trees. Although we analyze fuel loads in logged plots separately, three of the five logged plots had been thinned before fire but piles had not been burned before the fire occurred. Fuels from piles likely contributed to severe fire effects, which in turn contributed to the decision to log these plots postfire. Fine fuel loads in severely burned stands are similar to those in thinned unburned stands (~2 tons/acre) and are approaching loads in unthinned unburned stands (~3 tons/acre).

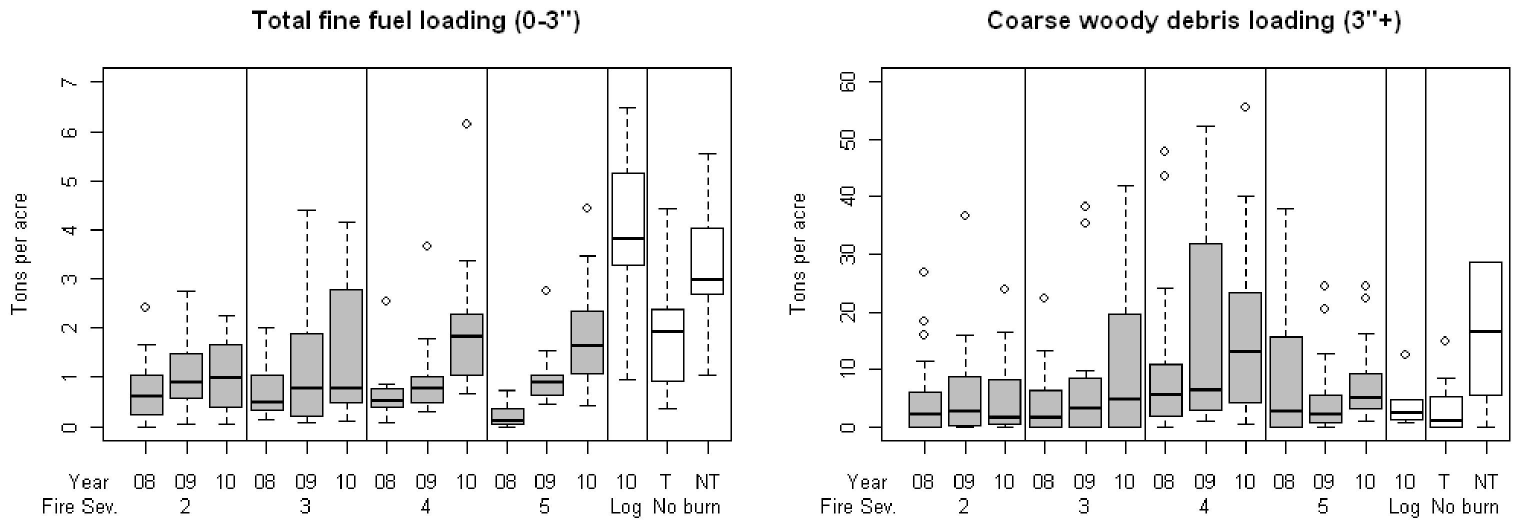

Figure 3. Fine and coarse woody fuel loads *by fire severity and year* (grey boxes). The rightmost three boxplots represent logged plots within the fire in 2010 (n=5), and thinned (n=9) and unthinned control plots (n=9) outside the fire, respectively.

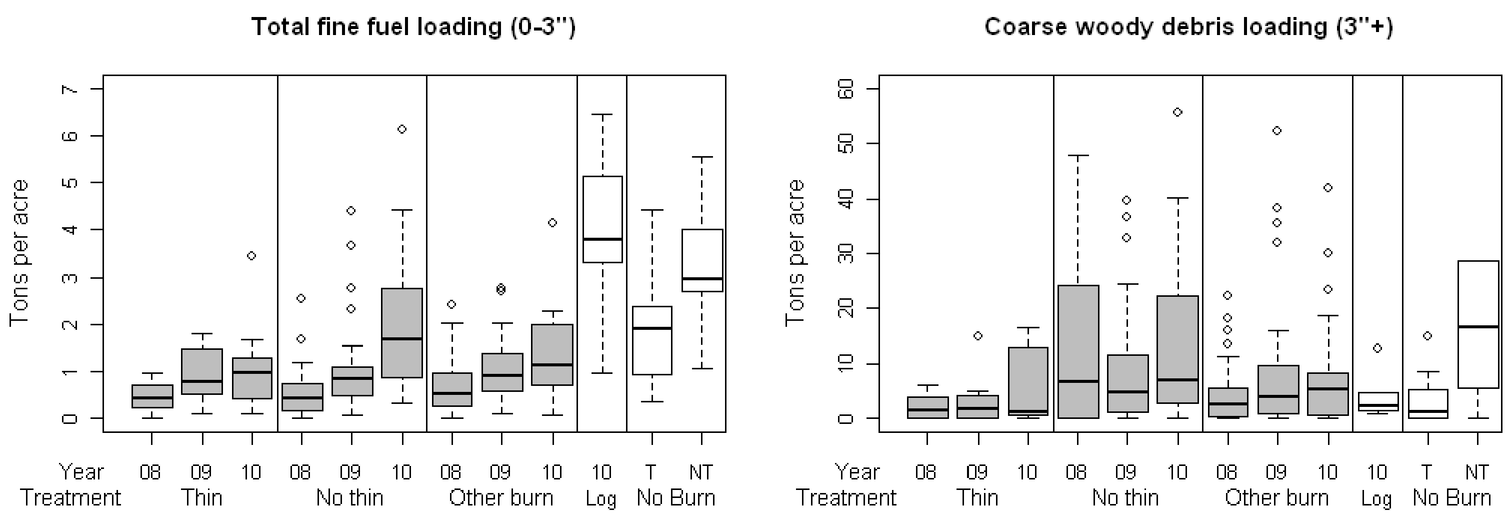

Figure 4. Fine and coarse woody fuel loads by *pre-fire treatment* (thinned, nearby unthinned, and "other" burned plots) and year. The rightmost three boxplots represent: logged plots within the fire in 2010 (n=5), thinned (n=9), and unthinned plots (n=9) outside the fire, respectively. Thinned plots include 13 plots which had been treated for fuels within a decade before wildfire. Unthinned plots include plots within 1000 m of thinned stands, excluding plots with riparian or montane chaparral vegetation. All other plots are lumped into the "Other burn" group.

Understory plant recovery

Understory cover is increasing most rapidly in severely burned areas, but understory species richness is higher in less severely burned stands. Mean understory cover in severely burned stands has increased from 2% in 2008, to 24% in 2010, while understory cover in less severely burned stands increased from 2% to 13% from 2008 to 2010 (**Figure 5a**). Mean understory species richness is 19.5 species per plot in less severely burned areas in 2010, an increase of about 5 species per plot since 2008. Understory richness in severely burned stands is lower, with 15.5 species per plot on average in 2010, an increase from 12 species per plot in 2008 (**Figure 5c**). Understory cover in logged plots is moderate with a mean of 18.5%. Understory richness in logged plots is surprisingly high, with a mean of 25.8 species per plot.

Understory species richness is also higher in stands thinned before fire. Thinned stands have a median of 20 species per plot , as compared to nearby unthinned stands which have a median 11 species per plot in 2010 (**Figure 5d**). If we considered only forb richness, the difference is larger. Thinned stands have a median 14 species per plot , and unthinned stands a median of 5 forb species per plot in 2010.

Invasive species are found at a high frequency, but low dominance throughout the fire. Severely burned plots are more likely to have invasive species present, and at a higher percentage cover (**Table 6**). Prickly lettuce (*Lactuca serriola*) was by far the most common invader, and was present at 20% and 42% of all regeneration plots in 2009 and 2010, respectively . Although *Lactuca serriola* had covers of up to 45%, the mean cover in 2010 was only 1% for all plots. Severely burned plots had higher rates of invasion, and higher mean covers of invasive species. Other invaders including Bull thistle (*Cirsium vulgare*), Cheat grass (*Bromus tectorum*) and Russian thistle (*Salsola sp.*) were seen around the burn at a low frequency. Bull thistle was noticeably more widespread in 2010 than in 2009, occurring on 2% of plots in 2010. We observed a healthy outbreak of *Bromus tectorum* on and around CSE plot 74 in 2010. Continued monitoring will reveal whether the *Lactuca serriola* infestation is transient or long-lasting, and will show whether severely burned areas continue to be more susceptible to invasion by non-native species.

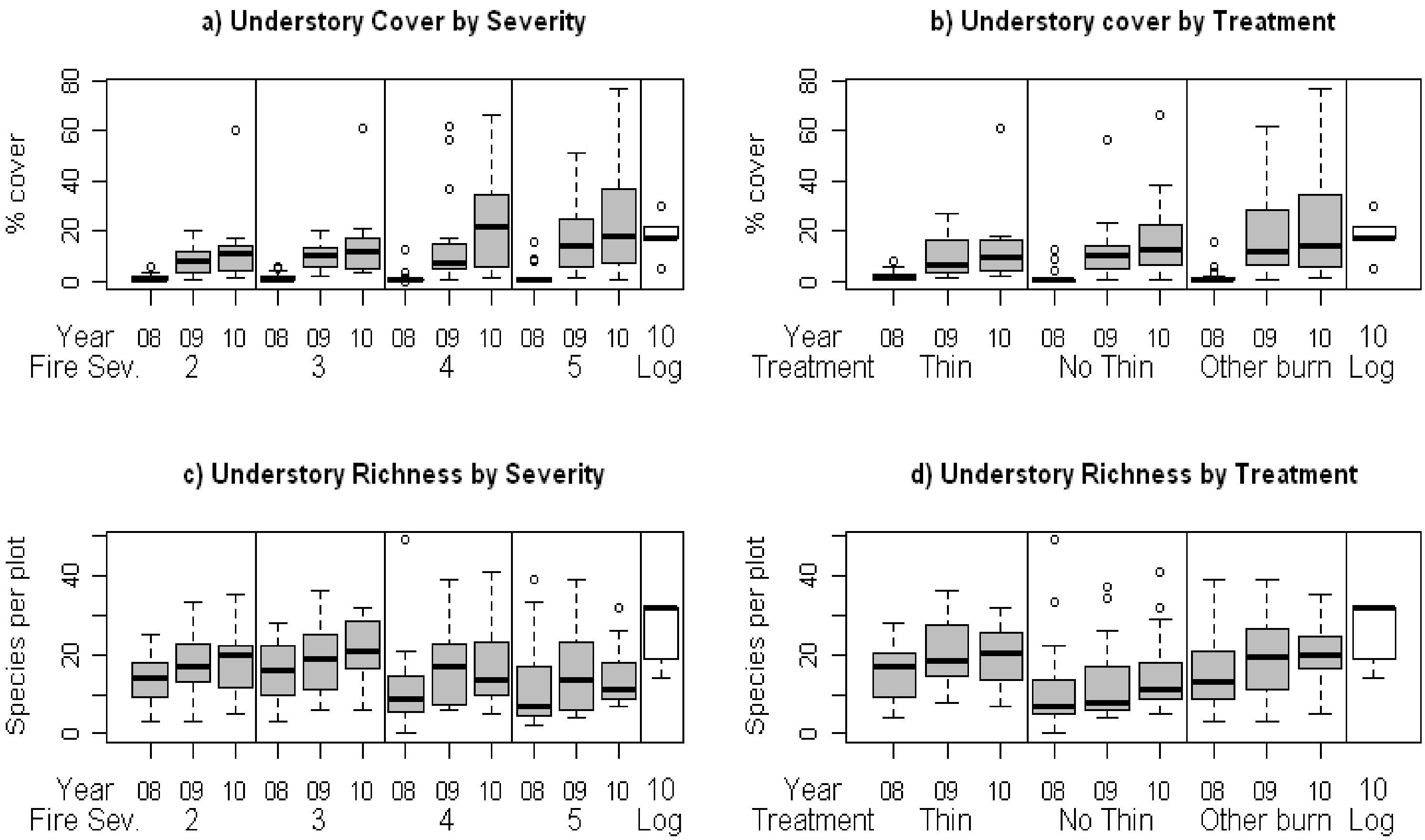

Figure 5a-d. a) Understory cover by fire severity and year (Shrub, forb, grass cover); b) Understory cover by treatment and year; c) understory richness by fire severity and year; d) Understory richness by treatment and year. Data from CSE plots.

Fire Sev.	% plots w/ Invasive sp. 2009	% plots w/ Invasive sp. 2010	Mean Overall Invasive cover 2009	Mean Overall Invasive cover 2010	Mean Invasive Cover when present 2009	Mean Invasive Cover when present 2010
1	0	17	0	0.08	0	0.5
2	9	24	0.05	0.14	0.5	0.6
3	24	49	0.44	0.31	2.06	0.65
4	26	56	0.51	2.32	1.96	4.14
5	29	70	0.18	1.24	0.62	1.77
Total:	20	42	0.28	1.04	1.42	2.24
Logged 2010:	NA	57	NA	0.37	NA	0.64

Table 6. Rates of invasion, mean percent cover of invasive species for all plots, mean percent cover of invasives on plots where they are present, 2009 and 2010. By far the most common invader was Prickly lettuce (*Lactuca serriola*). Bullthistle was present on ~2% of all plots in 2010. Data from regeneration plots.

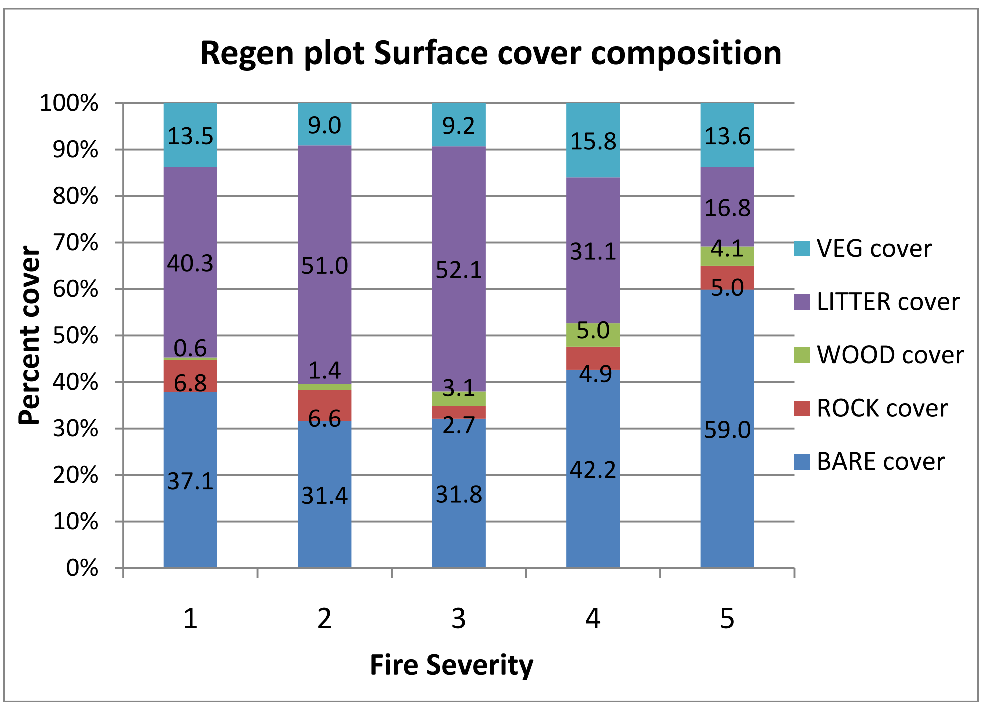

Figure 6. Average surface cover composition in 2010 by fire severity (not including overhead trees). Veg cover includes only understory vegetation, including shrubs, forbs and grasses. Wood includes fragments >3”, Rock includes any stones >1” . Data from regeneration plots

Surface cover and understory composition.

Stands which burned at a higher severity have less litter and more bare soil cover than less severely burned stands, despite having higher understory vegetation cover. Plots experiencing crown fire (severity 5) had 59% bare ground cover and 17% litter cover on average (**Figure 6**). Plots experiencing severe surface fire had less bare ground (42%) and more litter cover (31%). Plots experiencing low to moderate fire effects had about 35% bare ground cover, and 45% litter cover.

Understory vegetation cover was on average highest in severely burned stands. Mean shrub cover and forb cover both increased with increasing fire severity. Shrub cover was particularly high in severely burned stands (**Figure 7**). Live and dead tree canopy cover decreased over 2008-2010 (**Figure 8**). This is likely due to dead needles falling, branches breaking and continued tree mortality. As of 2010, average live canopy cover is about 12% in less severely burned stands, 6% in moderately burned stands, and less than 1% in severely burned areas. Dead tree canopy cover averages about 6% in severely burned stands.

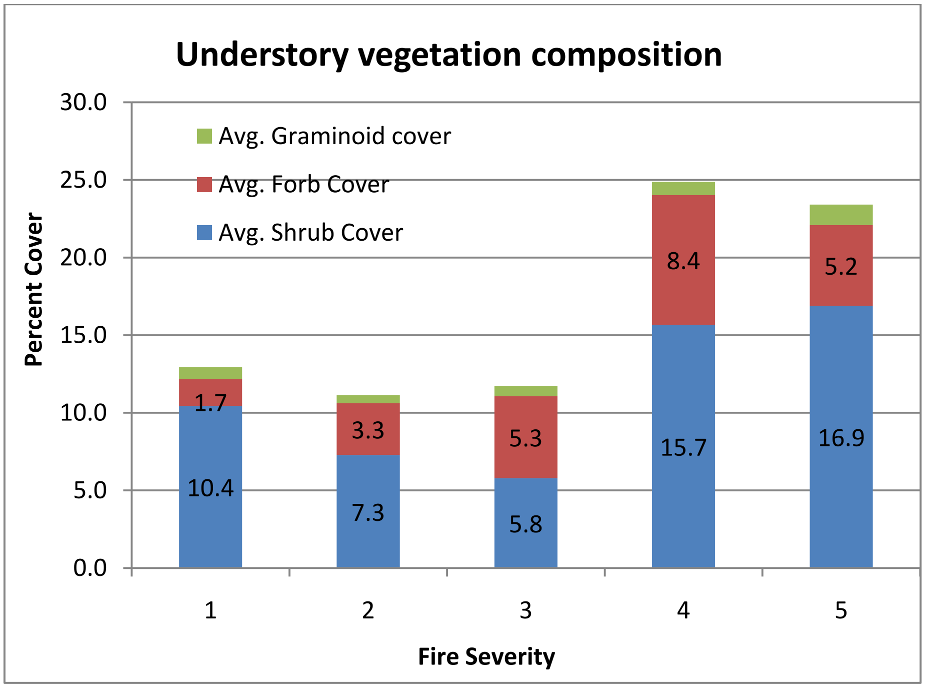

Figure 7. Understory vegetation composition in 2010, by fire severity. Forb cover includes invasive species. Data from regeneration plots.

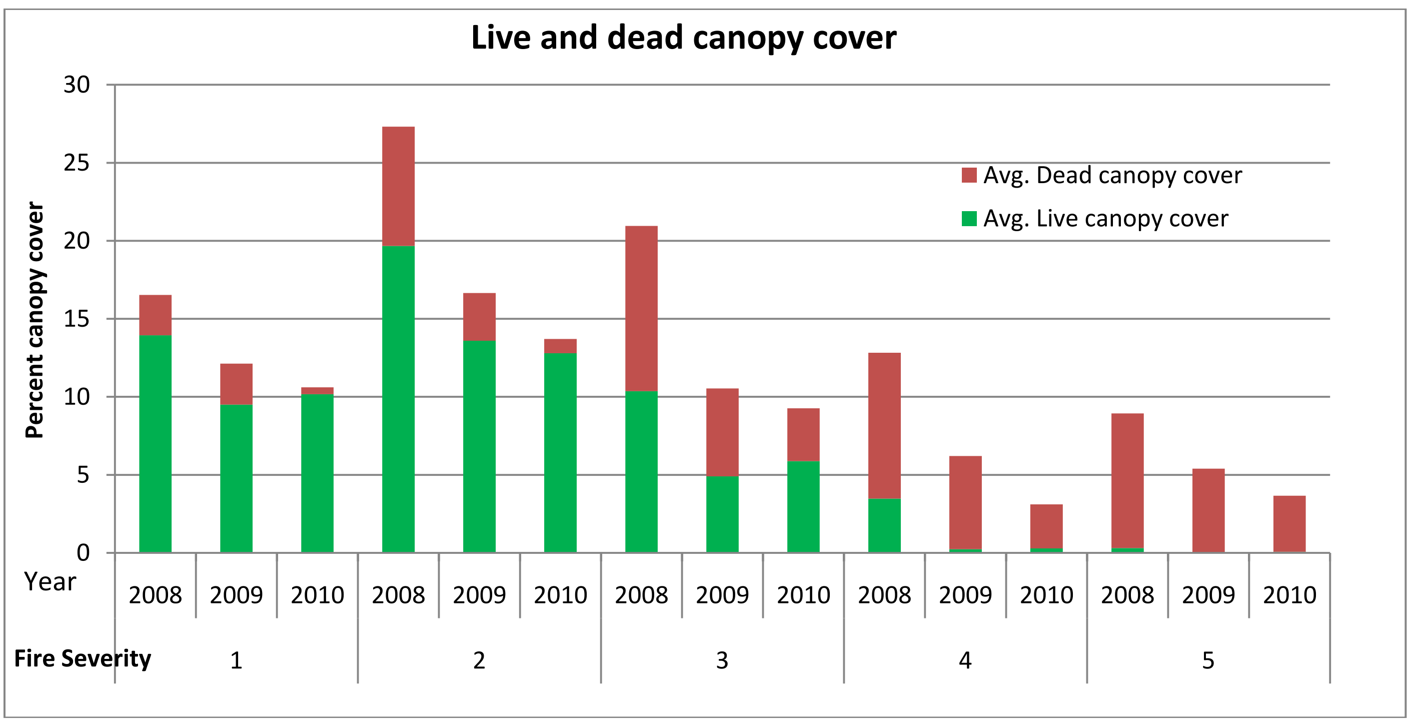

Figure 8. Average live and dead overhead canopy cover in 2010 by fire severity. Data from regeneration plots.

Conclusion

Three years after wildfire, vegetation and ecosystem structure within the Angora fire continue to be influenced by fire effects as well as pre- and post-fire management actions. Tree mortality rates during fire were significantly related to pre-fire live tree density. In 2010 we observed that severely burned areas have higher fuel loads, more bare soil exposure, more understory vegetation cover, and higher rates of non-native plant presence. Stands which were properly treated for fuels before fire continue to exhibit lower fuel loading and higher understory richness. Logged plots have fewer coarse woody fuels, but more fuels in the 10 and 100 hour size classes. Natural tree regeneration is highly variable across the fire area, but is generally highest in moderately burned stands and lowest in severely burned stands. About 35% of sampled plots support no seedlings 3 years after fire, but strong seed crops for fir species in 2009 and pine species in 2010 resulted in strongly increased seedling densities in many areas.

Lessons learned from the Angora fire will influence future post-fire management strategies in the Lake Tahoe Basin. Continued monitoring of forest structure and diversity in and around the Angora fire will be fundamental to understanding how wildfire, forest management, and landscape variation influence the evolution of post-fire landscapes, and will help inform management decisions intended to protect forest health and human communities.

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Thinned
Low intensity ground fire (severity 2)
CSE plot 29.

There was some post-fire logging done here before the 2008 survey.

Fire effects were moderate, with 50% of pre-fire basal area killed through 2010.

Understory richness is high, in the 80th percentile across fire severities (3 shrubs, 21 forbs, 3 grasses).

Fine and coarse woody fuel loads are in the 45% and 0% percentile overall (1.3 tons per acre <3”, 0 tons per acre >3”).

2008

2009

2010

Thinned
High intensity ground fire (severity 4)
CSE plot 68.

Fire effects were moderate, with 32% of pre-fire basal area dying through 2008, and an additional 16% of pre-fire BA dying 2009-2010 (48% overall mortality rate).

Understory richness is high, in the 94th percentile (10 shrubs, 19 forbs, 3 grasses).
Lactuca serriola and *Cirsium vulgare* are present.

Fine and coarse woody fuel loads are in the 85th and 75th percentile, respectively (3.4 tons per acre <3", 14 tons per acre >3").

2008

2009

2010

Not thinned. Logged in 2009 (Along system road in north part of fire) **High intensity ground fire and canopy fire (severity 5)** **CSE plot 84.** (photo in 2008 from different position) Fire effects were severe, with 100% of pre-fire basal area in the fire. Logging in 2009 removed all snags. Understory richness is moderate, in the 60th percentile (8 shrubs, 9 forbs, 2 grasses). *Lactuca serriola* and *Cirsium vulgare* are present. Fine and coarse woody fuel loads are in the 70th and 75th percentiles, respectively (2.2 tons per acre <3"; 16 tons per acre >3").	**2008** 
2009 	**2010** 

Not thinned
Intense ground fire (severity 4)
CSE plot 4. (2008 photo not taken from same position.)

No canopy fire, severe ground fire.

Fire related mortality was 98% of pre-fire BA. The one surviving Red fir died and broke in 2009, and broke due to fungal rot (shelf fungus)

This plot has the lowest understory diversity (3 shrubs, 2 forbs, 0 grasses).

Fine and coarse woody fuel loads are in the top 5% of all plots (6 tons per acre <3", 40 tons per acre >3")

2008

2009

2010

Not thinned
Intense crown and ground fire (severity 5)
CSE plot 44.

Fire related mortality was 100% of prefire basal area.

Understory richness is low, near the 20th percentile (4 shrubs, 5 forbs, 0 grasses)

This plot has fine fuel loads and coarse woody fuel loads near the 80th percentile (2.7 tons / acre <3", 22.4 tons / acre > 3" diameter, respectively).

Notice the Lodgepole pine near plot center that falls between 2009-2010.

2008

2009

2010