Effectiveness of litter removal in preventing mortality of yellow barked ponderosa pine in northern Arizona

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Abstract

Removal of deep litter and duff from the base of mature southwestern ponderosa pine trees is commonly recommended to reduce mortality following prescribed burns, but experimental studies that quantify the effectiveness of such practices in reducing mortality are lacking. Following a pilot study, on each of four sites in northern Arizona we monitored 15-16 sets of 8 matched trees (N=488) on areas designated to be burned and adjacent unburned sites and randomly assigned one of four litter removal treatments: 1) to 9" with raking, 2) to 9" with a leaf blower, 3) to 40" with raking, and 4) no litter removal. By 2-3 years post burn, no trees had died due to the fall prescribed burns, but litter removal prevented most cambial kill and bole char. Litter removal to 9" was as effective in preventing cambial kill and bole char as removal to 40" and there was no difference between removal by raking versus leaf blowing. These results suggest that litter and duff removal is not needed to prevent ponderosa pine mortality following fall prescribed burns, but removal to 9" is adequate to prevent spots of cambial kill or bark char.

Introduction

Recommendations to lessen mortality of old growth ponderosa pine trees often center on removing litter from the base of trees before prescribed burning. Current management practices call for raking the deep litter and duff accumulation away from the bole before prescribed burns to reduce mortality of mature southwestern ponderosa pine trees. These litter/duff removal efforts are intended to compensate for 100 years of fire suppression that allowed deep litter and duff to accumulate on the forest floor due to the altered fire frequency. In spite of the common perception that these efforts will enhance survival of old growth trees, there are few published findings that address whether this practice does, in fact, lead to higher survival of mature ponderosa pine trees following prescribed fire. Additionally, no studies have examined the direct mortality effects of just raking. The latter may be important since raking often occurs a few months before the actual burn, or in some cases, many months if burn prescription conditions do not materialize until the following burn season. Further, these litter/duff removal efforts are very labor intensive and there is not consensus for techniques to remove the litter and duff.

Retention of these old growth trees is important to both forest restoration efforts and wildlife management goals and is mandated for the protection of some threatened or endangered species. However, raking the litter and duff is time and labor intensive and may have other unintended consequences. The exposure of mineral soil at the tree base may alter tree and soil moisture relations during drought periods or enhance establishment of exotic plant species. However, the failure of restoration efforts to maintain old growth trees or the loss of old growth wildlife habitat may be of greater concern.

Several studies have noted an increase in mortality of large (> 18" dbh) ponderosa pine following prescribed fire (Harrington and Sackett 1990, Kaufmann and Covington 2001, Sackett et al. 1996, Thomas and Agee 1986, Swezy and Agee 1991). Many investigators have suggested that increased burning intensity and duration at the root crown due to the accumulation of fuels resulting from fire exclusion may be the causal factor (Harrington and Sackett 1990, Kaufmann and Covington 2001, Ryan and Frandsen 1991, Sackett 1988, Sackett and Haase 1998, Sackett et al. 1994, 1996, Swezy and Agee 1991).

The practice of raking litter/duff away from the bole of large (> 18" dbh) ponderosa pine to mitigate the potential increase in postfire mortality is widely recommended (Covington et al. 1997, Friederici 2003, Fule et al. 2002, Mast 2003, Moore et al. 1999), especially on some soils (Kolb et al. In Press); yet very little data exist to support the hypothesis that it reduces post-prescribed fire mortality. Thomas and Agee (1986) suggested that scraping some bark and needle accumulations may be necessary to reduce post-prescribed fire mortality in these trees, and in a later study, Swezy and Agee (1991) measured post-prescribed fire mortality on 9 old growth ponderosa pine in Crater Lake, OR: 3 not burned, 3 burned and raked, and 3 burned and unraked; each set including 1 tree of low, moderate, and high vigor. A "no treatment" effect (burned or raked) was not tested. In that study, only the litter was raked and only one tree died: 1 of 3 burned and raked trees, an initial low-vigor tree which also suffered an attack from western pine beetles. No data exist on raking effects in southwestern ponderosa pine ecosystems. Root collar cambium temperature data have been previously collected on mature southwestern ponderosa pine at Long Valley Experimental Forest, which show that there is a reduction in cambium heating during prescribed fire to below lethal temperature with the removal of forest floor material down to mineral soil, to a 9 inch distance using a leaf blower (Haase, data on file).

This study examined the effectiveness of litter/duff removal and controlled many other confounding factors that may also contribute to mortality of old ponderosa pine trees. We also utilized two removal techniques and two removal distances in order to standardize methods for managers to use if the goal is to retain old growth trees in the southwest region. The specific objective of this research was to evaluate the effectiveness of litter and duff removal in preventing cambial kill in large ponderosa pine trees in northern Arizona.

Methods

A pilot study was implemented at the Kachina Rx on the Coconino NF in Fall 2004 followed by the main study at four sites in Fall 2005: Bald Mesa Rx and the Skunk Canyon Rx on the Coconino NF; Scott Rx and the Road Hollow Rx on the Kaibab NF (figure 1). All sites were strongly dominated by ponderosa pine, and the prescribed burns were low intensity underburns designed to reduce fuel loads and raise crown base heights. The pilot study site had volcanic basalts as the soil parent material while the for main study sites had limestone-derived soils. We utilized eight different forest floor fuel treatments on each site with 15 ∃18-inch dbh ponderosa pines per treatment. The litter/duff removal techniques were: rake 9 inches, rake 40 inches, blow 9 inches (with leaf blower), and no removal. These four techniques were applied on both the burned and not-burned prescribed fire treatments. The effectiveness of these treatments was measured by testing for live cambium during stem tip elongation the first growing season after the fire, by measuring a subsample of cambial temperatures during the fire, and by tree mortality for 2-3 years post prescribed fire. Thus sample size was 120 trees for each site, and a total of 600 trees for the experimental study.

At each site, each tree meeting the selection criteria was tagged with a unique number.

Selection criteria were: trees ∃ 18 inches (46cm) dbh; litter/duff depth at least 5” (13 cm) within 9 “ (23 cm) of the bole; no logs (> 4" (10 cm) diameter) within the potential litter/duff removal radius (40 inches); no large woody fuel within 10 ft. (3 m) of the base of the tree; trees in good vigor; i.e., no obvious evidence of bark beetles, dwarf mistletoe, or past fire damage, etc.

The experimental design was structured with sites as randomized blocks and used three metrics: cambial kill, bole char (Ryan and Noste 1985), and tree mortality. Within each site (block), 15-16 sets of 8 matched trees (split plots) were selected with treatments randomly assigned to 4 trees of each set within both the burned and not-burned treatments. Sets of trees were matched by dbh, mean litter depth, and volume of woody fuels >3"in diameter within a 10-ft. (3-m) radius of the tree bole in that order of priority.

Pre-treatment tree measurements were dbh, height, live crown ratio, crown base height, slope, aspect, lightning scar size, burn scar size, bark (yellow or black), top (flat or pointed), dwarf mistletoe rating, and distance to and volume of logs and stumps within a 10-foot radius of the bole. Log and stump volume was calculated using average diameter and length. The forest floor material profile on the experimental trees was measured along four transects starting with the azimuth of the major tree asymmetry, then rotating 90^0 for each of the remaining three. The major tree asymmetry is defined as the azimuth of the longest live branch or the azimuth of a leaning bole whichever leads to the most asymmetric distribution of litter. Total litter and duff depth were measured at the base of the tree and then in one-foot intervals to the dripline. These litter depth measurements were taken by carefully wiggling a blunt ended metal ruler through the forest floor profile with the intent of minimizing disturbance of the litter profile yet adequately characterizing the pre-treatment total litter/duff depth.

Litter and duff were removed down to mineral soil using the three different techniques within 30 days of the prescribed burn treatments. Removed litter was scattered evenly under the same tree to avoid creating a mound of fuel.

Since our goal was to use cambial kill as one of our measurements to compare the effectiveness of litter/duff removal, cambium temperature profiles were measured on 12 trees at the Bald Mesa Rx following the methods outlined in Sackett and Haase (1992). The four treatments were grouped into three groups that covered the western edge of the prescribed burn. This was done to capture differences in fire behavior over the project area during the prescribed burn and to allow the complete capture of the four treatments if the ignition had to be terminated. Cambium temperatures during the burn were measured on each of the 12 trees by placing thermocouples in the root collar cambium using 18-inch chromal-alumel thermocouples. The system accommodates up to six thermocouples but some of the trees were too small to be able to use all six. A chain saw was used to make a 6-8 inch cut in the bark that ends 3-4 inches above the forest floor material. The thermocouple was forced between the bark and cambium so that the tip of the thermocouple was mid-way of the forest floor depth. The thermocouple connectors were attached to the extension cables which were extended outside the active fire area to an area cleared of fuels. A fire resistant patch of fiberglass insulation and fire tent material was placed over the cambium thermocouple to protect from external heating and to mark the top of the forest floor material. Cambium temperatures were measured and stored in five-minute intervals using a Cambell Scientific 21X datalogger allowing the capture of the maximum and duration of temperature changes.

Bulk density of the forest floor was determined by developing a forest floor depth/weight regression. This coefficient is then applied to the depths associated (duff pins, tree nail depths, thermocouple patch depths, etc.) with each tree to estimate the fuel loading for each of the temperature monitored treatment trees. The regression is based on at least 50 square foot samples collected in each area (burned and unburned) beneath trees not used and at various distances from the bole to the dripline at the Bald Mesa Rx site. The samples were collected by forest floor layer (Litter-, Fermentation-, and Humus-layers). Each layer was bagged and depths were measured in the center of each side of the sampling square.

Post-fire measurements for trees were started within 60 days of the prescribed fire. Litter/duff profiles were re-measured along with the following postfire damage variables: ground char class (unburned, light, moderate, and deep) (Ryan and Noste 1985), bole char (none, superficial, moderate, deep) (Ryan 1982), crown scorch volume (Peterson 1985), and live/dead tree status. The proportion of the surface area covered by each ground char class was visually estimated using cover classes (Daubenmire 1959). Midpoints of these cover classes were used to calculate the percentage of each ground char class for each sample point. A ground char value for each sample point was then calculated by a weighted average of light char (1x), moderate char (2x), and deep char (3x). During stem tip elongation in the first growing season post fire, the width of cambial kill at the root collar was measured by visual examination of cambial condition from increment borer samples beginning at the center of patch of moderate bole char (criteria in Ryan 1982) from the 2005 prescribed fires (if present) and if dead cambium was found, sampling at 2-inch intervals both directions until live cambium was encountered. At years 1, 2, and 3 after the fire, each tree was assessed as dead or alive using the presence/absence of green needles as the criterion.

Statistical analysis was performed using SAS/STAT® software, Ver. 9.1 of the SAS system for Windows 2000 (2002-2003). Statistical significance was determined by p#0.05. Table analysis was performed in PROC FREQ. The statistical associations were described using the Pearson Chi-square goodness-of-fit test to detect the presence of an association (Loether & McTavish, 1976). Cambial kill logistic regression models were developed in PROC GLIMMIX using Kenward-Roger denominator degrees of freedom and type 3 tests for fixed effects. GLIMMIX model fit was judged by the generalized χ^2 / degrees of freedom ratio where smaller is better; only statistically significant variables were retained. Standardized betas were obtained from PROC LOGISTIC using the STB option on the final GLIMMIX models.

Results

Experimental Trees

Descriptive statistics for pre-fire measurments of the large ponderosa pine trees selected for the prescribed burn and litter removal treatments are shown in Table 1, with post-fire measurements shown in Table 2. These measurements provide context for the mortality results and were used as possible variables in the subsequent logistic regression models of cambial kill. Depth/weight regression equations for layers of the forest floor on the burned / not-burned treatment plots at Bald Mesa Rx are shown in Table 3.

Tree Mortality

The pilot study site, Kachina Rx, was burned in October 2004. Trees were arranged in groups of 15, each group receiving a different raking treatment, either 9 inches or 40 inches, on both burned and not-burned sites. We were not able to get the 9 inch leaf blower treatment applied before the scheduled prescribed fire, so we effectively had 30 "no removal" trees on both burned and not-burned plots. At three years post prescribed fire, no fire related mortality has occurred on either the burned or not-burned plots (Table 4). However, two trees have died on the burned plot. One was a "rake 9" tree that did not get fire within 10 ft. of the base, the other was a "no removal" tree that did receive bole scorch, but both trees were struck by lightning in 2006 and died between the 2006 & 2007 growing seasons.

In October 2005, 15 matched sets of 4 burned/4 not-burned trees were selected for each of three main study sites, Bald Mesa Rx, Scott Rx, and Road Hollow Rx, along with 16 matched sets for Skunk Canyon Rx yielding a potential total of 61 trees for each of the four litter/duff removal treatments on both burned and not-burned plots (N=488 trees). However at Road Hollow, seven trees within the burned unit did not get fire at the base and one "rake 9" tree was just outside the final fireline. At two years post prescribed fire, no mortality has occurred on either the burned or not-burned plots (Table 4).

Cambial Kill

Although no trees were killed by prescribed fire in this study, some of the "no removal" trees did have areas of dead cambium the first post-fire growing season. With one exception, none of the litter/duff removal treatment trees had cambial kill as a result of the prescribed fires (Table 5). The exception was a "rake 40" tree at Road Hollow where a 26" dbh snag burned through at the base and fell next to the bole within the 40" raked radius. However, 17% of the "no removal" trees had some cambial kill (Table 5).

This association of cambial kill with no litter/duff removal is corroborated by thermocouple temperature measurements taken during the prescribed fire at Bald Mesa (Table 5). Maximum temperatures and duration of temperatures >150< F (66< C) were clearly higher for the "no removal" trees than for the litter/duff removal trees. Two of the "no removal" trees had cambial kill near the location of the maximum-temperature thermocouples.

Next we analyzed cambial kill for all 388 burned trees in the data set: i.e., both the experimental trees and the extra trees on the four burned sites that were not selected for the litter/duff removal experiment but which met the screening criteria. For these trees, we grouped the three litter/duff removal treatments into one treatment category and separated cambial kill into two types in the field based on location of the dead cambium: 1) above and 2) just below the soil surface. The former, bark char cambial kill, was also associated with "no removal" (Table 6), the single treatment tree with cambial kill was the above mentioned "rake 40" tree at Road Hollow.

Below the soil surface cambial kill was designated bark flake consumption cambial kill due to the amount of loose, vertical bark flakes which were trapped between the functional bark at root crown and the soil. If consumed by smoldering fire, this collar of bark flakes (and probably fine duff) left a narrow collar of gray ash and was an indication of possible dead cambium. Bark flake consumption cambial kill was also significantly associated with the "no removal" trees (Table 6). Only four trees had both bark char cambial kill and bark flake consumption cambial kill.

The litter/duff removal treatments also tended to prevent moderate bole char (Table 7) although only 34% of the "no removal" trees had moderate bole char. There was no significant difference in bole char between litter/duff removal techniques (rake 9 vs. blow 9, χ^2=2.6692 p=0.1023) or removal distance (rake 9 vs. rake 40, χ^2=2.7381 p=0.0980).

Cambial Kill Models

Using burned trees with no litter/duff removal treatment in the data set, we developed statistical models to see which pre-fire measurements would be the best predictors of cambial kill. Since, as previously mentioned, there were only four trees with both bark char cambial kill and bark flake consumption cambial kill, we modeled the two types separately. Using PROC GLIMMIX with site (Skunk Canyon, Bald Mesa, Scott, and Road Hollow) as a random effect, there were two significant variables for predicting the presence of bark char cambial kill: log volume ($F_{1, 390}$=5.66, p=0.0178) and tree height ($F_{1, 390}$=8.42, p=0.0039). Both increasing log volume and shorter tree height tended to increase the probability of bark char cambial kill. Treating site as a random effect gives inference that these variables are significant beyond the four sites in our data set. The same model in PROC LOGISTIC (without site as a random effect) using the STB option indicates that tree height is more influential than log volume.

The PROC GLIMMIX model for presence of bark flake consumption cambial kill with site as a random effect had dbh and mean distance to stump as significant predictors ($F_{1, 389.8}$=38.96, p<0.0001 and $F_{1, 389.8}$=10.35, p=0.0014 respectively). Increasing values of both tended to increase the probability of cambial kill. As above, PROC LOGISTIC with the STB option indicates a stronger influence for dbh. For both types of cambial kill models, the addition of ground char and mean litter consumed as post fire measurements proved non-significant.

Conclusions

Within the limits of a fuels-reduction type, fall prescribed fire in northern Arizona, the study conclusions at 2-3 years post prescribed fire are:

1. No fire related tree mortality has occurred on any of the 5 prescribed burns.

2. Litter removal may not significantly affect postfire mortality but does affect probability of cambial kill.

3. Litter removal alone does not increase mortality (not-burned treatment).

4. Litter removal prevents most cambial kill and bole char.

5. No litter removal has a 15-20% chance of causing some areas of cambial kill.

6. Litter removal distance to at least 9 inches is as effective in preventing cambial kill and bole char as at longer distances.

7. Litter removal by leaf blower is as effective in preventing cambial kill and bole char as removal by raking.

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Table 1. Means ± standard deviations for pre-fire measurements of trees selected for prescribed fire and litter removal treatments in northern Arizona. dbh = diameter at breast height (in), cbh = crown base height (ft), ht = tree height (ft), lcr = live crown ratio, bole lit = mean litter depth next to bole (in), max lit = maximum litter depth within 9 inches of bole (in), avg lit = mean litter depth under canopy (in). For the following measurements, means are for trees where heavy woody fuels (> 3 inches) were present (n = number of trees): lg vol = volume of logs (ft^3), st vol = volume of stumps (ft^3), lg dist = mean distance to logs (ft), st dist = mean distance to stumps (ft).

Variable	Total N=487	Skunk n=128	Bald Mesa n=120	Scott n=120	Road Hollow n=119
dbh	25.96 ± 4.33	24.23 ± 3.40	25.40 ± 4.30	26.83 ± 4.50	27.53 ± 4.35
cbh	20.47 ±12.80	13.07 ± 7.09	26.12 ± 12.26	12.37 ± 7.03	30.93 ± 12.27
ht	90.44 ±17.05	76.15 ± 11.96	96.95 ± 15.44	85.83 ± 12.81	103.90 ± 12.96
lcr	64.19 ±15.54	71.37 ± 12.17	55.25 ± 16.94	73.17 ± 11.26	56.05 ± 11.52
bole lit	4.16 ± 1.21	4.32 ± 1.31	3.78 ± 0.93	4.80 ± 1.21	3.73 ± 1.02
avg lit	2.63 ± 0.74	3.20 ± 0.85	2.36 ± 0.46	2.53 ± 0.69	2.39 ± 0.52
max lit	7.08 ± 1.97	7.44 ± 2.07	6.37 ± 1.64	7.49 ± 1.75	6.99 ± 2.19
st vol	2.82±5.29 n=106	2.02±2.61 n=44	5.21±5.12 n=6	1.75±1.75 n=26	4.46±8.96 n=30
lg vol	1.34±3.41 n=314	0.79±1.28 n=72	1.59±5.34 n=87	0.58±0.66 n=58	1.98±3.16 n-97
st dist	6.93±1.70 n=106	7.04±1.76 n=44	7.94±1.28 n=6	6.82±1.59 n=26	6.65±1.75 n=30
lg dist	6.63±1.44 n=314	6.48±1.58 n=72	6.71±1.45 n=87	6.75±1.48 n=58	6.60±1.30 n=97

Table 2. Means ± standard deviations for post-fire measurements of trees selected for prescribed fire and litter removal treatments in northern Arizona. lit cons = mean litter consumed under canopy (in), grnd ch = ground char (possible ratings of 0 - 3). For the following, means are given for trees with that type of fire damage measurement present (n = number of trees): bchar = moderate bole char (inches of bole circumference at base), crn = crown scorch volume %, ck / bf cons = cambial kill / bark flake consumption (inches of bole circumference at soil surface), ck / bchar = cambial kill / bark char = cambial kill / bark char (inches of bole circumference at base).

lit cons	1.81 ± 0.87	2.56 ± 0.89	1.64 ± 0.45	1.67 ± 0.84	1.33 ± 0.67
grnd ch	0.83 ± 0.39	0.96 ± 0.37	0.81 ± 0.42	0.90 ± 0.31	0.66 ± 0.39
bchar	16.08±19.08 n=26	20.86±31.49 n=7	6.25±5.91 n=4	18.1±15.62 n=10	13.2±7.43 n=5
crn sch	19.25±19.56 n=67	21.2±21.32 n=25	22.5±21.79 n=4	19.19±19.72 n=31	10.71±10.18 n=7
ck / bf cons	27.29±31.49 n=7	10.33±10.21 n=3	46±0 n=1	0 n=0	38±45.74 n=3
ck / bchar	6.5±3.08 n=6	4.67±2.31 n=3	0 n=0	10±0 n=1	7.5±3.54 n=2

Table 3. Summary of forest floor weight (tons per acre) regression equations (y = a + bx) for Bald Mesa prescribed burn site on the Coconino NF. Material included wood material with diameter of #3 inches, cones, and bark material.

	Regression equation to estimate tons / acre	R^2	Appropriate Range of Use (mm)
Bald Mesa - Burn site			
Total	y = -5.07 + (0.44*mm)	.89	13 to 173
L&F layers	y = -5.60 + (0.48*mm)	.85	12 to 107
H layer	y = 1.16 + 0.32*mm)	.62	1 to 66
Bald Mesa-Unburned site			
Total	y = -1.64 + (0.37*mm)	.87	10 to 128
L&F layers	y = 0.12 + (0.33*mm)	.71	9 to 53
H layer	y = -0.16 + (0.37*mm)	.73	1 to 75
Combined Bald Mesa sites			
Total	y = -4.34 + (0.41*mm)	.87	10 to 173
L&F layers	y = -3.35 + (0.42*mm)	.79	9 to 107
H layer	y = 0.61 + (0.34*mm)	.67	1 to 75

Table 4. Tree status at three years postfire for the pilot study prescribed fire site, Kachina Rx on the Coconino NF and at two years postfire for the main experimental study at four sites: Bald Mesa Rx and Skunk Canyon Rx on the Coconino NF, Scott Rx and Road Hollow Rx on the Kaibab NF. *Two burned plot trees were killed by lightning. **Eight trees at Road Hollow did not get prescribed fire.

Litter/duff removal treatments	Pilot study				Main study			
	Burned		Not-burned		Burned**		Not-burned	
	Live	Dead*	Live	Dead	Live	Dead	Live	Dead
rake 40	15	0	15	0	59	0	61	0
rake 9	14	0	15	0	60	0	61	0
blow 9					58	0	61	0
no removal	29	0	30	0	59	0	61	0

Table 5. Number of trees with areas of cambial kill in the burned plots for each of the four litter/duff removal treatments in the main experimental study (four sites) and maximum cambial temperatures / duration of cambial temperatures above 150< F for the 10 thermocouple trees at Bald Mesa Rx. * indicates failed thermocouple ** indicates trees with cambial kill near the thermocouple. Statistical association between treatments and cambial kill presence/absence was significant, χ^2=26.981 p<0.0001, n=236..

Litter/duff removal treatments	Cambial kill absent	Cambial kill present	Bald Mesa Temperatures <F / duration in hours
rake 40	58	1	62 / 0 57 / 0 *
rake 9	60	0	72 / 0 83 / 0 80 / 0
blow 9	58	0	84 / 0 82 / 0 *
no removal	49	10	281 / 6 ** 560 / 11 ** 380 / 5

Table 6. Number of trees with bark char cambial kill and bark flake consumption cambial kill by litter/duff removal treatment; the three removal treatments are combined. Statistical association of bark char cambial kill and bark flake consumption cambial kill presence/absence with treatment was significant, χ^2=15.0387 p=0.0001 and χ^2=16.8443 p<0.0001 respectively.		
Bark char cambial kill	No removal	With treatment
Absent	185	181
Present	19	1
Bark flake consumption cambial kill		
Absent	186	182
Present	18	0

Table 7. Number of trees with moderate bole char by four litter/duff removal treatments. The statistical association of moderate bole char with treatment was significant, χ^2=40.8767 $p<0.0001$.

Litter/duff removal treatment	Bole char absent	Bole char present
rake 40	58	1
rake 9	55	5
blow 9	57	1
no removal	39	20

Figure 1. Study area map showing Kaibab and Coconino NF boundaries and location of 5 prescribed burns. Pilot study site was burned in fall 2004, other study sites were burned in fall 2005.

Appendix I. Crosswalk between proposed and delivered activities for JFSP Project No. 04-2-1-112.		
Proposed	Delivered	Status
Workshops		Planned for week of Oct. 8, 2007: Road Hollow, Scott, and Skunk Rx sites
Regional conferences	Study design: Fowler, J. F., C. H. Sieg, L. Wadleigh, and S. Haase. October, 2005. Does raking work? Effectiveness of litter removal in preventing mortality of yellow barked ponderosa pine trees in northern Arizona. poster	Study results: planned for Oct. 29-Nov. 1, 2007, 9th Biennial Conference of Research on the Colorado Plateau. poster
Publication		Plan to submit manuscript to Forest Science by Feb. 1, 2008