Does Raking Basal Duff Affect Tree Growth Rates or Mortality?

Erin Noonan-Wright, Sharon M. Hood, and Danny R. Cluck

ABSTRACT

Mortality and reduced growth rates due to raking accumulated basal duff were evaluated for old, large-diameter ponderosa and Jeffrey pine trees on the Lassen National Forest, California. No fire treatments were included to isolate the effect of raking from fire. Trees were monitored annually for 5 years after the raking treatment for mortality and then cored to measure basal area increment. Results showed that raking basal duff and litter to mineral soil from the bole out to 60 cm had no effect on basal area increment or mortality for 5 years posttreatment. Results are pertinent to managers who question whether raking basal duff will decrease tree vigor or increase tree mortality of large and old ponderosa and Jeffrey pine trees in northern California.

Keywords: basal area increment, ponderosa pine, Jeffrey pine, fire effects, duff, mortality

Forest managers use prescribed fire as a surrogate natural process to create resilient forests or restore forest structure closer to historical conditions. Prescribed burning can decrease surface fuel loads, density of small trees, and subsequent probability of crown fire and high mortality. In fire-excluded areas with historically frequent, low-intensity fire regimes, such as ponderosa pine (*Pinus ponderosa* P.&C. Lawson) and Jeffrey pine (*Pinus jeffreyi* Grev. & Balf.) forests, deep accumulations of litter and duff are often found at the base of larger trees. Reintroducing fire in areas with deep basal duff may cause extensive cambium injury at the rootcollar and kill roots growing near the soil surface or in the lower duff, resulting in tree mortality (Sackett et al. 1996, Varner et al. 2005, Kolb et al. 2007). This potential loss of old-growth ponderosa and Jeffrey pine forests is of concern because these stands provide habitat for many wildlife species, contain pools of genetic diversity, are visually pleasing, take centuries to replace, and are much rarer than they once were (Fulé et al. 2007, Kolb et al. 2007).

Physically removing duff from the base of trees, such as by raking, is thought to decrease potential cambial and root injury (and mortality) from future prescribed burns or wildfires. However, raking treatments vary widely, and there are conflicting results regarding their effectiveness in limiting mortality. Furthermore, the effects of preburn basal duff removal have been questioned because of concerns about potential injuries to fine roots and the effects on tree vigor and survival. Few studies have examined the effects of raking on reducing tree mortality, and only Fowler et al. (2010) have examined the effects of a raking treatment separate from a raking and burning treatment. Fowler et al. (2010) reported no statistical difference in tree mortality between raked or unraked ponderosa pine trees following treatment in Arizona. Either rakes or leaf blowers were used to remove litter and duff to mineral soil from the first 23 cm or 1 m around ponderosa pine tree boles. No mortality occurred in any of the control or treated trees 3 years postfire. Other existing studies that include raking did not test the effects of raking apart from fire (Laudenslayer et al. 2008), raked all large trees prior to burning (Fulé et al. 2007), or had very low sample sizes (Swezy and Agee 1991). All these studies had prescribed burns with low-intensity fire behavior.

Reduced radial growth is a sign of tree stress and often a precursor to tree death (Pedersen 1998). Growth rate has been used to predict tree mortality (van Mantgem et al. 2003) and to identify response to thinning and burning (Sala et al. 2005, Skov et al. 2005). If raking the accumulated basal duff around large trees causes fine root mortality and subsequent moisture stress, then tree growth and vigor, as measured by radial growth, should be affected (Sala et al. 2005, Skov et al. 2005).

It is challenging to discuss the effect of raking without taking prescribed fire into consideration. However, a raking treatment alone should be evaluated to understand its effect on tree vigor and mortality without the confounding factor of fire. The effect of raking alone on tree growth and vigor has not been reported. The only raking study to date that included an unburned and raked treatment reported only differences in mortality and focused discussion on the burn treatments (Fowler et al. 2010). Our objective in this analysis was to determine whether basal duff removal negatively affected tree growth or caused tree mortality by measuring basal area increment (BAI) on raked and unraked large, old ponderosa and Jeffrey pine trees. No burning treatment was included.

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This article uses metric units; the applicable conversion factors are: millimeter (mm): 1 mm = 0.039 in.; centimeters (cm): 1 cm = 0.39 in.; meters (m): 1 m = 3.3 ft; hectares (ha): 1 ha = 2.47 ac.

Figure 1. Example of a raked tree (left) and an unraked tree (right). For raked trees, forest floor material was removed to mineral soil around the first 60 cm of the tree base and scattered. Forest floor around unraked trees was left intact.

Methods

Site Description

A 100-ha ponderosa and Jeffrey pine stand was selected on the Eagle Lake District of the Lassen National Forest, California (40.58655°N, −121.20496°W) to examine the effect of raking on growth rates and mortality. Mature ponderosa and Jeffrey pine dominate the site, with mature white fir (*Abies concolor* [Gord. & Glend.] Lindl. Ex Hildebr.) scattered throughout. The site is further characterized by a dense midstory of white fir ingrowth, with a heavy shrub component of snowbrush ceanothus (*Ceanothus velutinus* Douglas ex. Hook) and green leaf manzanita (*Arctostaphylos patula* Greene). The site has a north aspect, slopes between 0 and 25%, and elevation ranging from 1,920 to 1,980 m. Dominant soils are from the Yallini-Sheld-Portola families association, which are derived from igneous andesite and basalt lava flows, ash, pumice, or cinder (Natural Resources Conservation Service 2009). Average annual precipitation is 460 mm and occurring mostly as snow from October through May (Adams et al. 2008). This site has likely not burned in over 100 years based on Forest Service records, site characteristics, and a nearby fire history study (Taylor 2000). This area was an unburned control unit for a larger, ongoing study to examine the effects of raking and burning on tree mortality (preliminary results reported in Hood et al. 2007).

Treatment Description

We investigated the effect of raking on tree growth and mortality using paired trees. At each designated raked tree, a crew of two or three people used McLeod tire tools and rakes to remove all litter and duff to mineral soil within a radius of approximately 60 cm around the tree base (Figure 1). All shrubs located in this area were also clipped to ground level. The material was scattered to minimize the formation of a mound of raked material. Trees were raked in the late summer and fall of 2003; very few fine roots were observed in the duff during the raking treatment. Crews worked in groups of two or three and could clear the area in approximately 6 minutes/tree. Raking time increased with duff depth and shrub presence.

Sampling

Sixty ponderosa and Jeffrey pine trees greater than 63.5 cm dbh with no sign of insect attack were chosen randomly from the unit. Trees were paired if they were the same species and then on the basis of similar diameter and vigor, and a general proximity to each other of approximately 75 ft. Only trees with Keen vigor class ratings (Miller and Keen 1960) of A and B were selected, representative of crowns of moderate to high vigor. These trees are most likely to be targeted by managers for protection because they are likely to survive longer than low-vigor trees. We measured dbh (1.4 m above ground), total tree height, and crown base height and noted Keen's vigor class, species, and fire scar presence. Prior to raking, we also measured total forest floor depth (duff and litter) at 0, 30, 60, 90, and 120 cm from the tree bole and at the drip line in the cardinal directions by using a trowel to pull back litter and duff just far enough to insert a ruler to mineral soil.

One tree in each pair was then randomly selected to receive the raking treatment unless a fire scar was present, in which case, the tree with the fire scar was designated for raking (5 of 30 raked trees). In the event of a fire, trees with exposed fire scars are more susceptible to igniting and dying (Keane et al. 2006). Although this study does not have a fire component, trees with fire scars are more likely to receive higher priority for raking when raking is used as a prefire treatment.

We assessed mortality, crown vigor, and insect attacks annually for five growing seasons after raking. At the end of the fifth growing season (September 2008), we cored each tree to determine annual growth rates. We collected two cores from each tree at breast height, opposite each other on the cross-slope, to estimate BAI and tree age. One core was sampled to within a field-estimated 10 rings of the pith for aging, and a second core was extracted to include at least 100 years of prior growth. We remeasured dbh at the time of coring and

Table 1. Mean and range of measured variables for ponderosa and Jeffrey pine study trees by treatment. *P* values are from paired *t*-tests. BAI_{-5} is the basal area increment for the 5 years before treatment, BAI_{+5} is the BAI for the 5 years after treatment, $BAI_{-5} - BAI_{+5}$ is the difference between the two BAI measurements, dbh_{03} is the dbh pretreatment, and duff variables are average forest floor depths sampled at 0 cm ($duff_0$) and at the drip line ($duff_{DL}$).

Variable	Raked		Unraked		
	Mean	Range	Mean	Range	*P* value
BAI_{-5} (cm^2)	77.4	15.8–162.8	75.8	18.9–176.5	0.8538
BAI_{+5} (cm^2)	73.0	15.4–152.5	74.0	15.3–193.2	0.7735
$BAI_{-5} - BAI_{+5}$ (cm^2)	4.5	−19.7–56.5	2.0	−49.3–57.4	0.6719
dbh_{03} (cm)	88.4	70.9–110.2	89.2	66.3–113.3	0.3724
Age (years)	267.5	222–441	260.8	194–406	0.5505
$Duff_0$ (cm)	11.9	2.5–26.7	11.9	5.1–19.4	0.964
$Duff_{DL}$ (cm)	5.5	1.0–9.5	6.3	0.3–13.3	0.273

measured bark thickness at each coring site using a bark thickness gauge to the nearest millimeter. We did not core trees that died after the raking treatment (two raked trees, one unraked tree).

All cores were mounted on grooved boards and sanded with progressively finer grit paper, until the cellular structure of each core was visible through a binocular microscope. We assigned calendar years to tree rings using a combination of visual cross-dating of ring widths and cross-correlation of measured ring-width series (Holmes 1983, Grissino-Mayer 2001) by using a local chronology that we developed for the site. We excluded cores from eight trees that we could not cross-date. Age at breast height was estimated on the basis of the curvature of the innermost rings sampled (average correction, 8 years; Applequist 1958) for cores that missed the pith. We measured the width of the most recent 100 rings to the nearest 0.001 mm for each core, using a slide stage micrometer, an Acugage measuring system, and Measure 2JX software (version 3.1, Voortech Consulting, Holderness, NH).

Data Analysis

We calculated pretreatment BAI for the years 1999 through 2003 (BAI_{-5}) and posttreatment BAI for the last 5 years of radial growth (BAI_{+5}) using dbh, bark thickness, and yearly growth increments. BAI_{-5} and BAI_{+5} were averages of the two cores collected for each tree. BAI_{-5} was computed by subtracting the basal area of the tree up to growth year 1998 from the basal area of the tree including growth up to 2003, the year of treatment. BAI_{+5} was computed by subtracting the basal area of the tree, including growth up to 2003, from the basal area of the tree including growth up to 2008.

We compared the difference between BAI_{-5} and BAI_{+5} using a *t*-test to determine whether growth rates before and after treatment differed. We used paired *t*-tests and the Wilcoxon signed rank test to test for the effect of treatment (raked or unraked) on BAI_{-5}, BAI_{+5}, dbh measured in 2003 (dbh_{03}), tree height, age, and average pretreatment duff depths. This was done to determine whether some other factor, such as variations in a growing season, influenced pre- versus posttreatment BAI, other than the actual treatment. After these exploratory analyses, we used a chi-square analysis to detect differences in 5-year mortality between treatments. We used a generalized linear mixed model (SAS for Windows, version 9.2 2007, SAS Institute, Inc.) [1] to evaluate potential differences in BAI_{+5} for raked and unraked trees. Fixed-effect variables for the model included treatment, species, treatment × species, vigor (Keen's crown classification), 2003 diameter, age, and both linear and quadratic combinations of BAI_{-5}. Inclusion of quadratic effects in the model and the application of an exponential response distribution for BAI_{+5} were necessary to adequately model the residuals. Random effects included paired trees clustered by species. Variables were considered significant if the *P* value was less than or equal to 0.05.

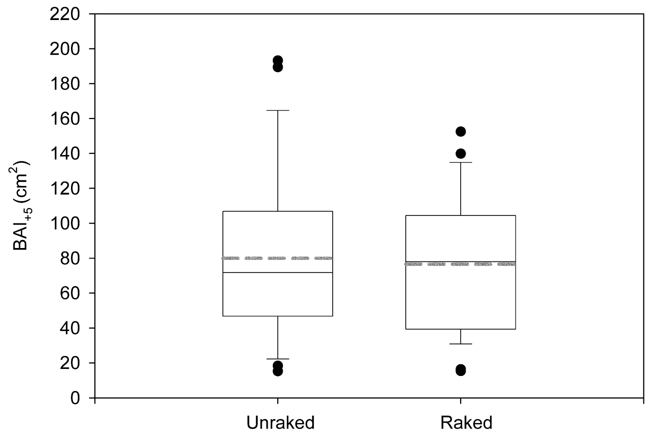

Figure 2. Box plot of basal area increment for 5 years after the raking treatment (BAI_{+5}). The lower box boundary represents the 25th percentile, a solid line within the box marks the median, and the upper box boundary represents the 75th percentile. The dotted gray line denotes the mean. Whiskers above and below the box represent the 90th and 10th percentiles, respectively. Outliers are shown as points beyond whiskers.

Results

There was no difference between raked and unraked pretreatment growth rates and posttreatment growth rates ($BAI_{-5} - BAI_{+5}$) ($P = 0.6719$) (Table 1). Furthermore, there was no difference in BAI_{+5} ($P = 0.9194$) (Figure 2) between raked and unraked trees. Five-year mortality was very low (3 of 60 trees), with no significant difference between treatments ($P = 0.5536$). None of the variables in the generalized linear mixed model were significant ($P > 0.05$) (Table 2). Random effects also did not influence the model. Prior to raking, there was no significant difference between raked and unraked trees for any of the tree or forest floor measurements ($P > 0.05$) (Table 1).

Discussion

Deep basal duff can accumulate in ponderosa and Jeffrey pine forests with years of fire exclusion, potentially making trees more susceptible to basal injury if burned. Removing duff and litter from the base of trees prior to burning can reduce cambium injury (Hood et al. 2007, Fowler et al. 2010). However, Swezy and Agee (1991) and Kolb et al. (2007) have suggested that raking the forest floor

Table 2. Results from the generalized linear mixed model for posttreatment basal area increment (BAI_{+5}).

Variable	*F* value	*P* ($\leq F$)
Treatment	0.02	0.9194
Species	0.06	0.8499
Treatment × Species	0.04	0.8761
Vigor (Keen's classification)	0.06	0.8518
span lang=PT-BR2003 diameter	0.01	0.9463
Age	0.00	0.9983
BAI_{-5}	3.54	0.3111
$BAI_{-5} \times BAI_{-5}$	1.23	0.4666

away from the base of old trees prior to burning may stress trees, especially low-vigor trees, by removing any roots growing in the lower duff. We did not measure root biomass in this study but found no indication that raking stressed large, old ponderosa and Jeffrey pine trees 5 years after treatment, either by reducing radial growth or by causing elevated tree mortality. We also included only high-vigor trees (Keen's class A and B) in this study. Results may differ for lower vigor trees. Both Fowler et al. (2010) and this study applied raking treatments in the fall, a time during which we observed very few roots. In contrast, Swezy and Agee (1991) raked in the spring, when root growth is highest, and they observed higher amounts of root biomass. This suggests that the effect of raking basal duff and litter may vary by site and season depending on the location of fine roots.

There was no difference in mortality for raked and unraked trees 5 years after treatment. However, two raked and one unraked ponderosa pine died from western pine beetle (*Dendroctonus brevicomis* LeConte) attacks after 2003. All three trees were located near an existing pocket of western pine beetle activity. The raked trees were attacked and died within 1 year of treatment. The unraked tree exhibited signs of dwarf mistletoe (*Arceuthobium* spp.) and decreased crown vigor 4 years after raking and subsequently died. These trees were not cored, so age and pretreatment growth rates are unknown. Consequently, no data are available to determine whether the trees had slower pretreatment growth rates and were more susceptible to western pine beetle attack (Pedersen 1998).

Our study found that raking duff and litter away from tree boles in the fall did not decrease radial growth rates or cause mortality of large, old ponderosa and Jeffrey pines in northern California. Late-season raking of litter and duff around the base of trees appears to be a viable option to mitigate deep basal duff accumulations, which may be important, because the implementation of a prescribed burn can be delayed for many years. Our results indicate that raking alone without burning should not affect tree mortality or growth regardless of whether the site burns. This allows managers time to rake well in advance of a future prescribed or wildland fire.

This study examined a relatively small sample of high-vigor trees from only one area. As with most case studies, the scope of inference is limited. The raking treatment occurred in the fall, when roots senesce. Duff was raked only 60 cm from the base of the tree bole, which possibly explains why we observed very few fine roots while raking. However, these sites are very dry during the growing season, and roots may never occur in the lower duff layers here. Research is needed to identify the horizontal and vertical distribution and abundance of fine roots adjacent to the tree and evaluate further the timing of raking treatments and their effect on growth rates and mortality of trees for all vigor classes.

Endnote

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