Contribution of landscape level bark beetle outbreaks to fuel loading and fire behavior in ponderosa pine forests of the Southwest

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INTRODUCTION

Record low precipitation, increased temperatures, and dense forests led to tremendous bark beetle incidence across the Southwest in 2002–2003 (Figure 1). During and after these outbreaks there was public concern over how beetle-caused tree mortality affects fuel loading and fire behavior. To date there has been a paucity of information addressing this concern in southwestern pine forests. Romme et al. (2006) hypothesized that bark beetles effects on fire behavior follow a fuel succession: 1) Increased risk of crown fire initiation immediately following outbreak, 2) Reduced crown fire spread and initiation after needle drop, 3) Increased crown fire initiation and spread after snags fall. This Forest Health Monitoring-funded study examines the effects of bark beetle outbreaks during the second and third stage of the hypothesized succession in changing fuels.

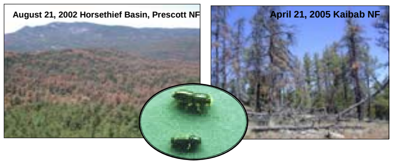


Figure 1. Bark beetle-caused ponderosa pine mortality during outbreak (left) and 2 years post-outbreak (right). Both Ips and Dendroctonus species (center) contributed to ponderosa pine mortality.

OBJECTIVES

1. Quantify the contribution of bark beetle outbreaks to fuel loading in ponderosa pine forests of the Southwest
2. Model potential fire behavior in areas of high, moderate, low and no beetle-caused tree mortality

METHODS

1. GIS maps used to determine plot location.
2. 60 sets of paired mortality/non-mortality 1/20th acre plots installed across a range of elevations and percent ponderosa pine on National Forests in Arizona.
3. Mensurational (tree species, size, crown base height, density) collected on live and dead trees.
4. Brown's (1974) planar transects used to measure surface fuels, fuel bed and duff depth.
5. For this presentation, 10 sets of paired mortality/non-mortality plots were used for analysis. Mortality plots had >50% ponderosa pine mortality. All plots had >60% ponderosa pine component in the overstory.

CANOPY FUEL MODELING METHODS

Fire Model Variable	Definition	Units	Reference
Canopy Fuel Loading (1-, 10-, 100-, 1000-hr woody fuels and canopy foliage biomass (needles))	Mass of canopy fuel load per unit area by time-lag size classes.	Mg ha^{-1}	Brown 1978; Reinhardt et al. 2000
Canopy Fuel for Crown Fire	Foliage biomass plus 50% of 1-hr woody canopy fuel load.	Mg ha^{-1}	Brown 1978; Reinhardt et al. 2000
Canopy Bulk Density	Mass of available canopy fuel per unit of canopy volume.	kg m^{-3}	Brown 1978; Reinhardt et al. 2000

FIRE BEHAVIOR MODELING METHODS

Fire Model Variable	Units	Reference
Fire Rate of Spread (ROS)	m min^{-1}	Rothermel 1972; Rothermel 1991
Fire Line Intensity (FLI)	kW m^{-1}	Byram 1959
Flame Length	m	Byram 1959
Fire Type	Surface fire, Passive and active crown fire	Alexander 1988; Van Wagner 1993
Torching Index	km h^{-1}	Rothermel 1972; Van Wagner 1977
Crowning Index	km h^{-1}	Van Wagner 1977; Rothermel 1991

Weather Parameter	97.5 Percentile
6 m wind speed (km h^{-1})	42.0
1-hr fuel moisture (%)	2.9
10-hr fuel moisture (%)	4.7
100-hr fuel moisture (%)	6.6
1000-hr fuel moisture (%)	9.3
Herbaceous fuel moisture (%)	51.1

Preliminary fire behavior modeling assumed all fires burned under the 97.5th percentile weather conditions for the Coconino National Forest for the month of June from 1968 to 2004.

PRELIMINARY RESULTS

1. Mortality plots had reduced tree size and stand density (Table 1), but greater surface fuels (Figure 2, Table 2).
2. Plots with no tree mortality had greater canopy fuels compared with plots contain tree mortality (Table 3).
3. Preliminary fire behavior models indicate greater fire hazard severity and probability of active crown fire in plots with no tree mortality compared with plots containing tree mortality 4-5 years post-outbreak (Table 4, Figure 3).

Table 1. Post-outbreak stand structure of ponderosa pine stands in Arizona.

	No mortality	Mortality
CBH 20% (m)	2.6	2.1
% PIPO	85.0	83.3
Height (m)	**13.4***	8.2*
QMD (cm)	**32.0***	19.8*
TPA	124.0	78.0
BA (m²/ha)	**22.7***	6.6*
SDI	**154.9***	53.0*

* Significant difference at the 0.05 level

Table 2. Surface fuel loading in no mortality and mortality ponderosa pine plots in Arizona.

	No Mortality	Mortality
Total Fuel Loading < 3 in (Mg/ha)	2.5*	**8.5***
1000hr Fuel Loading (Mg/ha)	2.7*	**11.7***
Total Surface Fuels (Mg/ha)	5.2*	**34.5***
Fuel bed depth (cm)	6.8	17.1
Duff Depth (cm)	1.2	1.4

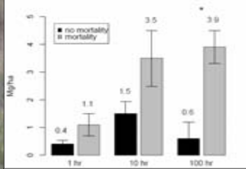
* Significant difference at the 0.05 level

Table 3. Canopy fuel loading in no mortality and mortality ponderosa pine plots in Arizona.

	No Mortality	Mortality
Foliage (Mg/ha)	**6.3***	2.5*
1hr (Mg/ha)	0.9	0.45
10hr (Mg/ha)	**7.1***	2.5*
100hr (Mg/ha)	**6.5***	2.0*
1000hr (Mg/ha)	**1.8***	0.45*
Total canopy fuel (Mg/ha)	**22.4***	8.07*
ACF (Mg/ha)	**6.7***	2.7*
CBD (Kg/m³)	0.181	0.041

* Significant difference at the 0.05 level

Figure 2. Surface fuel loading of 1, 10 and 100 hr fuels in no mortality and mortality ponderosa pine plots in Arizona.

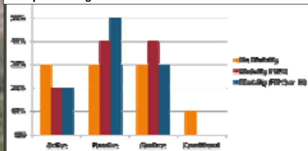


* Significant difference at the 0.05 level

Table 4. Preliminary results of fire behavior modeling based on 10 pairs of no mortality and mortality plots in ponderosa pine forests of Arizona.

	No Mortality	Mortality Fuel Model 9	Mortality Fuel Models 9 and 10
Rate of Spread (m/min)	19.2	12.6	15.2
Flame Length (m)	6.5	3.7	5.9
Fire Line Intensity (Kw/min)	4830.9	2528.9	4210.5
Torching Index (Km/hr)	70.5	33.7	19.6
Crowning Index (km/hr)	51.6	127.7	127.7

Figure 3. Preliminary results of fire behavior modeling based on 10 pairs of no mortality and mortality plots in ponderosa pine forests of Arizona. Predicted fire types with plots assigned as fuel model 9 or 10.



PRELIMINARY CONCLUSIONS

1. Surface fuels increase, but canopy fuels decrease, 4-5 years after bark beetle outbreaks in ponderosa pine forests of Arizona
2. Fire behavior models indicate decreased torching and crowning index 4-5 years post-outbreak
3. Fire behavior models indicate no decrease in crown fire initiation 4-5 years post-outbreak (partially due to the presence of other ladder fuels – piñon, juniper, oak)
4. Future work will focus on a) modeling crown fire behavior at other points along the fuel succession time series, b) the role needle retention plays in fire initiation immediately following outbreak, and c) fuels and fire behavior in piñon-juniper woodlands.

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Romme, W.H., Clement, J., Hicke, J., Kulakowski, D., MacDonald, L.H., Shoennagel, T.L., Veblen, T.T. 2006. Recent Forest Insect Outbreaks and Fire Risk in Colorado Forests: A Brief Synthesis of Relevant Research. Colorado State University, Fort Collins, CO, p. 24.