6.3 DOUGLAS-FIR BEETLE ATTACK AND TREE MORTALITY FOLLOWING WILDFIRE

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1. ABSTRACT

A major concern after wildfires is the buildup of bark beetle populations in fire injured trees, and subsequent attack and population buildup in adjacent unburned areas. To examine this concern, we documented fire injury and insect attacks in Douglas-fir (*Pseudotsuga menziesii*) on the 2001 Green Knoll Fire, Wyoming to determine attack preferences, brood production, and emergence densities in different levels of fire-injured trees. Tree injuries of crown scorch, ground char, bole char, and basal girdling were recorded in mixed-severity burn areas. Douglas fir beetle (*Dendroctonus pseudotsugae*) attack densities and brood production were sampled on two sides of infested trees in the fall of 2002. Sampled trees were organized into different combinations of crown scorch and basal girdling. Cages (1x2 ft) were installed on a subsample of trees in each category in spring of 2003 to sample beetle emergence densities. Crown scorch, pre-fire vigor, dbh, and the interaction of crown scorch and basal girdling were significant variables in explaining whether a tree was attacked by Douglas fir beetle. The number of brood sampled in fall was significantly affected by the percent crown scorch but not the percent basal girdling; however, the emergence the following spring was not significantly correlated with either crown scorch or basal girdling. Further analyses of attack and tree injury correlations are planned.

2. INTRODUCTION

Survival of conifers following wildfire depends on the type and degree of injuries sustained and the post-fire environment, which includes weather, stand attributes, and insect and disease population dynamics. Many species of wood-boring insects are attracted to fire-injured trees and may contribute to subsequent tree death and deterioration. Of particular concern to forest managers are the primary bark beetle species (*Dendroctonus)* which have the capacity to expand to outbreak levels in surrounding stands following buildup in fire weakened trees.

An accurate estimate of tree survival following fire injury is an important aspect of post-fire forest resource management. Research has shown that tree survival is species-specific and relative to root, stem, and crown damage. Although it is known that bark beetles can contribute to delayed tree mortality following wildfire, quantitative information necessary for more accurate predictions is unavailable, and little is known about bark beetle preference, brood production, and survival in fire-injured trees. Additionally, anecdotal evidence suggests that in certain bark beetle species, population levels could build in fire-injured trees and move into green, healthy stands adjoining fire affected areas.

Of particular concern to forest managers are the primary bark beetle species which have the capacity to expand to outbreak levels in surrounding stands following buildup in fire weakened trees. Surveys conducted after the 1988 fires in Yellowstone suggest that bark beetle population levels can increase in fire-injured trees and then spread to uninjured trees (Amman and Ryan 1991; Rasmussen et al. 1996; Ryan and Amman 1996). The level of insect activity following fire will depend on several factors including: 1) the surrounding insect population available to take advantage of the new resource (e.g. stressed trees), 2) the severity of tree stress due to fire injury to foliage, stem, and root tissues, 3) brood production in fire-injured trees, 4) the proximity of green, non-stressed trees, and 5) post-fire weather.

Heat-caused crown and cambium injury are typically used for predicting tree mortality following fire (Furniss 1965; Ryan et al. 1988). These variables were also the basis for a model developed by Ryan and Reinhardt (1988) for predicting mortality of fire-injured conifers. Bark beetles are an important part of the post-fire environment affecting tree survival, yet quantitative data is lacking to describe the role of bark beetles in delayed tree mortality. Guidelines for identifying trees that are at risk to subsequent bark beetle attack following fire injury are few and varied. A brief description is provided below, but

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for a more detailed, species-specific review see Gibson (2000).

The probability of bark beetle attack following fire is highest with moderately scorched crowns, and decreases to almost zero with complete crown scorch (Furniss 1965; Amman and Ryan 1994; Weatherby et al. 1994). In Arizona, McHugh and others (2003) found that trees attacked by *Dendroctonus* and *Ips* had more crown damage than unattacked trees. Infestation of fire-injured trees by bark beetles has also been found to be closely related to the percent of the basal circumference killed, although it varies by tree species (81-100% for lodgepole pine and Douglas-fir, and 41-60% for Engelmann spruce) (Ryan and Amman 1996). Bark thickness was also found to be an important predictor of tree mortality following fire (Ryan and Reinhardt 1988). When diameter at breast height (dbh) is related to bark thickness, dbh was also found to be an important predictive factor in post-fire tree survival in thick-barked trees (Weatherby et al. 2001). Of those systems investigated, Douglas-fir beetle was found to be the most attracted to fire-injured host trees (Furniss 1965; Amman and Ryan 1994; Weatherby et al. 2001). Quantification of the response of mountain pine beetle to fire-injured trees is varied. In some cases mountain pine beetle did not seem attracted to fire-injured lodgepole pine (Amman and Ryan 1991; Ryan and Amman 1996), while others observed moderate mountain pine beetle-caused mortality in fire-injured trees (Weatherby et al. 2001). Although mountain pine beetle attacks and total brood were reduced in injured versus healthy lodgepole pines after a prescribed burn, brood produced per attack did not differ in the control and burn areas (Safranyik et al. 2001). These results indicate that fire-injured trees could provide a resource for population buildup. Mountain pine beetle has been found infesting fire-injured whitebark pine and lodgepole pine on the Green Knoll and Mussigbrod fires (Hood, Bentz, and Ryan unpublished data, on file at RMRS Fire Sciences Lab, Missoula, MT). As with most beetle species, it is likely that the level of mountain pine beetle attack following fire injury is dependent on the proximity of mountain pine beetle-infested trees to the burn and level of tree injury.

Other than the work by Safranyik and others (2001), little information is available on bark beetle brood production in fire-injured trees. Although brood production was not investigated, Cunningham (1997) found that moderately fire-damaged Douglas-fir were colonized at higher densities than other host trees. It is therefore unclear what levels of fire-injury will result in good, adequate, or poor resources for population expansion. It is conceivable that heavily damaged trees could be attractive to beetles, but poor for brood production, and thereby act as a population sink.

This study addresses several questions. 1) Given different levels and types of fire injury, what is the probability of a Douglas-fir tree surviving? 2) If a tree does survive, what is the probability of a Douglas-fir beetle attacking it? 3) Do Douglas-fir beetles prefer fire-injured trees compared to unburned trees? 4) Of those trees attacked by beetles, is brood production affected by fire-caused injuries to trees? This paper addresses questions 3 and 4. Monitoring of additional mortality and additional analyses are needed for questions 1 and 2.

3. METHODS

We located plots in two areas that burned in 2001, the Moose Fire and the Green Knoll Fire. The Moose Fire was started by lightning on August 14, 2001 on the Flathead National Forest, Montana. It burned approximately 71,000 acres on the Flathead National Forest, Coal Creek State Forest, and Glacier National Park. The Green Knoll Fire was a human caused fire that started in late July 2001. It burned 4,515 acres on the Bridger-Teton National Forest, Wyoming south of the town of Wilson.

We initiated the project in the summer of 2002 by selecting areas in each fire dominated by Douglas-fir (*Pseudotsuga menziesii)* larger than 12 inches DBH that burned under mixed-severity conditions near bark beetle populations. These are areas that had some fire, but most of the trees' crowns still had some green remaining. We also were limited to areas with no proposed salvage activities in order to track the trees over several years.

We installed 73, 0.10 acre plots on the Moose fire and 28 plots on the Green Knoll fire in 2002. At each plot, all trees ≥ 5 inches DBH were tagged that were alive before the fire. We assessed tree injury by noting alive vs. dead, percent crown scorch, pre- and post-fire vigor, percent basal girdling, bark char depth and height, and ground char. We recorded vigor as high, moderate, low, very low, or dead. Tree vigor codes were based on the size and shape of the crown, canopy position, and signs of disease and stem damage. Prefire vigor was estimated by visually reconstructing the crown to its prefire state based on the crown scorch. We estimated basal girdling by sampling cambium from four locations spaced evenly around the base of the tree. We sampled the cambium by drilling into the tree with an increment borer to the bark-wood interface and visually determining whether the cambium was alive or dead. Bark char and ground char variables were also noted on four sides of the tree following the methods in Ryan (1983) and Ryan and Noste (1985).

All bark beetle-infested trees in plots were identified based on external bole signs such as frass and pitch tubes. Percent circumference of the tree bole attacked and height attacked was noted, and also whether attacks were in charred or uncharred areas. Attack density was estimated in one 12 x 12 inch section and one 12 x 24 inch section on 2 bole aspects (4 per tree). Fifty percent of the established plots with beetle-infested trees were randomly assigned to be destructively sampled. Bark was peeled from the lower half (12 x 6 inch) of each 12 x 12 inch sections, one on each bole aspect of all infested trees, both green and fire-injured. Within each sampled area the number of parent egg gallery starts was counted and the presence of blue staining fungi was noted. All samples, including bark and brood, were placed in ziplock bags, labeled, and returned to the RMRS Entomology Lab in Logan, UT where they were stored at 5 °C. All samples were dissected and the number of each life stage present (eggs, larvae, pupae and new adults) was tallied.

To measure brood survival, cages were placed on the two 12” x 24” sections of a portion of the sampled trees in the Green Knoll fire (from 2002) prior to flight in spring 2003. A pesticide strip was placed in each cage tube. Adult emergence was monitored biweekly.

Bark beetle attack data were analyzed using the glimmix macro in SAS (SAS Institute V8). Bark beetle attack preference by injury was examined for both the Green Knoll and Moose fire. Trees were placed into one of ten overall categories of injury based on combinations of crown scorch and basal girdling (Table 1). We only used Green Knoll data for the brood production analysis due to problems with caging on the Moose fire. For this analysis the scorch and girdle categories were divided into none (0%), low (1-33%), moderate (34-66%), and high (67-100%).

Table 1. Key of overall categories used for combination of crown scorch and basal girdling.

		Basal Girdling (%)			
		0	0-33	34-66	67-100
Scorch (%)	0	0	-	-	-
	0-33	-	1	2	3
	34-66	-	4	5	6
	67-100	-	7	8	9

4. RESULTS AND DISCUSSION

I. Do beetles prefer fire-injured trees compared to non-injured trees?

About 20% of the Douglas fir in our plots were attacked by DFB the first year after the fire (135 attacked trees/679 total DF). Fire-cause tree injury significantly influenced whether a Douglas fir tree was attacked by the Douglas fir beetle, although DBH was the most significant. Percent crown scorch, pre-fire vigor, and overall category were significant in explaining if a tree would be attacked. Percent basal girdling was not significant. There was a significant difference between overall categories 4 and 5, 5 and 8, and 5 and 9 in attack or not attacked (Table 2).

Table 2. Results of Type 3 tests of fixed effects of beetle attack preference.

Effect	Num DF	Den DF	F Value	Pr > F
Scorch	1	588	4.71	0.0304
Prefire vigor	3	588	3.36	0.0185
Dbh (cm)	1	588	46.11	<.0001
Overall Category	9	588	3.39	0.0005

Table 3 shows the number of trees in each category, the percent dead one year after the fire, and the percent attacked. We expect to see additional mortality and attacks two years after the fire. Trees with either high scorch or basal girdling are able to maintain green crowns for up to several years after the fire depending on weather, beetle attacks, and degree of damage.

Of those trees attacked on our plots 9.6% had no fire injury (13 trees/135 total trees attacked). Therefore, these results suggest that a large majority of the trees attacked had a fire injury.

Table 3. Number of Douglas-fir trees in each injury category, the percent dead 1 yr after the fire, and percent attacked by Douglas fir beetle in the Green Knoll and Moose fires.

	%Girdled			
%Scorched	0	1-33	34-66	67-100
0 n	54	-	-	-
% Dead	0	-	-	-
% Attacked	24	-	-	-
1-33 n	-	203	44	63
% Dead	-	0	0	2
% Attacked	-	14	25	35
34-66 n	-	52	21	31
% Dead	-	0	0	6
% Attacked	-	10	19	19
67-100 n	-	50	20	143
% Dead	-	18	20	52
% Attacked	-	14	15	25

II. Of those trees attacked by beetles, is brood production affected by fire-caused injuries to trees?

On the Green Knoll fire, total number of brood in October samples was significantly affected by the scorch category, but not the girdle category (N=93 samples) (Table 4, Figures 1-2). However, beetle emergence into cages (spring/summer 2003) on the Green Knoll fire was not significantly affected by the amount of crown scorch or basal girdling (N=43 cages) (Table 5, Figures 3-5).

Although beetle emergence from trees and October brood densities were greatest in trees in the low scorch category, compared to non-injured and more severely injured trees, the relationship was not significant. Results from one year of data suggest that fire-caused tree injury, based on crown scorch and basal girdling measurements, does not affect Douglas fir beetle brood production.

Table 4. Results of type 3 tests of fixed effects for brood production.

Effect	Num DF	Den DF	F Value	Pr > F
ScorchCat	3	72	2.91	0.0403
GirdleCat	3	72	0.98	0.4059

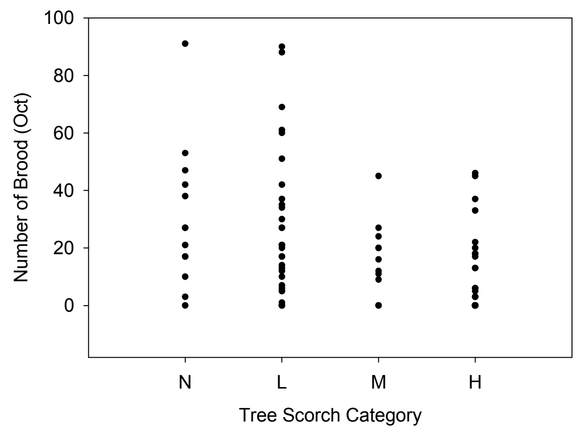

Figure 1. Number of brood produced by percent tree scorch category for the Green Knoll fire.

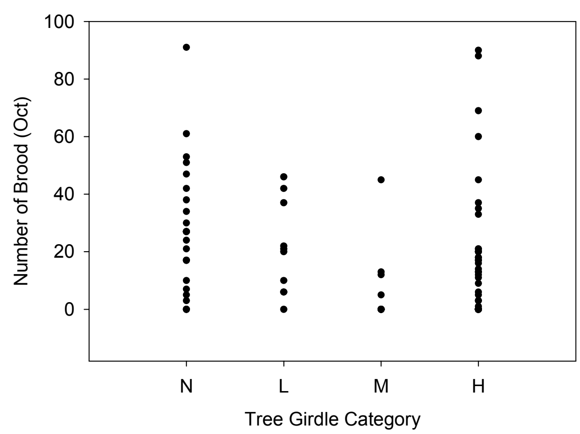

Figure 2. Number of brood produced by percent basal girdling category for the Green Knoll fire.

Table 5. Results of type 3 tests of fixed effects for beetle emergence.

Effect	Num DF	Den DF	F Value	Pr > F
ScorchCat	3	16	0.62	0.6125
GirdleCat	3	16	0.42	0.7433
ScorchCat * GirdleCat	4	16	1.01	0.4292

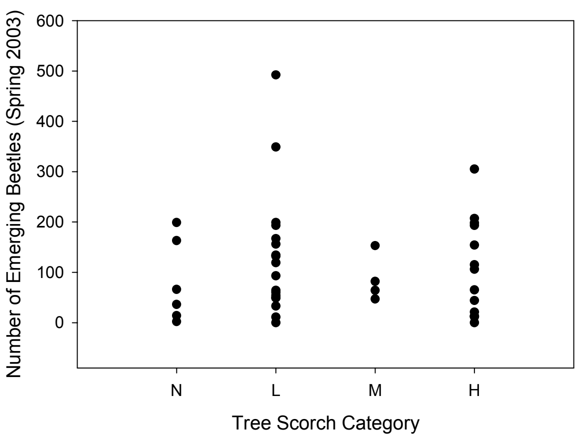

Figure 3. Number of emerging beetles by percent tree scorch category for the Green Knoll fire.

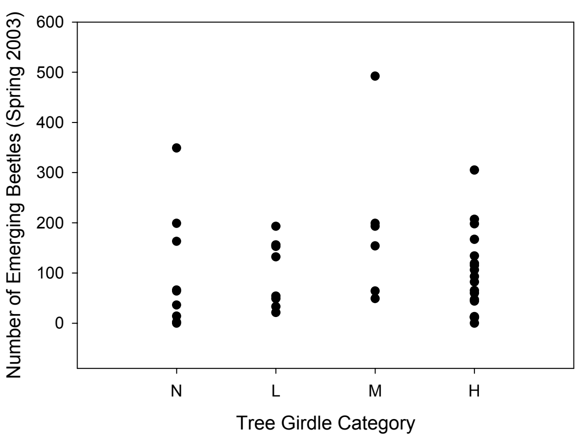

Figure 4. Number of emerging beetles by percent basal girdling category for the Green Knoll fire.

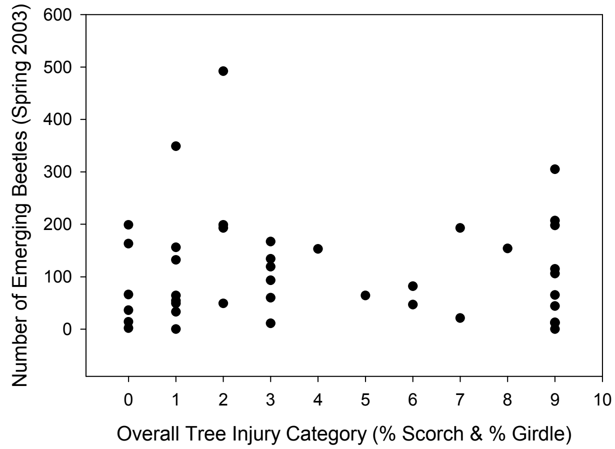

Figure 5. Number of emerging beetles by overall tree injury category for the Green Knoll fire.

6. CONCLUSIONS

Crown scorch, pre-fire vigor, dbh, and the interaction of crown scorch and basal girdling were significant variables in explaining whether a tree was attacked by Douglas fir beetle. The number of brood sampled in fall was significantly affected by the percent crown scorch but not the percent basal girdling; however, the emergence the following spring was not significantly correlated with either crown scorch or basal girdling.

Further analyses of the specific attack areas and associated bark char correlations are planned. Additional mortality will be noted for at least two more years in order to develop Douglas fir mortality predictions. Douglas fir beetle attack preferences will also be developed in order to help predict attacks based on tree injuries from fire.

7. Acknowledgements

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