Colonization of Fire-Damaged Ponderosa Pine by Bluestain Fungi and Insects
After the Hash Rock Fire of August 22, 2000

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INTRODUCTION

Numerous studies have been done to examine the rate of deterioration of wood following forest fires (Kimmey and Furniss 1943; Kimmey 1955; Lowell and others 1992; Hadfield and Magelssen 1996). Kimmey and Furniss (1943) defined two types of changes in wood that they called “limited deterioration” and “general deterioration.” Changes that do not render the wood unusable (e. g., stain) were termed “limited deterioration” while changes that make wood unsuitable (e. g., decay) were defined as “general deterioration.” Most of the previous studies have been concerned with decay and other changes in wood that occur two or three years after the fire (general deterioration). Little work has been done to monitor changes within the first year after the fire, a time when important agents of degrade such as bluestain fungi, bark beetles, wood boring insects and weather affect the fire-killed trees. These agents (causing limited deterioration), along with checking, are important in reducing the value of wood salvaged from the fire. Wurschmidt (1997) described the economic losses associated with these early changes in wood that take place in dead trees during the first year after a fire. Her examples compared salvage sales where harvest occurred within a few months of the fire, versus more than a year after the fire, and showed dramatic value losses of the harvested timber as time goes on.

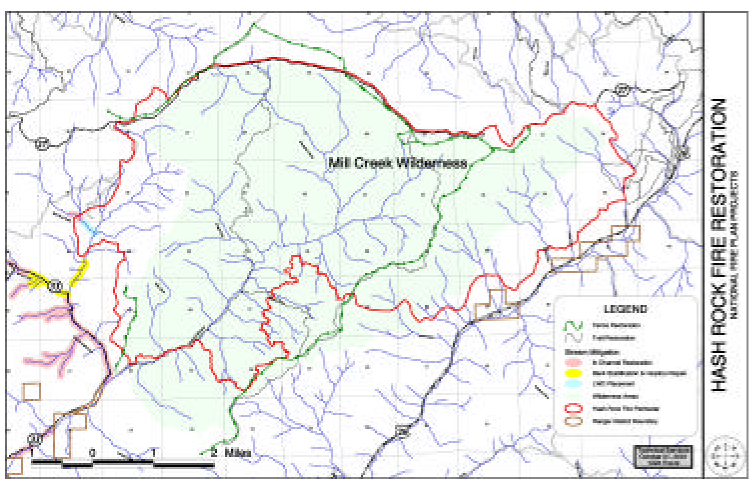

Figure 1. Location of Hash Rock Fire, west of Highway 26 on Lookout Mountain Ranger District, Ochoco NF, August 22, 2000.

The Hash Rock Fire on the Ochoco NF provided an opportunity to learn more about the insects and fungi that are responsible for wood deterioration. The wildfire began on August 22, 2000 and burned through the Mill Creek Wilderness Area on the Lookout Mountain Ranger District (Figure 1). Of the 18,276 acres burned in the Hash Rock Fire, 4,000 acres were outside the wilderness area.

The extreme variation in fire severity can be seen in

Figure 2, which shows some stands with nearly 100% crown loss and other stands with minimal fire damage.

The Lookout Mountain RD planned to conduct a salvage harvest of fire-damaged trees on slightly less than 2000 acres in the West Fork of Mill Creek, west of the wilderness area. This wood deterioration study was authorized for two severely burned units within this proposed salvage sale area.

Figure 2. Various levels of fire damage within the Hash Rock Fire, Mill Creek Wilderness, Lookout Mountain RD, Ochoco NF, August 22, 2000.
(Photo: July 6, 2001)

The purpose of this study was to determine the timing of the appearance of early agents of wood deterioration, primarily bluestain fungi, bark beetles and wood borers, within the first year after the wildfire. The study also intended to record checking as an agent of wood degradation in fire-killed trees.

BLUESTAIN FUNGI AND INSECTS

Many of the fungi causing "bluestain" belong to the Ascomycete genus *Ophiostoma.* Pre-1970s literature placed these fungi in the genus *Ceratocystis* with other fungi that are largely pathogenic (Harrington 1993). The sticky spores produced by these staining fungi lend themselves to dispersal by insects and small animals (Harrington 1993).

The association between bluestaining fungi and insects has been known for well over 100 years (Harrington 1993) and has been studied and reviewed very extensively (Francke-Grosmann 1967; Whitney 1982; Harrington 1988; Paine and others 1997). The most common insect association for these *Ophiostoma* fungi is with bark beetles, although other insects may also be important vectors (Harrington 1993). Most conifer bark beetles are vectors of one to several species of *Ophiostoma* (Harrington 1988; 1993). For instance, the red turpentine beetle, *Dendroctonus valens,* is associated with *O. wageneri* (Harrington 1988), *Ceratocystis schrenckiana* (Francke-Grosmann 1967) and *C. ips* (Mathre 1964a). The western pine beetle, *D. brevicomis,* is an important vector of *C. minor* (Francke-Grosmann 1967; Mathre 1964a). Several *Ips* species including *I. integer* and *I. pini* and a few species of *Dendroctonus* are associated with *Ceratocystis (=Ophiostoma) ips* (Mathre 1964a; Francke-Grosmann 1967). The relationship between bluestain fungi and bark beetles is quite variable depending on the species involved and on other factors; as such, it is not easy to make broad generalizations that are meaningful (Harrington 1993; Paine and others 1997). Clearly, though, the bluestain fungi and their associated bark beetles have similar habitat requirements (Francke-Grosmann 1967) and their mutualistic relationship is evident in many conifer hosts. In many cases the fungal activity helps the insects to overcome the host tree's defenses and also creates an environment conducive to bark beetle brood development.

The association between *Ophiostoma* species and wood borers is less well-known than the relationship with bark beetles, but has been documented by some authors. Goheen and Cobb (1978) isolated *Ceratocystis wageneri* from bodies of an adult cerambycid (*Spondylis upiformis*), a buprestid (*Cypriacis* [=*Buprestis*] *aurulenta*) and from their galleries. Harrington (unpublished) reported finding *Ophiostoma huntii* associated with *Spondylis upiformis* and also cited a number of European authors who noted associations between the cerambycid genera *Acanthocinus, Monochamus, Rhagium* and *Tetropium* with *Ophiostoma* fungi isolated from galleries and adult beetles (Harrington (1988).

Fungal growth and development are influenced by the nutrient, moisture and oxygen contents of the wood, and by ambient temperature (Seifert 1993). Bluestain fungi will grow in wood with at least 20% moisture content, and growth is optimal at 60-80% (Seifert 1993). Fungal growth is best at temperatures between 22 and 30 degrees C. Under suitable conditions, Seifert (1993) reported that bluestain fungi will grow 10-15 mm/wk in the radial direction and up to 50 mm/wk longitudinally. The ratio of fungal growth rates in the three possible directions ranges from 1:2:7 to 1:4:15 tangentially:radially:longitudinally (Nebeker and others 1993). In many cases, the bluestain fungi are not able to penetrate wood cell walls, but move from cell to cell through bordered pits (Seifert 1993). Tracheids, rays and resin canals are all colonized, with most rapid growth occurring in the tracheids (Gibbs 1993). The fungal penetration through woody tissue is largely mechanical, with some possible enzyme activity involved in breaking down the pit membranes (Gibbs 1993).

The genus *Pinus* is particularly vulnerable to bluestaining fungi because the cell walls, pith rays and resin ducts of the sapwood are extremely soft and may be easily broken down by the activity of the fungi (Francke-Grosmann 1967). In addition, pines have a high ratio of sapwood to heartwood, making the incidence of bluestain even more significant.

In general, bluestain fungi do not alter the strength properties of the wood (Seifert 1993). The same author points out that the popular belief that stained wood is more susceptible to subsequent decay has not been adequately proven or disproven.

MATERIALS AND METHODS

Study site location

Figure 3. View of wood deterioration study site and typical sample trees within Hash Rock Fire, West Fork Mill Creek (August 22, 2000). (Photo: September 9, 2001)

This study was conducted inside the western edge of the Hash Rock Fire, in proposed Salvage Units #28 and #32, along Road 213, 3.6 miles north of the junction with Forest Road 33. Unit #32 is relatively flat and Unit #28 slopes gently to the southwest. Figure 3 is a view from the northern edge of Unit #28, facing southwest and looking through the study area. The wildfire was fairly severe within the study area. Stand exam data collected for the salvage sale showed that only 20% of the residual volume was contained in live trees in these two units (#28 and #32) after the fire.

Criteria for selecting sample trees

An important consideration in this study was to eliminate as much variation as possible. The sample trees were chosen from a relatively small area (47 acres), and were all of one species (ponderosa pine). The trees were of merchantable size and had all sustained similar levels of fire damage. The trees selected for the study were ones that would have had no chance of survival after the fire (nearly 100% crown scorch) yet still retained suitable cambial tissue beneath the bark that could be colonized by insects and staining fungi. Typical sample trees can be seen in Figure 3. Even though the intent was to select trees with no green foliage, a small number of the sample trees flushed with new foliage from buds high in the crown by the time they were actually felled. The live crown ratio of these few trees would have been rated at less than 5% and the trees were considered unlikely to survive had they not been cut. Trees with all foliage completely burned off were not chosen for the study because they appeared to have suffered substantial cambial damage in the lower bole, and might not have been suitable for colonization by bark beetles and wood borers.

Seventy-two trees were selected between April 16 and April 18, 2001, and were randomly assigned to one of six felling periods. The pre-sampling tree data, averaging the 12 trees in each group, are shown in Table 1.

Table 1

Average diameters, percent crown ratios (in brown needles) and heights of bole scorch for the 12 ponderosa pine sample trees in each felling period, Hash Rock Fire (August 22, 2000), April 16-18/2001

Felling period	Diameter	% Crown ratio *	Height of bole scorch
May	25.4 +/- 3.5"	29 +/- 16%	41 +/- 10 feet
June	24.8 +/- 4.0"	33 +/- 7%	35 +/- 7 feet
July	25.2 +/- 3.9"	26 +/- 13%	38 +/- 7 feet
August	25.2 +/- 4.9"	36 +/- 14%	37 +/- 9 feet
September	24.8 +/- 5.1"	32 +/- 17%	38 +/- 8 feet
October	25.7 +/- 4.7"	36 +/- 12%	34 +/- 5 feet

*numbers represent a crown of brown needles expressed as a percentage of total tree height, determined by ocular estimation

Although the average diameters of sample trees were similar for each felling period, the diameters ranged from 17.6” dbh to 35.0” dbh. The typical sample tree retained a crown of brown needles equal to nearly a third of its total height (Table 1). The brown needle crown ratios for the sample trees ranged from 1% to 60%. Bole scorch was fairly extensive on the sample trees, averaging nearly 40 feet, based on ocular estimates (Table 1). In a number of cases, one side of the bole had significantly higher scorch than another, and an average value between the two extremes was used to describe the amount of bole scorch for those trees.

The following information helps to further characterize the condition of the sample trees before sampling began: On April 16 and 18, 2001, before the first felling period, all of the 72 sample trees were examined for presence of fire-induced pitch streams on the bole and for basal attacks by the red turpentine beetle, *Dendroctonus valens*. Forty-eight of the 72 trees had some fresh pitch streams on the bole, usually a fairly small amount, and most commonly toward the base of the tree. Forty of the trees had pitch tubes at or near the ground line, indicating fresh attacks by the red turpentine beetle, (Figure 4). It was not possible to determine when those attacks occurred but the majority, if not all of them, were most likely to have taken place in the fall of 2000, shortly after the fire. (Typically, the flight period of the red turpentine beetle does not begin until May and often extends into October). In total, 115 pitch tubes were noted on the 40 trees with evidence of red turpentine beetle attacks (average 2.9 +/- 2.0 per infested tree) with a maximum of 10 attacks on one tree. There appeared to be a strong connection between the presence of pitch streams on the boles of the sample trees and the incidence of turpentine beetle attack, since 34 of the 40 trees with pitch tubes also had fresh pitch present on the bole, and 34 of the 48 trees with fresh pitch streams also had pitch tubes from attacks by the red turpentine beetle.

Figure 4. Basal pitch tubes from attacks by red turpentine beetle, *Dendroctonus valens* (Photo: July 6, 2001)

All sample trees were re-examined one day before they were felled and red turpentine beetle pitch tubes were counted again at that time to determine the number of additional attacks that occurred during the spring and summer of 2001.

Four sample trees had small catfaces from previous fires, and four had some evidence of woodpecker activity, probably in response to turpentine beetles or wood borers that colonized the trees in the fall of 2000, immediately after the fire.

Sampling protocol and data collection procedures

The 72 trees selected for the study were numbered, mapped, and randomly assigned to one of six monthly felling periods (May through October 2001). Based on the results from the 12 sample trees felled in October 2001, it was apparent that more information could be obtained if additional trees could be felled and sampled during the following year. Accordingly, 12 additional trees with characteristics very similar to the original 72 trees were identified and added to the study, to be felled in September 2002, two full years after the Hash Rock Fire.

Figure 5. Sample tree felled and bucked into 16.5-ft logs, with disks removed. (Photo: July 6, 2001)

During each felling period, the 12 sample trees were bucked into logs 16.5 feet long and 2-inch thick disks were cut from the ends of the logs (Figure 5). Diameters were measured at the large and small end of each log. The disks and log ends were examined for presence of bluestain and galleries of wood borers. For bluestain, we recorded the number of quadrants in which the stain was evident and measured the maximum depth of penetration into the sapwood. Similarly, the maximum depth of penetration was also measured for wood borer larvae in each disk and log end. Bark was removed from the disks in order to determine the presence of bark beetle galleries, including the western pine beetle (*Dendroctonus brevicomis)* and the pine engravers (*Ips integer* and *I. pini*). In addition, small pieces of bark were removed with a hand axe at several points along the length of each log to determine the presence and extent of development of wood borer larvae and bark beetles.

All sample logs were examined for evidence of woodpecker feeding which was subjectively described as light, moderate or heavy.

Panel traps

Six unbaited Intercept ™ panel barrier traps (Figure 6), provided by Dr. Darek Czokajlo, (Advanced Pheromone Technologies, Inc. [formerly IPM Technologies, Inc.]), were placed throughout the sampling area on April 16, 2001. The contents of the traps were collected every two weeks beginning on April 25 and ending on October 30. The traps were monitored again in 2002, but insects were removed less frequently. In 2001, no killing agent was used in the collection cups, while in 2002 a small piece of pest strip was placed in the bottom of each cup.

Figure 6. Intercept™ Panel trap (Advanced Pheromone Technologies, Inc.) used for passive sampling of bark beetles and wood borers in the Hash Rock Fire

No trapping was done in 2003, but in 2004, six Lindgren funnel traps were relocated within the study area in order to sample insects flying through the stand in the fourth year after the fire.

RESULTS AND DISCUSSION

Incidence of bluestain

Bluestain was detected, but at very low levels, in the first sampling period (May), 8-1/2 months after the fire. Incipient stain was evident in the stump (Figure 7) and in the first log of one sample tree, and in the second log of another tree (Table 2). All other trees and logs were completely free of bluestain. The maximum depth of penetration of the stain in May was 1-1/2" (Figure 7).

Figure 7. Incipient bluestain in stump of sample tree, Hash Rock Fire (Aug 2000)

In the following sampling period (June), the incidence of bluestain increased substantially, but was still confined to the lower logs of the sample trees (Table 2). No log above the third log had any evidence of bluestain in the June sampling period, and no stain was detected in the boles of the higher logs until the September sampling period, one full year after the Hash Rock Fire (Table 2).

Table 2

Incidence of bluestain by felling period and log position.
Numbers indicate percentage of 16.5'-logs with bluestain for the 12 sample trees from each felling period (Log 1 = basal 16.5' log; Log 8 = log from within crown)

Log	May '01	Jun '01	Jul '01	Aug '01	Sep '01	Oct '01	Sep '02
*8	0	0	0	0	0	0	100
*7	0	0	0	0	20	0	100
*6	0	0	0	0	20	33	92
5	0	0	0	0	25	33	100
4	0	0	0	0	17	33	100
3	0	8	25	17	42	42	100
2	8	25	25	58	58	58	100
1	8	92	42	100	100	100	100

*Not all trees had logs # 6, 7, 8

Note that in the July sampling period, only five of the 12 basal logs had evidence of bluestain while 11 of 12 were stained in the June sample, and all basal logs were stained in the August sample (Table 2).

In the July and September sampling periods, a small number of the logs higher in the tree had isolated patches of bluestain that were primarily associated with the branches and barely extended beyond the juncture of the branch with the bole. As such, the stain was not evident in the sampling disks and thus the log was not recorded as being stained. In these few cases, wood borer galleries were always found in the branches that had bluestain. Even after the October sampling period, the incidence of bluestain was fairly low for Logs 4 through 8. However, bluestain in the lower two logs of most trees was extensive at that time. A typical disk from the October sampling period is shown in Figure 8. By September 2002 (the extra sampling period added to the study), two full years after the Hash Rock Fire, all of the trees and all logs but one had extensive bluestain in the sapwood, almost always in all four sampling quadrants (Table 2).

Figure 8. Sapwood of ponderosa pine sample disk colonized by bluestain fungi 13 months after the Hash Rock Fire [August 22, 2000] (Photo: October 9, 2001)

Bluestain fungi can only develop in the wood of living host cells (Gibbs 1993) and therefore are limited in their growth by the amount of sapwood available in the tree or log. The sapwood on most of the trees killed in the Hash Rock Fire was around five to six inches thick. The maximum depth of penetration by the bluestain fungi was not noted in any log before the August 2001 sampling period. By October 2001 (13-1/2 months after the fire), the bluestain had penetrated to the maximum depth (5-6") in most of the sample trees.

In addition to the depth of penetration, another measure of the occurrence of bluestain is in the number of quadrants of the log affected. Table 3 shows the total number of logs with evidence of bluestain by sampling period, and the number of quadrants in those logs that were stained by the fungus. It is interesting to note that in October 2001, less than one-third of the infected logs had stain in all four quadrants (Table 3). By September 2002, every log was stained and over three-quarters all of the infected logs had bluestain in all four quadrants (Table 3).

Table 3

Number of sample logs with bluestain and number of quadrants affected in those logs by sampling period, Hash Rock Fire (August 22, 2000)

Number of quadrants with stain	May ‘01	Jun ‘01	Jul ‘01	Aug ‘01	Sep ‘01	Oct ‘01	Sep ‘02
4	0	0	0	2	4	17	70
3	1	1	0	5	7	6	7
2	0	3	1	7	5	5	1
1	1	8	7	5	11	4	3
# of logs with bluestain	2	13	8	19	27	32	81
Total number of logs sampled	70	69	69	70	70	71	81

Panel trapping results

The insect groups most commonly collected in the panel traps included wood borers, bark beetles, bark beetle predators, click beetles, flies and wasps. Some scarabs, carabids and other insects were collected as well. Only the wood borers, bark beetles and some of their associates were kept for identification.

The wood borers collected in the Intercept ™ panel traps are summarized by family in Figure 9 (2001) and Figure 10 (2002). Representatives of both Cerambycidae and Buprestidae were present throughout the spring and summer, and even into the fall. In 2001, the wood borer collections were fairly steady throughout the flight season while in 2002, the bulk of the flight occurred during the four weeks between mid-June and mid-July. (Figures 9 and 10). The siricids (horntails) were not captured in 2001, probably because there were no pest strips in the collecting cups during that season. (Unlike the cerambycids and buprestids, the horntails will leave the traps if they are not killed shortly after arrival).

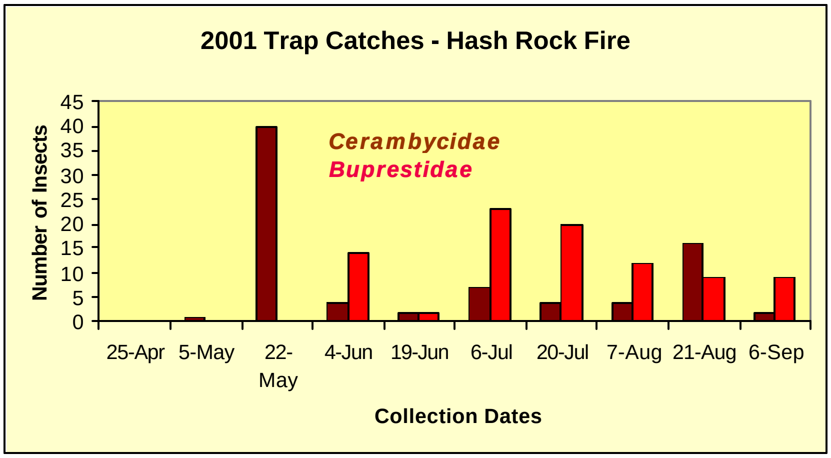

Figure 9. Wood borers collected in six Intercept panel traps during the 2001 flight season, Hash Rock Fire (August 22, 2000)

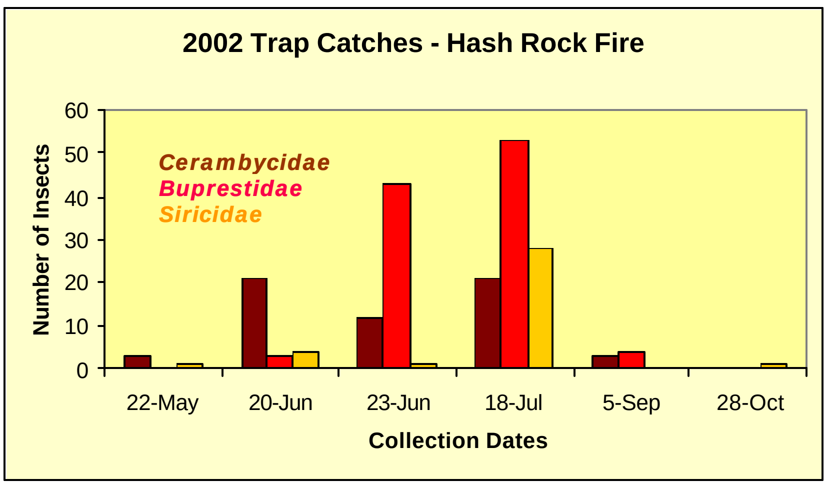

Figure 10. Wood borers collected in six Intercept panel traps during the 2002 flight season, Hash Rock Fire (August 22, 2000)

The individual species of wood borers and associated insects trapped in 2001 and 2002 are shown in Tables 4 and 5, together with their flight periods and the numbers collected in the panel traps. The total number of individuals collected in the traps was not great (253 wood borers and bark beetles in 2001; 276 in 2002) but the diversity of species was impressive, given that the traps were not baited. In 2001, the first year after the fire, nine species of buprestids and 12 species of cerambycids were collected. The following year, 13 species of buprestids and 14 species of cerambycids were trapped (Tables 4 and 5).

Table 4

Insect species and numbers collected during 2001 in six unbaited panel traps placed among fire-killed *Pinus ponderosa* within wood deterioration study area, in the **first year** after the Hash Rock Fire of August 22, 2000

Family	Genus/species	Apr 25	May 5	May 22	Jun 4	Jun 19	Jul 6	Jul 20	Aug 7	Aug 21	Sep 6	Oct 3	Oct 9	Oct 30
BOSTRICHIDAE	*Stephanopachys substriatus*			1										
	Stephanopachys sobrinus										1			1
BUPRESTIDAE	*Anthaxia sp.*					1				1				
	Buprestis connexa										1			
	Buprestis laeviventris									1				
	Buprestis lyrata								2	2	2			
	Chalcophora angulicollis				14	1	23	15	6	4				
	Chrysobothris leechi							1	2	1	1			
	Cypriacis aurulenta							2	1		1			
	Melanophila acuminata							1	1					
	Phaenops gentilis							1		2	4			
CERAMBYCIDAE	*Acanthocinus princeps*									1				
	Anastrangalia laetifica						2							
	Anastrangalia sanguinea					1	3							
	Asemum striatum							1						
	Leptura obliterata									2				
	Leptura plagifera								1					
	Megasemum asperum						2	2	3					
	Neanthophilax mirificus			1										
	Spondylis upiformis		1	19	3	1								
	Stictoleptura_canadensis_cribricollis							1		11	2			
	Tragosoma depsarius									1				
	Xestoleptura crassicornis									1				
CLERIDAE	*Enoclerus lecontei*									3		2		
	Enoclerus moestus										1			
	Enoclerus sphegeus			2										
	Enoclerus sp.			1	1	1		1		2	1	1		
CUCUJIDAE	*Cucujus clavipes*		1	2		1								
CUPEDIDAE	*Priacma serrata*			2										
MELANDRYIDAE	*Serropalpus substriatus*									2				
NITIDULIDAE	*Pityophagus rufipennis*			4								1		
OEDEMERIDAE	*Calopus angustus*				1									
SALPINGIDAE	*Elacatis lugubris*	1	1	6		1			6	6	12	11	1	
SCOLYTIDAE	*Dendroctonus brevicomis*											4	1	
	Dendroctonus valens			7	17	2	2	1	7	8		4		
	Hylastes gracilis											6	2	8
	Hylastes macer			1										
	Hylastes sp.			6	1									
	Hylurgops porosus	3	4	5										
	Hylurgops subcostulatus					1					1			
	Ips integer									1				
	Ips pini												1	1
	Pityogenes carinulatus			2										
SIRICIDAE	*Sirex juvencus californicus*										1			
TROGOSSITIDAE	*Temnoscheila chlorodia virescens*			6	20	3	17	2	1	4	1			

Table 5

Insect species and numbers collected during 2002 in six unbaited panel traps placed among fire-killed *Pinus ponderosa* within wood deterioration study area, in the **second year** after the Hash Rock Fire of August 22, 2000

Family	Genus/species	May 22	Jun 20	Jun 23	Jul 18	Sep 5	Oct 28
BOSTRICHIDAE	*Stephanopachys sobrinus*		6	3			
BUPRESTIDAE	*Anthaxia sp.*				1		
	Buprestis connexa			1			
	Buprestis laeviventris			2	1		
	Buprestis lyrata			5		2	
	Buprestis subornata			5		1	
	Chalcophora angulicollis		8	19	47		
	Chrysobothris leechi			4	1	1	
	Cypriacis adjecta			1			
	Cypriacis aurulenta			4	3		
	Dicerca tenebrosa		1				
	Melanophila acuminata			2			
	Phaenops californicus		1				
	Phaenops lecontei		1				
CERAMBYCIDAE	*Acanthocinus obliquus*				2		
	Acanthocinus princeps			1			
	Acmaeops proteus		6		3		
	Anastrangalia sanguinea		1		5		
	Callidium antennatum hesperum		1				
	Ergates spiculatus			1			
	Leptura plagifera				2		
	Megasemum asperum				1		
	Phymatodes dimidiatus				1		
	Rhagium inquisitor		5		1		
	Spondylis upiformis	3	7				
	Stictoleptura canadensis cribricollis			8	1	2	
	Tragosoma depsarius				1		
	Xylotrechus longitarsis			2	2		
CLERIDAE	*Enoclerus moestus*			2	2	2	
	Enoclerus sp.		2	6		1	2
CUCUJIDAE	*Cucujus clavipes*		1				
CUPEDIDAE	*Priacma serrata*	1	2				
ELATERIDAE	*Alaus melanops*				9		
MELANDRYIDAE	*Serropalpus substriatus*				1		
NITIDULIDAE	*Pityophagus rufipennis*		4		1		
OEDEMERIDAE	*Calopus angustus*		1				
SALPINGIDAE	*Elacatis lugubris*		10	1	1	1	
SCOLYTIDAE	*Dendroctonus valens*	1	12				
	Hylastes gracilis		2				
	Hylastes macer	1	11		2		
	Hylastes nigrinus		1				
	Hylastes sp.	1	14		1		
	Hylurgops porosus	2	4		1		
	Hylurgops subcostulatus		1				
	Ips integer		4		1	1	
	Ips pini	2	1				
SIRICIDAE	*Sirex juvencus californicus*						1
	Xeris spectrum townesi		4		10		
	Xeris tarsalis		3	1	18		
STENOTRACHELIDAE	*Cephaloon tenuicornis*		2				
TROGOSSITIDAE	*Temnoscheila chlorodia virescens*	2	11	5	12	1	

Some species such as the large buprestid *Chalcophora angulicollis* (Figure 11) showed a relatively long flight period (June – August) and were very abundant (Table 4, 5). Others such as the cerambycid *Spondylis upiformis* were among the first to fly in the spring and then were not collected again. *Stictoleptura canadensis cribricollis,* a common round-headed borer (Figure 12), was only collected late in the season (Tables 4, 5). The red turpentine beetle, *Dendroctonus valens*, was the most commonly collected scolytid in the year after the fire and was flying throughout the spring and summer (Table 4). Similarly, the bark beetle predators such as *Temnoscheila chlorodia* (Trogossitidae) and *Enoclerus* sp. (Cleridae) were collectively very abundant in the year after the fire and were trapped throughout the spring and summer (Table 4).

There was little discernable difference between the trap catches for 2001 and 2002. Virtually all of the species that were captured in 2001 were present again in the 2002 collection. In many cases, the numbers of individuals captured were also similar from one year to the next (Tables 4 and 5). The slight increase in total numbers of insects trapped in 2002 may likely be explained by the use of a pest strip in the collection cups, which kept some of the insects such as siricids from escaping. Overall, the total numbers of wood borers increased and bark beetles decreased from 2001 to 2002, by about 30% in each case. The increase in the number of wood borers collected was largely due to the 37 siricids that were captured in 2002. The most notable difference in the numbers of a particular species of wood borer was for the cerambycid *Spondylis upiformis*, with only 10 individuals captured in 2002 as compared to 24 in the previous year. The largest decrease in bark beetles was for the red turpentine beetle, with only 13 insects in the traps in 2002 as compared to 48 captured in 2001.

The most important point to be made with regard to the trapping results is that they demonstrate the high degree of insect biodiversity that is associated with a burned area. In the first two years of trapping, there were at least 11 species of bark beetles and 36 species of wood borers that are potentially utilizing fire-damaged trees as hosts. All of these species could be vectors of fungi that decompose and recycle the nutrients in the wood. In addition, they also serve as an important food source for predaceous insects and woodpeckers that occur in the same burned areas.

The results from the third season of trapping (fourth year after the fire) are shown in Table 6. At least six species of bark beetles and 16 species of wood borers were still present in the area although the total numbers captured were considerably lower than in the first two years after the fire. The expectation was that there would be a significant shift in the types of insects flying through the burned area in the fourth year after the fire, with a larger presence of insects associated with dead wood rather than dying trees. In fact, only a few species were captured in 2004 that are typically associated with dead wood, such as carpenter ants (*Camponotus* sp.), sapwood weevils, powderpost beetles (family Anobiidae) and the longhorned borer *Tragosoma depsarius* (Table 6). No wood borers were particularly abundant, including the buprestid *Chalcophora angulicollis* which had been the most commonly collected wood borer in the first two years after the fire. Numbers of the red turpentine beetle were also much lower in 2004, an expected result given that they are typically associated with fresh pitch flow and wounded host trees. Even though the numbers of other scolytids declined as well, it was surprising to see that many of their predators (*Temnoscheila chlorodia*) were still captured in 2004 (Table 6). The most commonly collected group in 2004 was the click beetles (family Elateridae), with numerous species represented. The family includes species that are predaceous on other insects, species that live in decaying wood, and others that feed on the roots of various plants. As such, the diversity and abundance of elaterids in the 2004 traps could be the result of various changes within the burned stand and not just with the fire-damaged trees themselves.

Table 6

Insect species and numbers collected during 2004 in six unbaited funnel traps placed among fire-killed *Pinus ponderosa* within wood deterioration study area, **four years** after the Hash Rock Fire of August 22, 2000

Family	Genus/species	May 17	Jun 14	Jul 7	Jul 27	Aug 17	Sep 7	Sep 30
ANOBIIDAE	Unknown species					1	2	
BOSTRICHIDAE	*Stephanopachys sp.*					2		
BUPRESTIDAE	*Anthaxia sp.*	1	1	4				
	Buprestis lyrata					4	4	
	Buprestis subornata			1	1	2	2	
	Chalcophora_angulicollis			4	2			
	Chrysobothris leechi						1	
	Phaenops sp.	1						
CERAMBYCIDAE	*Acmaeops sp.*			3				
	Anastrangalia laetifica			2				
	Anastrangalia sanguniea			4				
	Leptura sp.			3				
	Megasemum asperum				1			
	Spondylis upiformis	1						
	Stictoleptura canadensis							1
	Tragosoma depsarius				7	1		
	Xylotrechus longitarsis		1					
	Various species		1	3				
CLERIDAE	*Enoclerus sp.*					2	2	1
CUPEDIDAE	*Priacma serrata*	2		1				
CURCULIONIDAE	Various species				2			
ELATERIDAE	*Alaus melanops*		6	2				
	Various species	22	22	45	5	6	1	
FORMICIDAE	*Camponotus sp.*	3						
NITIDULIDAE	*Pityophagus rufipennis*		1	1				
SCOLYTIDAE	*Dendroctonus valens*		1					
	Hylastes sp.	3	5*	3**				
	Ips pini			3				
	Scolytus sp.					2^		
	Various species		2	1	1	2	1	3
TROGOSSITIDAE	*Temnoscheila chlorodia*	2	12	15	2	1		

* probably *macer*; ** probably *gracilis*; ^ probably *ventralis*

Note: Species determinations for 2004 collection were made by the author by comparing these insects with specimens identified in 2001 and 2002 by taxonomists J. R. LaBonte and R. Westcott

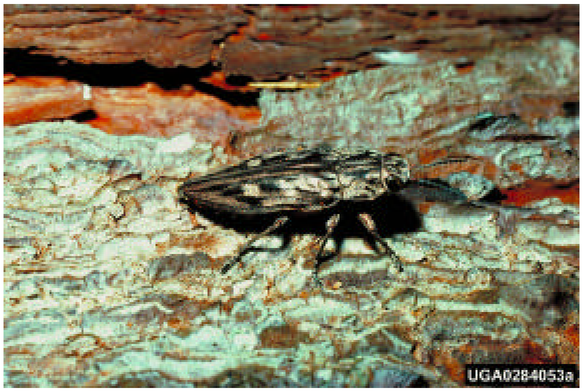

Figure 11. A southern species of *Chalcophora*, similar to *C. angulicollis* which was collected in abundance in panel traps, Hash Rock Fire (Photo: R. F. Billings, Texas Forest Service)

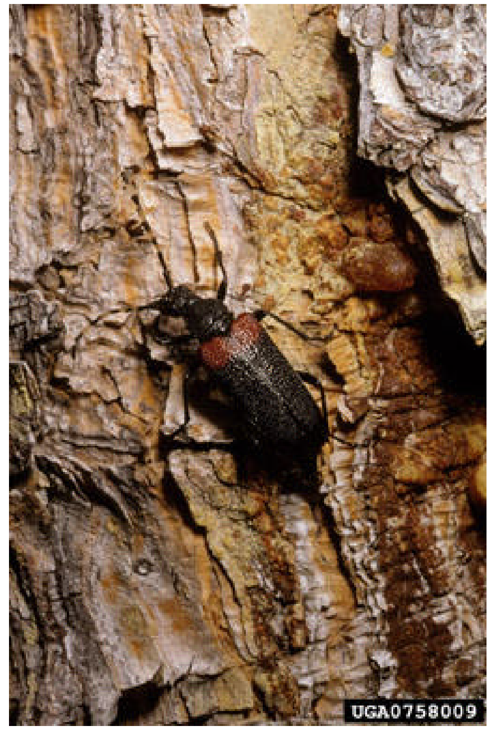

Figure 12. *Stictoleptura canadensis cribricollis* (Photo: W. M. Ciesla)

Red turpentine beetle

Some red turpentine beetle attacks were noted in October shortly after the fire and before the study began, but most of the beetle activity occurred during the following spring and summer. Table 7 displays the attack densities, determined by counting the number of basal pitch tubes on sample trees on the day before they were felled. It appears that the peak flight of the red turpentine beetle occurred in May and June, because the attack levels for trees in all of the felling periods after June were fairly similar (Table 7). Nonetheless, other red turpentine beetles were still flying in the area through August (Table 4).

Table 7

Red turpentine beetle (*Dendroctonus valens*) attacks on 12 sample trees, recorded one day before the indicated felling period, Hash Rock Fire (August 2000), Ochoco NF

Felling period	Range of attacks per sample tree	Average # attacks per tree
May '01	0 to 8	**1.5** +/- 2.5
June '01	4 to 23	**14.3** +/- 6.9
July '01	5 to 37	**20.3** +/- 9.8
August '01	2 to 56	**19.7** +/- 14.6
September '01	6 to 45	**24.9** +/- 13.3
October '01	1 to 48	**18.6** +/- 14.1
September '02	0 to 40	**17.6** +/- 12.6

An interesting observation was made with respect to the host colonization behavior of the red turpentine beetle. The logs felled in the May sampling period were re-examined in June and a large number of them had been infested on the undersides by the red turpentine beetle. Over 300 attacks were noted on these logs, including more than 100 on one tree. Many of these attacks occurred on some of the smaller logs. The stumps were also freshly colonized after the May felling, with pitch tubes averaging more than 20 per stump. Similarly, the logs of trees felled in June, July and August were also colonized on the undersides by the red turpentine beetle but at a lower rate than the logs of the May felling period.

The fire-killed trees in this study provided excellent habitat for the red turpentine beetle. By August and September 2001, the cambial tissue in the basal logs of most sample trees was completely consumed and the bark was easily removed to reveal the developing bark beetle broods. Last-instar larvae were found in three of the August sample trees, and by September, the pupal stage was found in one tree, with large larvae in most of the others. In October, half of the trees had brood adults beneath the bark and the other half had heavy concentrations of larvae (Figure 13). In the final felling period (September 2002), all of the basal logs had extensive red turpentine beetle galleries beneath the bark, and an abundance of exit holes, but no brood were found.

Figure 13. Brood larvae and pupae of red turpentine beetle typically found beneath the bark of basal logs (Photo: October 9, 2001)

Western pine beetle

The western pine beetle completes two generations per year on the Ochoco NF, which means that the flight period can span the entire spring and summer, beginning as early as May and extending into October (Miller and Keen 1960). The incidence of western pine beetle in relation to felling period is shown in Figure 14. Beetles were first detected in the August felling period, with two trees infested. In September, over half of the sample trees were infested, with nearly half of the logs in those trees having galleries and/or live beetles present (Figure 15). Eleven of the 12 trees felled in the September 2002 sampling period had been infested by the western pine beetle, with galleries present in nearly every log (Figure 14). Virtually all of the infested trees from the September 2002 sampling period had western pine beetle emergence holes, indicating that the attacks had probably occurred in 2001 or early 2002. Only one of the trees appeared to be freshly infested at the time of sampling in September 2002.

Although the western pine beetle is typically associated with large-diameter hosts, it was interesting to note in this study that attacks commonly occurred high in the tree, where diameters were small. The smallest log with western pine beetle galleries measured 10.8" at the large end.

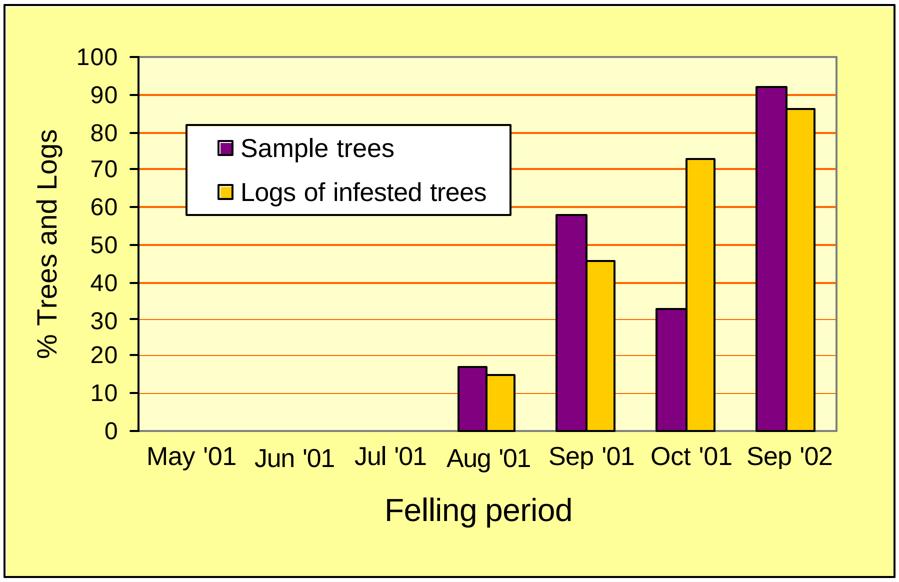

Figure 14. Incidence of western pine beetle, *Dendroctonus brevicomis*, in sample trees by felling period, Hash Rock Fire August 22, 2000

Pine engravers *Ips integer* and *I. pini*

Two species of pine engravers were found in 12 of the sample trees (15 logs), but these insects were considerably less common than the other bark beetle species previously discussed.

The first evidence of engraver activity was in June, when one sample tree had fresh attacks and young larvae of the larger *Ips* species (*I. integer*). At the same time, *I. integer* attacks were noted on the trees that had been felled in May; while those logs were infested on the undersides by the red turpentine beetle, the engraver attacks were on the top surfaces. As additional sample trees were felled in June, July and August, their logs also sustained fresh attacks on the top surfaces by *I. integer* shortly after felling. In September 2001,

Figure 15. Larvae of red turpentine beetle, *Dendroctonus valens* (left) and parent galleries of western pine beetle *D. brevicomis* (right) from typical sample taken 12 months after the Hash Rock Fire (August 22, 2000) (Photo: September 7, 2001)

four of the 12 sample trees had extensive infestations by *I. pini* (Figure 16), primarily in the smaller logs that averaged 8 to 14" in diameter. All stages of brood development were found at that time, including pupae and callow adults. Bluestain was usually present, even when the engraver galleries were recently formed. In October 2001, two sample trees had galleries and emergence holes of *I. integer*.

Figure 16. Larval galleries of *Ips pini* from small log near top of a sample tree (Photo: September 7, 2001)

Ips integer was less discriminating than *I. pini* with regard to size of the material infested. *I. integer* attacks were noted in logs ranging in size from 12 to 26 inches in diameter. It was interesting to note that the samples taken in September 2002, two full years after the fire, included a number of trees with live brood from both engraver species. Three trees contained larvae, pupae or callow adults of *I. integer*, and one of those was freshly infested by *I. pini* as well.

Brood development proceeds rapidly in these two engraver species that complete two generations in a year. For example, one of the sample trees felled in August had well-developed larvae of *I. integer* two weeks later. Similarly, one of the May-felled trees produced mature larvae and pupae of *I. integer* within one month.

Incidence of wood borers

As shown in Figures 9 and 10, the flight period of wood borers is lengthy, beginning in late April and extending into late September. As such, it is probable that some trees were infested immediately after the fire in August 2000. (Some species of wood borers are known to respond to the infrared radiation from fires while others are attracted to smoke). However, none of the trees felled in May 2001 had evidence of wood borers. By June 2001, small round-headed borer larvae were found in four of the 12 sample trees. These larvae were all less than ½" long and were mining in the cambial tissue. In the July sampling period, six of the 12 sample trees had roundheaded borer larvae, ranging in size from ½" to 1" in length. The smaller larvae were superficial and still feeding in the cambium, while some of the largest

Figure 17. Roundheaded wood borer larva beneath the bark of ponderosa pine 10 months after the Hash Rock Fire (August 22, 2000). (Photo: July 6, 2001)

larvae (Figure 17) were just beginning to enter the wood. In August, 10 of the 12 sample trees were colonized by round-headed wood borer larvae. The predominant size was from ¾” to 1” in length, with a number of smaller larvae present as well. The larger larvae were entering the sapwood and galleries beneath the bark were extensive by this time. Only one flat-headed borer larva was found in August, and it measured 1” in length. All but one of the September sample trees had larvae and well-developed round-headed wood borer galleries. Larvae of all sizes were common in September, with the larger ones entering deeply into the wood. (One gallery in a sample disk had penetrated to a depth of 4”). The first adult emergence hole was found in September 2001, indicating that the early-arriving borers (probably from August or September 2000) had already completed their development and left the tree. The flatheaded borers continued to be far less common that the cerambycids, and only two larvae were found in the sample logs. In the October sampling period, 10 of the 12 sample trees had been infested by wood borers, with attack levels being fairly light in two of those trees. Again, the cerambycids were far more common than the buprestids, although some flathead borer larvae were found. Borer larvae were of all sizes, including some that had penetrated deeply into the wood. The array of sizes indicates that there is probably a continuous infestation period and that new attacks are occurring on these trees throughout the flight season of the adult borers.

In all of the sampling periods during 2001, the roundheaded wood borer larvae were much more common in the largest three or four logs, and less common near the top of the tree.

The September 2002 sampling confirmed that the flight and host colonization period of wood borers is prolonged, even into a second year after the fire. All 12 of the September sample trees had been colonized by various wood borers (primarily the cerambycids), and in about half of the trees, larvae of all sizes were still present. Half of the trees (including one with larvae of all sizes) had emergence holes by mature adults that had left the trees. A number of these exits were made by the horntail wood wasps (siricids).

Figure 18. Typical roundheaded wood borer gallery and bluestain two years after the Hash Rock Fire (Photo: September 2002)

A typical sampling disk from this time period is shown in Figure 18, which demonstrates the amount of bluestain and wood borer gallery development that can be expected in a ponderosa pine two years after a wildfire.

Woodpecker activity

As the immature stages of bark beetles and wood borers develop beneath the bark of their hosts, they are subject to predation by several species of woodpeckers. In some cases this predation can significantly reduce the insect populations. In this study, the incidence of woodpecker feeding was subjectively rated as “low”, “moderate” and “heavy” and is shown for the sample trees (Figure 19) and for individual logs (Figure 20). Although bark beetle and wood borer larvae were found in June and in later sampling periods, the number of trees with indications of woodpecker feeding did not become significant until the August sampling period. Even then, only seven of the 12 sample trees showed evidence of woodpecker feeding, and that feeding was mostly light (Figure 19). In September 2001, the incidence of woodpecker feeding was still only evident on five trees, but was heavier than before. By October 2001, woodpecker feeding was more common and was heavier than in earlier sampling periods (Figure 19). By September 2002, all of the sample trees had some evidence of bark removal by woodpeckers and in most cases the feeding was substantial where it occurred.

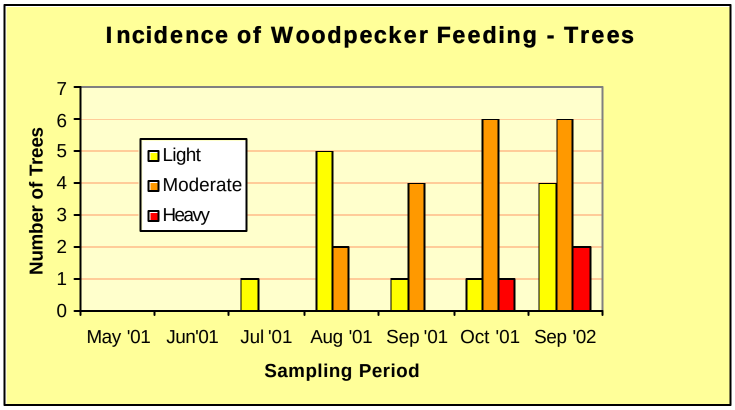

Figure 19. Incidence of woodpecker feeding on sample trees, Hash Rock Fire (August 22, 2000)

However, the overall level of foraging activity by woodpeckers was fairly low in the study area. Many logs with an abundance of beetle brood had no evidence of bark removal or foraging by woodpeckers. Through the 2001 sampling periods, many of the sample trees with woodpecker feeding had only one or two logs affected. This point is well illustrated in the October 2001 sampling period where eight trees had woodpecker feeding (Figure 19), but only total 14 logs within those trees were affected (Figure 20). Typically, the basal logs were the ones most likely to have signs of woodpecker activity.

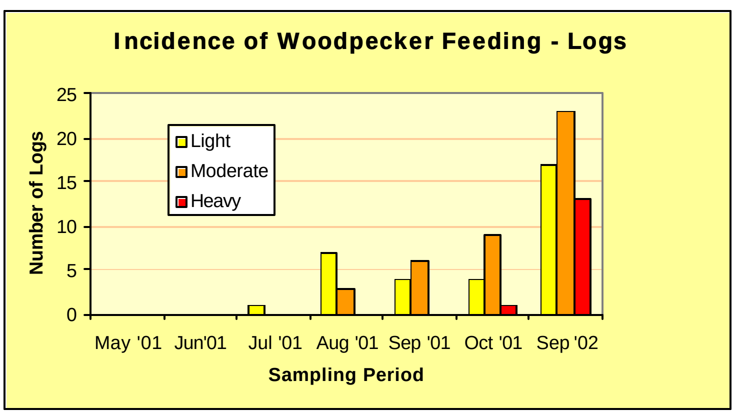

Figure 20. Number of sample logs with evidence of woodpecker feeding, Hash Rock Fire (August 22, 2000)

Figure 21 shows the relationship between woodpecker foraging activity and the availability of a wood borer and bark beetle food source. Throughout the six sampling periods in 2001, woodpecker feeding was always evident on less than half of the logs which contained insect larvae. In September 2002, a substantially larger portion of the available logs showed evidence of woodpecker foraging, but not all of the logs were utilized.

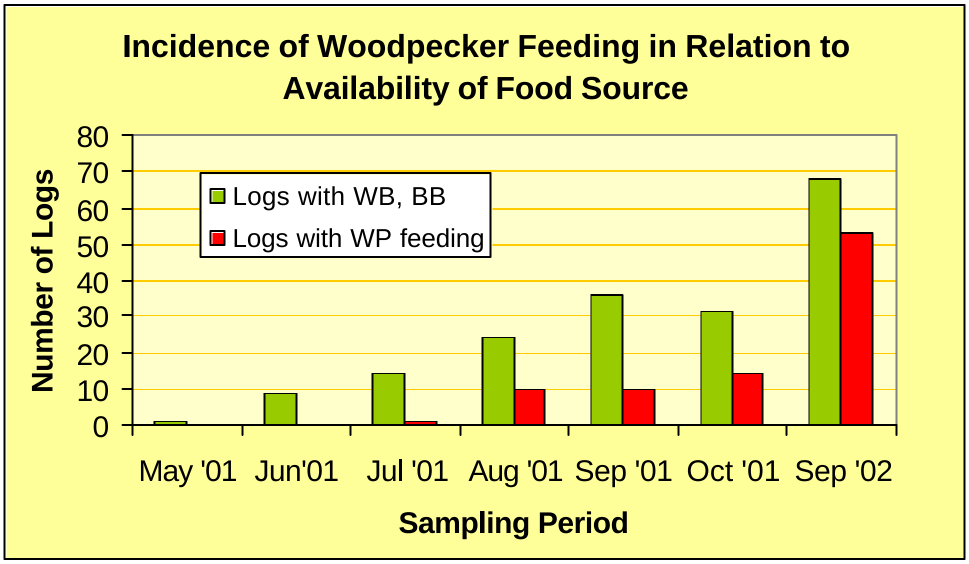

Figure 21. Number of insect-infested sample logs with evidence of woodpecker feeding, Hash Rock Fire (August 22, 2000)

Checking

No checking was noted in any of the sample logs during the course of the study.

CONCLUSIONS

The observations from this study help to confirm the strong relationship between the bluestaining fungi and the insects that infest recently killed trees. When bluestain was found in the sample logs in this study, there was almost always a life stage or gallery of a bark beetle or wood borer in the vicinity of the stained wood. In the Hash Rock Fire Study, the relationship between bluestain fungi and the red turpentine beetle appeared to be less reliable than the relationship between the stain and wood borers. When bluestain was found in a freshly cut stump, wood borer larvae were usually present beneath the bark directly behind the stain. When red turpentine beetle larvae were found, there seemed to be considerable variability as to the presence of the stain in the sapwood. More often than not, the sapwood was not stained where red turpentine beetle larvae were found.

Three important factors contribute to the fact that limited deterioration in fire-killed wood can occur in a very short time frame. The first is the extremely large variety of insects that can serve as vectors of bluestain fungi. Several species of bark beetles and over 20 genera of wood borers were collected within the study site. Secondly, there is a very lengthy time period during which the insect vectors are flying in search of new host material. Collectively, the bark beetles and wood borers engage in dispersal flights throughout the spring, summer and fall. That being the case, a recently dead tree is likely to be colonized very shortly after it dies, regardless of when that death occurs. Finally, the rapid rate at which bluestain fungi grow (10-50mm per week) insures that stain will be well-developed in the sapwood within a month after the insect vector has colonized the host tree and inoculated it with *Ophiostoma* fungi.

In a late-season wildfire such as the Hash Rock Fire (August 22), the bluestain was slow to develop, probably because relatively few insect vectors were in the area to be able to colonize the large number of dead trees that suddenly became available over 20,000 acres. It is very likely that many trees were not colonized by bark beetles or wood borers until the spring of 2001, six months after the fire. In a wood deterioration study in Washington, Hadfield (2000, personal communication) pointed out that ponderosa pine killed <u>before</u> August is likely to be bluestained in 2 months.

One of the surprising findings in this study was the slow rate of limited deterioration in the top logs of most sample trees. Whereas the bottom two logs in most August 2001 sample trees were heavily colonized by wood borers and bluestain fungi, the higher logs were virtually free of stain and borers. The reasons for this are not clear and the result is counter-intuitive, given that small trees typically deteriorate at a faster rate than larger trees (Hadfield 1994; Kimmey 1955).

In this study, there would have been no scalable defect and limited value loss in the first year after the fire. But beginning early in the second year, bluestain became pervasive in all quadrants of the sample logs and value loss would have occurred from that point on.

Another somewhat unexpected finding was the degree to which western pine beetles colonized the fire-killed trees in this study. Although less than half of the sample trees were colonized in the first year after the fire, the population buildup by the end of the second year was impressive (Figure 14). The bark beetle broods produced in these fire-killed trees may have been the source of the elevated mortality of ponderosa pine that occurred outside the perimeter of the Hash Rock Fire in 2003 and 2004.

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