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Evaluation of Douglas-fir (Pseudotsuga menziesii (Mirb.) Franco) seed tree mortality on the Clearwater National Forest, ID

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EVALUATION OF DOUGLAS-FIR

(*Pseudotsuga menziesii* (Mirb.) Franco)

SEED TREE MORTALITY

ON THE CLEARWATER NATIONAL FOREST, ID.

By Catherine A. Stewart

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Requirements for the degree of

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Evaluation of Douglas-fir seed tree mortality on the Clearwater National Forest, ID. (31 pp.)

Director: Dr. Ronald H. Wakimoto R.H.W.

Effects of fire, root disease, and bark beetles on Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) seed trees were evaluated on the Powell Ranger District, Clearwater National Forest, Idaho. Thirty trees on an underburned and an unburned site were sampled for xylem water pressure potential, root disease infection, bark beetle infestation, and fine root biomass. Fire intensity was moderate to light. Bark beetle girdling and root disease infection by *Armillaria obscura* (Schaeff.:Secr) was higher on the burned site but not significantly (P>.22 and P>.12, respectively). Infection by *Phaeolus schweinitzii* (Fr.) Pat. was not significantly different between the two sites. Visual estimates of stress were used as xylem water pressure potential results were not conclusive. The combined effects of fire damage, root disease infection, and bark beetle girdling caused stress and tree mortality.

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INTRODUCTION

The use of seed trees is an effective and cost efficient method for regeneration in the inland northwest. They provide seed well suited to the site, shade for seedling survival, and can help maintain the visual quality and other resources of the site. The failure of seed tree systems may require artificial regeneration of the site at an increased cost. Successful application of the seed tree method depends upon selecting healthy, undamaged, cone producing trees that will survive site preparation.

Seed tree mortality is a persistent problem on U.S. Forest Service lands on the Powell Ranger District, Clearwater National Forest, Idaho, in spite of precautions taken in selecting trees and protecting trees while underburning. Post-fire examination on one particular site showed most trees to be infected with *Phaeolus schweinitzii* (Fr.) Pat.. The disease had not been detected prior to marking the seed trees and site preparation.

Conifer mortality has been examined primarily within individual disciplines of research with little integration. Fire related mortality of trees has been studied in detail but most studies have concentrated on crown scorch and bole damage (Ryan et al. 1988, Ryan and Reinhardt 1988, Wyant et al. 1986, Peterson 1984, Bevins 1980). Root damage by fire has been associated with the physical effects of duff consumption on the site (Shearer 1975, 1976). Tree stress and secondary insects have been linked to tree survival following fire damage (Ryan 1982a).

Furniss (1965) found a strong association between fire damaged Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) and Douglas-fir bark beetles (*Dendroctonus pseudotsugae* Hopkins). The beetle attacks appeared to be concentrated in the area of bole scorch on trees seriously damaged with crown scorch. Vigorous trees (as measured by pressure bomb measurements of xylem pressure potential) are able to survive attack by "pitching out" the beetles making the attack unsuccessful (Ferrell 1978).

There is also a strong association reported between bark beetle attack and root disease infection. *Phaeolus schweinitzii* (Fr.) Pat. is a pathogen that primarily decays the heartwood of living trees causing structural instability but seldom death unless associated with a bark beetle infestation or Armillaria root disease (Hagle 1981, Geizler et al. 1980). Fire damage has also been found in association with *P. schweinitzii* decay by Geizler and others (1980).

Armillaria obscura (Schaeff.:Secr), on the other hand, infects the sapwood and cambium. It can act either as a primary pathogen, killing trees directly or a secondary pathogen which attacks trees weakened by other agents (Wargo 1983, Hadfield et al. 1986). Armillaria root disease also commonly predisposes trees to attack by bark beetles (Hadfield et al. 1986).

Fine root biomass (roots less than 2 millimeters in diameter) is also an indication of tree health as this is the component responsible for water absorbtion and uptake by the tree. The fine roots are concentrated in the top 15 to 20 cm organic layer of forest soil (McQueen 1973, Harvey et al. 1978). This vulnerable location exposes them to temperature changes from fire (Grier 1980, Vogt et al. 1980). In addition, 90-200% of fine roots are replaced annually (Persson 1979) with a spring and fall flush (Vogt et al. 1980). Without the recurring root flush in damaged roots, the numbers are drastically reduced along with the absorbing capacity of the root system. Disturbance to the organic layer and disruptions in the root production process would affect the water balance of the tree and yet have not been studied in association with fire damage.

Water stress as measured on a pressure bomb (negative bars of xylem pressure potential - Ritchie and Hinckley 1975) has been studied to measure the impact of environmental effects or tree damage. Ferrell and Smith (1976, 1978) used xylem pressure potential to determine the indicators of (*Heterobasidion annosum* (Fr.) Brey.) root decay in white fir (*Abies concolor* (Gord. and Glend.) and the susceptibility to bark beetles. Waring and Cleary (1967) used xylem pressure potential to evaluate plant moisture stress during summer drought periods. Grissom (1985) found reduced water stress on trees with crown scorch and hypothesized that reduction of the transpiring surface in vigorous trees was responsible.

In this study, I have evaluated some of the combined effects of fire, root disease, and bark beetle infestation on water stress, fine root biomass, and the resulting mortality of seed trees on a site on the Powell Ranger District, Clearwater National Forest, Idaho.

OBJECTIVE

The major objective of this study was to examine the possible causes contributing to the mortality of the Douglas-fir seed trees. This work was an ex post facto study undertaken 2 years after underburning treatment was performed.

METHODS

Study Area

Three conifer stands one half mile apart in the Lochsa drainage and similar in biological and physical type were selected for comparison on Powell Ranger District, Clearwater National Forest, Idaho. Aspects ranged from east to southeast and the elevation ranged from 1340 to 1400 m (4400 to 4600 feet). Slopes were 50 to 60 percent. Soils were all well drained sandy loams with mixed ash. All sites had similar infection levels of *Phaeolus schweinitzii*. Habitat types are all in the *Abies* *grandis* (ABGR) series (Cooper et al., 1985). The habitat type on the burned unit is predominantly Abies grandis/Clintonia uniflora with a beargrass phase (ABGR/CLUN/XETE) and Menziesia phase (ABGR/CLUN/MEFE) on the cooler, northeast aspect that grades into the unburned/unthinned unit. The unburned/thinned stand is in the Abies grandis/Asarum caudatum habitat type with a Menziesia phase (ABGR/ASCA/MEFE).

Climatic conditions are dominated by Pacific maritime airmasses and prevailing westerly winds. Annual precipitation is approximately 100 cm (40 inches) with 80 percent occurring during the fall, winter and spring. Climate during the summer months is influenced by stationary high pressure systems along the northwest coast. Temperature is variable with average annual temperature from -1°C to 9°C (30°F to 47°F).

Treatments

The stands each received a different treatment: 1. control (untreated), 2. seed tree cut and underburned, 3. seed tree cut without underburning. The study trees were 200- to 250-year-old Douglas-fir on all three sites. Tree characteristics were measured and found to differ slightly between the two treatment stands - trees on the unburned stand were generally smaller in diameter, shorter, and averaged 50 years younger than those on the burned site. Trees on the burned site were selected from the survivors and were in various stages of decline. Other species were present on all sites.

Burned/Thinned Stand - The burned/thinned stand was harvested in 1982 with approximately 18 residual trees per acre of primarily Douglas-fir with some ponderosa pine (*Pinus ponderosa* Laws.) and western larch (*Larix occidentalis* Nutt.) over 42 cm (17 inches) DBH (diameter at breast height or 1.4 m). This stand was underburned after harvest to reduce fuel loads and vegetative competition for natural regeneration.

Burning of the stand was accomplished 2 years before the initiation of this study. Slash was cleared in a 3.5-meter square area around the seed trees prior to burning. Pre-burn fuel loads were 21 tons per acre (6 tons per acre in the <1 inch size class) and the ignition pattern was a strip head fire. Burning occurred in the evening of August 16, 1983 under standard operational prescribed burn conditions. Weather conditions were within prescribed limits (22°C or 72°F and 42 percent relative humidity, no wind) to ensure minimum intensity and flame length (1.2 m or 4 feet) for seed tree survival. Levels of damage to the residual trees were determined to be within acceptable limits based on post burn analysis conducted in the same season. However, heavy mortality occurred primarily in the Douglas-fir trees one year after the burn in 1984.

Previous to burning, the burned site was classified as NFFL Fuel Model levels 11 and 12 or low-to-moderate fuel loadings (Anderson 1982, Albini 1976). The burn was observed to be light to moderate in intensity for a prescribed underburn. Observations showed maximum flame length of less than 2 meters (6 feet) with an average of 0.9 to 1.2 m (3 to 4 feet) and little smoldering combustion which is associated with high ground temperatures (personal communication with Dave Thomas, formerly of Powell Ranger District). Measured fuel moistures were 8 to 17 percent for one hour fuels and within prescription limits. The standard external indicators showed insufficient damage to trees to explain the delayed mortality that appeared in the spring of 1984, one year after the burn.

Tree mortality from prescribed fire was predicted using the model of Reinhardt and Ryan (1989). Variables used in the model were average stand diameter and average crown scorch percent (35 %) estimated 2 years after the burn. The predictions of tree mortality made with the tree mortality prediction model resulted in .1 probability of mortality given the average tree diameters of the underburned stand. This is well below the resulting 40 percent mortality that occurred 1 year after the burn, indicating that this situation was not typical of most fire mortality cases.

Unburned/Thinned Stand - The unburned stand was harvested in 1981 with 12 trees per acre retained as a seed source. This stand was scheduled for a prescribed burn in 1984 which was not accomplished due to contracting complications. Preliminary observations showed stump infections with *P. schweinitzii* similar to the burned stand. Only one dead tree had been observed in this stand since harvest.

Control Stand - This stand, adjacent to the burned stand on private land and similar in site characteristics, was used to sample for water stress only. No harvesting or burning occurred but infection by *P. schweintizii* was observed on the site.

Sample Selection

Fifteen trees were sampled in each stand representing the full range of crown symptoms including those trees without obvious signs of disease infection. Due to the mixed species on both treated sites and high mortality on the burned site most of the live Douglas-fir seed trees present were included in the sample. A dead tree was also included on both of the treatment sites.

Root Disease Infection

Root disease infection extent was determined for a subsample of the root systems in the treated stands. Seven trees per stand were randomly selected, cut and the stumps were excavated using water gel explosives (Hagle 1981). The gel explosives loosened the soil around the root system with minimum damage. Excavation was completed using hand tools.

Each root system was ocularly divided into cardinal (longitudinal) quadrants to detect root disease throughout the system. Within each quadrant roots from three zones were subsampled at 1 meter from the root collar, one half meter, and at the root collar. Three diameter classes within each zone were sampled: <1cm, 1-5 cm, and 5 cm and above. Disease location was determined based on visual symptoms from cross-sections cut from each sample. Visual symptoms included red discoloration, pitch streaking, decay, mycelial fans, and callous tissue. Random samples of symptomatic roots were selected for fungus isolation to confirm pathogen identification.

Specimens were kept cool during the day and isolates were made each evening from symptomatic tissue. Symptomatic tissue was surface sterilized by dipping in 95 percent alcohol and flaming for 1 second using standard laboratory procedures. Cultures were made on petri plates with Nobles' special agar (1964) and transported back to the laboratory. As isolates grew, they were subisolated onto agar slants in screw cap test tubes for storage. Isolates were kept at room temperature and subisolated monthly for 1 year. They were grown on Nobles' special agar and tannic acid agar (Nobles 1964) for identification. Six-week old cultures were identified with the assistance of Dr. Sue Hagle (Plant pathologist, USDA, Forest Service, Missoula, MT) using Nobles (1948, 1964) and Stalpers' (1978) keys for basidiomycetes in culture.

Bark Beetle Impact

After trees were cut bark samples measuring 20 cm by 20 cm were cut and removed from two sides (sun and shade) of the bole at three locations; 3 meters from the ground, 3 meters down from the 12 inch top diameter and half way between the first two locations. Square bark samples were cut down to the cambium layer and peeled off of the tree to examine for beetle galleries. Percent of sample that was occupied by larval galleries was recorded. Secondary beetle galleries were present but only those of the Douglas-fir beetle were counted.

Direct Fire Impact

Direct fire damage was assessed on the burned site using methods described by Ryan (1982b) and Ryan and Noste (1983). These methods involved visual estimates of percent bole scorch, percent crown scorch, percent live cambium, and ground char. Bole scorch on the circumference of the tree at dbh (4.5 feet, 1.37 m) was estimated in percent. Percent of the original crown scorched by fire was visually estimated 2 years after the burn with the assistance of Kevin Ryan, U.S.F.S. Fire Research Lab, Missoula, MT. Percent of the cambium at stump height that was alive was estimated with the use of a solution of orthotolidine (Ryan 1982b). Orthotolidine reacts with the enzyme peroxidase which is present in living cambium tissue. Ground char was categorized from circular areas around the base of the tree to determine the amount of litter consumption and ground char that occurred (Ryan and Noste 1983). The classifications were unburned, light burn, moderate burn, and deep burn.

Fine Root Biomass

Soil cores were taken in mid-June 1985 to sample the fine root biomass. Samples were taken with a 10-cm by 30-cm tube driven flush into the ground. Two soil core samples were taken per tree 1 meter uphill and 1 meter downhill from the root collar. Samples were immediately bagged and kept cool to minimize continued respiration. Samples were sieved using a 2-mm screen to separate root material from soil and organic matter. All roots were placed in formalin acetic acid for preservation until counted and weighed. Root samples were sorted to separate live Douglas-fir roots from dead or non-Douglas-fir roots. Fine Douglas-fir roots less than 1 mm diameter were separated, oven dried at 70°C for 48 hours and then weighed.

Water Stress

Leaf xylem pressure potential (water stress measured in negative bars) was selected to test as a variable to represent the overall vigor of the tree. As a measure of the water potential of the xylem sap, it indicates the amount of water flow through the soil-plant-atmosphere continuum and reflects any relative deficiencies in tree moisture.

The leaf xylem pressure potential was measured at midday using pressure chamber methods of Ritchie and Hinckley (1975) on the burned, unburned, and control stands. Branches with 2 years' growth from midcrown samples were used. Midday measurements were used in place of predawn measurements in an attempt to measure tree physiological water stress responses during periods of most active uptake and not soil water deficits.

Radial growth for the past 10 years was measured in millimeters (1/20 inch) on the two treatment sites to determine if there was any difference in overall vigor before the burn.

Statistical Analysis

All samples were averaged and statistical tests were performed using SPSS-X and BMDP software. Analysis was done to evaluate the data for significance in variables between the treated sites to determine those that might be contributing to stress. Although root disease was present in the control stand, extent of infection was not measured. Xylem pressure potential was the only variable measured in the control stand.

A test for homogeneity of variance was performed and results indicated analysis of variance (ANOVA) was not appropriate. Therefore, a Bonferroni's multiple comparison test was used to compare the xylem pressure potential between the three sites - burned, unburned, and control. A student's T test was used to determine the significance of differences of all other variables between the burned and unburned site trees. Correlation coefficients were calculated for all variables on the burned site.

RESULTS

Root Disease Infection

The level of general root disease infection was similar on both sites based on the results of the statistical test (table 2) and supported by visual estimates. On both sites many large roots were extensively infected by *P. schweinitzii* and rotted off at the one-half or 1 meter length indicating many decades of infection activity. Roots were commonly stubbed with callous tissue. Incipient decay by *P. schweinitzii* was evident even in small adventitious roots 3 mm in diameter.

The extent of *A. obscura* infection was significantly higher at the root crown on the burned site. These data were supported by field observations. Armillaria incidence also appeared to be greater on the burned site. Percent of trees on the burned site with Armillaria infection was 27 percent compared to 2 percent on the unburned site. The presence of *Armillaria obscura* in both stands seemed to be limited to dead or nearly dead trees (table 1).

Heterobasidion annosum (Fr.) Bref. occurred in small, localized infections on 11 trees on both the burned and unburned site (table 4). The infections did not appear to be significantly affecting the trees. The pathogen was not considered to be aggressive in this situation. By comparison, *A.*

obscura infection was much more extensive and found higher up on the roots closer to the root crown.

Bark Beetle Impact

There were many more dead trees on the burned site that had indications of past infestations with bark beetles that were not included in the sample. Of the sample trees infested, 55 percent of the infestations were found in the bottom portion of the bole compared with 35 percent in the middle portion of the bole. There was no difference in beetle galleries between the sunny and shaded sides of the boles.

Many of the beetle galleries produced successful brood. In cases where brood did not survive galleries still were extensive and killed the phloem. Few galleries were observed to have resin that would indicate a wound response and resistance of a healthy tree to attack. All Douglas-fir beetle galleries were found in the middle or lower bole samples. Galleries of species of secondary Scolytid beetles and wood borers were present in all portions of the bole and in some cases overlapped the Douglas-fir beetle galleries. These were a different size and were distinctive upon close examination.

Direct Fire Impact

Duff consumption and ground char around 5 sample trees on the burned site was classified as moderate duff consumption with 4 classed as moderate or less ground char. For the observed flame length these classifications were determined to be insufficient to cause direct mortality (Ryan and Noste 1983). Root injury due to fire was sustained on only 2 main roots of one tree as observed in the root system excavation.

Table 1--Measured variables

	Stress Bars	Root Disease	Fine Root	Beetles		Direct Fire Damage			
Tree #		% all	% *A. obscura*	Gm weight	% girdle	% cambium	% crown	% bole	Ground char
Burned Site									
06	dead	86	16	*	47	0	0	99	Light duff consumption
08	24			.261	31	99	15	50	Mod. ground char
07	23	91	62	123	9	70	80	99	Mod.duff/ground char
13	20	72	00	.389	0	99	05	35	Light duff consump
01	17			.769	0	90	30	50	Mod.duff/ground char
12	16	86	07	.647	0	99	10	35	Light duff consump
04	16	66	29	.406	49	15	85	99	Mod. ground char
15	15	80	52	.606	0	99	05	40	Light duff consump
11	14	74	24	.547	0	35	35	90	Light duff consump
10	14	69	02	.295	0	99	05	99	Light duff consump
09	14			.790	0	99	05	40	Mod. duff consump
14	13			.571	0	95	75	60	Light duff consump
02	11	84	07	.030	0	99	15	00	Light duff consump
05	11	66	02	.623	0	90	60	99	Mod. duff consump
03	11			.612	47	40	50	99	Mod. duff consump

Tree #		% all	% *A. obscura*	Gm weight	% girdle	% cambium	% crown	% bole	Ground char
Unburned Site									
29	dead	86	22	*	33				
28	16	83	05	.418	0				
26	16	83	05	.076	0				
23	15	70		.594	0				
25	14	95		.160	0				
30	14	02		.437	0				
22	14			.956	0				
17	14	76		.481	0				
20	14			.932	0				
27	13			.527	0				
19	13	81	17	.401	0				
24	13	70		.678	0				
16	12	77		136	0				
21	10			.368	0				
18	9	75		.629	0				

* Indicates value not measured

Fine root biomass

Fine root biomass averaged slightly less per tree core on the burned site than on the unburned site but was not significantly different (table 1). I feel these results may not be meaningful as I had difficulty distinguishing Douglas-fir from the non-Douglas-fir roots. This confusion may have affected the results. Black mycorrhizae were observed but not counted on rootlets from both sites.

Water Stress

Temperatures were 28 and 26 degrees C (82 and 79 degrees F) and relative humidities were 25 percent and 39 percent on the two days that pressure chamber measurements were taken, June 18 and 20, 1985. Drought conditions existed the spring season previous to when measurements were taken. However, during root system excavations on the treatment sites soil moisture appeared adequate and not limiting. I had difficulties in obtaining samples with current-season growth on the burned sites because trees had produced little or no new growth. Samples with new growth were available on the unburned and control sites.

The Bonferroni test for multiple comparisons indicated that the water stress (negative bars of xylem pressure potential) on the burned stand was significantly higher than the control stand at the 90 percent level of confidence (table 1). The burned stand stress was not significantly higher than the unburned stand. However, environmental factors were not measured and the pressure readings are not adjusted to reflect the diurnal fluctuations inherent in mid-day xylem pressure potential measurements.

Other observations were used to generally represent stress as the xylem pressure potential measurements were not conclusive. The absence of new growth on samples from the burned site was an obvious indication of complications. In addition, crowns were more chlorotic on the burned site although this variable was not measured.

Student T Test

The average percent bark beetle girdling was higher but not significantly on the burned site (table 1). There was clearly no significant difference between the average level of *P. schweinitzii* infection on the burned and unburned sites. The levels of *Armillaria obscura* at the root crown were significantly higher on the burned site. Fine root biomass and 10-year radial growth also were not significantly different between the two treated sites.

Table 2--Means and multiple comparison test using Bonferroni and Student's T Test.

	BURNED SITE		UNBURNED SITE		CONTROL		P
	Mean	Std dev	Mean	Std dev	Mean	Std dev	
WATER Bars			15.6	(4.16)	12.9	(2.50)	0.08*
STRESS Bars	15.6	(4.16)	13.4	(1.98)			0.16
FINE ROOT (dry weight)	.47 gm	(.23)	.48 gm	(.26)			1.84
INFECTION All disease	77%	(.09)	79%	(.07)			1.20
INFECTION *A. obscura*	27%	(.22)	2%	(.08)			0.10*
INFECTION *P. schweinitzii*	58%	(.27)	36%	(.42)			0.34
10 YEAR	14 mm	(6.14)	18 mm	(6.84)			0.56
GROWTH	(11/20")		(14/20")				
BARK BEETLE	12%	(.20)	2%	(.08)			0.22

*Statistically significant at the 90 percent level of confidence.

Correlation Coefficients

Correlation coefficients in general were very low. No results were over r = .77. Some of the most highly correlated readings were between the degree of bark beetle infection and percent live cambium, percent bole scorch, and percent crown scorch, in descending order (table 3). Fine root biomass was negatively correlated with the amount of total root disease infection (r = -.57). Separating Armillaria infection data from that of *P.schweinitzii* resulted in a correlation of r = .67 between *A. obscura* and moisture stress. Correlations within the fire damage variables alone were all very high - percent live cambium was highly negatively correlated with bole and crown scorch.

Table 3--Correlation coefficients.

Variable	r	n	Sig
BARK BEETLE with % live cambium	-.6992	15	.002
with % crown scorch	+.4792	15	0.35
with bole scorch	+.4450	15	.048
with root biomass	-.2928	30	.058
with *A. obscura*	+.2463	21	.141
with *P. schweinitzii*	-.2042	21	.187
ROOT BIOMASS with % root disease	-.5737	21	.003
with % live cambium	+.3872	15	.077
with % crown scorch	-.2493	15	.185
with % bole scorch	-.0932	15	.370
with water stress	-.2197	28	.131
% CROWN SCORCH with % bole scorch	+.6624	15	.003
with % live cambium	-.7712	15	.000
% BOLE with % live cambium	-.6922	15	.002
A. obscura with water stress	+.6748	19	.001
in Root with % live cambium	-.7376	10	.007
Crown with % bole scorch	+.4130	10	.117
with % crown scorch	+.6481	10	.020

Cultures

Species confirmed from culture identification are listed in table 4. Eighty-eight isolates were made initially. Of these, 41 were hymenomycetes. These were retained for further study. Forty one basidiomycete isolates were identified as nine species of known root pathogens. In some cases multiple species were isolated from the same sample. *Phaeolus schweintzii* was typically very difficult to isolate in culture in spite of obvious visual symptoms of the disease on samples. *Armillaria obscura* was present but only cultured and identified three times as it was easily confirmed in the field. *Heterobasidion annosum* was the most common species isolated and identified in culture with 13 occurrences.

Table 4--Identified cultures

Species Identification	Frequency	Tissue Type
Fomitopsis pinicola (Swartz:Fr.) Karst.	3	Red heartwood decay
Heterobasidion annosum ((Fr.) Bref.	13	Red heartwood decay
Perenniporia subacida (Peck) Donk	6	Red heartwood decay
Phellinus weirii (Mrr.)Gilb.	2	Red heartwood decay
Phellinus spp. B *	4	Red heartwood decay
Phellinus pini (Thore.:Fr.) A.Ames	2	Red heartwood decay
Resinecium bicolor (Alb. et Schw.:Fr.)Parm.	5	Red heartwood decay

* Not identified to species

DISCUSSION

The high level of mortality observed in the burned stand was a result of the amount of combined damages imposed on the trees. Although the xylem pressure potential was significantly higher on the burned site it was only by about 3 bars. Without environmental data to explain the variation in these measurements it is difficult to be totally conclusive based only on the water stress. Therefore, the visual estimates of poor vigor (new branch growth, poor crown condition) are relied upon to draw conclusions concerning the impact of fire damage, root disease infection, and bark beetle infestation.

Root Disease Infection

Infection by *P. schweinitzii* alone seldom causes standing mortality except on rocky, dry sites in the northern Rocky mountains.[1] It predisposes host trees to infection by other pathogens such as *A. obscura* or to bark beetle attack (Hadfield et al. 1986, Hagle 1981). Similar infection rates by *P. schweinitzii* on both the burned and unburned sites and between trees with the least and most severe crown symptoms indicates that mortality on the burned site was not attributable to *P. schweinitzii* infection alone. Within the 2 years since burning the stress imposed by underburning did not cause an increase in the level of infection of *P. schweinitzii* on the burned site. All of the trees sampled had high rates of infection by *P. schweinitzii*. This is supported by the insignificant difference in 10-year radial growth between the two treatment sites. The infection probably contributed to the visible decline, and subsequent infection by *A. obscura*, in conjunction with the effects of burning.

The significantly higher level of *A. obscura* ($P < .10$) on root crowns on the burned site follows patterns observed elsewhere. Armillaria has been observed to form localized, latent infections on Douglas-fir roots which become more active and extensive as the tree loses resistance (Wargo and Shaw 1985). Wargo (1983) states that a strong relationship exists between stress and

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[1] Unpublished report on file with Dr. Susan Hagle, USDA Forest Service, P.O. Box 7669, Missoula, MT 59806

Armillaria mellea as a tree pathogen in eastern hardwoods. Hagle (1981) also found Armillaria invading and killing roots previously infected with *P. schweinitzii*. Although there was no reliable correlation found between Armillaria infection and other damage factors it was more extensive on the burned site and in locations on the roots that would indicate primary, advanced infections. Its prevalence on dead or dying trees demonstrates its tendency to infect trees weakened and predisposed to attack. This would support the hypothesis that the combined effects of fire damage and *P. schweinitzii* infection would result in increased stress and infection by Armillaria.

Once infected by *A. obscura*, the tree is further stressed by that infection. Tkacz and Schmitz (1986) hypothesized that Armillaria interfers with water absorption as it kills the phloem (although in this case *A. obscura* was not highly correlated in a negative manner with percent live cambium) and decays the stem. Ferrell and Smith (1976) found *Abies concolor* (Gord. and lend) Lindl. saplings exhibiting high moisture stress (-20 bars in mid August, predawn readings) when greater than 95 percent of the root system was infected by *Heterobasidion annosum*. Root disease infection lowers the resistance of trees to secondary attack by bark beetles (Geizler et al. 1980, Hertert et al. 1975).

Hagle (1981) found *P. schweinitzii* associated with dead rootlets and frequent adventitious rooting on severely infected Douglas-fir roots. The levels of *P. schweinitzii* infection in her study were similar to these stands. She suggested that adventitious roots may compensate for rootlets lost due to infection and aid in tree survival by supplementing water uptake. Adventitious rooting was observed in this study on both thinned stands. However, fire damage to the root systems may have counteracted any benefits of the adventitious roots resulting in greater restriction of water uptake on the burned site.

Phaeolus schweinitzii is difficult to capture in live culture and is sensitive to drying out (personal communication, Dr. Sue Hagle). The high frequency of *H. annosum* among isolates reflect its relatively easy isolation and identification. It was infrequently diagnosed from visual symptoms in the field. The paucity of annosus root disease symptoms in the root system indicates that *H. annosum* was relatively unaggressive in this situation compared to *P. schweinitzii* and *A. obscura*.

Bark Beetle Impact

The relationship between Douglas-fir beetle mortality and fire damage has been documented (Furniss 1965) as has the association between beetle mortality and disease infection (James and Goheen 1981, Hertert et al. 1975, Partridge and Miller 1972) and beetle mortality and water stress (Rudinsky 1966, Ferrell 1978). The slightly higher (although not statistically significant) level of cambium girdling by bark beetle ($P < .22$) on the burned site suggests the beetles played a similar role in this situation. The association is compounded by two unrelated, predisposing factors; root disease infection and fire damage.

White fir has been found to have a moisture stress threshold of -20 bars (predawn) for susceptibility to fir engraver beetle (*Scolytus ventralis* Leconte) attack (Ferrell 1978). Also, trees with xylem pressure potential above -15 bars produced resinosis which limited beetle mining. Berryman (1969) found a similar relationship in grand fir (*Abies grandis*). The average moisture stress readings for trees attacked by beetles in this study was -17 bars (table 2), but two of the five attacked trees had died. These trees may have represented the high end of the population with regard to moisture stress. Water stress measurement only on survivors probably yielded an artificially low level of stress in the burned stand where nearly half of the trees had died.

The association between root disease and bark beetles is partially represented in this study by the correlation between the percent infection by *A. obscura* and beetle girdling (table 3). Though the correlation and significance level was not high between *A. obscura* and percent bark beetle girdle, the association was negative with percent *P. schweinitzii* infection and percent beetle girdling. This reflects the additional water stress Armillaria imposes as it kills the cambium and decays the sapwood (Tkacz and Schmitz 1986) or zone of water transport. *Phaeolus schweinitzii* acts more slowly to kill rootlets and stub roots. Adventitious roots produced in response to *P. schweinitzii* infection also may offset some of the root damage. This is also supported by the positive correlation between Armillaria infection and moisture stress (r = +.5365). Ferrel and Smith (1976) found that susceptibility of white fir to bark beetles was only evident in trees with medium to severe root decay by *H. annosum* which, like Armillaria, also infects the cambium and sapwood area.

Increased susceptibility of root diseased trees to infestation by bark beetles occurs by one of two theoretical methods (Tkacz and Schmitz 1986) - 1) reducing the resin exudation for wound response in the tree or 2) causing the tree to produce primary attractants to draw the beetles for attack. Resin was not observed in most of the Douglas-fir beetle galleries in this study indicating the trees were sufficiently stressed to be unable to respond. In lodgepole pine, infection is thought to possibly cause production of trans-verbenol, the aggregating pheromone for mountain pine beetle (*Dendroctonus ponderosae* Hopk.), which predisposes trees to attack (Pitman et al. 1968). In either case, the beetles preferentially attacked stressed trees infected with root disease and injured by fire.

Douglas-fir beetle attacks in this study were most highly correlated with all forms of fire damage (table 3). This follows similar patterns to those found by Furniss (1965). Location of attacks support this also because most attacks were observed in the lower portion of the bole where fire damage was concentrated on trees in the burned site. The variable most highly correlated with beetle damage was percent live cambium. This was not surprising as the beetle damage was measured as percent of the sample girdled by larval galleries. The correlation with percent bole scorch, which would be assumed to be related to percent live cambium and percent beetle girdling, was much lower.

Crown scorch, the second highest correlation with beetle damage, is the most common indicator of fire damage and is used to rate fire damaged trees for potential mortality (Ryan et al. 1988, Ryanand Reinhardt 1988, Reinhardt and Ryan 1989, Wyant et al. 1986, Peterson 1984, Bevins 1980, Furniss 1965). Peterson and Arbaugh (1986) found that crown scorch and insect damage were the best predictors for survival of Douglas-fir and concluded that crown scorch reduced the photosynthetic capacity of a tree lowering resistance to insect damage. The correlation between crown scorch and beetle girdling supports this pattern in spite of the lack of statistical correlation with moisture stress.

Direct Fire Impact

The contribution of fire to root system damage is a function of duff consumption and soil moisture reduction (Shearer 1975, 1976). The greater the duff consumption, the more heat flux generated through the mineral soil and to the superficial roots. The low levels of duff consumption and ground char in this study should have resulted in relatively light fire impact on the roots. In the large size class of roots (greater than 5 cm diameter) only 2 roots on one tree exhibited fire injury. Yet with a reduced root system this damage may have been sufficient to affect the fine root production capacity. Ryan (1989) states that increased moisture stress, stomatal closure, and reduced photosynthesis can result from a reduced root volume size. Ultimately, the combined effects of fire, root disease, and bark beetles resulted in high rates of tree mortality.

In addition, the lethal rate of crown scorch is reported to be 60 percent for mature Douglas-fir (Norum 1977, Wyant et al. 1986). The average percent crown scorch measured in this study was

37 percent. This would also indicate that fire damage alone was not sufficient to cause high levels of mortality. Ryan (1989) and Chambers and others (1986) state that vigor and crown ratio influence survival of mature trees with crown scorch. As trees age, they have less allocated carbon for repair and defense due to large respiring areas. Crown reduction in this study could have resulted in stress due to extreme pest damage combined with impaired photosynthesis due to crown damage.

Crown scorch and bole scorch, the two most reliable predictors of fire related mortality, both showed a highly negative relationship to percent live cambium. This was not surprising as the primary factors in cambial damage are bark thickness and duration of the fire (Ryan 1982b). Although not measured, bark was observed to be very thick as would be expected in this species and size class (average diameter of 67 cm or 27 inches). The correlation between percent live cambium and extent of infection by *A. obscura* was much lower than for the fire variables or bark beetles.

Large trees are more resistant to fire due to bark thickness which reduces injury to the cambium (Ryan and Reinhardt 1988, Ryan et al. 1988, Peterson and Arbaugh 1986, Wyant et al. 1986) and higher crowns reducing crown scorch. The trees in this study would normally escape damage due to their large size class and the fact that the average percent live cambium was 79 percent. This is also confirmed by the results from using Reinhardt and Ryan's model (1989). Ryan and others (1988) also found a high probability of mortality if greater than 25 percent of the cambium is dead at breast height. Ryan (1989) suggests that carbohydrate flow to roots may be disrupted with extensive cambial killing leading to moisture stress.

The relatively low percent of dead cambium directly from fire damage in this study suggests that cumulative effects must have played a part in the high rate of mortality. Several trees had greater than 25 percent dead cambium resulting from the combination of damages and have high probabilities of death. Increased conifer mortality when crown scorch was accompanied by root and bole damage was also observed by others (Peterson and Arbaugh 1986, Wagener 1961, McConkey and Gedney 1951). In this case, the damage was inflicted by pest interactions.

Fine Root Biomass

As the primary source of absorbed water and nutrients for conifers, the fine root system plays a crucial role in tree survival. Damage to the root system of trees by fire and disease infection would reduce the overall size of the system with consequences for water uptake. Due to the concentration in the top 15 to 20 cm of forest soil the roots are in a vulnerable location exposed to temperature changes from fire (Vogt et al. 1980). Without the recurring root flush in damaged roots, the numbers are drastically reduced along with the absorbing capacity of the root system. Moisture requirements of the tree are not satisfied and water stress can result due to the reduced absorption capacity.

Grier and others (1980) found greater fine root biomass in the forest floor litter layer of mature (180 year old), subalpine forests and associated it with detritus accumulation. They suggested disturbance of the forest floor would reduce the litter layer and consequently the zone of maximum fine root production. Harvey and others (1978) also found the greatest number of ectomycorrhizal root tips in the organic soil fractions in Montana and suggested soil wood reduction would reduce mycorrhizae. These works imply that prescribed burning for site preparation would reduce the amount of fine root biomass produced.

Insignificant results between the burned and unburned sites for fine root biomass are felt to be partly a result of difficulty in species identification, as stated previously. Although fine root biomass was not significantly lower on the burned site it was found to be negatively correlated with the percent of all disease infected roots. This reflects the reduction in the effective size of the root system.

Water Stress

The xylem pressure potential measurements documented here do not approach the extremes for water stress documented by other researchers. Base potential (predawn pressure potential) readings reported by Waring and Cleary (1967) for Douglas-fir at the peak of summer drought were -14 bars. Running (1976) reported diurnal xylem pressure potential thresholds of -20 bars in Douglas-fir in Oregon. As soil moisture appeared not limiting, it was hoped that mid-day water stress measurements would reflect the physiological stress imposed by fire, insect, and root disease damage on water uptake and transport. The results were not conclusive as diurnal environmental changes were undoubtedly responsible for some of the differences in water stress readings.

Although the use of xylem pressure potential to measure relative stress was not successful, visual observations of crowns indicated increased stress on the burned site. New growth was not common on lateral branches of burned site trees. *Cryptoporus volvatous* (Pk.) Shear conks were present on some of the more extensively burned but living trees indicating sapwood decay in the stem. The significantly higher level of infection by *A. obscura* at the root crown also indicated a rapid and advanced colonization of the root system.

The reduced root system size caused by root disease probably caused some reduced water uptake even though this was not reflected in the xylem pressure potential data. Teskey et al. (1985) found a decline in xylem pressure potential when half of the root system of *Abies amabilis* (Dougl.)

Forbes was severed. Running (1980) found that water relations in lodgepole pine (*Pinus contorta* Dougl ex. Loud) were controlled primarily by root and soil resistance. Root systems reduced in overall size would be less likely to compensate for this resistance and produce a favorable flow of water.

The slightly decreased xylem pressure potential on the burned site in spite of reduced vegetative competition could be influenced by the cumulative effects of the damage agents. Thinning and removal of understory vegetation reduces vegetative competition for soil moisture (Brix and Mitchell 1986, Petersen et al. 1988). Though not conclusive, the slightly lower pressure potential might suggest a degree of water stress that is supported by visual estimates of tree vigor. The additional impact of fire on the infected root system stressed the trees to the point that new growth was absent on crown samples and crown condition was poor. In addition, trees attacked by bark beetles were unable to resist attack by producing resins in a wound response.

Grissom (1985) measured water stress on 10-year-old crown scorched slash pine and found a less negative xylem pressure potential compared to the unscorched trees. He postulated that the difference was due to reduction in the transpiring area of the tree. Reinhardt and Ryan (1988) found that individual tree growth was not reduced by low levels of crown scorch. Chambers and others (1986) state that tree growth and survival are correlated to tree vigor at the time of fire impact. The trees examined in this study were overmature and not vigorous. Therefore, the impact of crown scorch would have a negative effect on the carbon balance of the tree overriding any potential water balance benefits.

CONCLUSIONS

The high frequency of mortality of unsampled trees in the burned stand reflects the combined impact of fire damage, bark beetle infestation, and root disease infection. The level of fire damage on the burned site, as reflected by low crown scorch percents and relatively high percent live cambium, was judged not to be sufficient to cause death. Nevertheless, the combination of fire damage to some subsurface lateral roots, root system reduction by advanced *P. schweinitzii* and *A. obscura* infection, and girdling of the phloem by beetle galleries resulted in stress of the residual trees based on crown condition observations.

The use of xylem pressure potential to measure the moisture stress was not conclusive due to diurnal environmental variation. In addition, the most extremely stressed trees died prior to this study perhaps resulting in an unbalanced range of samples for water stress. It is postulated that some water stress was present due to a reduced root system size caused by root disease infection. This, when combined with disturbance of the organic layer where fine root production occurs, resulted in impaired fine root production and reduced water absorption. Reduced water transport in the xylem due to infection and decay would also be a contributing factor.

The water stress combined with reduction of the photosynthetic area probably resulted in carbon stress, and in many cases death, as the trees on the burned site were not capable of maintaining growth or resisting insect and disease attack. Trees were predisposed due to extensive *P. schweinitzii* infection for many years previous to the burn. The limited sample sizes produced high levels of variation. Combined with the ex post facto nature of the study it was difficult to produce conclusive results.

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