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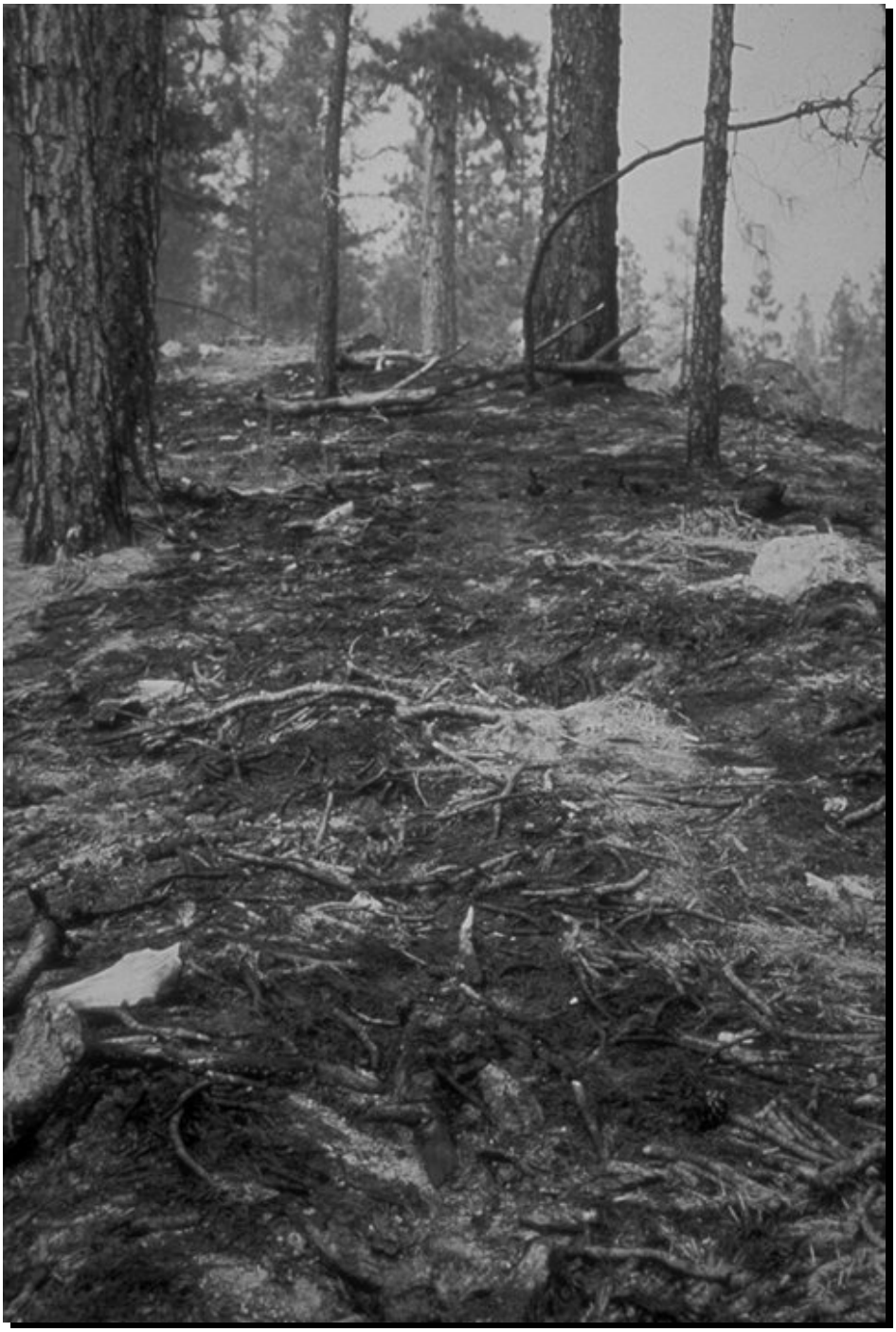
Evaluation of Tree Survival on the Payette National Forest 1995-1999



Evaluation of Tree Survival. on the Payette National Forest 1995-1999

by
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Abstract

Fire is the most important influence on forest vegetation dynamics and ecosystem processes in western forests. Ecological and anthropogenic forest values are dramatically altered by wildfires. Information on the size, number and species of residual trees is essential to interpret fire impacts. Following the 1994 Payette fires a 100% survey of all living trees greater than 5 inches dbh was conducted on established study plots. Annual surveys were conducted evaluating dbh, percent crown scorch, percent root and bole char, and cause of tree mortality (fire or beetle killed) of Douglas-fir, grand fir, lodgepole pine, ponderosa pine, Engelmann spruce, and subalpine fir for the following five years. The variables examined had different effects on tree survival according to species. Crown scorch was the single most consistent variable associated with tree mortality. Mortality related to bole and root char was also significant for most of the tree species, however char related mortality incurs destructive sampling and is not consistent. Other factors play a significant role in determining tree survival following fire and the variables examined should be applied with prudence in assessing wildfire impacts.

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Introduction

Fire is one of the most important mechanism affecting forest vegetation dynamics and plays a highly influential role in the ecosystems of the west (Romme and Knight 1981, Peet 1988). The ecological and economic impacts of fire are important considerations of forest management. Accurate estimates of the effects of fire are pertinent to meeting forest resource management objectives in some areas. Information on the size, number, and species of trees in a residual stand is essential for forest managers and ecologists to interpret the impacts of fire on forest stand structure and function. Unfortunately, there are insufficient data from which to develop accurate estimates of postfire survival for most conifer species in the intermountain region of the western U.S.

The survival of conifers after fire depends on the type and extent of injury (Dieterick 1979, Herman 1954, Wagener 1961, Lynch 1959, Ryan 1982, Peterson 1985, Ryan et al. 1988, Reinhardt and Ryan 1988), the initial tree vigor, time of the fire in relation to the growing season (Wagener 1961, Dieterick 1979), site conditions (Wagener 1961, Dieterick 1979), stand conditions following fire that include the influence of insects (Miller and Patterson 1927, Miller and Keen 1960, Furniss 1965, Dieterick 1979, Fischer 1980), and disease and weather (Ryan and Amman 1996). The probability of mortality increases with the degree of fire injury and also the severity of each of these external factors.

Many authors (Peterson 1985, Peterson and Arbaugh 1986;1989, Ryan et al. 1988) identify the proportion of crown kill as the primary injury contributing to tree death, but injury to bole cambium, roots, or both may precede crown injury in causing tree mortality (Ryan et al. 1988). Wyant (1986) found that the probability of mortality increases with percent crown kill and decreases with increasing bark thickness. Mortality resulting from crown kill is often apparent by the end of the first growing season following fire, while death from bole and root injury does not become apparent before the second growing season (Ryan et al. 1988). On average, ponderosa pine trees that have sustained more than 75% crown kill or scorch are likely to die (Herman 1954, Salman 1933, Wagener 1961, Weatherby et al. 1994). However, Reinhardt and Ryan (1988) report that ponderosa pines greater than 20 inches in dbh (diameter at breast height) may tolerate more than 75% crown scorch. Local data from the Lowman fire (Weatherby et al. 1994) support higher estimates of crown scorch for larger trees. Douglas-fir trees withstand as much crown scorch as ponderosa pine, however fire damaged trees are frequently attacked by Douglas-fir beetles. Data from the Lowman fire of 1989 indicate that large Douglas-fir over 24 inches dbh were frequently attacked by beetles (Weatherby et al. 1994). Smaller Douglas-fir are less likely to be attacked and the response to fire should be near that of ponderosa pine.

Significant tree mortality is frequently associated with bark beetles and woodborers following fire. In the absence of significant bole or root injury, the likelihood of attack by primary bark beetles is low with light needle kill, increases

with moderate to heavy defoliation and declines with complete needle mortality and the concomitant fire kill (Furniss 1965).

Objectives

The objectives of this study were to: 1) determine the levels of crown scorch, bole char and root collar char associated with the survival of Douglas-fir (*Pseudotsuga menziesii*), grand fir (*Abies grandis*), lodgepole pine (*Pinus contorta*), ponderosa pine (*Pinus ponderosa*), Engelmann spruce (*Picea engelmannii*), and subalpine fir (*Abies bifolia*) within a 5 year period following the Payette fires; 2) determine accurate and practical means to rate tree damage; and 3) monitor individual tree survival potential following a fire.

Methods

In 1995, study plots were established within the bounds of the 1994 Payette fire complex in the French Creek and Pony Creek, Trail Creek and Twenty-mile Creek drainages. On plots within these four areas we conducted a 100 percent survey of all trees greater than 5 inches that had been damaged by fire but still retained green foliage at the time of plot establishment. Tree boles were divided into quadrants by bisecting lines running N to S and E to W, intersecting in the middle of the tree. Each tree was numbered and an orange dot of paint applied at DBH within each quadrant of the tree to aid in relocation. Crown scorch was measured to the nearest 10 percent using clear plastic rulers to proportionately quantify crown area. Bole char and root collar char (as defined below) were evaluated in each tree quadrant. A short increment core was taken from each cardinal direction at DBH and as near to ground level as possible. The cambium from these cores was inspected and classified as dead or alive by color. Live cambium was white, dead cambium was darker than healthy cambium. The plots were visited annually during the fire year study period and the condition of each tree, either beetle or fire-caused mortality or alive, was recorded. Additionally, during the first year of the study 25 trees of each species were subsampled (DBH $\geq$ 10") by coring every 4 inches around the base and examining the cambium to classify mortality to validate the quadrant method.

Definitions:

Crown Scorch (scorch): The percent of live crown volume killed by a fire. Ponderosa pine buds are somewhat fire resistant so it is possible to have browning of the foliage without bud kill. Indicators of crown kill include: needles dried in an abnormal windswept position and/or no evidence of green on the needles, particularly on the fascicle. The best indicator of crownkill is the lack of new growth during the season following the fire.

Bole and root char (char): The percentage of the bole/root circumference killed by fire. Fire damage that is sufficient to cause cambial death on aboveground portions of the main trunk and in areas extending from the root collar to deeper subsurface roots. The intensity of the char and the proportion of the circumference of the tree affected are the two aspects needed to accurately rate

bole and root char. When the fissures of thick bark ponderosa pine are no longer distinguishable, char is likely intense enough to kill cambial tissue. It is more difficult to rate bole char of Douglas-fir because the bark fissures remain even though the bole has been severely burned. Spruce, subalpine fir, and lodgepole pine possess thin bark and therefore withstand minimal bole or root char. The potential for severe root collar and root char is highest on wetter sites where a deep duff layer accumulates and a slow burning fire roasts the roots. Wagener (1961) and Ryan et al. (1988) note that the most accurate indicator of mortality resulting from fire for Douglas-fir is the number of quadrants of cambial kill on the bole. Tree death is likely if more than one quadrant is dead at breast height. Little fire damage data are available for grand fir, Englemann spruce, lodgepole pine or subalpine fir.

Survival/mortality categories

Fire-injured beetle killed

Trees that were placed in the “Beetle” category were killed by beetles as indicated by galleries, pitch tubes or boring dust, etc. Trees that were strip attacked were not killed and placed in the “Live” category.

Fire-injured fire killed

Trees placed in the “Fire” category were dead at the time of the annual survey, suffered fire damage and had no signs of beetle activity.

Fire-injured living

Fire injured trees that were alive at the time of the annual survey and may have been strip attacked by beetles.

Analyses

Univariate discriminant analysis (Legendre and Legendre 1998) was used to test if the explanatory variables 1) dbh, 2) crown scorch and 3), bole/root char had a significant impact on tree survival following wildfire. Testing for differences among group means is identical to ANOVA for a single explanatory variable. Multiple comparisons were made using a Tukey-Kramer HSD (honest significant difference) test ($P \leq 0.05$) for each parameter. This test is conservative for unequal sample sizes. Nominal logistic regression (SAS 1995) was used to estimate the probability of choosing one of the response levels as a function of the category of survival.

Results and Discussion

During the course of this study the impact of fire on 593 trees over a five-year period was evaluated. The majority (254, (43%)) of the trees in the study plots were Douglas-fir. Table 1 shows the number (percent) and status of study trees by species five years postfire. Table 2 shows the descriptive statistics for the variables analyzed for the six tree species studied. Some of the tree species evaluated contained too few trees (sample size too small) to accurately evaluate fire impacts.

Table 1. Species, number (%) and status of trees evaluated for the impact of wildfire five years after the 1994 Payette NF fire complex.

Species	Count	Live (%)	Fire killed(%)	Beetle killed (%)
Douglas-fir (*Pseudotsuga menziesii*)	254	154 (61%)	33 (13%)	67 (26%)
Grand fir (*Abies grandis*)	117	61 (52%)	29 (25%)	27 (23%)
Lodgepole pine (*Pinus contorta*)	83	37 (44.5%)	37 (44.5%)	9 (11%)
Ponderosa pine (*Pinus ponderosa*)	44	35 (80%)	4 (9%)	5 (11%)
Engelmann spruce (*Picea engenmannii*)	44	11 (25%)	26 (59%)	7 (16%)
Subalpine fir (*Abies bifolia*)	41	12 (29%)	29 (71%)	-

Douglas-fir

Sixty-one percent of the Douglas-fir trees were living five years after wildfire, 13% of the trees died because of fire and 26% because of Douglas-fir beetle (*Dendroctonus pseudotsugae*).

Figure 1. Douglas-fir survivorship five years after wildfire.

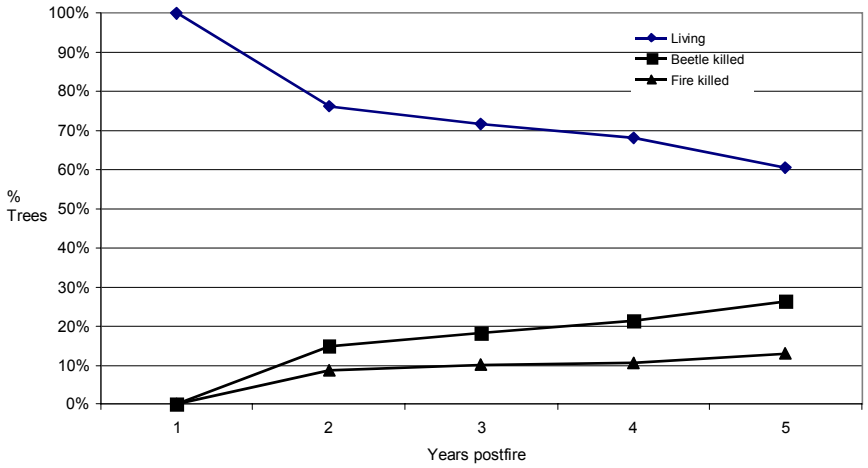


Figure 1 shows the cumulative Douglas-fir mortality over the course of the five-year study. Mortality directly related to fire was observed by the end of the second postfire year, beetle attributed mortality continued for 5 years after fire. We could detect no significant ($P \leq 0.05$) impact of dbh on the survival of trees as a direct result of fire (Figs. 2 & 3). Larger diameter trees have thicker bark and are reported to better withstand fire (Martin 1963, Hare 1965), however these larger diameter trees also tend to be the preferred host of Douglas-fir bark beetles. Weatherby et al (1994) noted that the average dbh of trees surviving the Lowman fire of 1989 was 19.33 inches, and those dying from fire and beetles were 14.14 and 20.20 inches, respectively. In the Greater Yellowstone fires, Amman and Ryan (1991) found that dead trees were not significantly smaller than live trees suggesting that root charring near the soil surface may contribute to higher than expected mortality. They also noted that insect attack appeared to be responsible for part of the additional mortality. Two years following the Greater Yellowstone fires of 1988 Amman and Ryan (1991) found that nearly 70% of the Douglas-fir trees on their plots were infested by beetles. Nominal logistic regression (Fig. 4) indicates the probability of a Douglas-fir tree dying from fire declines, but beetle mortality increases with increasing tree diameter.

Table 2. Species, status and descriptive statistics of sample trees five years after the 1994 wildfires on the Payette National Forest

Species	Parameter	Status	Mean	Count	Std. Err.	Std. dev.	Min.	Max.	Range
Douglas-fir	DBH	Live	15.2	154	0.4	5.3	5.9	28.3	22.4
		Beetle	22.3	67	0.9	7.1	8.9	40.4	31.5
		Fire	14	33	0.8	4.6	7.4	24.7	17.3
	%Scorch	Live	11	154	1.8	21.9	0	90	90
		Beetle	35.7	67	4.1	33.9	0	90	90
		Fire	49.4	33	6.9	39.8	0	90	90
	%Char	Live	26.1	154	1.7	21.6	0	87.5	87.5
		Beetle	35.3	67	3.3	27.6	0	87.5	87.5
		Fire	61.7	33	5.0	28.6	0	100	100
Grand fir	DBH	Live	16.9	61	0.7	5.9	5.5	26.6	21.1
		Beetle	16	27	0.9	4.6	7.6	24	16.4
		Fire	16.7	29	0.7	5.9	5.5	26.6	21.1
	%Scorch	Live	6.0	61	1.6	12.4	0	80	80
		Beetle	9.3	27	3.1	16.4	0	60	60
		Fire	21.0	29	5.3	28.3	0	90	90
	%Char	Live	30.3	61	2.5	19.8	0	75	75
		Beetle	50	27	3.8	19.9	12.5	87.5	75
		Fire	73.3	29	4.2	22.8	0.25	100	75
Lodgepole pine	DBH	Live	13.7	37	0.4	2.8	7.9	20.7	12.8
		Beetle	16.0	9	1.23	3.7	11.8	22.2	10.4
		Fire	13.7	37	0.7	4.1	5.7	23.6	17.9
	%Scorch	Live	1.6	37	0.7	4.4	0	20	20
		Beetle	16.7	9	9.0	26.9	0	70	70
		Fire	21.6	37	5.1	31.3	0	90	90
	%Char	Live	34.1	37	3.4	21	0	100	100
		Beetle	54.1	9	8.3	25.0	12.5	87.5	75
		Fire	57.4	37	4.2	25.6	12.5	100	87.5
Ponderosa pine	DBH	Live	24.5	35	1.4	8.4	9.7	41.8	32.1
		Beetle	33.9	5	4.6	10.3	18.2	45.8	27.6
		Fire	20.7	4	8.6	17.3	5.4	41.3	36
	%Scorch	Live	11.4	35	3.69	21.84	0	80	80
		Beetle	22	5	15	3.5	0	80	80
		Fire	55	4	19.4	38.7	0	90	90
	%Char	Live	14.6	35	3	18	0	75	75
		Beetle	20	5	15.5	32	0	75	75
		Fire	65.6	4	17	34.4	25	100	75
Engelmann spruce	DBH	Live	11.8	11	1.0	3.3	5.5	17.2	11.7
		Beetle	10.1	7	1.2	3.3	5.3	15	9.7
		Fire	12.0	26	0.8	4.1	6	21.7	15.7
	%Scorch	Live	4.5	11	2.5	8.2	0	20	20
		Beetle	0	7	0	0	0	0	0
		Fire	0.5	26	0.05	13.9	37.5	75	37.5
	%Char	Live	36.3	11	7.2	24.0	0	87.5	87.5
		Beetle	53.6	7	5.2	13.9	37.5	75	37.5
		Fire	69.2	26	5.1	26.0	12.5	100	87.5
Subalpine fir	DBH	Live	7.9	12	0.4	1.6	5.4	10.5	5.1
		Fire	9.4	29	0.5	2.9	5.3	16	10.7
	%Scorch	Live	7.5	12	2.8	9.6	0	30	30
		Fire	42.7	29	6.3	33.8	0	100	100
	%Char	Live	26	12	4.2	14.5	0	50	50
		Fire	62	29	5.2	28.0	12.5	100	87.5

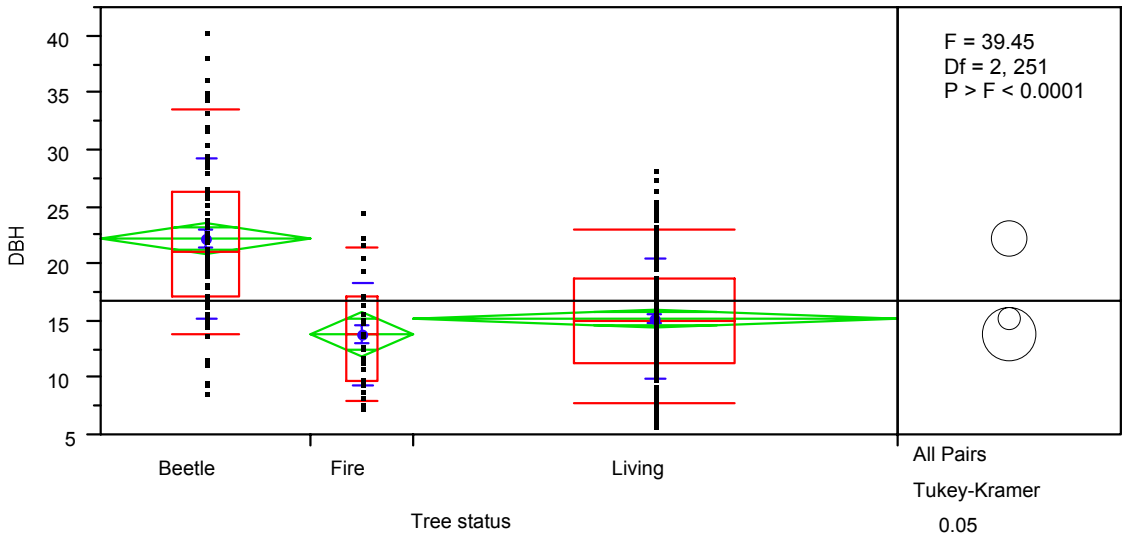
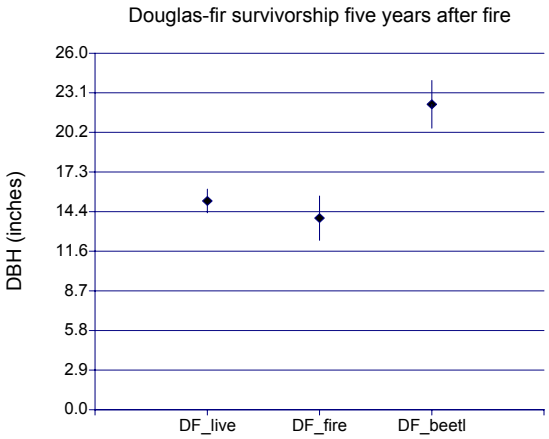


Figure 2. Comparison of Douglas-fir dbh among survival categories shows that tree diameter was significantly higher among trees killed by beetles. (Circles that overlap indicate non-significant differences (P ≤ 0.05) among means in the diagram to the right).

Figure 3. Average dbh ±2SE for each survival category of Douglas-fir.



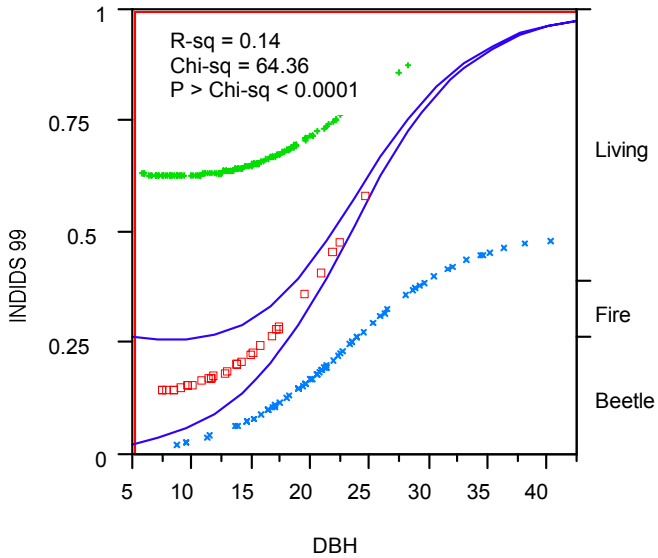


Figure 4. Nominal logistic regression plot of Douglas-fir dbh by tree survival category. Probability of occurrence is on the Y-axis, dbh (inches) is on the X-axis.

However, the probability of beetle attack increased with dbh (Fig. 4). The probability of occurrence (Y) at a specified X-value is the distance from the X-axis to the first curved line for beetle caused mortality, between the two sigmoid lines for fire caused mortality, and from the upper sigmoid line to the top of the figure for surviving trees. For example at a dbh of 15 there was approx. a 16%

probability of the tree dying from beetle attack, 13% from fire related causes and 61% of surviving after five years. Discriminant analysis (Fig. 2) indicates that beetles cause significant mortality of fire-injured trees. Large trees that survived fire were in a weakened condition and more susceptible to attack by beetles. In some burned over forests, trees that are likely to be attacked by bark beetles would normally recover from fire damage (Miller and Patterson 1927, Furniss 1965). Furniss (1965) reported that the incidence of Douglas-fir beetle attacks increased with the degree of crown and cambial injury, but abruptly declined in completely defoliated trees. Beetle brood survival is reduced in fire-damaged stands, when compared to unburned areas because of pitch invasion and sour sap (Miller and Patterson 1927, Furniss 1965). There is some contradiction in the literature regarding the capacity of beetle populations to build in fire injured trees to levels that may overcome the defenses of uninjured green trees. Some authors note that most fires do not contribute to large bark beetle outbreaks (Miller and Keen 1960, Furniss 1965). Elevated levels of beetle caused mortality have been observed within a 2-3 year period following fire but were confined to damaged trees (Miller and Patterson 1927). Other authors have found that populations have increased in the fire-injured trees and spread to uninjured trees (Bedard 1950, Amman and Ryan 1991, Pasek 1991). Our data indicate that beetle attacks were still occurring in our plots 5 years after fire (Fig. 1).

Crown scorch has been considered a primary factor in causing fire-attributed tree mortality. In this study, the average crown scorch of surviving Douglas-fir five years postfire was 11%, those killed directly by fire or subsequently by beetles experienced 49.4% and 35.7% crown scorch, respectively. Figure 5 shows that crown scorch ranged from 0-90% for all three categories of tree survival. There were few beetle attacks of trees that received more than 60% crown scorch. Figure 6 shows the distribution of the means among the tree survival categories. We found no significant difference in the amount of crown scorch between beetle and fire killed trees, however those trees living after five years had significantly less crown scorch than fire/beetle killed trees (Figs. 5 & 6).

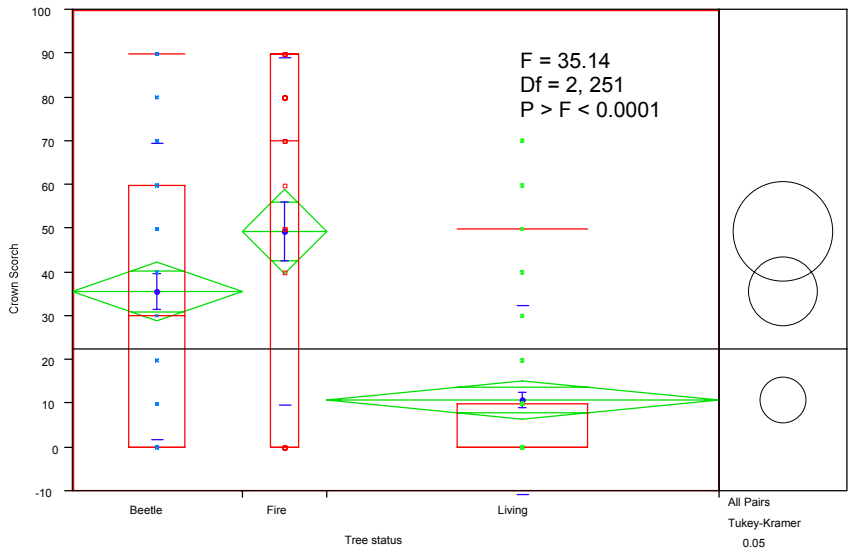


Figure 5. Comparison of % crown scorch among Douglas-fir survival categories shows that scorch has a significant impact on tree survival. Trees in the living category had significantly less scorch than beetle or fire killed trees (P ≤0.05).

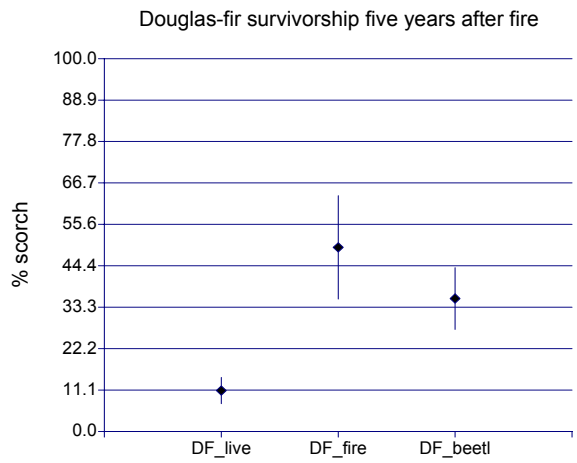


Figure 6. Average Douglas-fir % scorch ±2SE for each survival category.

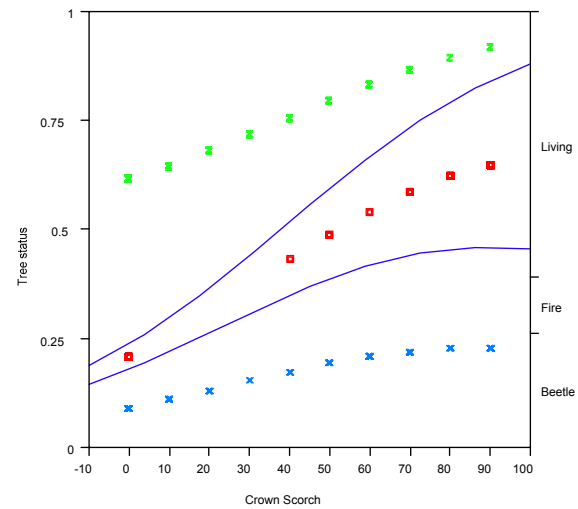


Figure 7. Plot of nominal logistic regression of Douglas-fir crown scorch by survival category shows that the probability of survival decreases with increasing scorch (top series).

Weatherby et al. (1994) found that the average crown scorch of Douglas-fir trees surviving the 1989 Lowman fire was 20%, and those killed by fire and beetle attack 74% and 39%, respectively. Ryan et al. (1988) found that the average crown scorch was 39% for dead trees. They also noted that percent crown scorch varied considerably, 0-80% for living trees and 0-100% for dead trees. Ryan et al. (1996) found that beetles preferred trees with less than 75% crown scorch. Although scorch is an easily measured parameter in assessing fire related tree survival, other less discrete factors exert considerable influence over the probability of tree mortality.

Bole and root char also exerted a significant impact on survival of Douglas-fir (Figs. 7 & 8). The average char sustained by trees surviving fire was 26.1% and ranged from 0-87.5%. Our data correspond to studies by Wagener (1961) and Ryan et al. (1988) who stated that trees sustaining cambial fire damage of more than a single quadrant were unlikely to survive. The average char sustained by beetle killed trees was 35.3% (range 0-87.5%) and by fire-killed trees 73.3% (range 0-100%). Ryan et al. (1996) noted that Douglas-fir beetle preferred trees

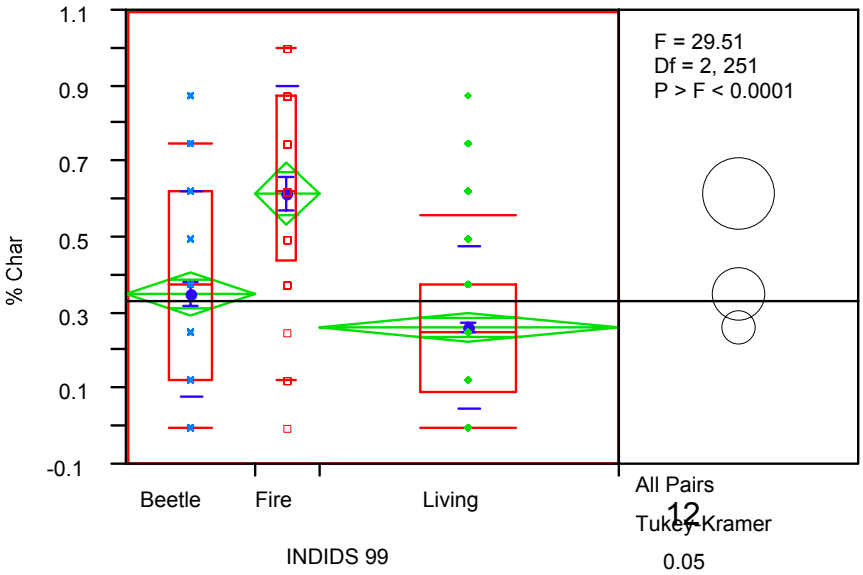
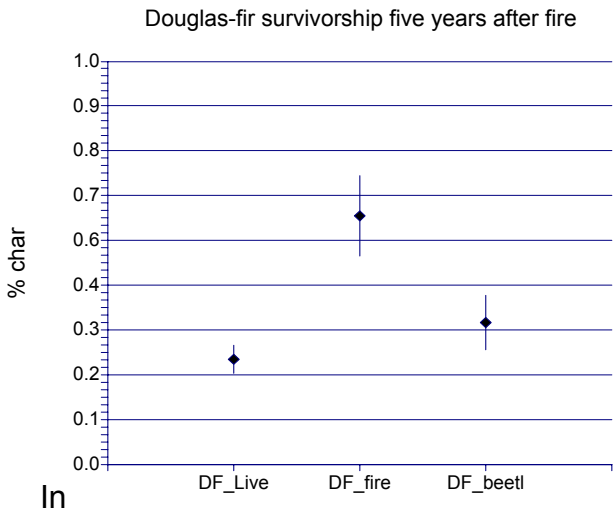


Figure 8. Comparison of percent char of Douglas-fir show significant greater char of fire killed trees (non-overlap among the circles at right indicates significance (P ≤ 0.05)).

with more than 50% basal girdling. We did not find a strong relationship between char and beetle attack (Fig. 10). Our data suggests a relationship of increasing/declining beetle attack corresponding to increasing bole char as described by Furniss (1965).

Figure 9. Average % char ±2SE of Douglas-fir for each survival category.



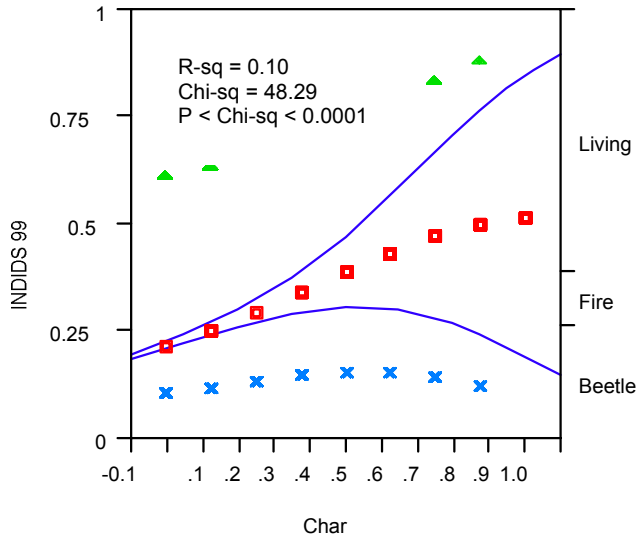


Figure 10. Plot of nominal logistic regression of Douglas-fir bole/root char by survival category shows that the probability of survival decreases with increasing char (top series).

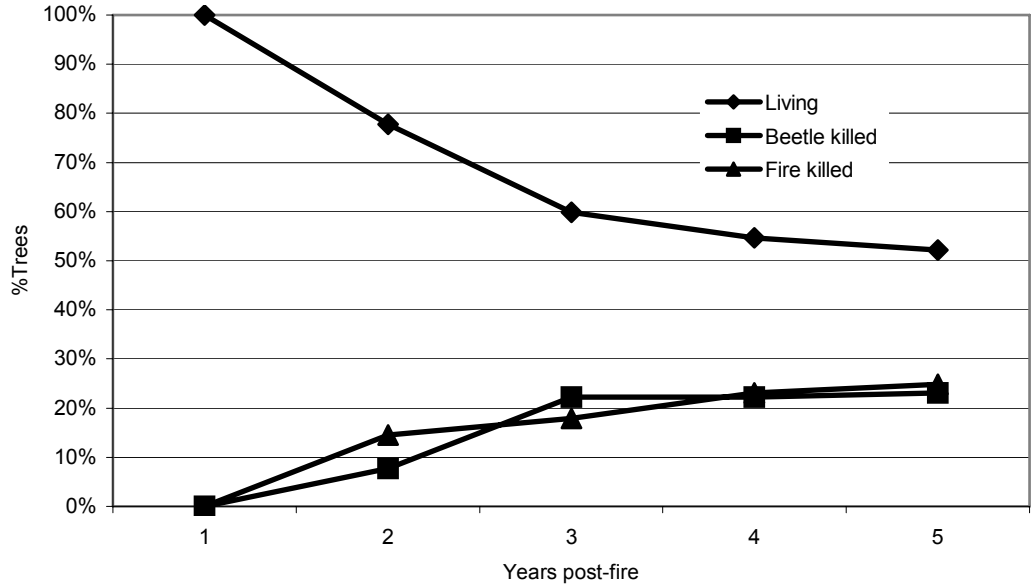
In 1994, Weatherby et al. found that the model developed by Reinhardt and Ryan (1988) based on bark thickness and percent crown scorch accurately classified trees as alive or dead following fire 83% of the time. Applying the current data set to the model indicated that 6% (9) of the trees that survived were predicted to die. An additional 71 trees (28% of total) that died were expected to survive the fire based on the model. Of these, 56 (22% of total) were killed by bark beetles and 15 (6% of total) by fire. Those trees killed by beetles after the fire represent a large portion (22%) of the misclassification.

Grand fir

Five years after wildfire, 52% of the 117 grand fir trees in our study were living, 25% were killed by fire and 23% were killed by bark beetles (*Scolytus ventralis*). Figure 11 shows the cumulative mortality of grand fir over the course of the five-year study. Beetle attributed mortality was as severe as direct fire-related tree death.

Table 2 shows the descriptive statistics for the three conditions of mortality evaluated in this study. Univariate discriminate analysis showed no significant ($P \leq 0.05$) impact of dbh on grand fir survival (Fig. 12).

Figure 11. Grand fir survivorship five years after fire.



There has been little fire related research conducted in grand fir stands, however, the morphological characteristics of grand fir are similar to those of white fir (*Abies concolor*) which has moderate fire resistance with fire resistance increasing with increasing age (Flanaghan 1996). Burns and Honkala (1990) note that grand fir fire resistance may be based largely on habitat. On moister sites it is easily killed by ground fires. On drier sites, deeper root systems and thicker bark increase resistance to fire. We found that dbh had no observable effect on the susceptibility of grand fir to fire related mortality (Fig. 12).

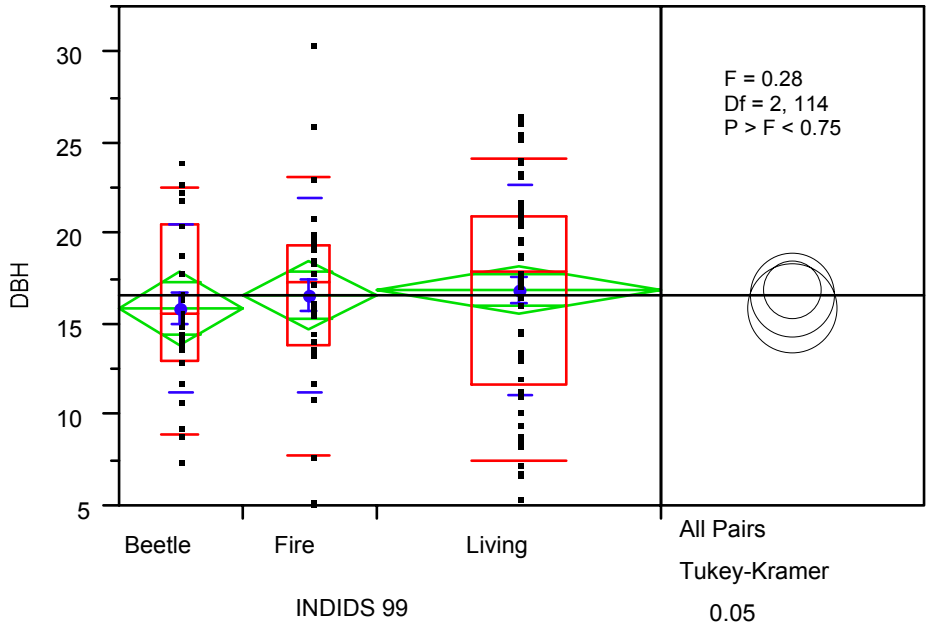


Figure 12. Comparison of dbh among grand fir survival categories shows no significant differences among tree survival categories. (Overlapping circles in the figure at right indicate non-significant differences ($P \leq 0.05$)).

Crown scorch (Figs 13 & 14) averaged 6% (range 0-80%) in those trees surviving fire, 9.3% (range 0-60%) in trees attacked and killed by beetles and 21% (range 0-90%) in those trees killed directly by fire. The relatively weak relationship of crown scorch in grand fir to tree mortality is shown in figure 15. Note the association of scorch with beetle attack is minimal as indicated by the near horizontal aspect of the lower series corresponding to beetle mortality.

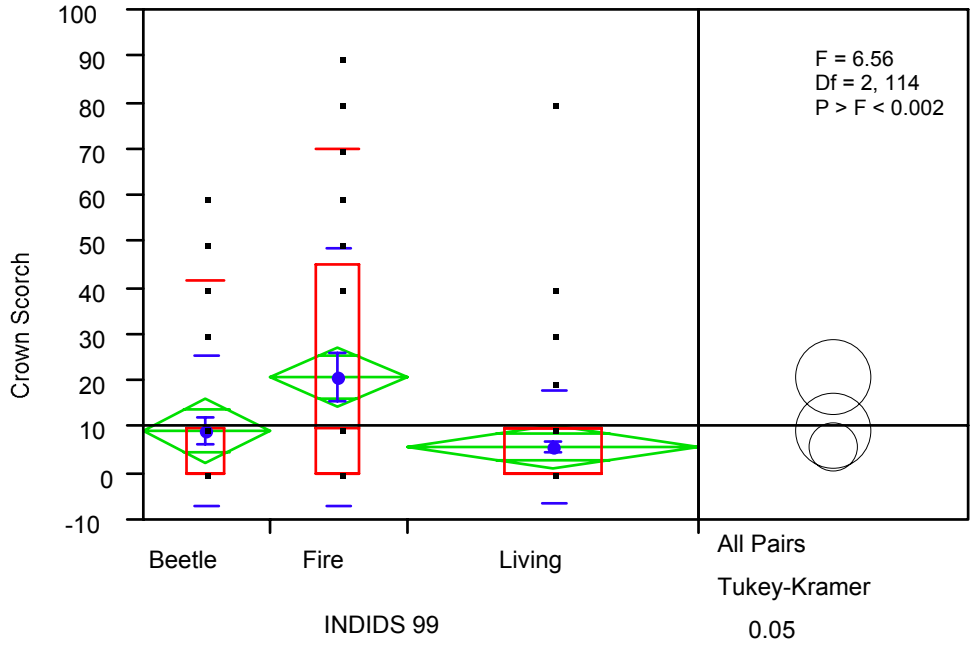
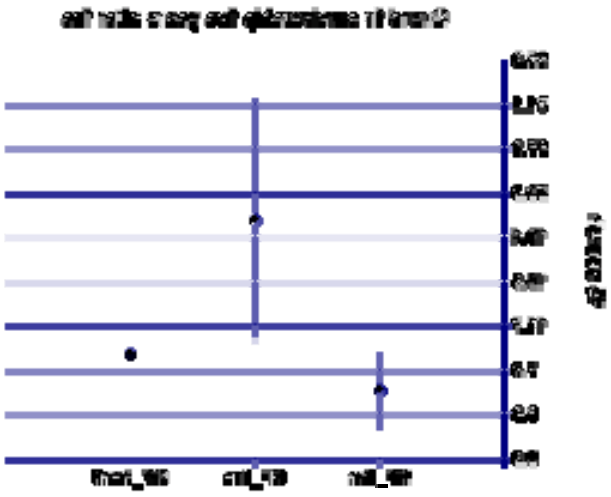


Figure 13. Comparisons of grand fir crown scorch show significantly lower scorch in living trees than those killed by fire. (Overlapping circles in the figure at right indicate non-significant differences (P ≤ 0.05)).

Figure 14. Average % crown scorch ±2SE for each grand fir survival category.



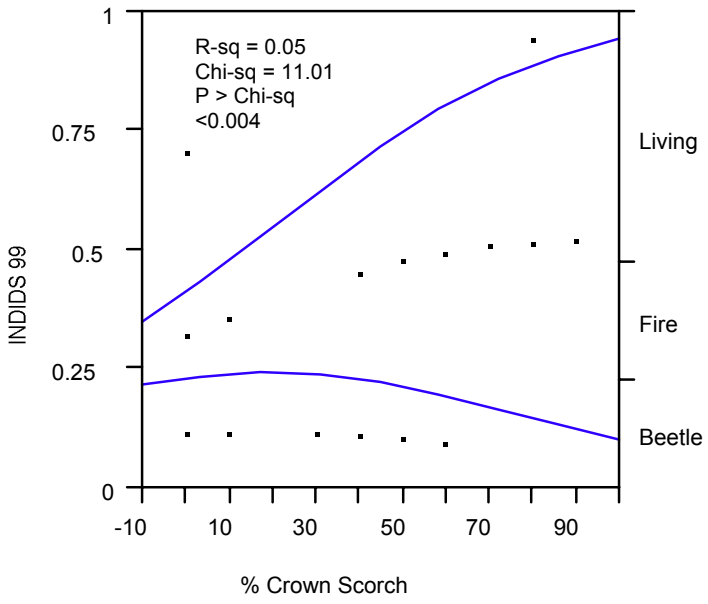


Figure 15. Plot of nominal logistic regression of grand fir crown scorch among survival categories shows that the probability of survival decreases with increasing scorch (top series).

Grand fir bole and root char, unlike crown scorch, showed a strong relationship with tree survival. Figure 16 indicates bole and root char significantly increased grand fir mortality and influenced susceptibility to beetle attack. The variability of char among survival categories (figs. 16 & 17) was lower than values observed for dbh or scorch, indicating that char is an improved parameter for evaluating fire related mortality of grand fir over dbh or crown scorch. Figure 18 shows the strong relationship of char with tree survival. The relationship of char with beetle attack is shown in the lower series.

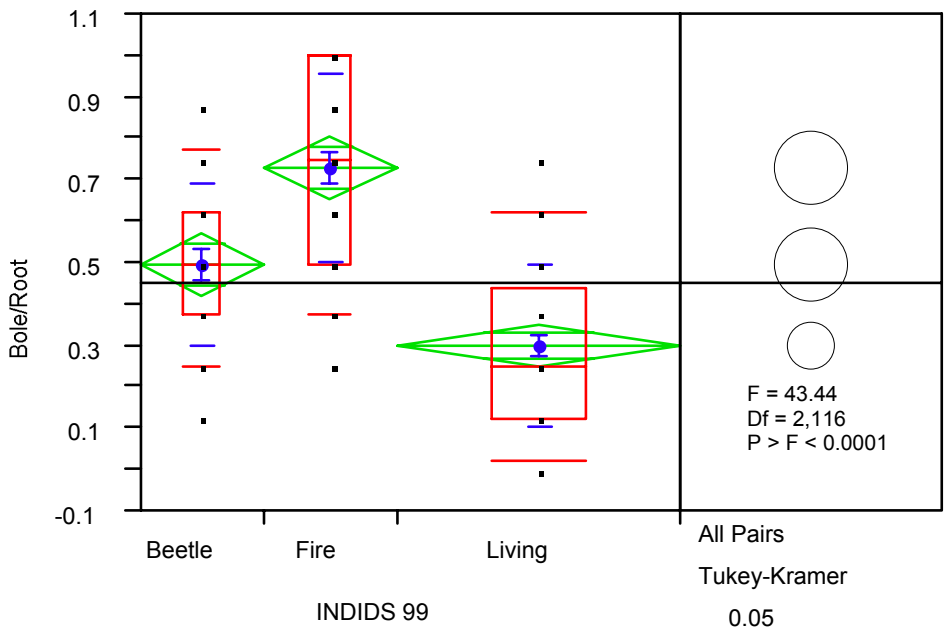
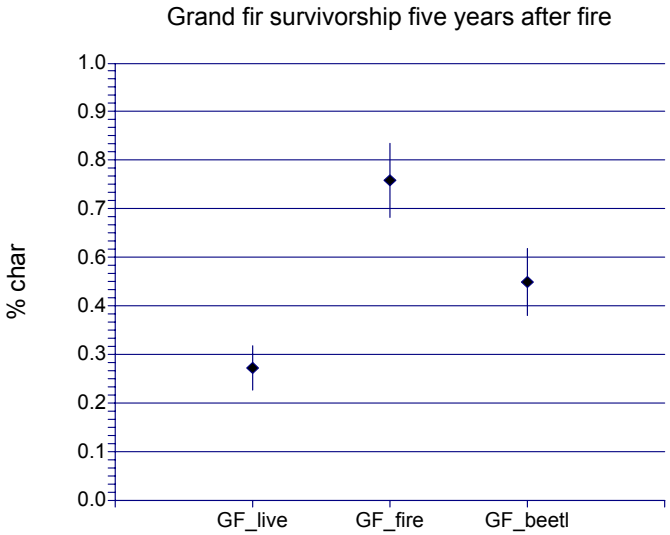


Figure 16. Comparison of grand fir bole/root char shows significant differences between the three survival categories. (Non- overlapping circles in the figure at right indicate significant differences among the groups (P ≤ 0.05)).

Figure 17. Average % bole/root char ±2SE for each grand fir survival category.



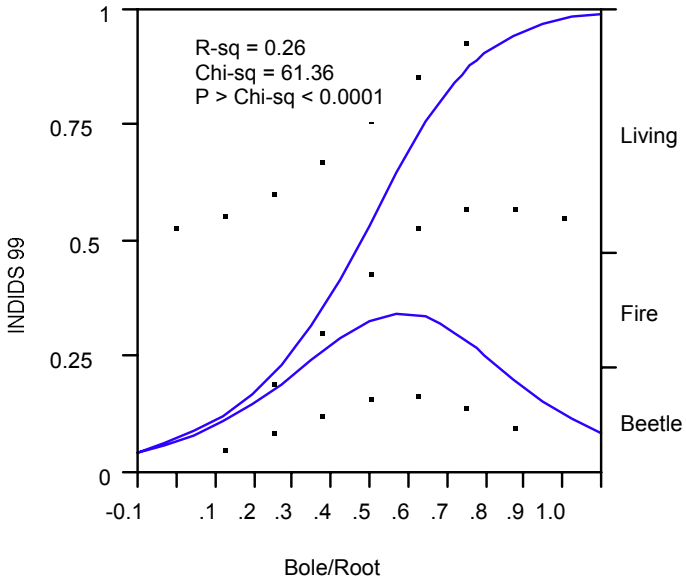


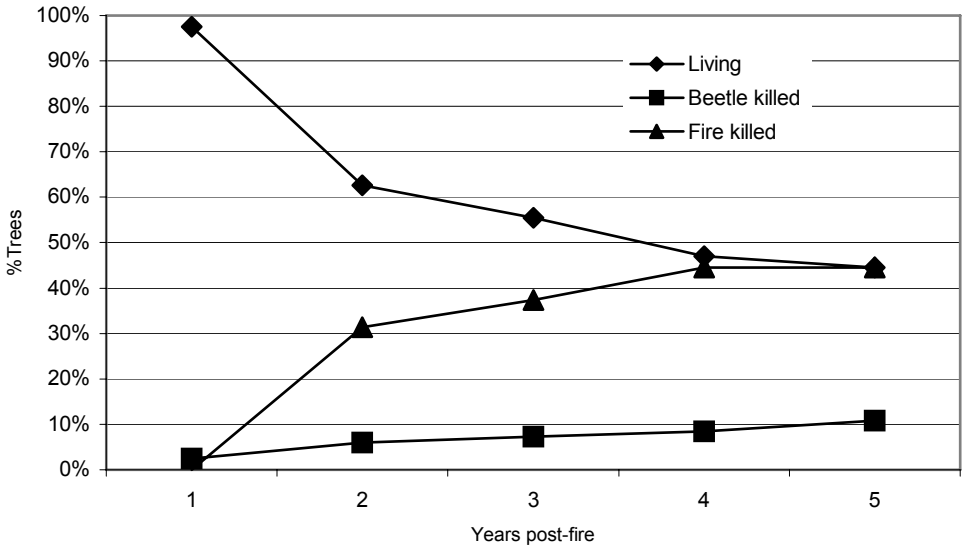
Figure 18. Plot of nominal logistic regression of grand fir bole/root char among survival categories shows that the probability of survival decreases with increasing char (top series).

The hump-shaped distribution (Fig. 18) of the lower series corresponding to beetle mortality is stronger than the response observed in Douglas-fir. The probability of beetle attack increases with % char and exhibits a corresponding decline at higher percentages of char. The middle series indicates that char related mortality occurs above 25% and increases dramatically above 50%.

Lodgepole pine

There were 83 lodgepole pine trees sampled in our study. Lodgepole is considered to have low resistance to fire because of its thin bark (Flanagan 1996). The cycle of lodgepole stand replacement by beetle caused mortality, followed by fire and regeneration from serotinous cones has been well established (Stuart et al. 1989). In this study, 44.5% (37) of the trees were living five years after fire, 44.5% (37) were killed as a result of fire and 11% (9) were killed by mountain pine beetles (MPB) (*Dendroctonus ponderosae*). Figure 20 shows the cumulative mortality of trees over the course of the five-year study. Ryan and Amman (1996) found in their study that 61% of 151 lodgepole pines were attacked and killed by insects.

Figure 19. Cumulative lodgepole pine survivorship five years after fire.



Mountain pine beetle is not strongly attracted to fire-damaged lodgepole pine (Amman and Ryan 1991, Ryan and Amman 1996). It was suggested that most of the trees killed by insects were more than 75% girdled by fire and primarily infested by pine engraver (*Ips* spp.) (Amman and Ryan 1991, Ryan and Amman 1996).

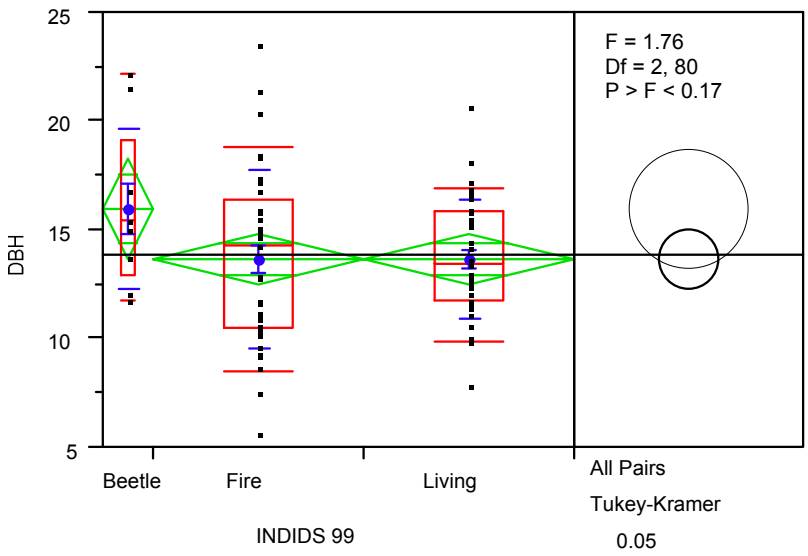


Figure 20. Comparison of lodgepole pine dbh shows no significant differences between the three survival categories. (Non-overlapping circles in the figure at right indicate significant differences among the groups (P ≤ 0.05)).

The average dbh of trees surviving fire was 13.7 inches. Those trees killed by fire had an average dbh of 13.7 inches and those killed by beetles were 16 inches in diameter. Figure 20 shows the average dbh did not significantly differ among tree survival categories. We found no relationship between the diameter of lodgepole pine and tree survival.

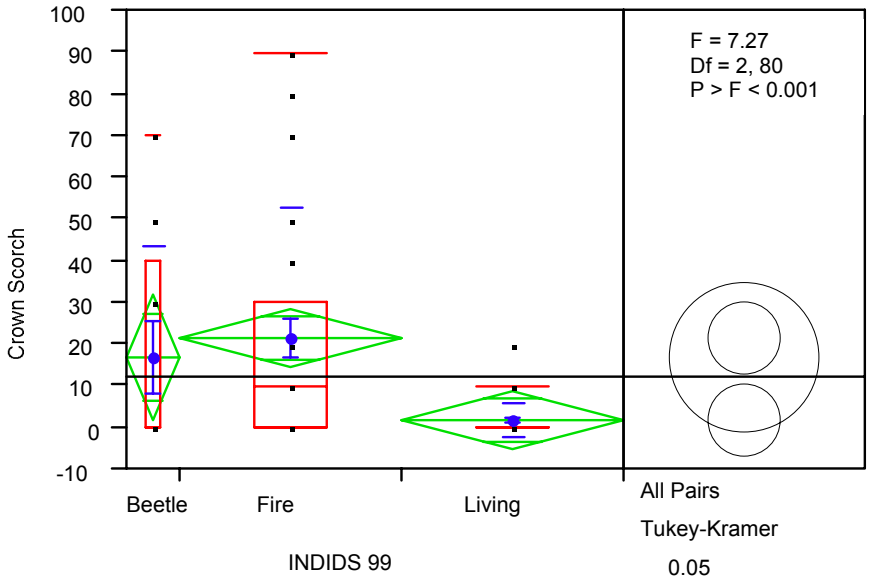


Figure 21. Comparison of crown scorch of lodgepole pine shows fire killed trees had significantly higher scorch than living trees. (Non-overlapping circles in the figure at right indicate significant differences among the groups (P ≤ 0.05)).

As expected, crown scorch was significantly higher (P ≤ 0.05) in fire-killed trees than in trees living after five years (Figure 21).

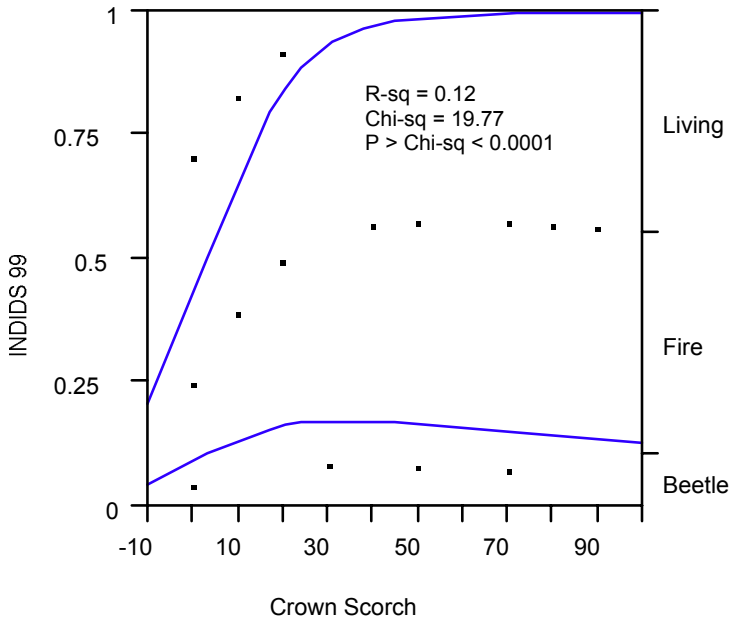


Figure 22. Plot of nominal logistic regression of lodgepole pine crown scorch among survival categories shows that the probability of survival dramatically decreases above 25% scorch (top series). Probability of occurrence is on the Y-axis, degree of scorch is on the X-axis.

We found lodgepole pine to be extremely intolerant of crown scorch, exhibiting a sharp decline in survival with increasing scorch (Fig 22). Our data correspond to the findings of Ryan and Amman (1996) who noted that surviving trees sustained less than 25% crown scorch.

Root and bole char also had a significant (P ≤ 0.05) impact on lodgepole survival (Fig. 23). As would be expected, living trees exhibited significantly less bole and root char than those killed by fire.

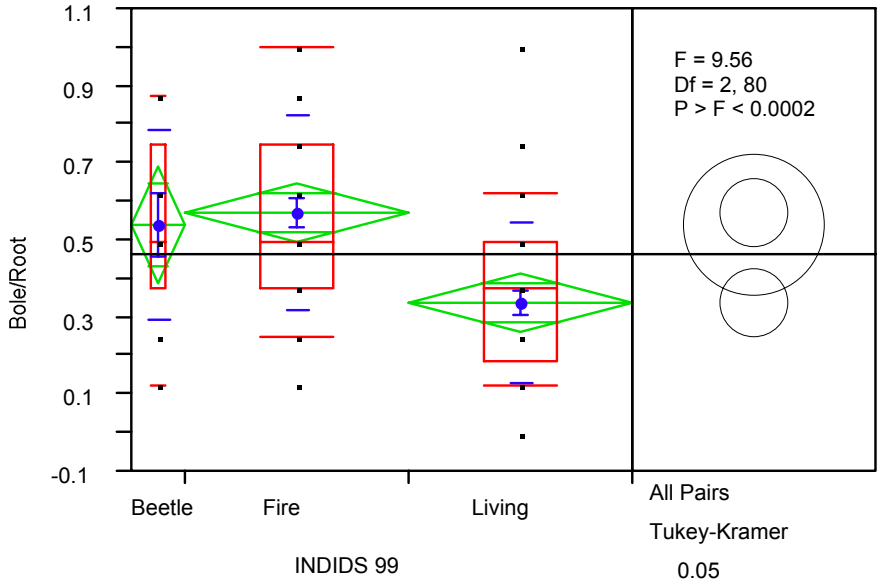


Figure 23. Comparison of bole and root char of lodgepole pine shows fire killed trees had significantly higher char than living trees. (Non-overlapping circles in the figure at right indicate significant differences among the groups (P ≤ 0.05)).

Figure 24 indicates that in our study char had a marginal effect on beetle attack as shown by the lower series, however char strongly affected tree survival as shown in the upper two series.

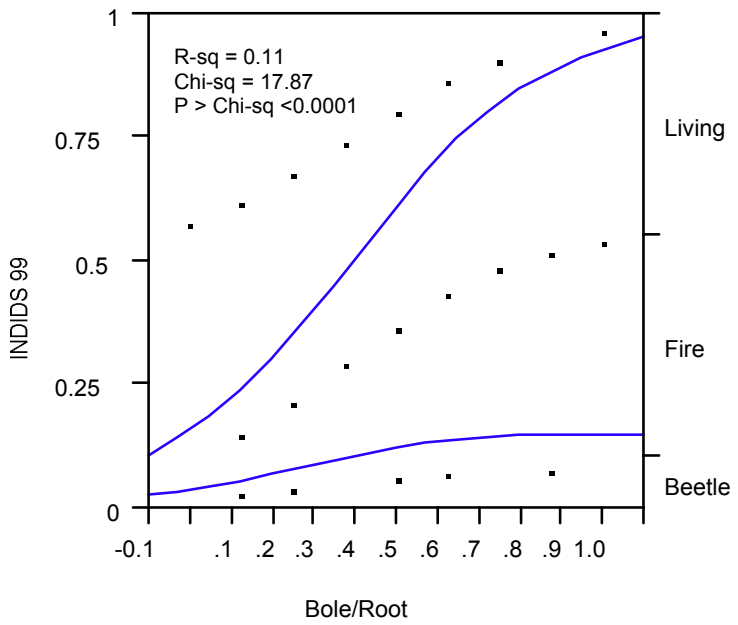


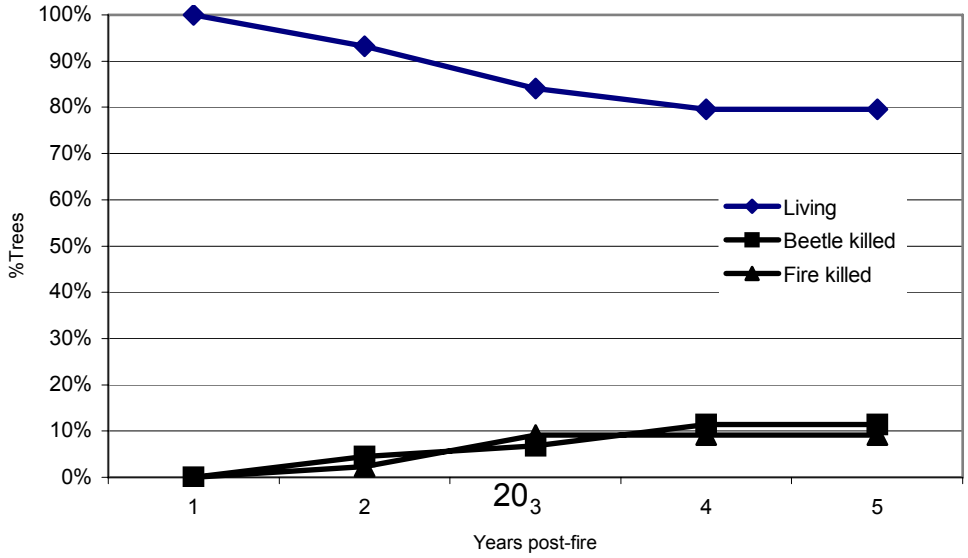
Figure 24. Plot of nominal logistic regression of lodgepole pine bole and root char among survival categories shows a nearly linear relationship of mortality increasing with increasing char (middle series). Probability of occurrence is on the Y-axis, degree of char is on the X-axis.

Ryan and Amman (1996) found that the average basal girdling of living trees was 56%. We found bole/root char girdled an average of 34% of the trunk in living trees and 57% in trees killed by fire.

Ponderosa pine

Fire impacts were evaluated on 44 ponderosa pine trees. Five years after wildfire, 80% (35) were living, 9% (4) were killed by fire and 11% (5) by bark beetles (*Dendroctonous brevicomis*). Figure 25 shows the cumulative mortality of ponderosa pine during the five-year study. Ponderosa pine exhibited the highest percent survival rate of all tree species in our study. The primary cause of fire-induced mortality in ponderosa pine is crown scorch (Dieterich 1979). Mann and Gunter (1960) state that cambial injury is significant when all four quadrants are injured in a tree with greater than 50% crown scorch. Wagener (1961) stated that fire has a greater impact on tree survival when occurring early in the season. The Payette fire complex occurred late in the season from July through September 1994. Wagner (1961) noted that trees may survive complete crown scorch if fully formed buds and twigs were not extensively damaged.

Figure 25. Ponderosa pine survival five years after fire.



The average dbh of ponderosa pine surviving fire was 24.5 inches, those killed directly by fire were 20.7 inches and trees killed by beetles 34 inches (Table 2, Fig 26). The lack of significant differences in dbh among the categories of

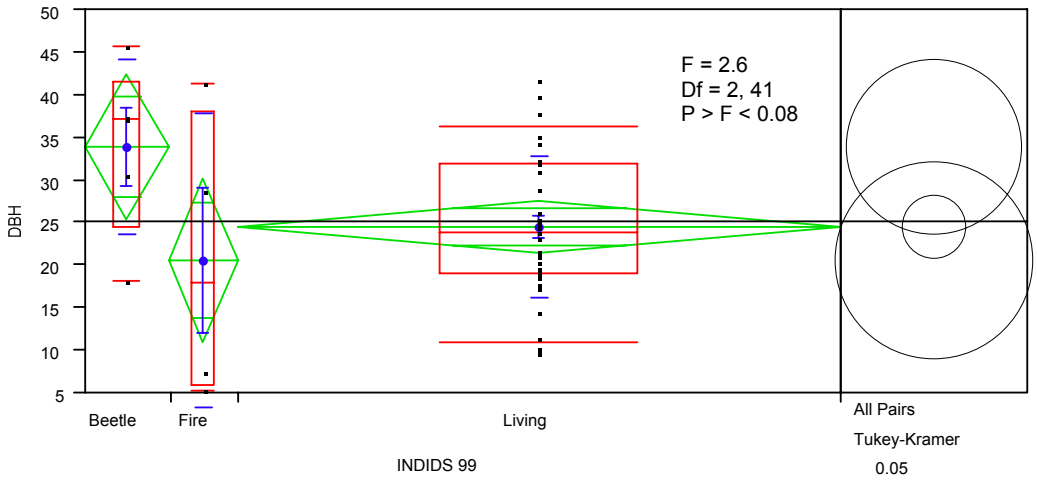


Figure 26. Comparison of dbh of ponderosa pine among categories of survival shows no significant difference. (Overlapping circles in the figure at right indicate non-significant differences among the groups (P ≤ 0.05)).

survival may be attributed to the small sample size. Figure 27 indicates a sharp decline in fire related mortality may occur with increasing dbh.

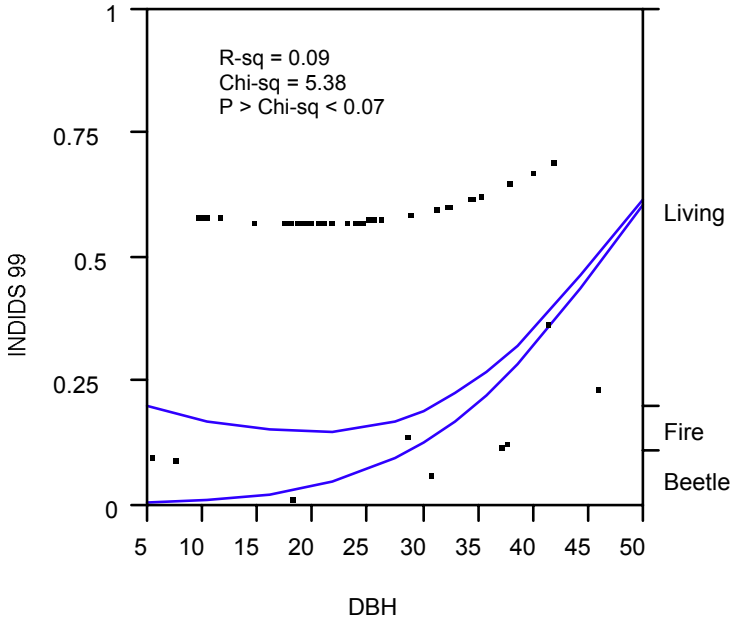


Figure 27. Nominal logistic regression of ponderosa pine dbh among survival categories indicate a sharp decline in mortality may occur with increasing dbh. Probability of occurrence is on the Y-axis, dbh is on the X-axis.

Significant differences (P ≤ 0.05) in the average percent of crown scorch were found between trees killed by fire and those surviving (Fig. 28). Fire killed ponderosa pine had an average crown scorch of 55%, those killed by beetles had 22% and those surviving wildfire had an average scorch of 11% (Table 2). These values are comparable to the percent scorch in fire-killed and surviving Douglas-fir. As noted earlier, Douglas-fir and ponderosa pine may exhibit similar

resistance to fire. Burns and Honkala (1990) note that survival is higher if less than 50% of the crown is scorched. Weatherby et al. (1994) showed that few ponderosa pines greater than 4 inches dbh were killed by fire if crown scorch was less than 80%.

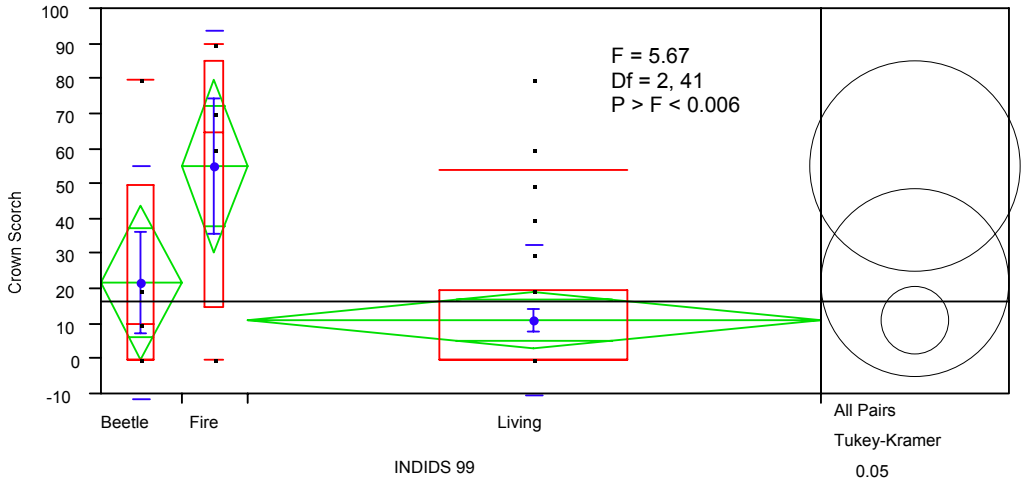


Figure 28. Comparison of crown scorch of ponderosa pine show significant differences between those surviving and those killed by fire. (Overlapping circles in the figure at right indicate non-significant differences among the groups (P ≤ 0.05)).

Figure 29 shows the probability of survival declining above 50% crown scorch.

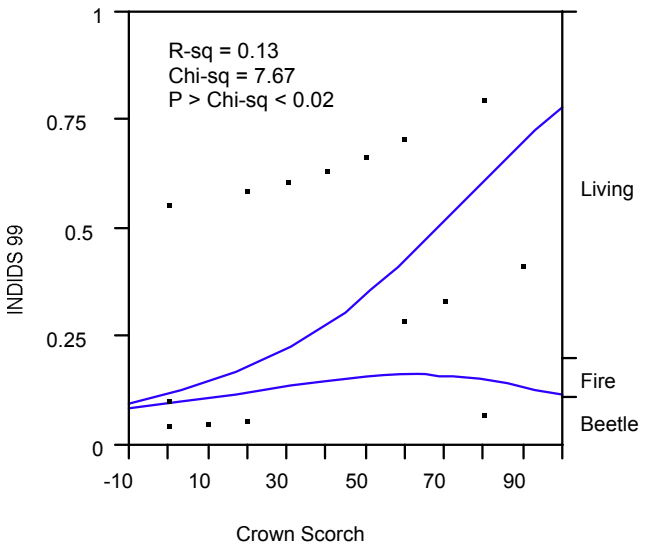


Figure 29. Plot of nominal logistic regression of ponderosa pine crown scorch among survival categories indicate the probability of mortality rapidly increasing above 50% scorch. Probability of occurrence is on the Y-axis, degree of scorch is on the X-axis.

As expected, trees surviving wildfire exhibited significantly less (P ≤ 0.05) bole/root char than those killed by fire (Fig. 30). The average char of surviving ponderosa pine was 14.6%, trees killed by fire averaged 65% char and those killed by beetles averaged 20% char. It is emphasized that the small sample size does not represent all ponderosa pine, other studies (Weatherby et al. 1994, Ryan and Amman 1996) indicated a higher fire tolerance of ponderosa pine than shown in this study.

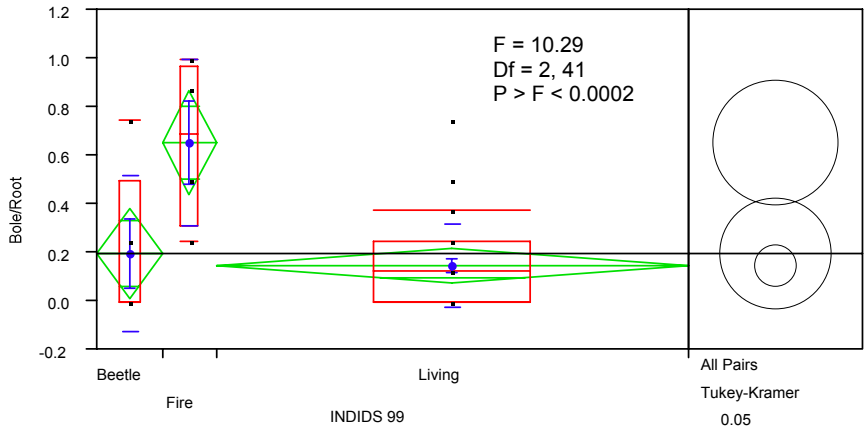
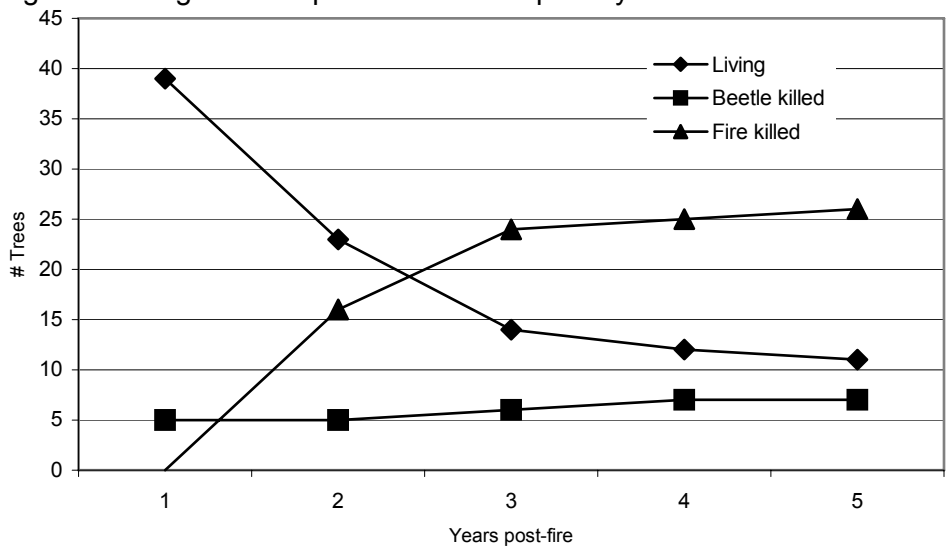


Figure 30. Comparison of bole/root char of ponderosa pine show significantly higher char in fire-killed trees. (Overlapping circles in the figure at right indicate non-significant differences among the groups (P ≤ 0.05)).

Engelmann spruce

There were forty-four Engelmann spruce trees in our study. Five years following wildfire, 25% were living, 59% were killed by fire and 16% were killed by spruce beetle (*Dendroctonous rufipennis*) (Table 1). Figure 31 shows the cumulative impacts of fire on trees in the plots over course of the five-year study. Fewer fire-effects studies have been done in Engelmann spruce stands than most other

Figure 31. Engelmann spruce survivorship five years after fire.



species. Amman and Ryan (1991) found that 83% of the 17 trees in their study were killed by fire or beetles. Rasmussen et al. (1996) found 31.9% of 439 Engelmann spruce trees in the Greater Yellowstone fires were killed by fire related injury and 6.6% by insects (half of these were spruce beetle).

Our data support the conclusions of Ryan and Amman (1994) who noted that mortality did not vary with tree diameter. Diameter at breast height did not affect tree survival as shown in Figure 32. The average dbh of surviving spruce trees

in our study was 11.8 inches, those killed by beetles were 10.1 inches and trees killed by fire averaged 12.0 inches.

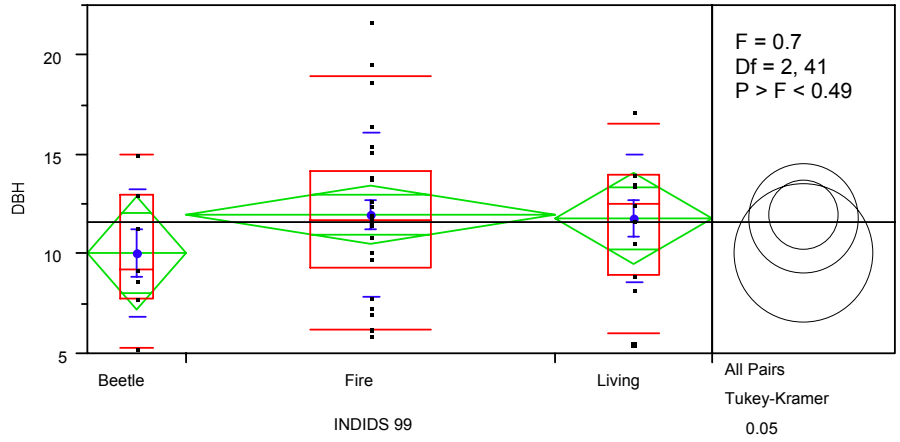


Figure 32. Comparison of dbh of Engelmann spruce shows no significant effect on tree survival. (Overlapping circles in the figure at right indicate non-significant differences among groups (P ≤ 0.05)).

There was little crown scorch observed among the spruce trees in this study. Four trees had 10% crown scorch, 2 trees had 20% and 1 tree had 70%.

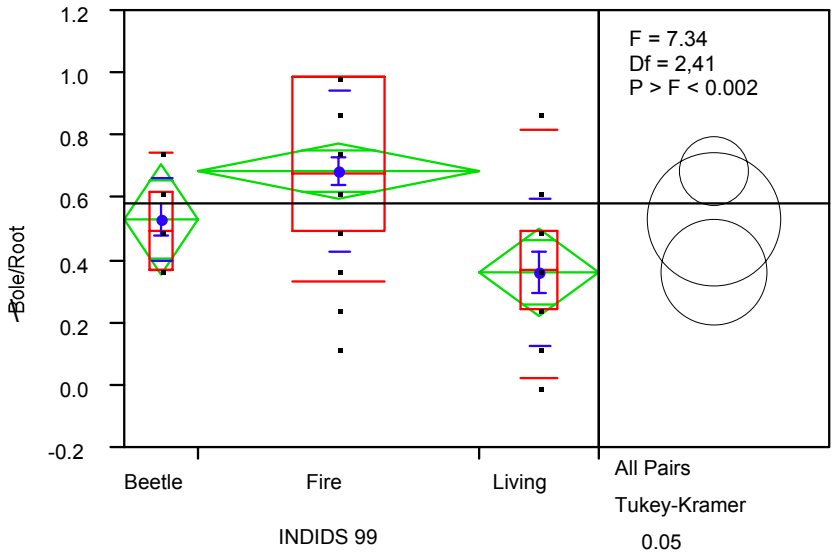


Figure 33. Comparison of bole/root char of Engelmann spruce among shows significant differences between those surviving and those killed by fire. (Overlapping circles in the figure at right indicate non-significant differences among the groups (P ≤ 0.05)).

Bole and root char were the primary impacts of fire on spruce trees. Trees surviving fire had significantly less char than those killed by fire (Fig. 33). The average bole/root char of Engelmann spruce surviving fire was 36.3%, those trees killed by beetles had 53.6% char, and fire-killed trees had 69.2 % char. Since spruce is a thin barked species and sensitive to fire, the probability of char related mortality showed a sharp increase with increasing char (Fig. 34). At 50% char the probability of mortality is greater than 50%.

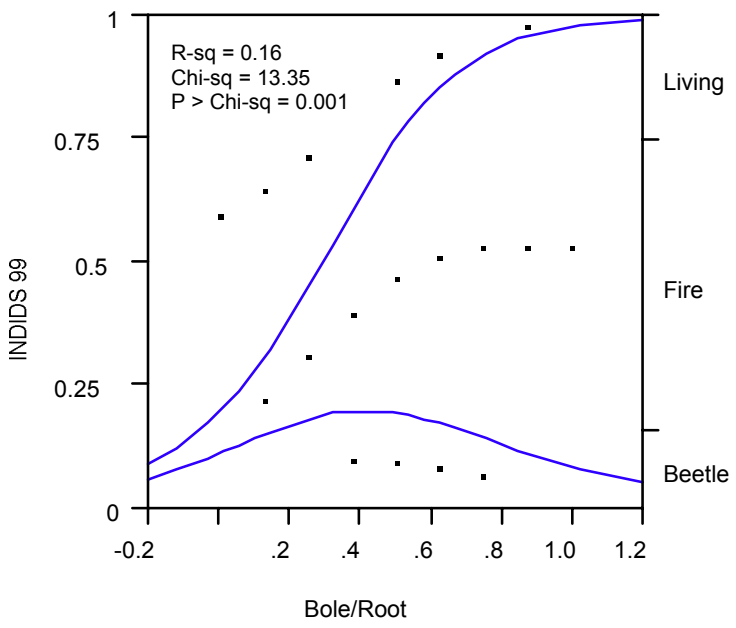
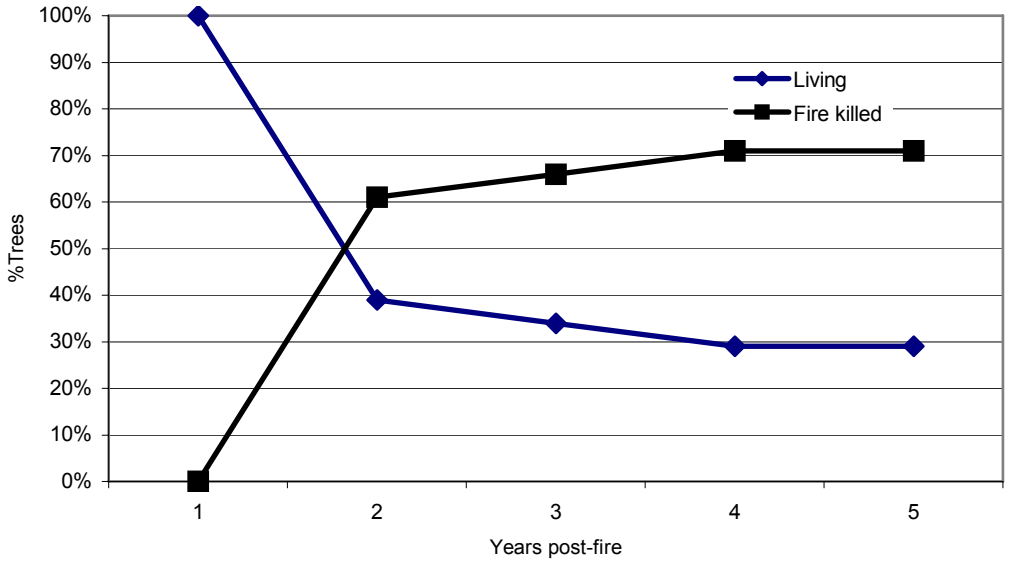


Figure 34. Plot of nominal logistic regression of Engelmann spruce bole/root char among survival groups. Probability of occurrence is on the Y-axis, degree of char is on the X-axis.

Subalpine fir

Subalpine fir are noted for their lack of fire resistance because of their thin bark (Ryan and Amman 1994). Fire vigorous enough to scorch the bark will kill the cambium. Twenty-nine percent of the subalpine fir were alive following fire in this study (Table 1). Most of the fire caused mortality had occurred by the third year (Figure 35). Rasmussen et al. (1996) stated that 37.3% of 134 subalpine fir survived fire in their study. Fifty percent of the mortality was attributed to fire injury and 7.5% to insects. All 17 of the subalpine fir in the study by Ryan and Amman (1994) were killed by fire that girdled over 80% of the tree bole.

Figure 35. Alpine fir survival five years after fire.



We found no significant differences in dbh between fire killed and surviving trees (Fig. 36). Beetle attack of subalpine fir was not observed. Trees killed by fire averaged 9.4 inches dbh, and those surviving were 7.9 inches in diameter.

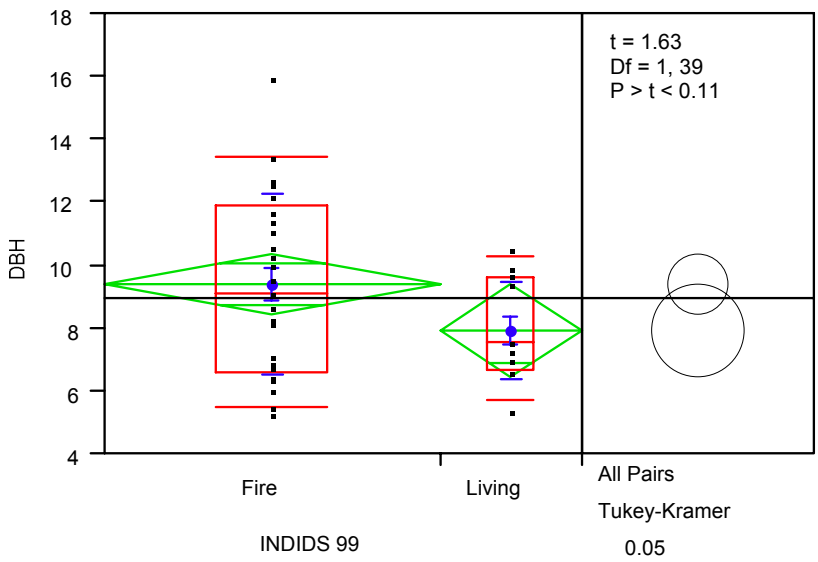


Figure 36. Comparison of dbh of subalpine fir shows no significant effect. (Overlapping circles in the figure at right indicate non-significant differences between groups (P ≤ 0.05)).

Crown scorch was significantly higher in trees killed by fire (42.7%) than those living (7.5%) five years later (Fig. 37).

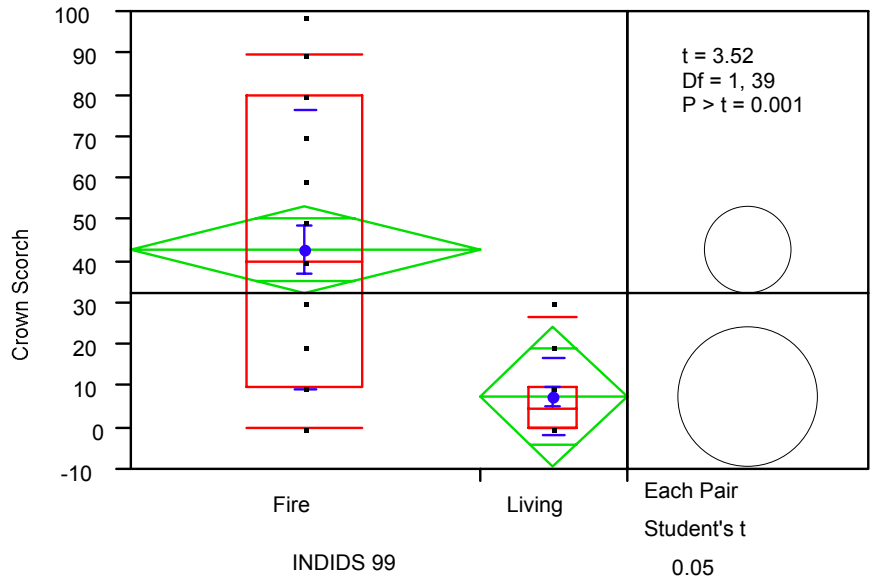


Figure 37. Comparison of crown scorch of subalpine fir show significantly higher scorch in trees killed by fire. (Non-overlapping circles in the figure at right indicate significant differences between groups(P ≤ 0.05)).

Figure 38 shows the relationship between percent crown scorch and probability of survival. Note the sharp increase in the probability of mortality with increasing crown scorch.

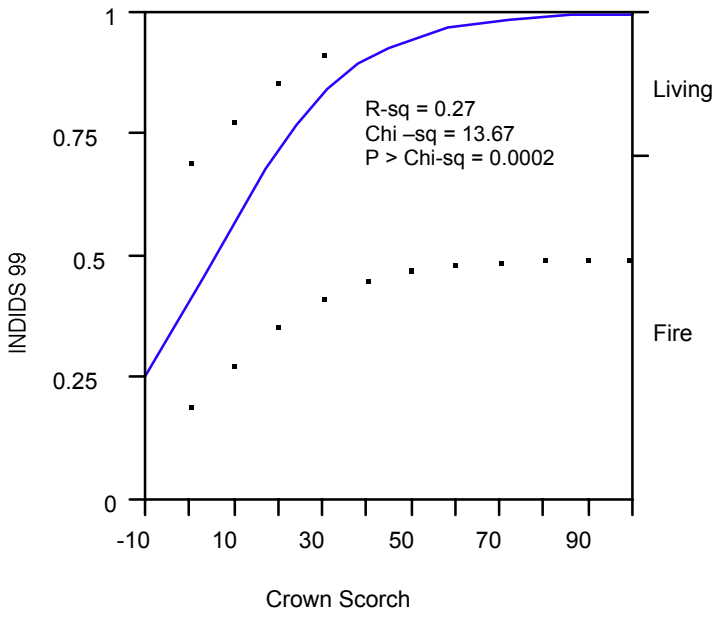


Figure 38. Plot of nominal logistic regression of subalpine fir crown scorch between living and fire-killed trees shows the probability of mortality rapidly increasing with increasing scorch. Probability of occurrence is on the Y-axis, degree of scorch is on the X-axis.

Subalpine fir was also sensitive to bole and root char. The average char of trees surviving fire was 26% and the mean of trees killed by fire 62%. Figure 39 indicates that % char was significantly less in surviving trees.

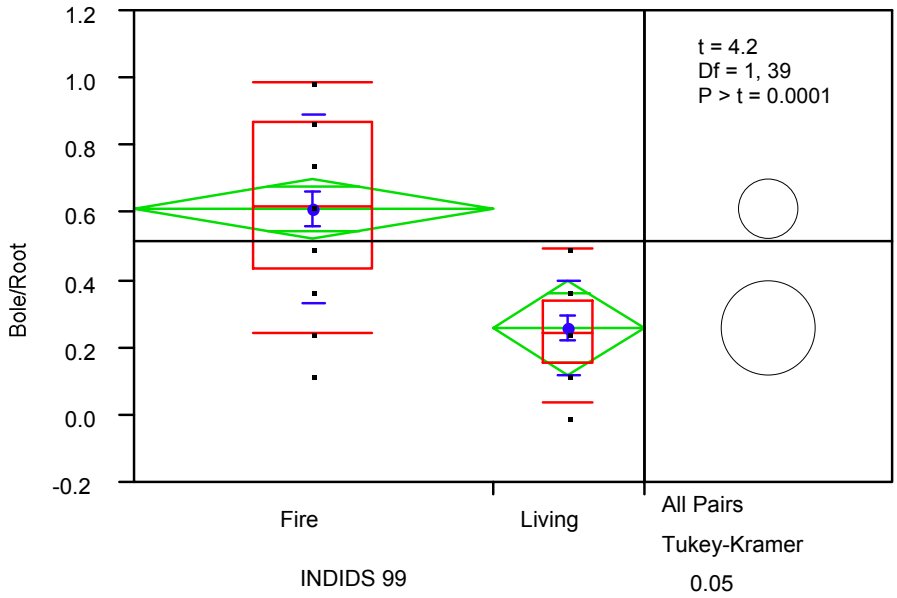


Figure 39. Comparison of bole/root char of subalpine fir between categories of mortality shows significantly higher char in trees killed by fire. (Non-overlapping circles in the figure at right indicate significant differences between group (P ≤ 0.05)).

Figure 40 shows the lack of tolerance of bole and root char of subalpine fir. Note the sharp rise in the probability of mortality above values of 30%.

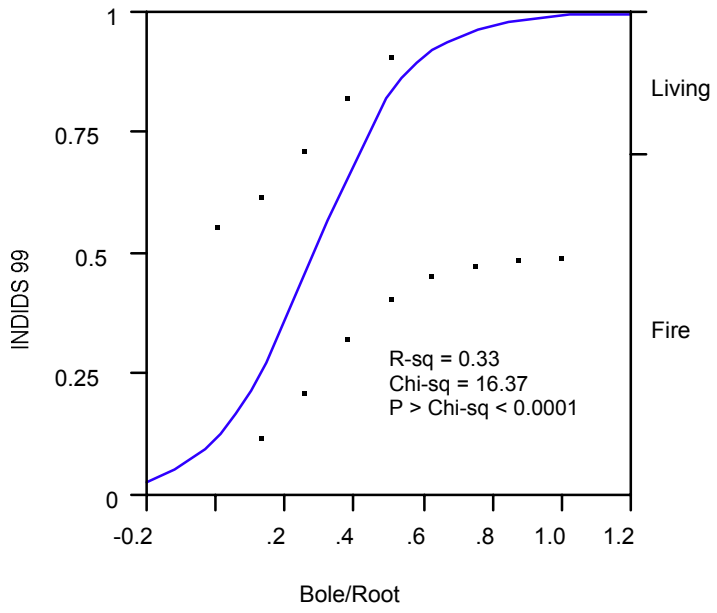


Figure 40. Plot of nominal logistic regression of subalpine fir bole/root char between living and fire-killed trees shows the probability of mortality rapidly increasing with increasing scorch. Probability of occurrence is on the Y-axis, degree of scorch is on the X-axis.

Conclusions

The impact of wildfire varied with the parameter examined among tree species. Although dbh, crown scorch, and bole and root char are measurable and are shown to significantly influence tree survival following wildfire, the influence of initial tree vigor, site and stand conditions, season of the fire, and factors in combination impact tree survival. Within species, different levels of tree survival were sustained at similar degrees of variable impact in the Lowman fires and the Greater Yellowstone fires when compared to the Payette fires of 1994.

The variables evaluated to assess the impact of fire on tree survival/mortality in this study were the most evident and easiest to obtain. Rating of bole and root char in particular is difficult because it requires destructive sampling and it is difficult to assess cambial death. Models combining dbh and crown scorch are good predictors of tree survival when bark thickness is related to tree diameter as observed in the thick-barked trees, and bark beetle induced mortality is negligible or is not relevant. However, dbh in thin-barked species had no impact on tree survival. Thick-barked species (ponderosa pine and Douglas-fir) had a much higher survival rate than the thin-barked species (subalpine fir, Engelmann spruce and lodgepole pine). Crown scorch was the single most relevant variable in assessing tree survival, however, the impact of crown scorch on tree survival varied widely within and among tree species.

The role of external unmeasured variables significantly influences tree mortality.

A significant factor causing tree mortality as an indirect result of fire was the propensity of beetle attack. Since most tree species are more susceptible to beetles as a result of wildfire, it is difficult to predict the impact of fire on tree mortality. Bark beetles were responsible for the majority of Douglas-fir mortality. Crown scorch and bole char are the most accurate parameters related to post wildfire tree survival, but need to be applied with the foreknowledge that they are associated with considerable variability and should be applied with caution.

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