

## CONDITION OF LIVE FIRE-SCARRED PONDEROSA PINE TREES SIX YEARS AFTER REMOVING PARTIAL CROSS SECTIONS

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### ABSTRACT

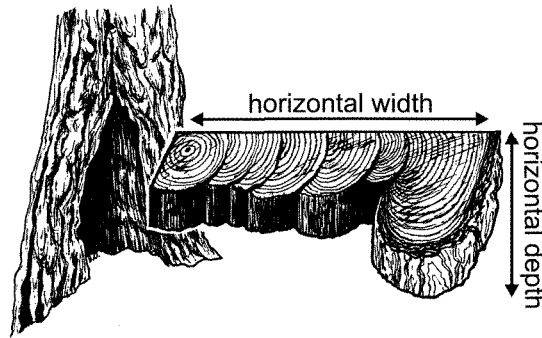
Our objective was to document the effect of fire-history sampling on the mortality of mature ponderosa pine trees in Oregon. We examined 138 trees from which fire-scarred partial cross sections had been removed five to six years earlier, and 386 similarly sized, unsampled neighbor trees, from 78 plots distributed over about 5,000 ha. Mortality was low for both groups. Although mortality was significantly higher for the sectioned trees than their neighbors (8% *versus* 1%), removing a partial section did not appear to increase a tree's susceptibility to death from factors such as wind or insect activity. Specifically, the few sectioned stems that broke did so well above sampling height. Most sectioned trees (79%) had evidence of insect activity in 1994/95, while only an additional 5% had such evidence in 2000. Mortality among sectioned trees in this study was low probably because we removed relatively small sections, averaging 7 cm thick and 8% of the tree's cross-sectional area, from large trees of a species with effective, resin-based defenses against insects and pathogens. Sampling live ponderosa pine trees appears to be a non-lethal method of obtaining information on past fire regimes in this region because it only infrequently led to their death in the early years after sampling.

*Keywords:* ponderosa pine, fire history, Oregon, effect of sampling, partial cross sections, fire scars, wounding.

### INTRODUCTION

Ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) is widely distributed in fire-dependent ecosystems across western North America (Little 1971; Thompson *et al.* 1999). Some individuals of this long-lived species have survived repeated wounding by frequent, low-severity fires during which the vascular cambium was lethally heated around a portion of the circumference of the lower bole (Dieterich and Swetnam 1984; Gutsell and Johnson 1996; Figure 1). Trees that are repeatedly injured before cambium can re-establish around

the full circumference often have a cavity that is surrounded by woundwood ribs (Smith and Sutherland 2002) and called a catface. Our understanding of the historical role of surface fires in ponderosa pine ecosystems is based on the records of fire preserved in these catfaces. This record has been extracted from many dead ponderosa pine trees, and indeed some fire history studies use dead wood exclusively. However, it has also been extracted from thousands of live trees across western North America (*e.g.* Heyerdahl *et al.* 1995) by removing a partial cross section from one or both



**Figure 1.** Schematic of a tree scarred by six fires, showing a catface with a deep cavity and a fire-scarred partial cross section typical of those sampled for this study (after Anderson *et al.* 1987). The horizontal dimensions (width and depth) that we measured within the sampling cavity are indicated on the section.

sides of the catface with a chain saw (Arno and Sneek 1977). Concern over the effects of removing partial cross sections may limit live-tree sampling and consequently restrict the development of science-based management in these widespread forests (Barrett and Arno 1988). Casual observation indicates that sampling wounds generally do not kill trees. However, the effect on tree mortality of removing fire-scarred partial cross sections has not been reported in the literature.

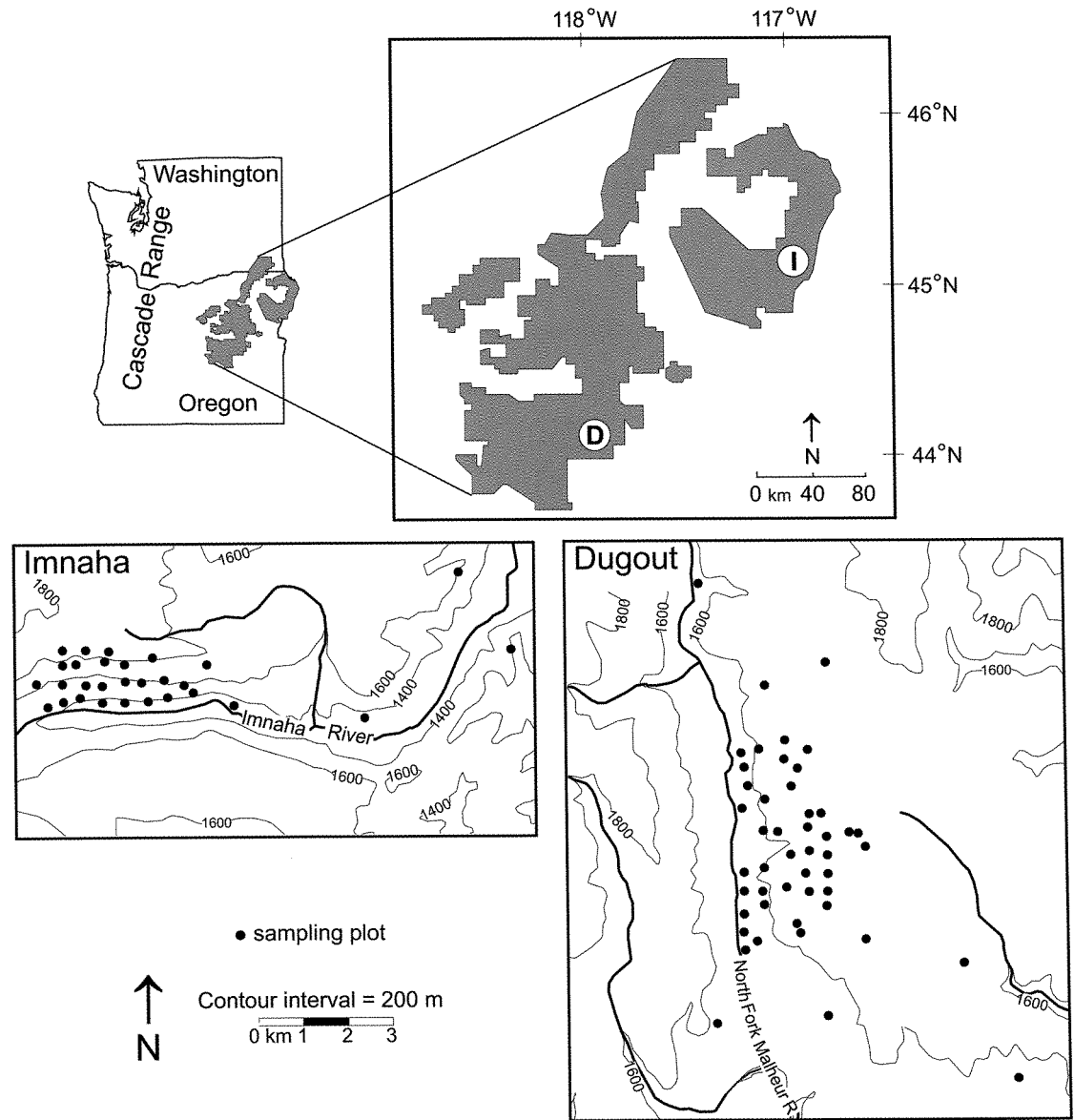
Removing partial cross sections from live ponderosa pine trees might increase their susceptibility to killing agents such as insects, pathogens, drought, wind or fire and that susceptibility may depend on the size of the section that is removed. For example, open bole wounds can be invaded by insects or pathogens. To inhibit such invasions, ponderosa pine trees, like other species of *Pinus*, possess a well-developed system of vertical and horizontal ducts that release resin in response to mechanical wounding, creating a barrier against invading pathogens (Berryman 1972; Shigo 1984; Christiansen *et al.* 1987; Owen *et al.* 1987; Kozlowski and Pallardy 1997; Langenheim 1990). However, the wounds created by removing partial cross sections might be large enough to overwhelm available resin reserves, rendering sectioned trees more susceptible to invasion than trees that have not been sectioned. Sectioned trees might also be more susceptible to drought stress than unsectioned trees because removing phloem and xy-

lem may reduce the trees' capacity to transport nutrients and water. Furthermore, resin production is partly dependent on water availability (Vité 1961; Gibbs 1968; Kolb *et al.* 1998), so that if reduced water transport reduces resin production, a tree might be less able to defend itself against invasion. Removing a partial cross section also weakens a tree structurally, so that wind might break the stems of sectioned trees more often than those of unsectioned trees. Ponderosa pine trees secrete resin in response to wounding by fire. However, the mechanical wounding caused by sectioning also results in resin secretion and may increase the flammability of the catface. Such a catface might be more likely to be consumed by a subsequent fire than an unsectioned catface, perhaps resulting in the death of the tree. The effect of sampling may differ among trees and stands, because these killing agents do not act uniformly over the landscape or among species, and probably varies with the size of the section removed.

Our goal was to determine whether removing partial cross sections from live ponderosa pine trees in the Blue Mountains led to higher mortality among the sectioned trees relative to similarly sized, unsectioned neighbor trees. For the sectioned trees, and comparable neighbor trees, we estimated the size of the partial cross section that was removed and evaluated the tree's current condition (alive/dead, insect activity, crown condition, resin production, and callus formation).

## STUDY AREA

Fire-scarred ponderosa pine trees in the Blue Mountains of northeastern Oregon were used in a previous study to reconstruct the history of surface fires by removing partial cross sections from live and dead trees in two watersheds in 1994 and 1995 (Heyerdahl *et al.* 2001; Figure 2). Most of the trees we examined were on southwest aspects (115°–305°) with gentle to moderate slopes (1–47%), lying between about 1400 and 1800 m elevation. In the sampled areas, ponderosa pine co-dominates with Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) or grand fir (*Abies grandis* (Dougl.) Lindl.). Individual trees recorded multiple fires in both watersheds (averaging 5 and 8 fires at the



**Figure 2.** The Blue Mountains of Oregon and Washington, showing the location of the two watersheds (I = Imnaha, D = Dugout) and plots within each watershed. Partial cross sections were removed from an average of 2 live fire-scarred ponderosa pine trees in each plot in 1994 or 1995 and these trees were examined again in 2000. Shaded areas are managed by the US Forest Service.

Imnaha and Dugout watersheds, respectively). The sectioned trees in both watersheds were of similar minimum age (average = 310, range = 174–644 years, based on the innermost ring sampled).

The climate of the Blue Mountains is generally continental, with low annual precipitation, most of

which falls as snow during the winter (mean 446 mm, 1985–1996; EarthInfo 1990; Mock 1996). Winters are cold and summers warm (mean: January  $-3.2^{\circ}\text{C}$ , July  $18.8^{\circ}\text{C}$ , 1895–1991; NOAA 1997). Although the Blue Mountains are near the northern extent of ponderosa pine, the climate of

the study area is not extreme for the species (Thompson *et al.* 1999). Furthermore, the weather from the time of sampling to the present was moderate compared to the previous 100 years (Oregon climate division 8 Palmer Drought Severity Index: -4 to 3 during 1994–2000 versus -7 to 6 during 1895–1994; NOAA 1997).

## METHODS

We examined 138 fire-scarred ponderosa pine trees in the two watersheds (Figure 2). A single partial cross section had been removed from one side of the catface of each of these live trees in 1994 or 1995 (111 and 27 trees, respectively), and the resulting wound was not treated (Heyerdahl *et al.* 2001). We did not include two trees that were alive when sampled, but dead by 2000, because the plots they were in burned since the time of sampling, largely consuming their catfaces. Consequently, we could not clearly identify one of the sectioned trees and could not determine the dimensions of the sample cavity for the other.

To determine if the relative size of the partial cross sections affected mortality, we measured tree diameter and the dimensions of the sample cavities. For each sectioned tree, we measured diameter (*d*) at breast height (dbh, 1.4 m above ground level) and at sampling height. We estimated cross-sectional area at sampling height as  $\pi(d/2)^2$ , but because many catfaces had deep cavities (Figure 1), we subtracted the cross-sectional area of cavities deeper than 5 cm from the cross-sectional area of the tree at sampling height by assuming the cavities were triangular in cross section:

$$\begin{aligned} &\text{cross-sectional area of catface cavity} \\ &= \sqrt{s \cdot (s - a) \cdot (s - b) \cdot (s - c)} \end{aligned}$$

where  $s = 0.5 \cdot (a + b + c)$ , and *a*, *b*, *c* = lengths of sides of the triangle.

We estimated the cross-sectional area of the fire-scarred section that was removed as the product of its horizontal depth and width (Figure 1), measured in the sample cavity. We also measured the vertical depth of the section in the sample cavity.

To assess the possible role of insect activity since 1994/95 in tree mortality, we noted the presence of fine sawdust in the sample cavity. As a

measure of insect activity prior to 1994/95, we noted insect galleries on the sanded surfaces of the fire-scarred sections, assuming that insect activity after the time of sanding would have marred this surface. As indications of tree vigor, we noted crown condition (dead, sparse, or full, where sparse corresponds to vigor classes C and D in Keen [1943]) and the presence of resin and callus tissue in the sample cavity.

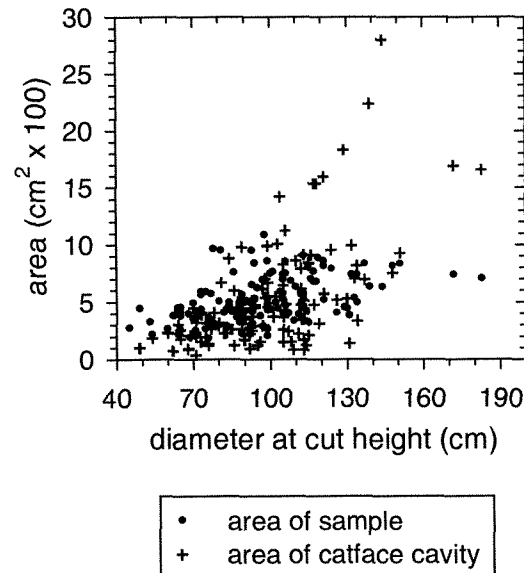
We assessed whether the dead and surviving sectioned trees were different using non-paired two-sample *t*-tests that account for differences in variance, to test for differences in tree diameter (mean dbh), size of sample removed (mean cross-sectional area and mean vertical depth), number of recorded fires per tree, and minimum tree age.

Ponderosa pine trees die from causes unrelated to the removal of partial cross sections. To estimate mortality from these other causes, we examined up to three of the nearest neighbors of the sectioned trees, including only ponderosa pines of comparable diameter (mean distance = 16 m, range = 1–69 m). For these neighbors, we measured dbh and noted crown condition (dead, sparse, or full) and the presence of catfaces. Because neighbor trees had not been identified in 1994/95, we included both live and recently dead neighbors, assuming that trees that had died since 1994 would retain at least some dead needles and be standing in 2000. We did not date recent tree deaths by crossdating increment cores because the annual rings of slowly dying trees are often narrow or absent in these forests, and hence difficult to date accurately.

We assessed whether sectioning led to more deaths among sectioned than neighbor trees by testing for a difference in the proportion of trees that died in each group (equivalent to a  $\chi^2$  test of homogeneity; Zar 1984). We estimated annual mortality as the percentage of trees that died divided by the number of years since a fire-scarred section was removed. We computed this value separately for trees sampled in 1994 versus 1995 and report the geometric mean of these two values.

## RESULTS

The 138 sectioned trees were large, having a mean dbh of 86 cm (range = 39–160 cm) and

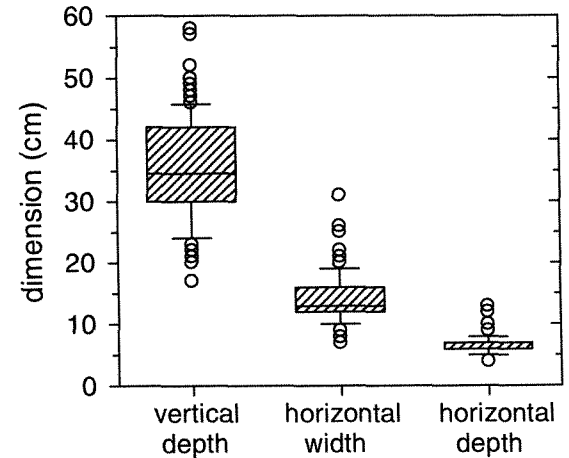


**Figure 3.** Cross-sectional area of samples removed for fire history reconstruction and cross-sectional area of catface cavities, compared to tree diameter. Only catfaces with cavities deeper than 5 cm are shown.

mean cross-sectional area at sampling height of  $0.7 \text{ m}^2$  (range =  $0.2\text{--}2.5 \text{ m}^2$ ). Most catfaces had cavities deeper than 5 cm at sampling height (86%). These cavities were small compared to the tree's cross-sectional area (mean = 6%, range =  $0\text{--}17\%$ ; Figure 3). Fifteen trees had more than one catface (11%) and a few had sparse crowns (8%).

The partial cross sections we removed were small. They had mean dimensions of 35 cm horizontal width, 13 cm horizontal depth, and 7 cm vertical depth (Figure 4). They were small relative to tree diameter, averaging only 8% of cross-sectional area at sampling height (range =  $3\text{--}25\%$ ), and for reference, were comparable in area to the catface cavities (Figure 3).

The sample cavities appeared relatively unchanged since they were cut (Figure 5). However, we found fine sawdust in the sample cavities of many trees (40%), although most of these (87%) already had insect galleries when we removed a partial cross section in 1994/95. Trees in the Dugout and Imnaha watersheds had roughly equal rates of insect activity, with 77% and 83% of trees having insect galleries when sampled, respectively. Most trees (93%) had secreted some resin into the



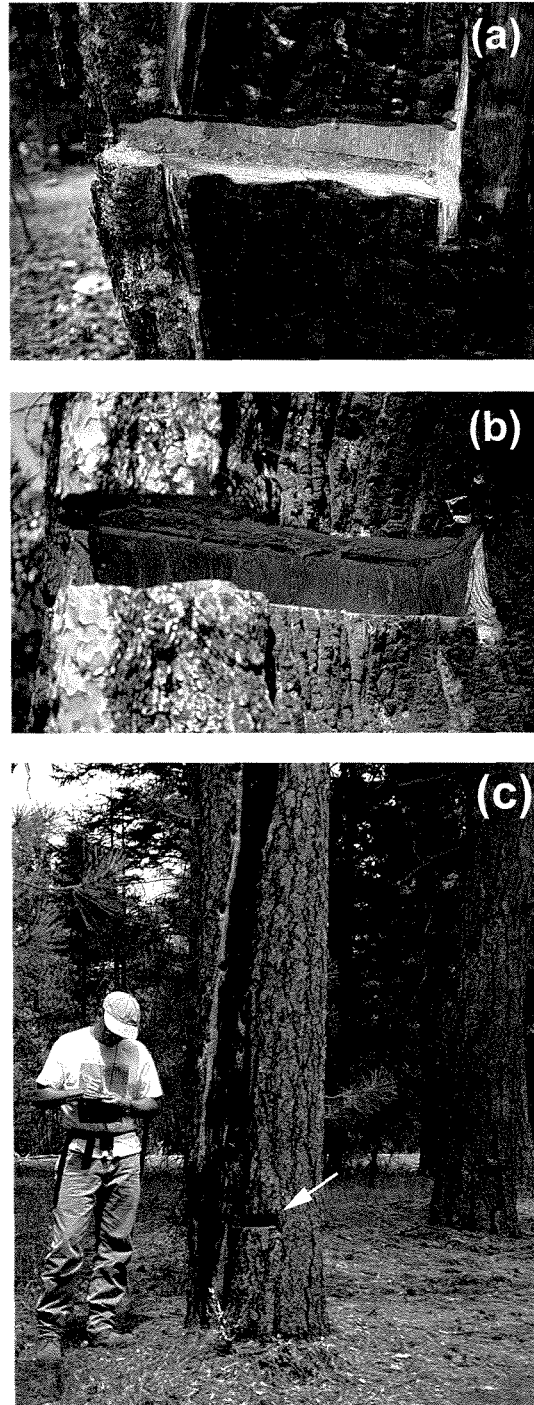
**Figure 4.** Dimensions of fire-scarred partial cross sections removed from live ponderosa pine trees. See Figure 1 for an explanation of horizontal depth and width. For vertical depth, the 50th and 75th percentiles are the same (7 cm).

cavity, generally on the upper surface and most (75%) had new callus tissue along the vertical margin of the cavity.

Among the sectioned trees, there was no significant difference in the diameter of trees that died versus those that survived (mean dbh;  $p = 0.25$ ; Figure 6). Nor was there a significant difference in the size of the partial cross sections that we removed (cross-sectional area,  $p = 0.83$ ; vertical depth,  $p = 0.94$ ), the number of recorded fires ( $p = 0.39$ ) or minimum age ( $p = 0.50$ ).

The 386 neighbor trees were also large, with a mean dbh of 79 cm (range =  $38\text{--}112 \text{ cm}$ ), and were similar in size to their corresponding sectioned trees (average = 97% of dbh, range =  $53\text{--}140\%$ ). There were three neighbors of comparable diameter within 70 m of most sectioned trees (121/138 trees or 88%); the remaining sectioned trees had fewer neighbors. Some of the neighbor trees had catfaces (110/386 trees or 28%) and a few had sparse crowns (8%).

Since the time of sampling, a significantly larger fraction of the sectioned trees died than did their neighbors (11/138 versus 2/386;  $p < 0.01$ ). However, the significance of the difference in mortality between these two groups should be interpreted cautiously because only a small proportion of the trees in either group died (Zar 1984). Most of the trees that died were in the Dugout watershed (9 of



**Figure 5.** Typical condition of wounds resulting from the removal of partial cross sections from ponderosa pine trees for fire history reconstruction in the Blue Mountains. The sections were removed from all three trees six years before the photos were taken. The trees in (a), (b), and (c) are 71, 95 and 59 cm

the sectioned trees and both of the neighbors). Five of the sectioned trees broke 1.5 to 7 m above sampling height. One of the dead neighbors had a cat-face.

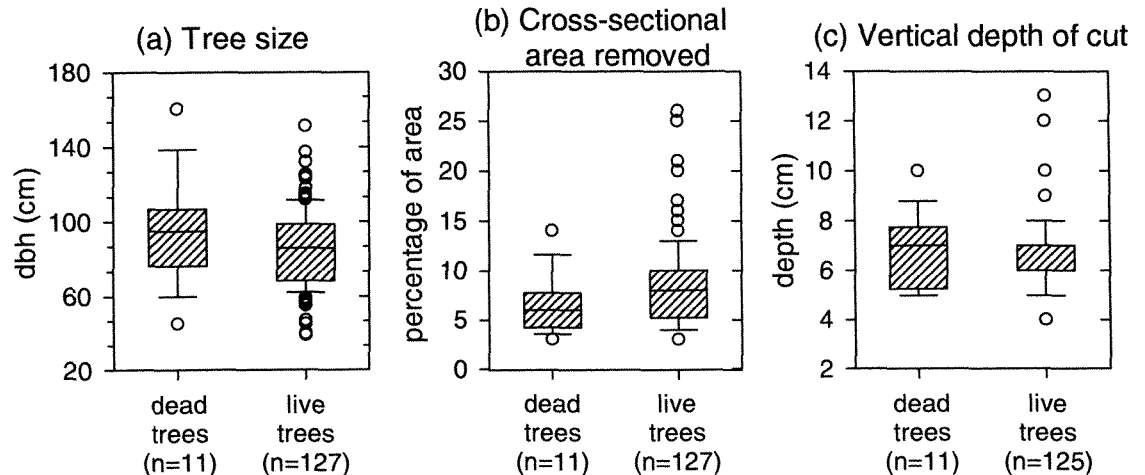
## DISCUSSION

Mortality was significantly higher among the sectioned trees (8%) than their neighbors (1%). However, we expect that our future assessments of these trees will reveal similar mortality between the groups because we probably underestimated the number of dead neighbor trees. We did not identify neighbors at the time of sampling and were conservative in identifying dead neighbors in 2000. We overestimated the time required for snags to lose their needles and fall over by assuming that snags that had died within the previous five years would be standing and retain dead needles in 2000. In fact, within only three years of death, ponderosa pine snags in a nearby forest of similar composition had lost the majority of their needles (97%) and a few had fallen over (Bull 1983), while snags of a closely-related species, Jeffrey pine (*Pinus jeffreyi* Grev. & Balf.), in California, lost all of their needles within only 2 years (Raphael and Morrison 1987). Consequently, we probably did not identify some of the neighbors that were alive in 1994/95 but dead in 2000.

Other evidence suggests that mortality may be similar among both sectioned and neighbor trees in the future. First, tree vigor, inferred from crown condition, was similar in the two groups. Equal proportions of sectioned trees and their neighbors had sparse crowns (8%). In forests similar to those of the Blue Mountains, ponderosa pine trees with sparse crowns were more likely to die than those with full crowns (Keen 1943). Second, mortality among our sectioned trees was comparable to mortality of ponderosa pine trees elsewhere. Of our sectioned trees, 1.4% died per year on average, compared to ponderosa pine trees in south central Oregon, of which about 1% died per year (Miller and Keen 1960). Similarly, mature trees of the

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dbh and we removed 8%, 5% and 15% of their cross sectional area, respectively. The wound in (c) is indicated with an arrow.



**Figure 6.** Physical characteristics of live versus dead sectioned trees. All 138 trees were alive in 1994/95 when fire-scarred sections were removed from them. Eleven of these were dead in 2000. We could not determine the vertical depth of cut on two trees because the sample cavities had been partially consumed by fire since the time of sampling. The boxes enclose the 25th to 75th percentiles and the whiskers enclose the 10th to 90th percentiles of the distribution of trees. The vertical line across each box indicates the median and all values falling outside the 10th to 90th percentiles are shown as circles. For live trees, the median vertical depth of cut, 7 cm, is the same as the 75th percentile.

same species in eastern Oregon, eastern Washington, and northeastern California died at rates ranging from 0.3 to 3.2% per year (Keen 1943).

Mortality among our sectioned trees was low probably because we removed relatively small sections on one side of the catface, from mature trees of a species with effective defenses against insects and pathogens. The sections we removed were small relative to the size of the stem and were comparable in area to the catface cavities (Figure 3) even though we probably overestimated the percentage of the tree's cross-sectional area for two reasons. First, we assumed that the sections were roughly rectangular in shape. In fact, some sections had large outer curls and may be better approximated as triangles. Second, we assumed that the catface cavities were triangular in cross section, when in fact they are often concave in cross section. Consequently, we probably underestimated their cross-sectional area. In combination, these errors overestimate the proportion of the cross-sectional area that we removed.

Removing a partial cross section did not appear to result in tree death from factors such as insects or stem breakage from wind during the first five or six years after sampling. Only a few of the sec-

tioned trees without evidence of insect activity in 1994/95 (13%) had such evidence in 2000. Given the remarkable percentage of sectioned trees that had evidence of insect activity when sampled (79%), this small increase is not a substantial change. Furthermore, none of the sectioned trees that broke after sampling did so at sampling height. These trees have survived many years with a catface cavity comprising 0–17% of their cross-sectional area. Removing a thin section similar in cross-sectional area to the catface cavity (8–25% of area) did not noticeably decrease the strength of the stem in the early years after sampling.

We found that removing small partial cross sections from large, live ponderosa pine trees in the Blue Mountains infrequently leads to their death in the early years after sampling. These results suggest that sampling fire scars from live trees can be an important and generally non-lethal method of obtaining information on past fire regimes. However, we are not suggesting that fire historians ignore the information on past fire regimes that is contained in dead fire-scarred trees. Our results may be applicable to other species that secrete resin in response to wounding, particularly among *Pinus* species. However, the factors that contribute

to post-sampling mortality, *e.g.* insects, pathogens, resin production and size of sample removed, vary across the landscape and among fire history studies so that different species of trees may experience different levels of post-sampling mortality. Modern hand-held global positioning systems, such as the one we used for this study, make finding sectioned trees and neighbors relatively easy even many years after sampling. This technology can facilitate documentation of the impact of removing fire-scarred partial cross sections from live trees of different species across landscapes and regions. Consequently, we recommend recording the location and status of sectioned trees and their comparable neighbors, both at the time of sampling and at intervals after sampling.

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