

PACIFIC SOUTHWEST Forest and Range Experiment Station

FROST CRACKS... a common defect in WHITE FIR IN CALIFORNIA

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USDA Forest Service
Research Note PSW-209
1970

Frost crack is a widely recognized defect in many tree species. Its occurrence in tree trunks was first reported many decades ago, yet most foresters know little about this defect. Frost cracks are frequent in white fir (*Abies concolor* [Gord. & Glend.] Lindl.), an increasingly important timber species in the Western United States. To add to knowledge about frost cracks, I have drawn on unpublished records in old field notes, which I helped to take in 1917-1918, on decay and associated defects in white fir in California.

The cause of frost crack and the high susceptibility of white fir to this defect was noted more than 50 years ago by Meinecke, who wrote:

In cold weather, the wood cylinder shrinks more in a tangential than in a radial direction. . . Particularly at sudden low temperatures, when the volume of the outer layers decreases rather suddenly while the inner layers are still free from frost and have shrunk but little, differences in external tension will cause the outer layers to split vertically. With rising temperatures, the frost crack closes.¹

The crack or split follows the grain of the wood. The result is a spiraling longitudinal check in boards or timbers which strongly degrades them and restricts the use of the log for plywood. Losses chargeable to frost crack have not, in the past, been separated from those of rot and other defects.

In this note, quantitative data on frost cracks in white fir in California are reported for the first time.

THE STUDY AREAS

To compare the occurrence of frost cracks in different parts of the central Sierra Nevada in California, I compiled data from three study areas: Ellis Meadow, and Madsen's Mill on the Sierra National Forest, represented the comparatively mild climate of the west slope; and Smith Mill, on the Tahoe National Forest, represented the continental type of climate of the east slope north of Lake Tahoe.

ABSTRACT: Frost crack, a radial split of wood and bark, reduces the merchantability of commercial timber. Data on this defect in white fir stands of the Sierra Nevada, California, showed that frost cracks were two to three times more prevalent on trees of the east slope than those of the west slope. Percent of trees with frost cracks increased as tree diameter growth increased on the east slope, but decreased on good sites of the west slope. About 85 percent of the frost cracks were in the first 16-foot log of the lower trunk. Slow-growing trees less than 30 inches d.b.h. were the most susceptible to the defect.

OXFORD: 174.7 *Abies concolor*: (794):416.5.

RETRIEVAL TERMS: *Abies concolor*; Sierra Nevada; frost crack.

Ellis Meadow, now renamed Benedict Meadow, lies at 5,700 feet elevation about 7 miles northeast of North Fork, Madera County, California. The timber stand at the time of the study in 1917, was of uneven-aged, virgin mixed conifers, with white fir predominant. The study area included the timbered slopes of a basin surrounding the meadow.

The Madsen's Mill area was in a stand of virgin timber about 3 miles east of Shaver Lake, Sierra National Forest. It lies about 14 miles, airline, southeast of Ellis Meadow and averaged about 140 feet higher in elevation. The modal d.b.h. of the trees cut was somewhat greater than at Ellis Meadow—37 inches vs. 30 inches.

The Smith Mill site adjoins the Little Truckee River about 11 miles north of Truckee, Nevada County, California. The study area was on gentle to moderate, northerly facing slopes at 6,000-foot elevation, above the south bank of the river. The stand when sampled in 1913 was almost pure, uneven-aged, virgin white fir, with a high percentage of defect from brown stringy heart rot.

WINTER CLIMATES

Winters at Ellis Meadow are relatively mild for the 5,700-foot elevation, where temperatures usually do not fall below 0°F., although in occasional severe winters they may drop as low as -12°F. Rapid temperature changes to far below freezing, common in some parts of North America, are not characteristic for the area. The duration of a winter snow cover, which may help protect the base of a tree, varies from year to year. In a white fir stand at a comparable location and elevation, the duration varied from 25 to 147 days in a 7-year period.² The maximum meas-

ured snow depth during those years was 65 inches, reached in 1 year only.

Winter climate at Madsen's Mill is very similar to that at Ellis Meadow.

At Smith Mill, winters are significantly cooler than at comparable elevations on the west slope of the Sierra Nevada. The diurnal temperature range is often greater. At Truckee, fairly comparable to the Smith Mill site, the average maximum temperature for January up to 1920 was 37.9°F. and the average minimum 15.6°F. The lowest temperature recorded was -28°F. Only rarely does the temperature quickly drop to far below freezing. At Boca, near the Smith Mill site, snow on the ground rarely exceeds 30 inches, and that for only a few days but persists longer than on the west slope. As at all middle elevations in the Sierra Nevada, snow cover varies greatly in depth from year to year.

FIELD PROCEDURES

To avoid clearcutting, white firs were felled along meander lines through the stand. These were chosen to include as many firs as possible. At Ellis Meadow and Madsen's Mill, the trees cut were tallied by age classes, and late in the season, an attempt was made to fill out classes poorly represented.

At Smith Mill, an attempt was made in the early cutting to include as many trees as possible having rot from the fungus *Echinodontium tinctorium* Ell. & Ev. which was quite prevalent in the stand. Later, this objective was abandoned and cutting judged to be representative for the stand ensued. A subsequent survey of the cut trees indicated that a downward adjustment of about 8 percent would be needed to make the Smith Mill results comparable on a stand basis with those from the other areas chosen (*table 1*).

Table 1 — Percent of frost cracks and other comparisons of white firs on east and west slope sites of the Sierra Nevada, California

Item	Smith Mill (east-side)	Ellis Meadow (west-side)	Madsen's Mill (west-side)
Trees in study No.	147	276	251
Mean diameter breast high inch	26.2	27.4	35.4
Mean age at stump height year	198	175	177
Maximum age at stump height . years	350	350	338
Mean 10 year d.b.h. increment . inch	1.35	1.63	2.08
Trees with frost cracks pct. ¹	² 68.2	24.3	12.7

¹Internal frost cracks omitted because of incomplete data.

²Adjusted from 76.2 percent (see text).

HEALING TIME SPAN

Newly formed frost cracks that extend to the bark surface close tightly as soon as rising temperatures release the tensions that formed them. The tree attempts to repair the damage as soon as growth starts in the spring by forming callus tissue over the surface of the split in the cambial region.

The initial callus formed over the frost crack rarely remains intact through the following winter. When low temperatures return, reestablishing a tensile pull, the frost crack reopens along most of its length. Only near the ends, where the original split was very narrow, does the callus often remain intact. The process of alternate healing and breaking of the callus over the crack commonly continues over a span of years. Each year, the length of the reopened part shortens until permanent healing is achieved in most cases. These healing lines persist throughout the life of the tree and often offer easily recognizable evidence of frost crack.⁴

Data on age involvements were available only for the west slope areas and were compiled only for Ellis Meadow. The time span from frost crack formation to permanent healing varied widely from tree to tree; for 59 permanently healed frost cracks it ranged from 2 to 162 years, with a mean of 37 years. These figures should be regarded as approximate because there was

no assurance that age counts were always made in the zone of last healing. In trees with multiple frost cracks, the healing time range was not wide but tended to be individual for each particular tree. There was only a slight correlation of healing span with rate of tree growth as expressed by mean 10-year d.b.h. increments.

Because the average frost crack requires a number of years to heal, it not only widens radially but produces raised lips of callus tissue that persists for many years after the crack has healed. Frost cracks with leakage caused by fermenting organisms remain open indefinitely.

NOTES

¹Meinecke, E. P. *Forest pathology in forest regulation*. U.S. Dep. Agr. Bull. 275, 62 p. 1915.

²Kittredge, Joseph. *Influences of forests on snow in the ponderosa-sugar pine-fir zone of the central Sierra Nevada*. *Hilgardia* 22: 1-96. 1953.

³Barwick, James A. (compiler) *Annual meteorological review, State of California, year 1888*. Sacramento, Calif. 183 p. 1889.

⁴Records on hazardous trees by Federal and State forest agencies and by private forest owners, on file at the Pacific Southwest Forest and Range Experiment Station, Berkeley, California. They show no breakages or accidents directly chargeable to frost crack in 133 true firs (52 white fir).

The Author

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Table 3.—White firs with frost cracks, and 10-year diameter increments (breast high), at east and westside locations, Sierra Nevada, California (Basis: 674 trees)

Location	Frost cracks, all trees	10-year d.b.h. increment						
		All trees mean	With frost cracks			Without frost cracks		
			Min.	Max.	Mean	Min.	Max.	Mean
Percent		Inches						
Eastside:								
Smith Mill	¹ 76.2	1.35	0.57	2.68	1.38	0.68	1.98	1.24
Westside:								
Ellis Meadow	24.3	1.60	.74	2.90	1.36	.64	2.90	2.01
Madsen's Mill	12.7	2.08	1.10	3.52	2.01	.72	3.97	2.09

¹Not adjusted; trees compared individually.

formed in only 11 of the 20 winters, indicating that in many winters conditions do not favor frost crack formation in places comparable to Ellis Meadow.

For 43 of the 67 winters, only one frost crack was recorded as having started, but for 5 different winters three or more started. The most defects—seven—occurred in 1882-83. The only available weather records pertinent to the Ellis Meadow area show that a minimum temperature of 22°F. was recorded at Sacramento on January 20, 1883, the lowest temperature at that station between 1878 and 1887.³

EFFECTS OF TREE SIZE, AGE, AND GROWTH RATE

Frost cracks formed principally in white firs of medium diameter. At Ellis Meadow, 73 percent of them appeared in trees 18 to 28 inches d.b.h. At Smith Mill, most frost cracks appeared in trees above 18 inches d.b.h. At both locations, nearly all remaining frost cracks had formed in slow-growing trees under 18 inches d.b.h.

At Ellis Meadow, the youngest tree in which a frost crack had formed was 52 years at stump height, 1.5 feet, at the time. The oldest was 214 years. However, 78 percent of the frost cracks formed in trees 61-150 years old at the time. Within these

limits, the number of frost cracks per 10-year tree age class was rather evenly dispersed and showed no modal maximum. The few trees more than 170 years of age at stump height when frost cracks formed in them all grew slowly.

Incidence of frost cracks and mean tree growth—gauged by 10-year d.b.h. increments calculated from age at stump height and d.b.h.—showed variable trends in the three study areas (table 3; fig. 2). Calculation of biserial correlation coefficients for these three sets of data showed: At Smith Mill, the percent of trees with frost cracks increased as mean tree growth increment increased; here the correlation coefficient was positive and significant at the 5 percent level (“t” test 2.080 with 145 DF). At Ellis Meadow, the percent decreased as growth increment increased; here the correlation coefficient was negative and highly significant at the 1 percent level (“t” test -5.898 with 274 DF). At Madsen’s Mill, the correlation was negative but not significant (“t” test -.638 with 249 DF). The over-all comparisons between mean growth increment and frost crack incidence in areas of similar frost regimes clearly suggest that the trees at Madsen’s Mill had more diameter growth and fewer frost cracks than trees at Ellis Meadow (table 3).

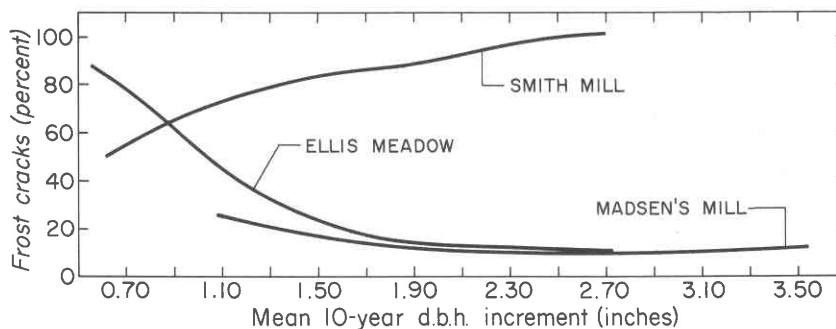


Figure 2—Percentage of white firs with frost cracks increased as 10-year d.b.h. increments increased on the east slope (Smith Mill) of the Sierra Nevada. The percentage decreased on the west slope (Ellis Meadow and Madsen's Mill).

FROST CRACKS

Incidence and Position

Frost cracks were much less prevalent at the two west slope sites than at the east slope site. About one-fourth of the trees at Ellis Meadow and about one-eighth of those at Madsen's Mill had frost cracks, as compared to about two-thirds of the firs at Smith Mill (*table 1*). Frost cracks at Smith Mill averaged shorter than those at Ellis Meadow and were closer to the ground (*table 2*). At Smith Mill, only five frost cracks extended higher than 20 feet from the ground, and these were in two trees. Most frost cracks were short. At Ellis Meadow (*fig. 1*) more than 80 percent did not extend above the first 16-foot log. At each location, a small percent of trees appeared to be more prone to frost crack formation than the rest.

Year of Origin

Age and frequency of frost cracks is of considerable interest but was determined only at Ellis Meadow because of some limitations on the accuracy of the dating method. Frost cracks start during the winter dormant season, which extends over parts of 2 calendar years. From callus formation over a newly formed crack, it is difficult to tell whether it formed late in a calendar year or early in the next.

The oldest frost crack recorded at Ellis Meadow was formed in the winter of 1687-88, when the affected tree was 68 years old at stump height. The most recent ones at the time of the study in 1917, were three formed in the winter of 1915-16. Of the 230 winters elapsing between 1687-88 and 1916-17, frost cracks formed in 67 different winters. Some of

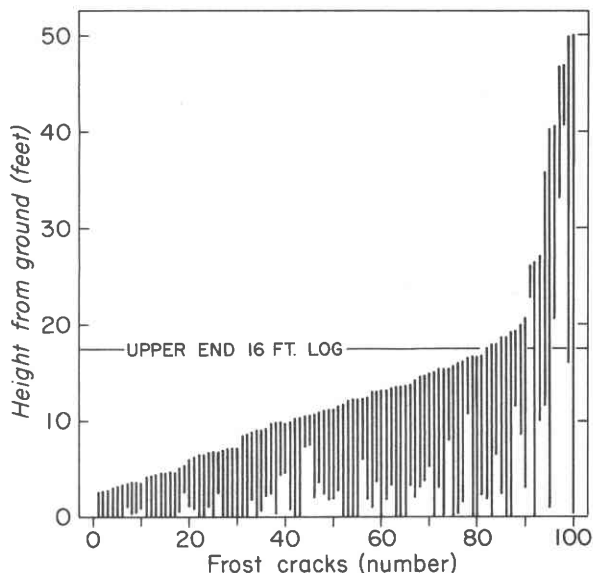


Figure 1—Frost cracks in white fir at Ellis Meadow, Sierra National Forest, arranged in order of upper limit in the tree trunk. Each line represents an individual frost crack. The defect was concentrated in the lower trunk.

these were only a year apart; others were separated by as much as 45 years. The record cannot be considered complete, however, for during the 230-year span many trees with frost cracks undoubtedly were lost from the stand. For the two decades before 1917 the record can be considered as virtually complete, as there was no evidence of loss of trees from the sample area during that time. Frost cracks

Table 2. — Frost cracks in trees at Ellis Meadow (westside) and Smith Mill (eastside) on the Sierra Nevada, California

Item	Ellis Meadow (westside)	Smith Mill (eastside)
Average frost cracks per tree No.	1.51	2.09
Trees with one recorded frost crack pct.	57	38
Trees with more than three recorded frost cracks pct.	4.3	12.8
Maximum frost cracks per tree No.	5	6
Frost cracks with measurements ¹ recorded . . . No.	101	217
Lower limit within 1 ft. of ground pct.	58	89
Upper limit within first 16-ft. log pct.	81	90
Mean length of frost cracks feet	10.5	7.6
Upper limit of highest frost crack feet	49.9	44

¹Frost crack measurements at Smith Mill apparently estimated to nearest 0.5 ft. in most cases. Percentages for trees with varying number of frost cracks were based on total number of trees with frost crack and not on the entire sample of trees.



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