

Rate of increase of blue stained volume in mountain pine beetle killed lodgepole pine in northeastern Oregon, U.S.A.

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Recently killed lodgepole pine (*Pinus contorta* Dougl.) were examined to determine rate of spread of blue stain fungi introduced by mountain pine beetle (*Dendroctonus ponderosae* Hopk.). Trees were felled, dissected at 2.5-m intervals, and photographed at each cross section to determine area of stain. Rate of spread is so rapid that salvaging mountain pine beetle killed lodgepole pine prior to severe staining is difficult.

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L'examen de pins lodgepole (*Pinus contorta* Dougl.) a été fait peu de temps après la mort des arbres dans le but de déterminer le taux de progression du bleuissement occasionné par le dendroctone du pin ponderosa (*Dendroctonus ponderosae* Hopk.). Les arbres furent abattus et sectionnés à intervalle de 2.5 m. Chaque découpe fut photographiée pour déterminer la surface affectée par le bleuissement. Le taux de progression s'est avéré si rapide qu'il serait difficile de récupérer les arbres tués par le dendroctone avant que le bleuissement n'ait pris des proportions importantes.

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Introduction

Blue stain caused by fungi results in degradation of logs and lumber, with a consequent loss of economic value. As early as 1911 and 1929, annual estimated losses of \$8 200 000 and \$10 000 000, respectively, were attributed to blue stain fungi in the United States alone (Scheffer and Lindgren 1940). Following introduction into trees, blue stain fungi spread rapidly through the parenchymous tissues but remain almost exclusively confined to the sapwood (Scheffer and Lindgren 1940). Actual staining is caused by brown pigmented mycelium produced by the fungi and results in heavy staining only in boards (No. 3 common and better) according to Standard Grading Rules for Western Lumber, effective September 1, 1970. With increasing supplies and development of specialized uses, stained wood is now gaining acceptance and even commanding higher prices than its unstained counterparts in some markets. Although there is a slight reduction in modulus of elasticity (Safranyik et al. 1974), Findlay (1959) reports that the effects of staining on the mechanical strength of wood to be used for building purposes are not significant. In Canada, considerable dollar loss results from consumer preference for clear versus stained wood because this type of stain can mask

other defects (H. S. Whitney, personal communication). It is probable that similar losses also occur elsewhere. An association between insect damage and blue stain fungi, mostly species of *Ceratocystis*, has been recognized since 1878 (Rumbold 1931) and insect-blue stain relationships have been demonstrated by Rumbold (1936), Reid et al. (1967), and Whitney (1971). Blue stain fungi are pathogenic to trees and can cause girdling if enough tangential lesions overlap (Reid et al. 1967). Spread rate is dependent on temperature and moisture content of wood (Scheffer and Lindgren 1940; U.S. Department of Agriculture 1941) and fungus species involved. Mountain pine beetle (*Dendroctonus ponderosae* Hopkins) is known to be a vector for blue stain fungi (Robinson 1962; Shrimpton and Whitney 1967). According to Whitney (1971) "There are no reports of *D. ponderosae* infestations without blue stain fungi and yeasts being present if looked for."

Mountain pine beetle is a periodic pest in stands of lodgepole pine, *Pinus contorta* Dougl., and is currently in outbreak status on more than 647 000 ha (1 ha = 10 000 m²) of forest land in northeastern Oregon. Trees containing nearly 5 200 000 m³ of wood have been killed between 1967 and 1977. These large outbreaks have generated a need to know the rate of blue stain fungi development to aid in planning salvage operations. The following study was

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therefore made to determine rate of spread of blue stain fungi in mountain pine beetle killed lodgepole pine in northeastern Oregon. Although several genera of blue stain fungi have been reported from mountain pine beetle killed lodgepole pine, by far the most prevalent is *Ceratocystis*; therefore, while this study did not involve fungal identification, the assumption was made that *Ceratocystis* spp. caused the staining. These fungi produce a pigment which, although brown in the mycelium, appears blue in the cells of the wood (Scheffer and Lindgren 1940). The intensity of the staining is a function of fungal-pigment physiology and density of mycelium.

Methods

Trees chosen for evaluation were in an expanding mountain pine beetle infestation and ranged in size from 12.7 to 43.0+ cm diameter at breast height (dbh). Fifty-four trees were selected in August 1976 to fill the following centimetre size classes: 15(12.7–17.5 cm), 20(17.6–22.6 cm), 28(22.7–32.8 cm), 38(32.9–42.9 cm), and 48(43.0+ cm). Except for the 48-cm class that contained 6 trees, all classes had 12 trees.

Trees selected exhibited successful establishment of at least three recent beetle galleries per square foot (1 sq. ft. = 929.0304 cm²) of bark surface, distributed around the bole without regard for height, in such a manner as to insure tree death (D. J. Curtis, personal communication). Successfully established galleries were defined as those in which the insect was not pitched out and were characterized by cream to reddish pitch tubes generally containing boring dust. One tree (15-cm size class) was eliminated from the sample because it had numerous apparently successful gallery establishments but was neither dead nor stained 3 months after initial attack.

Each month from August through November 1976, and again in June 1977, two trees were dissected in each size class except for the 48-cm class where one was sampled. Trees were cut 30.5 cm above ground, measured for total length to a 7.6-cm-diameter top, and cut into 2.5-m logs. A 2.5-cm-thick cross section was removed from the base of each log and the 7.6-cm-diameter top, and blue stain was outlined with a felt-tip marker. Annual rings were counted on the stump. Each cross section was photographed with a Polaroid SX-70³ camera using color film. Most photographs were taken from a standard distance; however, large cross sections had to be photographed from a greater distance. A tape measure in the photograph facilitated scale correction.

Pictures were identified by tree number and height of cross section above ground. Surface areas of clear and stained wood were measured on the photograph with an electronic planimeter connected to a Hewlett-Packard model 9830A desk-top computer. This method of measuring provides greater than 95% accuracy in calculating surface areas (W. G. Theis and R. D. Harvey, in preparation). Measurements from photographs were expanded by appropriate factors to represent actual cross-section size. Given that the entire stem between cross-sectional cuts was attacked and stained in proportion to the two ends, the predictable volumes of clear and stained wood

in each 2.5-m log could be calculated by Smalian's formula (volume = height($\frac{1}{2}$ area of base + $\frac{1}{2}$ area of top)). The percentage of volume affected was thus determined for each size class and sample date. However, unless galleries are close enough together so that the associated lenticular-shaped areas of stain (Reid et al. 1967) coalesce for the entire length and girth of the log, this method will not be accurate. To determine the date when mountain pine beetle attacks were initiated, several gallery lengths in four trees were measured during the first sampling period. Average gallery length was divided by a gallery production rate of 1.5 cm per day (Amman 1972; McCambridge 1969) to arrive at an approximate attack date. In some areas mountain pine beetles appear to attack one tree at a time on a moving front over a 3- to 4-week period (H. S. Whitney, personal communication). Although this might be true for the study area, sample trees were in such close proximity to one another that any dating bias would probably be insignificant.

Diameter at breast height and number of successful attacks within 45 cm of breast height were recorded for each tree during sampling. The area between 91.4 and 182.9 cm above ground was chosen for recording attack density and has been shown to contain a high percentage of initial attacks (Rasmussen 1974; Safranyik et al. 1974).

Stepwise regression procedures were used to compare the percentage of tree volume affected by blue stain, the dependent variable, with the number of days since attack and the square root of the number of days since attack.

Results

Average percentage of tree volume stained is presented by tree size class and sampling date (Table 1). Stained wood comprised a smaller percentage of total tree volume in the 15-cm size class, approximately half as much as in other classes. Average age and attack densities for trees in all size classes are presented in Table 2. Although the stand appeared to be even aged, the 48-cm size class had a greater average age than other classes. The square root of the number of days since attack was statistically significant. The regression equation developed to describe rate of spread of blue stain was % blue stain = $-5.057 + 3.465(\text{no. of days})^{1/2}$. Regression was very highly significant ($P = 0.01$) when the

TABLE 1. Average percentage of blue stain (percentage of tree volume^a) in mountain pine beetle killed lodgepole pine in northeastern Oregon

Size class (dbh), cm	No. of days since attack				
	6	40	64	91	288
15	4.46 ^b	7.83	6.38	22.08	28.08
20	4.68 ^b	13.16	9.32	32.70	57.22
28	0.00	17.48	41.76	52.06	65.26
38	0.00	13.05	43.08	49.56	52.48
48	0.00	17.55	36.71	15.73	65.24
Average	1.83 ^b	13.81	27.45	34.43	53.66

^a $n = 2$ except 48-cm class where $n = 1$.

^bStain resulting from previous injury.

²The use of trade, firm, or corporation names does not constitute an official endorsement or approval by the Canadian Journal of Forest Research or the U.S. Department of Agriculture of any product or service to the exclusion of others which may be suitable.

TABLE 2. Average stump age and pitch-tube density of sampled mountain pine beetle killed lodgepole pine in northeastern Oregon, by size class

Size class, cm	Average age, years	Average pitch-tube density, no./m ² ^a
15	79.9	74.28
20	86.0	100.47
28	86.3	101.23
38	83.7	94.00
48	113.0 ^b	78.16

^aSampled between 91.4 and 182.9 cm.

^bIncludes 182-year-old residual from previous stand.

square root of the number of days was included in the equation. Figure 1 presents the predicted increase of blue stain over time as developed by the regression equation.

Discussion

Smaller diameter trees have a lower ratio of sapwood to heartwood than larger trees in an even-aged stand. Since blue stain fungi remains almost exclusively confined to sapwood, the total percentage of volume stained will be lower in small trees. The 15-cm size class exhibited approximately one-half the percentage of total volume stained of the larger size classes although sapwood in this smaller class was completely stained by the last sampling period.

Discrepancy in average age between the 48-cm class and other classes can be partially explained by the small sample size (five) and by the high age (182) of one tree in the class. Size differences resulted from competitive position of individual trees; the 48-cm size class being primarily open grown.

The hypothesis was made that the greater the attack density, the larger the volume of stained wood. Although density of attack did not prove to be a significant variable ($P \geq 0.1$) it is possible that the

effects of individual attacks were masked by the high number of attacks. Blue stain fungi spread through sapwood from points of inoculation. The percentage of volume becoming stained and the spread of fungi from individual inoculation points can be measured if the number of beetle attacks is low. With a large number of attacks, however, individual fungal colonies rapidly coalesce and cannot be followed thereafter.

Although blue stain fungi appears during the first 40 days following bark beetle attack, the volume affected at that time is small and stained wood might be excised completely or nearly completely in trimming logs. However, affected trees may be difficult to locate during this period as foliar color change is slight. By the time easy identification can be made from crown characteristics, about 9 or 10 months after initial attack, more than 50% of the cubic volume or nearly 100% of the sapwood is stained. If, however, a salvage operation is in progress and green infested trees are cut during early fall, an operator could sort and load them separately, thereby maximizing the proportion of clear wood shipped to the mill.

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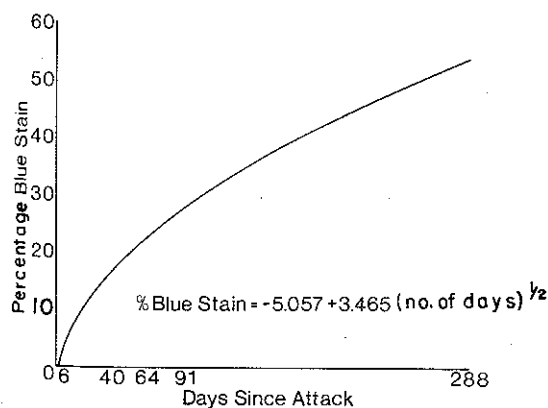


FIG. 1. Predicted increase of blue stain volume in mountain pine beetle killed lodgepole pine in northeastern Oregon.

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