

# Changes in bark beetle susceptibility indicators in a lightning-struck loblolly pine<sup>1</sup>

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Received July 26, 1984

Accepted November 6, 1984

BLANCHE, C. A., J. D. HODGES, and T. E. NEBEKER. 1985. Changes in bark beetle susceptibility indicators in a lightning-struck loblolly pine. *Can. J. For. Res.* 15: 397-399.

Xylem resin flow in a lightning-struck loblolly pine was too low to be measured for the first few days after the strike, but flow was restored after 3 weeks. The content of  $\alpha$ -pinene, camphene and myrcene in the oleoresin increased 3 weeks after the strike while the level of  $\beta$ -pinene showed a dramatic decline. Limonene and  $\beta$ -phellandrene also decreased, but not as dramatically as the decline in  $\beta$ -pinene. The implications of these changes to known bark beetle attack behavior are discussed.

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L'écoulement de résine du xylème d'un pin frappé par la foudre fut trop faible pour être mesuré les premiers jours après l'évènement, mais l'écoulement fut restauré après 3 semaines. La teneur en  $\alpha$ -pinène, en camphène et en myrcène de l'oléorésine a augmenté 3 semaines après l'évènement, alors que la teneur en  $\beta$ -pinène a subi une diminution importante. La teneur en limonène et en  $\beta$ -phellandrene a aussi diminué, mais pas aussi fortement que la diminution de  $\beta$ -pinène. L'article discute des implications de ces changements sur le comportement d'attaque des insectes de l'écorce.

[Traduit par le journal]

## Introduction

Lightning-struck trees appear to be attractive to bark beetles (Thatcher 1960; Johnson 1966; Schmitz and Taylor 1969; Hodges and Pickard 1971; Howe et al. 1971; Lorio and Bennett 1974). Johnson (1966) reported that 80% of all mature ponderosa pines (*Pinus ponderosa* Dougl. ex. Laws.) struck by lightning were attacked and killed by the western pine beetle, *Dendroctonus brevicomis* Le Conte (Coleoptera: Scolytidae). In a survey of infestations by southern pine beetle, *D. frontalis* Zimmermann (Coleoptera: Scolytidae), Lorio and Bennett (1974) found that in August 1965 alone, 77% of the infestations included lightning-struck trees. The nature of this attractiveness is not fully understood, but several hypotheses have been suggested (Johnson 1966; Anderson and Anderson 1968; Hodges and Pickard 1971; Howe et al. 1971; Taylor 1974) and have been recently reviewed (Blanche et al. 1983).

A lightning strike on one of our experimental plots on April 29, 1982 (about 16:00 central standard time) afforded an opportunity to investigate changes in characteristics suspected to influence susceptibility on a lightning-struck loblolly pine. These changes, which may influence the observed preference for lightning-struck pines by bark beetles, are discussed in relation to known bark beetle attack behavior, since there was no beetle activity in the area at the time of sampling.

## Materials and methods

### Plot and tree descriptions

The subject trees for this investigation were on an experimental plot established to study the influence of thinning-related damages on

southern pine susceptibility to pine bark beetles. The stand was established in 1958 from a local seed source. Prior to the lightning strike of April 29, 1982, measurements obtained were total resin flow, initial resin flow rate, oleoresin exudation pressure, stem electrical resistance, and levels of individual monoterpenes. The lightning strike completely removed the crown of one tree. Two major fissures, with strips of bark removed from the top to the bottom occurred on two other adjacent trees. The lightning also caused some soil excavation at the base of the topped tree, exposing a portion of the root system. Only one of the struck trees (dbh = 23 cm) was intensively studied since the other struck tree did not have measurements prior to the strike. A tree of similar size and crown class on which measurements of total resin flow and monoterpene concentrations had been made was used as a control. The tree was about 25 m from the struck tree.

### Resin sampling

Xylem resin was collected at breast height by drilling a hole (0.95 cm diameter  $\times$  2.54 cm deep) through the bark and into the outer layers of the xylem. A section of glass tubing 10 cm long with an internal diameter of 2.5 mm and an external diameter of 9.0 mm was driven into the hole leaving a gap between the end of the tube and the end of the hole to serve as a resin reservoir. Resin was collected by attaching a 10-mL pipette, with the bottom end cut and stoppered with a cork, to the external end of the flow tube. Total resin flow for an 8-h period was read directly from the pipette. Resin flow from the struck tree and control tree was determined on four occasions: April 30 (1 day after the strike), May 1, May 10, and May 20, 1982.

After measuring total flow, an aliquot of the resin was placed in a 1-dram vial and stored in a freezer until analysis. Monoterpene analysis was performed on a Hewlett-Packard 5830A gas chromatograph equipped with flame ionization detector. A 2.44-m glass column, with internal diameter of 2 mm and packed with 10% Carbowax 20M on 80- to 100-mesh acid-washed Chromosorb W, was used. Samples were run isothermally at 115°C using *n*-heptane as the solvent and *p*-cymene as the internal standard. Carrier flow rate was 20 mL N<sub>2</sub> per minute. Detector and injection port temperatures were 200 and 225°C, respectively. Identity of the monoterpenes was verified by comparing the relative retention times of these compounds with those of authentic monoterpene samples and enrichment chromatography. Quantification of monoterpenes was accomplished by using the response factor for each monoterpene relative to *p*-cymene. Monoterpene quantities were expressed in milligrams per 100 mg of oleoresin.

<sup>1</sup>Journal contribution No. 5772 of the Mississippi Agricultural and Forestry Experiment Station. This study was supported by the Integrated Pest Management Research, Development and Applications Program, Pineville, LA, United States Forest Service grant 19-82-023, Mississippi State University and Mississippi Agricultural and Forestry Experiment Station. The findings, opinions, and conclusions are the responsibility of the authors.

<sup>2</sup>Revised manuscript received November 2, 1984.

TABLE 1. Changes in the levels of monoterpenes (milligrams per 100 mg oleoresin) and total resin flow (millilitres per 8 h) in lightning-struck and control trees

Variables	Before lightning strike (April 1, 1982)		After lightning strike*			
	Struck tree	Control tree	May 10, 1982		May 20, 1982	
			Struck tree	Control tree	Struck tree	Control tree
<b>Monoterpenes</b>						
$\alpha$ -Pinene	21.43	25.38	20.20	18.60	34.65	23.42
$\beta$ -Pinene	9.11	7.16	0.24	5.32	0.33	6.38
Limonene	1.12	4.07	0.23	2.88	0.29	3.54
Myrcene	0.31	0.44	0.26	0.29	1.13	0.38
$\beta$ -Phellandrene	0.31	Trace	0.07	Trace	0.15	Trace
Camphene	0.24	0.26	0.24	0.20	0.39	0.21
Unknown 1	0.01	—	0.05	0.04	0.04	0.04
Unknown 2	0.02	0.03	0.03	0.02	0.02	0.01
Total resin flow	0.99	2.11	0.09	1.80	2.10	2.00

\*The lightning discharge took place on April 29, 1982 at 1600.

## Results and discussion

### Total resin flow

No oleoresin exudation could be detected in the lightning-struck tree for at least 3 days following the strike. Eleven days after the strike (May 10, 1982), a small amount of exudate was obtained (Table 1). The flow was about one-tenth of that before the strike on the 11th day, but after 21 days flow had increased and was about 2.3 times as high as before the strike. Resin flow in the control tree was relatively constant during the observation period, thus indicating a stimulation of flow in the struck tree after 21 days. The lack of xylem resin flow during the first few days after the strike can be attributed to reduced resin pool size and to extremely low oleoresin exudation pressure (OEP), which is a result of the loss of turgidity of the epithelial cells. Hodges and Pickard (1971) demonstrated that OEP dropped to as low as 0.04 atm (1 atm = 101.325 Pa) near the lightning-damaged portion of the stem as opposed to an average OEP of 7.7 atm in the control trees.

Total flow of loblolly pine resin has been implicated as the first major line of defense against southern pine beetle attacks (Hodges et al. 1979). Anderson and Anderson (1968) found that *Ips* were unsuccessful where oleoresin exudation rate exceeded 0.1 mL per hour from a standard wound (circular wound using a No. 5 cork borer). In a controlled attack study using southern pine beetle, Hodges et al. (1979) found that a marked decline in OEP, total resin flow, and resin flow rate above and below the infested zone rendered the host relatively defenseless.

Hence, lightning strikes are responsible for creating windows of host vulnerability, the width of which may depend on the extent of damage and the ability of the struck tree to recover. Since xylem resin flow is one of the most significant factors in host resistance against bark beetle attacks, its absence in struck trees therefore renders the tree extremely susceptible for a period of time.

### Monoterpenes

Dramatic changes in the levels of monoterpenes were observed in the lightning-struck tree (Table 1).  $\alpha$ -Pinene was 71% higher on May 20 than on May 10, and the level of May 10 was no different from the level before the strike. In the same period, myrcene and camphene followed the same pattern of increase, with myrcene exhibiting more than a threefold

(335%) increase. The most significant decline was in  $\beta$ -pinene. The level on May 10 was 37 times (3696%) lower than before the strike and continued at this level to May 20. Limonene and  $\beta$ -phellandrene decreased in similar fashion but in an attenuated manner. Unknown monoterpene 1 increased fourfold after the strike and then leveled off. Unknown monoterpene 2 was relatively unchanged.

The monoterpenes are known to be involved in the intriguing chemical communication of southern pine bark beetles (*Dendroctonus* and *Ips*).  $\alpha$ -Pinene is considered the most important host tree volatile in the behavioral complex of the southern pine beetle (Renwick and Vite 1969). It synergizes the attractive property of frontalin in aggregating beetles on host trees (Kinzer et al. 1969). Moreover,  $\alpha$ -pinene is metabolized by the southern pine beetle and black turpentine beetle into *cis*- and *trans*-verbenol (Hughes 1975). While only *D. ponderosae* (Hopkins) is known to use *trans*-verbenol as an attractant (Pitman et al. 1968), it synergizes the activity of frontalin and even substitutes for  $\alpha$ -pinene and loblolly turpentine in attracting flying beetles (Payne et al. 1978). Therefore, the significant increase of  $\alpha$ -pinene makes a lightning-struck tree a very attractive host.

$\beta$ -Pinene, by itself, has not been demonstrated to exhibit an attractant property to bark beetles. However, it has been shown to be oxidized by the southern pine beetle into *trans*-pinocarveol and pinocarvone (Renwick et al. 1973). Heikkinen and Hrutfiord (1965) found that  $\beta$ -pinene repels the Douglas-fir beetle (*Dendroctonus pseudotsugae* Hopkins). They also found that a high ratio of  $\alpha$ -pinene to  $\beta$ -pinene was related to attacks on standing trees. The lightning-struck loblolly pine tree had an  $\alpha$ -pinene to  $\beta$ -pinene ratio of 84:1 as opposed to 2.3:1 before the strike. The control tree had a ratio of 3.5:1 over the same time period. It seems possible that the sharp decline in  $\beta$ -pinene could be contributory to the attractiveness of a lightning-struck tree.

Myrcene serves as precursor in the synthesis of *Ips* pheromones, ipsenol and ipsdienol (Hughes 1974; Hendry et al. 1980). This monoterpene is also known to enhance the response of the western pine beetle to the female-produced attractant, bicyclic ketal exobrevicomin (Bedard et al. 1969). Hence the threefold increase of myrcene in the struck tree may contribute to the aggregation of bark beetles, especially the *Ips*.

Limonene has been shown in bioassays to have toxic properties to *Dendroctonus* beetles. Coyne and Lott (1976) found this monoterpene to be the most toxic monoterpene to the southern pine beetle. Smith (1963) rated limonene as the most toxic among monoterpenes present in pines to three species of *Dendroctonus*. Therefore, a decline in limonene may increase the attractiveness of a host.

Very little is known about the role of camphene in bark beetle communication. The general observation is that it is involved in the aggregation of *Dendroctonus* spp. (Furniss and Schmitz 1971; Rudinsky 1966).

Overall, it appears that in a lightning-struck tree, the monoterpene fractions that have attractive or synergistic properties increase, while those with repellent or relatively toxic properties decrease. Hence the attractiveness of a lightning-struck tree may be dependent on the quantitative changes in the monoterpene components of the resin.

Therefore, in light of current knowledge, the observation that lightning-struck trees almost invariably serve as focal points of bark beetle infestations may be the result of one or all of the following: (a) increased susceptibility owing to the absence of or reduction in xylem resin flow immediately after the strike; (b) increased attractiveness as a result of quantitative changes in the monoterpene fractions; and (c) increased suitability owing to carbohydrate alteration and reduction in the relative water content of the bark (Hodges and Pickard 1971).

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