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Management implications of inhibitors for Dendroctonus frontalis (Col. Scolytidae)[1,2]

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A *Dendroctonus frontalis* infestation was treated with a mixture of the inhibitors *endo-* and *exo*-brevicomin and verbenone placed on host trees. The treatment effected an 84% reduction in landing, a 92% reduction in gallery construction and an 88% reduction in estimated eggs laid compared to data from control trees. Significantly more *Ips avulsus* landed on treated trees and constructed more galleries than on control trees. There were no significant differences in the numbers of the predator *Thanasimus dubius* caught on treated vs. control trees.

The southern pine beetle, *Dendroctonus frontalis* ZIMMERMAN, is recognized as the most destructive forest insect pest in the southern United States. In addition, it causes extensive damage in Mexico and Central America. Since 1976, infestations in the United States have occurred in over 30 million hectares of pine forests.

Research and development efforts aimed at suppressing infestations of *D. frontalis* have been limited and fragmented since A.D. HOPKINS first reported the pest in the southeastern United States in the late 1800's. However, within the last fifteen years intensive efforts have been underway to develop effective controls against the pest. In this regard, behavioral chemicals offer considerable potential for use in management of populations of *D. frontalis,* although to date, they have not yet been integrated into management systems.

Several behavioral chemicals are believed to mediate the secondary attraction behavior of *D. frontalis* (BORDEN, 1974; VITÉ *et al.,* 1964; PAYNE *et al.,* 1978). Of these compounds, those considered as attractants or inhibitors would appear to offer the greatest potential for use in pest management. Efforts have been carried out to evaluate the effectiveness of the attractant mixture frontalure (frontalin, 1,5-dimethyl-6,8-dioxabicyclo [3.2.1] octane, KINZER *et al.,* 1969, plus *alpha*-pinene) in a trap-tree application incorporating the herbicide, cacodylic acid (VITÉ, 1970). The method resulted in limited success and was influenced by several variables (COULSON *et al.,* 1973ab, 1975). In an aerial application, frontalure was also evaluated for its effectiveness in suppressing an infestation through disrupting communication of flying beetles and the process by which they colonize new host trees (VITÉ *et al.,* 1976). The treatment did not reduce attack by the beetles and resulted in increased aggregation on host trees.

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Subsequent efforts toward developing behavioral chemicals for use in managing *D. frontalis* populations have focused on inhibitors. In concept, inhibitors have obvious potential for use in the prevention of beetle attacks on individual trees. In addition, inhibitors appear to offer potential for use in infestations to increase dispersal flights, and hopefully, in-flight mortality.

Results from earlier field bioassays showed that the aggregation of *D. frontalis* on attractant-baited traps could be significantly reduced with the addition of one or more inhibitors. Vité & Renwick (1971) found that *endo-* and *exo-*brevicomin (7-ethyl-5-methyl-6,8-dioxabicyclo [3.2.1] octane, Silverstein *et al.,* 1968) greatly reduced response to frontalure-baited traps. Based on these results and their own findings, Payne *et al.* (1977) evaluated a controlled release formulation of the compounds to determine their effect on flight and landing behavior of *D. frontalis.* The inhibitors effected a 70% reduction in landing trap catch on host trees compared to catches without the presence of inhibitors. Later field bioassays revealed that the addition of verbenone to *endo*-brevicomin resulted in an even greater inhibitory effect (Payne *et al.,* 1978). These results led to the following effort to demonstrate the potential of inhibitors to protect individual host trees from attack by *D. frontalis* within an active infestation.

MATERIALS AND METHODS

The investigation was conducted in an active *D. frontalis* infestation in loblolly pine *(Pinus taeda)* - mixed hardwood forests in San Jacinto County, Texas. The infestation had ca. 10 newly attacked trees with an estimated basal area/acre of ca. 150 sq. ft., with ca. 88 trees/ha (host and non-host trees).

Pines selected as test trees were of similar diameter (DBH) (X ± SE DBH = 29.0 ± 1.8 cm) and height (X ± SE height = 25.7 ± 1.2 m). Only pines showing no evidence of *D. frontalis* visitation were selected (e.g., no pitch tubes, no boring dust, and no clerid predators swarming on the pine bole). There was a control (= untreated) tree for each treated tree.

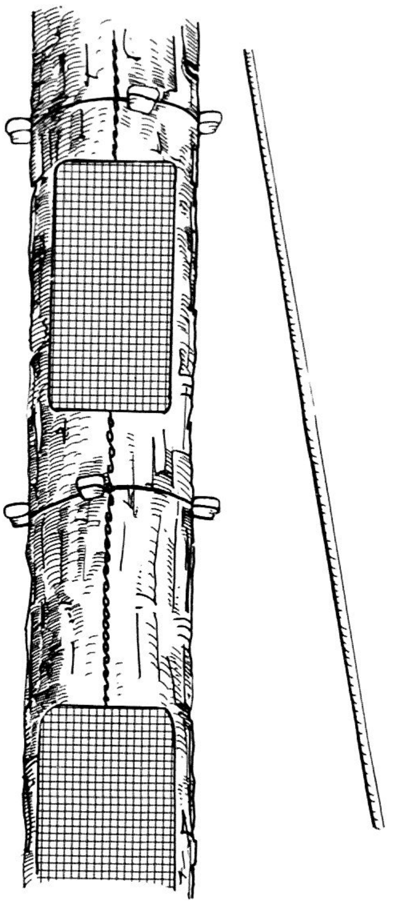
Treated and control trees were ca. 3–4 m apart. They were initially located ca. 10 m from the most recently attacked trees. Host tree and non-host tree spacing was non-uniform. Pines were estimated to be ca. 2–4 m apart.

The inhibitors were 99% pure via GLC analysis. Polyethylene caps were used as elution containers (Glass *et al.,* 1970). The release rate of each inhibitor was determined gravimetrically; the brevicomin isomer mixture and verbenone eluted at 10 mg/day/cap and 5 mg/day/cap at 25–28 °C, respectively. Sufficient compound (500 µl) was placed in each cap to provide up to 50 days of release of the inhibitors.

Treatment

A 50:50 *endo-* and *exo-*brevicomin mixture + verbenone treatement was evaluated at the 32 caps/tree. A total of 16 caps containing verbenone was placed at 2, 4, 6, and 8 m, 4 caps/height. A total of 16 caps containing the 50:50 *endo- exo-*brevicomin mixture was placed at 3, 5, 7, and 9 m, 4 caps/height (fig. 1). The test was conducted from August 12 to September 1, 1977.

Fig. 1:
Diagram of pine bole
with landing traps
and inhibitor elution caps.



Monitoring beetle activity

Activity of *D. frontalis* was monitored by:

(1) daily counts of the number and sex of beetles caught on unbaited landing traps on test trees,
(2) daily inspection of the infestation for evidence of fresh beetle activity, and
(3) an estimate of beetle attack density and brood production from a series of 100 cm^2 bark samples taken from each test tree at the conclusion of each test.

Landing trap catch: Data from daily trap catches were used as an indicator of the intensity of *D. frontalis* and associated insect activity on treated and control trees. The landing traps were single 15 x 30 cm pieces of ⅓ cm mesh hardware cloth (fig. 1). Each trap was coated with Stickem-Special®[3]. There were 4 traps/ tree suspended by a chain to facilitate raising and lowering for collecting beetles. In position, a single trap was located at 3, 5, 7, and 9 m and was in contact with bark surface on each test tree. All landing traps were picked clean of *D. frontalis* and *Ips* ssp. (Coleoptera: Scolytidae) by 10.00 hr CDT each day. *Thanasimus dubius* (SAY), a clerid predator of the *D. frontalis,* was monitored in the same manner as an indicator of scolytid activity and to determine if the inhibitors affected

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[3] Michael and Pelton Co., Emeryville, CA.

the predator's aggregation behavior (CAMORS & PAYNE, 1973; DIXON & PAYNE, 1978). Beetles collected from each trap were placed in separate vials labelled with the appropriate information of trap height, tree identification number and date. All *D. frontalis* were counted and sexed on the day of collection. All *T. dubius* were counted the day of collection. The *Ips* spp. were counted and sexed after the test series was concluded because of the large number of beetles and the tediousness of sexing. Landing traps were monitored until the peak catch of *D. frontalis* had passed and the catch had dropped to an arbitrarily chosen 5 beetles/trap.

Assessing beetle activity: Each infestation was inspected daily to locate all newly attacked trees (in addition to the treated and control trees). Freshly attacked trees were flagged and marked with the Julian date.

Bark sampling: At the conclusion of trap monitoring, a single bark sample (100 cm^2) was taken at each of the 4 landing trap heights on either side of the trap. The number and length of all *D. frontalis* and *I. avulsus* galleries were recorded.

RESULTS AND DISCUSSION

Dendroctonus frontalis

Landing trap catch

Daily trap catch data indicated that all control trees in each of the test series had undergone the mass attack phenomenon described by COSTER *et al.* (1977). In

Table 1: Landing trap catches of *Dendroctonus frontalis* on inhibitor-treated and control trees.

	$\bar{X}$ ± SE beetles caught/tree[ab]		
Trap height(m)	Treated (n=3)	Control (n=3)	F prob.[c]
3	45 ± 16 a	181 ± 40 ab	*
5	46 ± 2 a	236 ± 78 a	*
7	15 ± 3 b	201 ± 74 a	*
9	8 ± 1 c	85 ± 34 b	*
Total catch	343	2108	*

[a] Means and SE are rounded to nearest whole number.

[b] Means followed by same letter within columns are not significantly different at the 5% probability level based on pairwise comparison of means using a one-way analysis of variance.

[c] One-way analysis of variance based upon pooled trap catch data/treatment. * = 5% probability.

Table 2: Gallery lengths of *Dendroctonus frontalis* from 100 cm^2 bark samples from inhibitor-treated and control trees.

Sample height (m)	$\overline{X}$ ± SE gallery length (mm)[ab] Treated (n)	Control (n)
3	66 ± 10 (5)	65 ± 5 (41)NS
5	73 ± 12 (5)	82 ± 7 (28)NS
7	120 ± 0 (1)	63 ± 6 (34)*
9	89 ± 27 (3)	89 ± 27 (25)NS

[a] Gallery lengths based upon 1 sample/height. Means and SE rounded to nearest whole number. n = number of galleries.

[b] One-way analysis of variance calculated on total number of gallery lengths/ height/treatment. F probability level: * = 5%, NS = non-significant.

the first 4 days of attack, beetle catches were concentrated at 3–5 m with more females than males caught. Over 60% of the total numbers of beetles caught over the trapping period were taken during the first 3 days. None of the inhibitor-treated trees underwent mass attack by *D. frontalis*. Significantly fewer beetles were caught on landing traps on the inhibitor-treated trees than on the control trees, an 84% reduction (table 1). There was a greater percent reduction in trap catch at 7 and 9 m (> 90%) than at the lower traps (< 81%) (table 1).

The vertical distribution of *D. frontalis* caught on treated and control trees was not significantly affected by the inhibitor treatment (table 1) (χ^2 prob. < 5%). In general, the number of the beetles caught decreased with increased trap height. This is in accordance with data reported for the distribution of natural populations of *D. frontalis* landing on untreated trees (COSTER *et al.*, 1977).

Less than 50% of the total number of beetles trapped were females. The sex ratio was variable (range 0.21–4.3, female/male). This wide range was evident at each trap height and between days of the tests and may have been due to the duration of the test. Sex ratios of beetles at trees under attack varies by time of day, height of attack on the tree, and day of attack (COSTER *et al.*, 1977). Traps were monitored through practically all phases of beetle attack: pre-attack, initial attack, mass attack, post-mass attack and re-emergence of parent adults. In spite of the variation, the overall sex ratio (ca. 1:1) is generally in agreement with those previously reported (see COSTER *et al.*, 1977).

Bark sampling

There were significantly fewer total numbers of *D. frontalis* galleries in the inhibitor-treated trees; an 89% reduction (table 2). However, the mean length of beetle galleries on the inhibitor-treated trees was not different from that in the control trees (table 2).

FOLTZ *et al.* (1976) reported an average of 1.59 eggs/cm of gallery length. Using this estimation of egg production, the inhibitor treatment affected an 88% reduction in the estimated number of eggs laid in the treated trees (table 3).

Table 3: Estimated percent reduction in the total number of *Dendroctonus frontalis* eggs laid in inhibitor-treated vs. control trees[a,b]

Trap height (m)	Inhibitor Treatment % Reduction
3	88
5	84
7	94
9	84
$\bar{X}$ Total	88

[a] Based on Foltz et al. (1976) estimator of 1.59 eggs/cm gallery length.

$$\frac{\text{No. of eggs in control trees - no. eggs in treated trees}}{\text{No. eggs in control trees.}} \times 100$$

[b] % = rounded to nearest whole number.

Associated insects

I. avulsus was the most abundant of the various associated insects trapped on the treated and control trees. The inhibitors affected a substantial increase in the number of *I. avulsus* on treated trees (table 4). The cause of this increase is not understood. We suggest that the inhibitors may function as «sign» stimuli which enable *I. avulsus* to locate host trees suitable for attack. The sequence of arrival of *I. avulsus* generally follows attack by *D. frontalis* (THATCHER, 1961; DIXON, 1977) at a time when the inhibitors would likely be present.

The vertical distributions of *I. avulsus* caught on treated trees was altered from that on control trees (table 4).

There were significantly more *I. avulsus* galleries in treated trees than in control trees (table 5). The distribution of galleries was uniform over all sample heights for inhibitor-treated trees (table 5). *Ips* galleries were not found in control trees.

There were no significant differences in the mean numbers of *T. dubius* caught on treated and control trees. Approximately 70% of the *T. dubius* were trapped at the 3 and 4 m heights, which is in agreement with previously reported data for *T. dubius* (DIXON & PAYNE, 1978). These findings suggest that the use of inhibitors in *D. frontalis* pest management would not affect either the numbers or distribution of this predator.

Evaluation of efficacy of treatments

We failed to achieve our primary goal of protecting individual trees in an active *D. frontalis* infestation by providing them with an «olfactory barrier»

Table 4: Landing trap catches of *Ips avulsus* on inhibitor-treated and control trees.

Trap height (m)	$\bar{X}$ ± SE beetles caught/tree[ab] Treated	Control	F prob.[c]
3	139 ± 7 a	14 ± 1 a	*
5	111 ± 5 a	17 ± 1 a	*
7	114 ± 5 a	42 ± 2 b	*
9	97 ± 3 a	67 ± 2 c	NS
Total catch	1390	402	

[a] Means and SE are rounded to nearest whole number.

[b] Means followed by same letter within columns are not significantly different at the 5% probability level based on pairwise comparison of means using a one-way analysis of variance.

[c] One-way analysis of variance based upon pooled trap catch data/treatment. * = 5% probability, NS = non-significant.

(BORDEN, 1977). The inhibitors did not provide sufficient protection to prevent fatality, although mass attack by *D. frontalis* did not occur. Even though inhibitor-treated trees showed highly significant reduction in total numbers of attacking beetles and estimated egg deposition, the treated trees still died from beetle attack. The increased *I. avulsus* activity could have been responsible for this tree mortality, either by their own attack or in conjunction with the *D. frontalis*. This *Ips-D. frontalis* interaction requires further study to insure we do not cause «competitive

Table 5: Gallery lengths of *Ips avulsus* from 100 cm^2 bark samples from inhibitor-treated and control trees.

Trap height (m)	$\bar{X}$ ± SE gallery lengths (mm)[a] Treated (n)	Control (n)	F prob.[b]
3	50 ± 4 (31)	0 ± 0 (0)	1%
5	57 ± 5 (37)	0 ± 0 (0)	1%
7	59 ± 5 (44)	0 ± 0 (0)	1%
9	41 ± 3 (32)	0 ± 0 (0)	1%

[a] Measurement based upon 1 sample/height. Means and SE round to nearest whole number. n = number of galleries.

[b] One-way analysis of variance calculated on individual gallery lengths/height.

replacement» of the *D. frontalis* by *Ips*. However, the apparent reduction in egg deposition may have a negative impact on the subsequent population dynamics in the infestations and therefore, has management implication. Conceivably, the presence of the inhibitors in an infestation area over an extended period of time (60 days) could affect brood production through reduced attack and egg laying, and subsequently the syncrony of pheromone production and beetle emergence. Such an effect could result in an early demise of beetle activity in the infested area. The interaction between *D. frontalis* and *I. avulsus* evident in our study suggests that use of only the inhibitors reported here to protect individual uninfested trees will not succeed. However, it is possible that a broadcast application of these compounds to inhibit beetles from perceiving and/or responding to attractant behavioral chemicals may succeed. The necessary tests and evaluations are currently underway to determine if these inhibitors can be developed in this regard.

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