A *Scents*ible Approach to Controlling Southern Pine Beetles

Two New Tactics Using Verbenone

Two new tactics for controlling southern pine beetle infestations use a beetle-produced inhibitor: verbenone. The techniques, verbenone-only and verbenone-plus-felling, reduce tree loss by disrupting infestation growth. In three years of field tests, the verbenone-only tactic completely suppressed 69 percent of the treated infestations, and the verbenone-plus-felling tactic suppressed 86 percent. The tactics provide much-needed alternatives to current control techniques and will allow suppression of infestations where tree felling is restricted or prohibited. In anticipation of registration of the pheromone by the Environmental Protection Agency, a technology transfer program has been developed to provide the materials and training necessary for effective use of the treatments.

By Stephen R. Clarke, Scott M. Salom, Ronald F. Billings, C. Wayne Berisford, William W. Upton, Quintin C. McClellan, and Mark J. Dalusky

Many insects, including bark beetles, emit chemicals known as pheromones to communicate with members of their own species. Pheromones produced by insects serve a variety of functions, including sexual attraction, aggregation on suitable hosts, warning signals, and inhibition of oviposition. In forestry, scientists have developed methods of using insect pheromones for such purposes as monitoring populations and disrupting the mating of forest pests (Skillen et al. 1997). Pheromones have also shown promise for preventing or reducing losses of forest trees to bark beetles, including the southern pine beetle, *Dendroctonus frontalis* (Payne and Billings 1989; Billings et al. 1995; Goyer et al. 1998).

The southern pine beetle is the most important forest insect pest of southern pines in the United States, periodically causing economic losses in excess of $200 million annually (Price et al. 1997). From late spring through early fall, most beetles are concentrated in expanding infestations called spots. When spots are small, new attacks are generally concentrated in one area on the periphery of the infestation. Spots tend to expand in only one direction. Direct control measures can be applied to these spot "heads," stopping further spot growth and reducing tree loss (Swain and Remion 1981). Four methods of direct control are available:

• *Cut-and-remove.* All currently infested trees plus a buffer of uninfested

Ronald F. Billings

In an active southern pine beetle infestation, or "spot," light green trees are currently infested and indicate the direction of spot growth.

Reprinted from the *Journal of Forestry,* Vol. 97, No. 7, July 1999. Not for further reproduction.

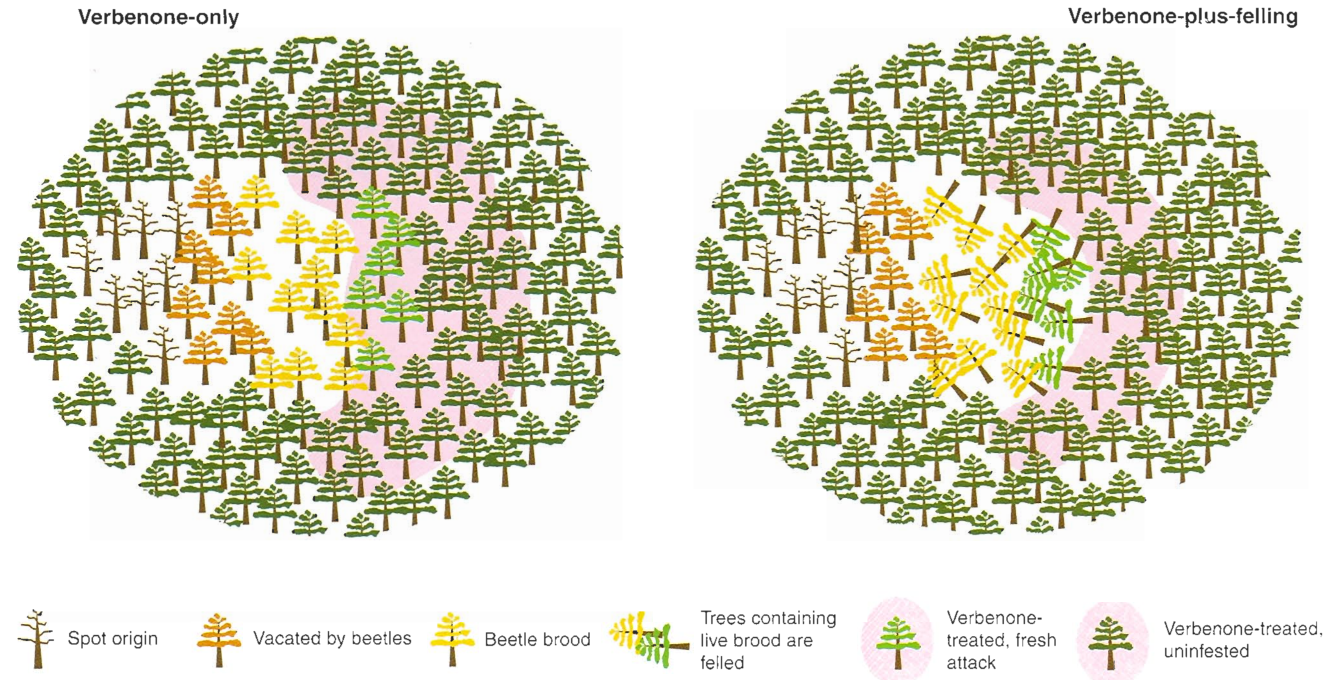


***Figure 1.* Schematic of verbenone-only and verbenone-plus-felling tactics. Note the increased size of the treated buffer for the verbenone-only treatment.**

pines around the expanding spot head are felled and removed.

- *Cut-and-leave.* All currently infested trees plus a buffer of uninfested pines around the expanding spot head are felled toward the center of the spot and left in place.
- *Cut-and-hand-spray.* All currently infested trees are felled toward the center of the spot and bucked into sections; the entire bark surface is sprayed with an approved insecticide.
- *Pile-and-burn.* All currently infested trees are felled toward the center of the spot, pushed into a pile, and burned.

Those control methods generally halt spot growth and reduce tree loss, usually with one application (Redmond and Nettleton 1990). During 1992–93, infestations in Texas in nonwilderness areas where cut-and-remove or cut-and-leave were promptly applied averaged only 1 acre, whereas untreated spots in wilderness averaged over 41 acres per infestation (Billings 1995). Cut-and-remove is generally the treatment method of choice because the landowner receives a monetary return on the treated trees. On national forest land, cut-and-remove was the method used on 78.8 percent of treated spots, with cut-and-leave applied 16.4 percent of the time (USDA-FS unpubl. data). Cut-and-hand-spray and pile-and-burn are seldom used.

All those suppression techniques involve tree felling; cut-and-remove and cut-and-leave also require the felling of an uninfested buffer around the expanding head of the infestation. Felling—whether of infested or uninfested trees—often is not desirable, however, because of management objectives. Also, environmental conditions, limited availability of felling crews, or poor markets for the wood during epidemics may delay the implementation of control measures. New treatment options are needed to overcome such limitations.

Suppression with Verbenone

Southern pine beetles use a complex of behavior-modifying chemicals to aggregate on and mass-attack hosts, then spread the infestation to adjacent pines (Gara 1967; Renwick and Vité 1969). Verbenone is one such pheromone, produced primarily by male beetles, which at high concentrations inhibits aggregation of both sexes (Rudinsky 1973). Thus, verbenone helps prevent overcolonization of hosts and shifts the focus of attack to adjacent pines, leading to spot expansion.

The inhibitory effect of verbenone on aggregation suggested that placing synthetic verbenone on uninfested trees at the leading edge of an infestation might disrupt spot growth. Presumably, the beetles would disperse, and most would die before reaching other infestations or initiating new attacks, particularly during summer months. Payne et al. (1978) demonstrated that high concentrations of verbenone significantly reduced the number of beetles caught when added to traps baited with southern pine beetle attractants. Further research led to the development of effective verbenone-elution devices, and continued field-testing indicated that verbenone applications could successfully disrupt infestations (Payne and Billings 1989; Payne et al. 1992; Salom et al. 1992; Billings and Upton 1993; Billings et al. 1995). The results of these trials were used to develop standardized operational techniques (detailed below) for two tactics using verbenone to suppress infestations: verbenone-only and verbenone-plus-felling (Salom et al. 1997).

For the verbenone-only treatment, all freshly attacked trees plus a buffer of uninfested trees are treated with verbenone *(fig. 1, left).* The elution

Table 1. Number of verbenone pouches per tree based on tree diameter at breast height (DBH).

DBH range (inches)	Pouches per tree
≤4	1
5–8	2
9–14	3
15–17	5
18–19	7
≥20	9

Table 2. Minimum number of verbenone pouches required for southern pine beetle infestation treatment using the verbenone-only tactic, at 40 milliliters of verbenone per square foot of infested trees, and the verbenone-plus-felling tactic, at 25 milliliters of verbenone per square foot of infested trees.

Pouches required for verbenone-only method

Average DBH	*Currently infested trees* 10	20	30	40	50	60	70	80	90	100	110	120
6 inches	50	50	50	63	79	95	110	126	142	157	173	189
8	50	56	84	112	140	168	196	224	252	280	308	335
10	50	88	131	175	218	262	306	349	393	437		
12	63	126	189	252	315	377	440	503				
14	86	171	257	342	428	513	599	684				

Pouches required for verbenone-plus-felling method

Average DBH	*Currently infested trees* 10	20	30	40	50	60	70	80	90	100	110	120
6 inches	50	50	50	50	50	60	70	80	90	100	109	118
8	50	50	54	70	88	105	122	140	158	175	192	210
10	50	55	82	109	137	164	191	218	246	274	300	328
12	50	80	120	160	200	240	280	320	360	400	432	472
14	54	107	161	214	267	322	374	428	481	534	588	642
16	70	140	210	280	349	419	489	558	628	698	768	

device is the verbenone pouch, provided by Phero Tech Inc., Delta, British Columbia. The device consists of a 4.5-by-7-centimeter cellulose sponge containing 5 milliliters of a 34 percent [+] : 66 percent [–] mixture of verbenone and sealed in a 6.5-by-10-centimeter, 1.5-mil white polyethylene pouch. The pouch is designed to elute verbenone for 40 to 50 days, longer than one generation of southern pine beetles. The pouches are tacked to trees at a height of about 4 meters using a tool called the Hundle hammer. The number of pouches per tree is based on tree diameter *(table 1);* the number of currently infested trees and the average tree diameter determine the total number of pouches applied *(table 2).* The treated buffer must extend for at least 12 meters or three rows of trees beyond the last infested tree. This buffer is comparable to the buffers used for cut-and-remove and cut-and-leave treatments.

Similar tables were developed for the verbenone-plus-felling tactic *(table 2).* For this tactic, verbenone pouches are deployed on uninfested trees in a buffer around the expanding spot head, and then all currently infested trees are felled toward the center of the spot *(fig. 1, right).* The treated buffer must be at least 8 meters wide and include two rows of trees.

Neither treatment is recommended if the average tree diameter exceeds 41 centimeters or the number of infested trees exceeds the upper bounds given in the tables. The tactics are most effective when applied in warm weather, generally when the daily high temperature reaches 27° C (80° F) or higher.

Field Tests and Results

The standardized procedures were tested in infestations throughout the southeastern United States in 1995–97. All infestations were monitored for at least one week before treatment, then weekly for six weeks when possible. The pretreatment monitoring period ensured that only active, expanding infestations were treated and allowed for comparisons in the rate of spot growth. The infestations were in stands of loblolly pine *(Pinus taeda),* shortleaf pine *(Pinus echinata),* or pond pine *(Pinus serotina).* The number and diameter of new infested trees were recorded on each visit. Three spots treated by felling only the infested trees (no verbenone buffer) and 28 untreated spots also were monitored weekly for up to six weeks for comparative purposes. At the end of the six-week posttreatment monitoring period, treatment efficacy was evaluated as follows:

Total suppression. Spot growth was stopped within six weeks and spot did not advance beyond treated buffer.

Partial suppression. Treatment reduced the rate of spot growth by 50 percent or more in six weeks, but attacks extended outside the treated buffer.

Ineffective. Treatment failed to reduce spot growth by at least 50 percent in six weeks.

Treatment by either tactic reduced mean spot growth to less than 0.5 trees per day *(table 3),* while untreated infestations grew at a rate of almost two new infested trees per day. The mean numbers of new trees attacked during the posttreatment period were 16 for verbenone-only and 13.5 for verbenone-plus-felling, less than half the number of trees that would normally be cut in a buffer. For the verbenone-only tactic, 31 of the 45 spots were totally suppressed, four were partially suppressed, with 10 ineffective treatments. Eighteen of the 21 infestations treated by verbenone-plus-felling were totally suppressed, two were partially suppressed, and only one treatment was ineffective. Spots treated by verbenone-plus-felling tended to be larger than infestations treated by verbenone-only. All 28 untreated infestations expanded during the monitoring period, and the growth rate for 22 of them averaged one or more trees per day—an indication that most infestations would not have become inactive without treatment during the period of the study. The verbenone buffer was essential for successful treatment, as all three treatments of felling-only were ineffec-

Table 3. Growth rates of southern pine beetle infestations treated by verbenone-only, verbenone-plus-felling, and felling-only, plus untreated checks (1995–97).

Treatment	Infes-tations	Mean DBH (inches)	Infested trees at treatment		Trees killed per day: Pretreatment		Trees killed per day: Posttreatment		Mean monitoring period (days) posttreatment	New trees attacked	
			Mean	Range	Mean	Range	Mean	Range		Mean	Range
Verbenone-only	45	9.2	45.7	15–101	1.5	0.3–4.1	0.4	0–2.0	37.9	16.0	0–84
Verbenone-plus-felling	21	9.0	75.4	30–125	2.1	0.3–4.6	0.3	0–2.4	41.2	13.5	0–94
Felling-only (no verbenone)	3	8.5	45.0	20–74	1.1	0.5–1.8	0.7	0.4–1.0	39.0	24.0	16–32
Untreated checks	28	9.5	55.1	18–158	1.8	0.3–7.7	*		36.1	65.4	13–306

**Infestations not treated. Pretreatment growth rate applies to entire monitoring period.*

tive. Billings and Upton (1993) had previously demonstrated that felling only infested trees, without including a buffer of uninfested trees treated either by felling or with verbenone, significantly reduced spot growth in only 40 percent of treated infestations.

The percentages of spots totally suppressed by verbenone-plus-felling and verbenone-only in our studies, 86 percent and 69 percent respectively, are slightly lower than the success rate of 90 percent for cut-and-leave treatments from 1987 to 1991 (USDA-FS unpubl. data). Nevertheless, foresters may determine that the value of trees protected by not felling a buffer may justify the slightly increased risk of using the verbenone treatments in situations where removal is not feasible.

Treatment Costs

Cut-and-remove will likely remain the most widely applied treatment for southern pine beetle infestations, and the verbenone tactics will generally be considered alternatives to cut-and-leave or for use in situations where tree-felling is limited or prohibited. Treatment costs for the verbenone tactics should be comparable to those for cut-and-leave treatments (see "Cost Comparison," p. 30). At an estimated $4 per pouch, verbenone may seem expensive, but this cost is offset by the stumpage value of the buffer trees that would be sacrificed in the cut-and-leave treatment. Furthermore, this analysis does not consider the future increase in value (from $3 per tree for pulpwood to $35 for sawtimber) of the uninfested trees protected and not felled in a buffer when using the verbenone tactics. The ability to protect these potential sawtimber trees would favor the use of verbenone over cut-and-leave even in pulpwood stands, despite the initial higher costs of the verbenone tactics.

There are three potential options to lower treatment costs:

1. Use a less expensive mix of verbenone in the pouches.
2. Make application techniques less time-consuming, perhaps by lowering the application height of the pouches.
3. Fell only freshly attacked trees in the verbenone-plus-felling tactic.

Technology Transfer

Before the tactics are approved for operational use, verbenone must be registered by the US Environmental Protection Agency (EPA). Phero Tech Inc. has submitted a complete application package to the EPA for verbenone, and it is currently under review. The EPA recently adopted guidelines designed to streamline the registration process for semiochemicals, so verbenone may soon be available.

The impending registration of verbenone and the successful testing of the tactics led the authors to develop a three-phase technology transfer program (Clarke et al. 1997):

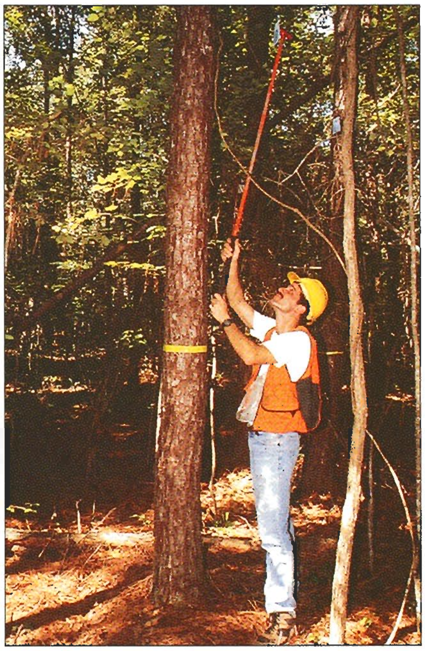
Phase 1. An initial survey of potential users.

Phase 2. Preliminary technology transfer sessions with small groups before final product registration.

Phase 3. Formal technology transfer sessions with user groups once the product is registered.

The goal of the technology-transfer program is to ensure that users have the necessary experience and training to apply the tactics properly so that a high level of confidence in these techniques is developed. We also wanted to know whether the standardized application methods were acceptable to foresters and to gather feedback on potential revisions in methodology that might increase usage.

The initial survey, completed in 1995, was designed to assess the respondents' knowledge of southern pine beetle biology and control and gauge their interest and acceptance of alternative suppression tactics. The results indicated a desire for inhibitor-based suppression tactics (Salom et al. 1998) but also the need for additional training in three areas: differentiating between engraver beetle (*Ips* spp.) and southern pine beetle infestations, judging when a tree has been vacated by southern pine



Ronald F. Billings

The verbenone pouch is attached to a tree using the Hundle hammer. The pouch remains effective for 40 to 50 days—longer than a southern pine beetle generation.

Cost Comparison: Verbenone Applications versus Cut-and-Leave

The expected costs associated with operational applications of verbenone-only and verbenone-plus-felling were compared with those of the cut-and-leave method for suppressing southern pine beetle infestations. The following scenarios and assumptions were based on current costs, the standardized application procedures, and results from field trials.

Scenario 1. A southern pine beetle spot infestation in a pine plantation with 300 trees per acre is 0.5 acre with 60 infested trees, 8-inch average DBH, 0.1 cord per tree. The buffer for cut-and-leave is 40 feet wide × 50 percent of spot circumference. The number of verbenone-treated buffer trees that will become infested is equivalent to 35 percent and 18 percent of the number of infested trees in the verbenone-only and verbenone-plus-felling treatments, respectively.

Cost of verbenone-only method	
168 verbenone pouches @ $4 per pouch	$ 672
Stumpage value of 21 buffer trees lost @ $30 per cord	63
Labor @ $10 per hour	40
Total	$ 775

Cost of verbenone-plus-felling method	
105 verbenone pouches @ $4 per pouch	$ 420
Felling 60 trees @ $2 per tree	120
Stumpage value of 11 buffer trees lost @ $30 per cord	33
Labor @ $10 per hour	40
Total	$ 613

Cost of cut-and-leave method	
Felling 60 infested trees @ $2 per tree	$ 120
Felling 89 buffer trees @ $2 per tree	178
Stumpage value of 89 buffer trees felled	267
Total	$ 565

Scenario 2. A southern pine beetle spot infestation in a sawtimber stand with 120 trees per acre is 0.5 acre with 40 infested trees, average 14-inch DBH, 100 board feet per tree. The stumpage value is $350 per MBF. The buffer for cut-and-leave is 60 feet wide × 50 percent of the spot circumference. The number of verbenone-treated buffer trees that will become infested is equivalent to 35 percent and 18 percent of the number of infested trees in the verbenone-only and verbenone-plus-felling treatments, respectively.

Cost of verbenone-only method	
342 verbenone pouches @ $4 per pouch	$ 1,368
Labor @ $10 per hour	60
Stumpage value of 14 buffer trees lost	490
Total	$ 1,918

Cost of verbenone-plus-felling method	
214 verbenone pouches @ $4 per pouch	$ 856
Labor @ $10 per hour	50
Felling 40 trees @ $2 per tree	80
Stumpage value of 7 buffer trees lost	245
Total	$ 1,231

Cost of cut-and-leave method	
Felling 40 infested trees @ $2 per tree	$ 80
Felling 58 buffer trees@ $2 per tree	116
Stumpage value of 58 buffer trees felled	2,030
Total	$ 2,226

beetles, and determining whether a tree is currently under attack.

Phase 2 tech transfer sessions are ongoing. The training consists of a classroom workshop followed by a field demonstration—the format favored by respondents in the phase 1 survey (Salom et al. 1998). Foresters attending the training are eligible to earn 7.5 hours in the Society of American Foresters' Continuing Forestry Education program.

Feedback from the training sessions thus far indicates that the participants viewed the application procedures favorably. All but one of the evaluations reported the procedures were practical, and all rated the tables easy to use. Because some attendees expressed concern that trees within the treated buffer were attacked, future training sessions must continually reinforce the idea that verbenone is a spot disruptant and does not provide absolute tree protection. Even though trees within the treated buffer may be killed, the tactics reduce or halt spot growth and save many trees in the buffer that otherwise would be felled using current suppression techniques. In successful treatments, some treated trees with signs of attack (pitch tubes) are often not successfully colonized, and those trees survive.

Preparations for phase 3 of the technology transfer program are under way, and the knowledge gained during phase 2 will be incorporated into these training sessions. A World Wide Web site (http://everest.ento.vt.edu/~salom/SPBinfodirect/spbinfodirect.html) has been created to provide potential users with the information and application methods required to use the verbenone tactics. Current plans include adding interactive testing and video clips of southern pine beetle spot evaluations and verbenone applications. The site will provide resource managers with instant access to the procedures and materials required for safe, effective application of the tactics.

Literature Cited

BILLINGS, R.F. 1995. Direct control of the southern pine beetle: Rationale, effectiveness at the landscape level, and implications for future use of semiochemicals. In *IUFRO Proceedings, Behavior, Population Dynamics, and Control of Forest Insects*, eds. F. Hain et al., 313–25. Maui, HA.

BILLINGS, R.F., C.W. BERISFORD, S.M. SALOM, and T.L. PAYNE. 1995. Applications of semiochemicals in the management of southern pine beetle infestations: Current status of research. In *Application of semiochemicals for management of bark beetle infestations: proceedings of an informal conference,* eds. S.M. Salom and K.R. Hobson, 30–38. USDA Forest Service Technical Report INT-GTR-318.

BILLINGS, R.F., and W.W. UPTON. 1993. Effectiveness of synthetic behavioral chemicals for manipulation and control of southern pine beetle infestations in east Texas. In *Proceedings of the Seventh Biennial Southern Research Conference,* 555–63. Mobile, AL. USDA Forest Service General Technical Report SO-93.

CLARKE, S.R., R.F. BILLINGS, S.M. SALOM, and C.W. BERISFORD. 1997. Technology transfer of treatments using verbenone for the suppression of southern pine beetle infestations. In *Integrating cultural tactics into the management of bark beetle and reforestation pests,* eds. J.C. Gregoire, A.M. Liebhold, F.M. Stephen, K.R. Day, and S.M. Salom, 95–100. USDA Forest Service Technical Report NE-236.

GARA, R.I. 1967. Studies on the attack behavior of the southern pine beetle. I. The spreading and collapse of outbreaks. *Contributions from Boyce Thompson Institute* 23:349–354.

GOYER, R.A., M.R. WAGNER, and T.D. SCHOWALTER. 1998. Current and proposed technologies for bark beetle management. *Journal of Forestry* 96(12):29–33.

PAYNE, T.L., and R.F. BILLINGS. 1989. Evaluation of (S)-verbenone applications for suppressing southern pine beetle (Coleoptera: Scolytidae) infestations. *Journal of Economic Entomology* 82:1,702–08.

PAYNE, T.L., R.F. BILLINGS, C.W. BERISFORD, S.M. SALOM, D.M. GROSMAN, M.J. DALUSKY, and W.W. UPTON. 1992. Disruption of *Dendroctonus frontalis* (Coleoptera: Scolytidae) infestations with an inhibitor pheromone. *Journal of Applied Entomology* 114:341–47.

PAYNE, T.L., J.E. COSTER, J.V. RICHERSON, L.J. EDSON, and E.R. HART. 1978. Field response of the southern pine beetle to behavioral chemicals. *Environmental Entomology* 7:578–82.

PRICE, T.S., C. DOGGETT, J.M. PYE, and B. SMITH. 1997. *A history of southern pine beetle outbreaks in the southeastern United States.* Southern Forest Insect Working Group.

REDMOND, C.H., and W.A. NETTLETON. 1990. An economic analysis of southern pine beetle suppression activity on the Gulf Coastal Plain national forests during 1985 and 1986. *Southern Journal of Applied Forestry* 14:70–73.

RENWICK, J.A.A., and J.P. VITÉ. 1969. Bark beetle attractants: Mechanisms of colonization by *Dendroctonus frontalis. Nature* 224:1,222–23.

RUDINSKY, J.A. 1973. Multiple functions of the southern pine beetle pheromone verbenone. *Environmental Entomology* 2:511–14.

SALOM, S.M., R.F. BILLINGS, C.W. BERISFORD, S.R. CLARKE, Q.C. MCCLELLAN, T.J. ROBINSON, and J.E. JOHNSON. 1998. Basis for technology transfer of an inhibitor-based suppression tactic for the southern pine beetle. *Southern Journal of Applied Forestry* 22:24–34.

SALOM, S.M., R.F. BILLINGS, C.W. BERISFORD, S.R. CLARKE, Q.C. MCCLELLAN, W.W. UPTON, and M.J. DALUSKY. 1997. Integrating tree felling with application of an inhibitor pheromone for suppressing southern pine beetle infestations. In *Integrating cultural tactics into the management of bark beetle and reforestation pests,* eds. J.C., Gregoire, A.M. Liebhold, F.M. Stephen, K.R. Day, and S.M. Salom, 39–53. USDA Forest Service Technical Report NE-236.

SALOM, S.M., R.F. BILLINGS, W.W. UPTON, M.J. DALUSKY, D.M. GROSMAN, T.L. PAYNE, C.W. BERISFORD, and T.N. SHAVER. 1992. Effect of verbenone enantiomers and racemic endo-brevicomin on response of *Dendroctonus frontalis* (Coleoptera: Scolytidae) to attractant-baited traps. *Canadian Journal of Forestry Research* 22:925–31.

SKILLEN, E.L., C.W. BERISFORD, M.A. CAMANN, and R.C. REARDON. 1997. *Semiochemicals of forest and shade tree insects in North America and management applications.* USDA Forest Service, Forest Health Technology Enterprise Team, FHTET-96–15.

SWAIN, K.M., and M.C. REMION. 1981. *Direct control methods for the southern pine beetle.* Agriculture Handbook No. 575, US Department of Agriculture.

Stephen R. Clarke (e-mail: sclarke/r8_tx@fs.fed.us) is forest entomologist, Forest Health Protection, USDA Forest Service, 701 North 1st Street, Lufkin, TX 75901; Scott M. Salom is assistant professor and Quintin C. McClellan is research associate, Virginia Tech, Blacksburg; Ronald F. Billings is principal entomologist and William W. Upton is staff forester, Texas Forest Service, Lufkin; C. Wayne Berisford is research professor and Mark J. Dalusky is research coordinator, University of Georgia, Athens.