SUPPRESSION OF BARK BEETLES AND PROTECTION OF PINES IN THE URBAN ENVIRONMENT: A CASE STUDY

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Abstract. Southern pine beetles (SPB), and associated bark beetles, have long been recognized as major pests of southern forests. Tactics used for controlling infestations in conventional forest settings have not proven effective at achieving area-wide control, nor are they suitable for the control of infestations in high-value stands such as homesites or wildlife habitat areas. Limited options exist for protecting high-risk uninfested pines of urban forests and often pose undesirable risks. One of the most promising areas in bark beetle research currently being experimentally tested on a large-scale is the use of deterrent behavioral chemicals (semiochemicals), produced by the insects or their host trees, as biopesticides to disrupt or inhibit infestations. In addition to traditional suppression tactics instituted in an unprecedented SPB outbreak in Gainesville, Florida, a semiochemical, 4-allylanisole (4-AA), was successfully tested as a protectant of pines in residential areas. 4-AA is a host-produced compound with repellent properties to many species of conifer-feeding bark beetles. The "freak" SPB outbreak in this urban environment and successful actions taken to mitigate damage are discussed.

Bark beetles (Coleoptera: Scolytidae) are by far the most destructive pests of pines in the southeastern United States. The 5 predominant species of indigenous bark beetles responsible for killing millions of pines annually throughout the south include the southern pine beetle (SPB), *Dendroctonus frontalis*; the black turpentine beetle (BTB), *Dendroctonus terebrans*; and 3 pine engraver (Ips) species (*Ips avulsus, I. calligraphus,* and *I. grandiculus*). Of these, SPB is much more pernicious than BTB or Ips.

BTB has relatively few generations per year (2–3), is attracted to weakened or wounded pines, and typically attacks fresh stumps or live trees near their bases. Trees often survive successful attacks; infestations generally result in limited damage to healthy trees and stands. Ips infestations are even less threatening to healthy, undamaged trees than are BTB. Ips attacks are typically restricted to stressed, weakened, and damaged trees and freshly felled host material. Ips attacks may occur along any portion of the bole or stem as well as in limbs of crowns, and are generally lethal when successful.

SPB, on the other hand, is notorious for its ability to overcome numerous healthy and vigorous trees in rapid succession during outbreaks. This highly destructive nature of SPB is due, at least in part, to a unique combination of life history characteristics. These characteristics include a congregative mass attack process, the ability to attack more than one host per generation, and multiple generations per year (up to 8). SPB tends to initiate attacks on living trees at the mid-bole and can infest the entire bole from near ground level up into the lower crown (upwards of 18 m).

The female SPB initiates attack and bores through the bark to the vascular layer of the bole. During this process she emits a chemical signal into the air, a pheromone, that attracts additional beetles of both sexes in mass numbers. These beetles bore into and begin to reproduce in the host pine. The tree's immediate defense is the outflow of resin at an attack site, which forms what is referred to as a pitch tube. This resin flow may result in the "pitching out" of the beetle. However, under heavy attack, even the healthiest tree may be overwhelmed. As the beetles and their offspring bore, successfully colonizing a tree, they typically introduce fungi into the tree. This combination of beetle boring and fungal growth inevitably causes tree mortality. During low bark beetle populations, trees under some physiological

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stress, such as from lightning, wounding, windstorms, severe drought, or flooding, appear to be most vulnerable. When bark beetle populations are high, even healthy trees may succumb in rapid succession to the mass attack and colonization by beetles. SPB outbreaks throughout the south have occurred with cyclic frequency at approximately 7- to 10-year intervals and tend to persist for 2 to 5 years. In a recent historical review, SPB damage to pine forests over the last 30 years has been estimated at $900 million (13).

Not included in this impressive figure are pine losses suffered each year by homeowners and by communities with tree-lined streets and parks (4). These trees are valued not for their timber but for their contributions to a community's air and water quality, real estate values, energy conservation, wildlife habitat, and aesthetics. As in campgrounds and other scenic areas, these trees are prominent features of the landscape and therefore irreplaceable. As trees mature and increase in size and value, they become more vulnerable to bark beetle attack. Protection of these highly prized trees, particularly in the urban, suburban, and rural forest interface areas, is of great importance.

Bark Beetle Management Tactics in Forested Areas

In conventional forest settings, SPB suppression tactics focus on reducing beetle populations and creating barriers to the spread of individual infestations using "cut-and-remove," cut-and-leave," or "cut-and-handspray" techniques (14). In each of these tactics, all infested trees are felled along with a buffer strip of uninfested trees surrounding the active front or "head" of the infestation for cut-and-remove and cut-and-leave. These tactics rely on disruption of the typical pattern of infestation growth by eliminating immediately available, acceptable host material and reducing the overall number of attacking individuals. While essential for limiting infestation growth, these tactics have not proven effective at achieving area-wide control, nor are they suitable for the control of infestations in high-value stands such as homesites or wildlife habitat areas. In addition, none of these methods provides direct protection for high-risk uninfested pines of urban forests. Three traditional pesticides are registered for use in control and prevention of SPB infestations: lindane, chlorpyrifos, and fenitrothion (2,3, reviewed in 7).

The forestry research community has intensified its efforts, particularly in the last decade, to develop and transfer biorational technology as an alternative to pesticide use. Widescale use of traditional pesticides for bark beetle population suppression is limited. Aerial applications are impractical because the active ingredient cannot penetrate the tree canopy to reach the targeted attack area of the bole. Biorational technology emphasizes methods and materials that effectively control only target pest species while reducing adverse impacts to nontarget organisms or the environment. Biological control, the use of one organism to regulate the numbers of another, is one of the most common forms of biorational technology. Others include semiochemical technology, which involves manipulation of insect populations through strategic use of the insect's airborne chemical communication system to effect control of behaviors.

One promising area in bark beetle research currently being tested on a large scale is the use of the insects' own communication signals (semiochemicals) as biopesticides to disrupt or inhibit infestations. In addition to the chemical attraction signal emitted by females in the initial stages of colonization, there is a chemical inhibitor, or deterrent, produced primarily by males. This inhibitor pheromone signals that the host tree under attack is fully colonized and causes newly arriving beetles to land on and infest nearby trees; hence, the infestation (spot) enlarges in area. Although pheromones may be similar among closely related beetle species, they are generally species specific. For example, a primary inhibitory chemical produced by SPB, verbenone, is being experimentally used in place of felling a buffer strip of uninfested trees and has been shown to effectively disrupt spot growth under certain conditions (12). Similarly, of the bark beetles that attack conifers in the western United States, an inhibitory pheromone produced by the spruce beetle, methylcyclohexenone (MCH), has been successfully used experimentally as a biopesticide (15).

New Advances in Beetle Management for Single Trees

Another form of biorational technology is the area of host resistance, the use of host attributes to reduce susceptibility, including a multitude of characteristics from morphological (such as bark features) to chemical (such as host-produced chemicals as deterrents and antifeedants). A semiochemical produced by certain plants, with repellent properties to many species of conifer-feeding bark beetles (8,9,10) is 4-allylanisole (4-AA). The oleoresin (pitch or sap) of pines is predominantly composed of compounds known as monoterpenes. 4-AA belongs to a class of compounds known as phenylpropanoids, produced in a metabolic pathway unique from the monterpene pathway. It is typically found in small quantities in the oleoresin of many pines, including those utilized by SPB, such as loblolly (*Pinus taeda*), shortleaf (*P. echinata*) longleaf (*P. palustris*) and slash (*P. elliottii*) pines.

In laboratory studies, >80% of SPB, regardless of sex, were repelled by the presence of this chemical. In field studies the addition of 4-AA significantly reduced SPB collections relative to collections in traps with attractant only or attractant plus verbenone, SPB's own inhibitory compound. At the same time, natural enemies of SPB, such as the predatory clerid beetle, did not seem to be affected.

SPB in Urban Areas

In 1992 two lightning-struck pines in residential settings in Pineville, Louisiana, were treated with 4-AA. Treatment consisted of placing nine 20-mm polyethylene vials equipped with cotton wicks at 1 m (1.1 yd) intervals on the damage side of the tree trunk from level up to 8 m (8.7 yd). In both cases, the trees were not attacked by SPB for the 30 days of 4-AA treatment. These results encouraged us to consider the use of 4-AA in urban settings to protect high-value trees from SPB attack. Pines in urban areas are as vulnerable to SPB as they are to lightning strikes. In fact, the two often follow one another; a general rule of thumb is that if the lightning doesn't kill the tree, the beetles attracted to it probably will. Although generally no data are kept on pine loss in urban areas, a call to local private tree contractors suggests that 30 to 40 pine trees are removed from residences annually because of lightning strikes and beetle infestations, at an average cost of approximately $250 per tree.

Under any of these circumstances, 4-AA and other biorationals may provide an environmentally neutral means of protection from infestation. Once the threat of infestation has subsided, treatment can be immediately ceased. While no nonlethal material can be expected to provide 100% protection, 4-AA has the potential to significantly lower the risk of bark beetle infestation in landscapes in urban habitats where pines are often highly prized features.

SPB Outbreak in Gainesville, Florida

An unprecedented and severe SPB outbreak occurred throughout a 155 km^2 area of greater Gainesville, Florida (Alachua County) during 1994, killing nearly 17,000 pines and impacting more than 320 public and private landowners. In 1995 the outbreak spread throughout the county, with beetles killing another 22,000 pines on about 300 ownerships in just the first 6 months of the year. The beetles infested not only loblolly pine, the preferred host of SPB, but also attacked slash, longleaf, spruce (*P. glabra*), and, in 1995, included the Florida endemic sand pine (*P. clausa*), a rarely reported host of SPB.

While Ips and BTB have been common colonizers of dead and dying pines, there is no record of SPB for at least the past 50 years in the Gainesville area. The nearest known infestation occurred in old-growth loblolly pines in 1947 near Silver Springs, about 65 km (40 miles) south of Gainesville (5,6). Since 1960, most SPB in Florida have been in the central and western sections of the Panhandle (13), and only recently have there been scattered infestations in northeastern Florida close to the Georgia border.

The pine mix, stand structure and condition, and history of land use in the Gainesville area undoubtedly contributed directly or indirectly to the intensity and duration of the outbreak. The majority of the pines in the urban Gainesville area at the time of the outbreak were mature, sawtimber size (>25 cm or 10 inch diameter at breast height, dbh) and somewhat patchily distributed, and included an unnatural abundance of loblolly. Within many areas, trees tended to be densely stocked (high basal area), even within residential areas that have been reclaimed from forested lands. Urbanization of forests created innumerable intensively and variably micromanaged plots of different sizes: modest-sized public parks (20–200 acres), large acreage preserves (up to 6000 acres), and relatively small residential lots (0.25–2 acres), for example. The setting is thus typical of many urban environments. Beyond the biological factors exists an overlay of economical and sociological influence that cannot be ignored.

That no SPB had been trapped or infestations previously reported (5,6) naturally raises the question as to the origin of the Gainesville outbreak. Several tenable hypotheses have been put forth. One theory is that SPB has been in the area at low (endemic) levels for some time and have gone unnoticed, possibly being confused with or coinhabiting Ips-infested trees. Another theory is that a recent introduction occurred (via the transport of infested materials, for example), and expanded rapidly when provided with the appropriate conditions. The occurrence of numerous new and widespread infestations in April through June 1994 (Figure 1) suggests that (unbeknownst to foresters) beetle populations were established and increasing in the latter portion of 1993. In May 1994, the first-ever aerial survey (1) for SPB infestations in the area revealed four obvious spots that had come through the winter and apparently expanded in the spring (Figure 2a).

The Florida Division of Forestry, with federal assistance, worked with the City of Gainesville and Alachua County to contact landowners and control all active infestations. With all known infestations originally located within a 40 km^2 area, it was widely believed that a cooperative, community-wide effort to rapidly detect and suppress all active infestations could put a halt to the impending crisis and minimize losses, both ecological and economical. However, despite an aggressive educational campaign and steady progress toward suppressing known infestations, new spots continued to show up with regularity throughout an ever-expanding zone of infestation. By September, suppression efforts were effectively eliminating infestations and relatively few new spots were being detected. A survey of SPB activity utilizing pheromone traps was then implemented to 1) evaluate the success of suppression efforts, 2) locate areas of "hot" beetle activity, 3) identify peaks of fall/winter dispersal, and 4) predict future levels of activity.

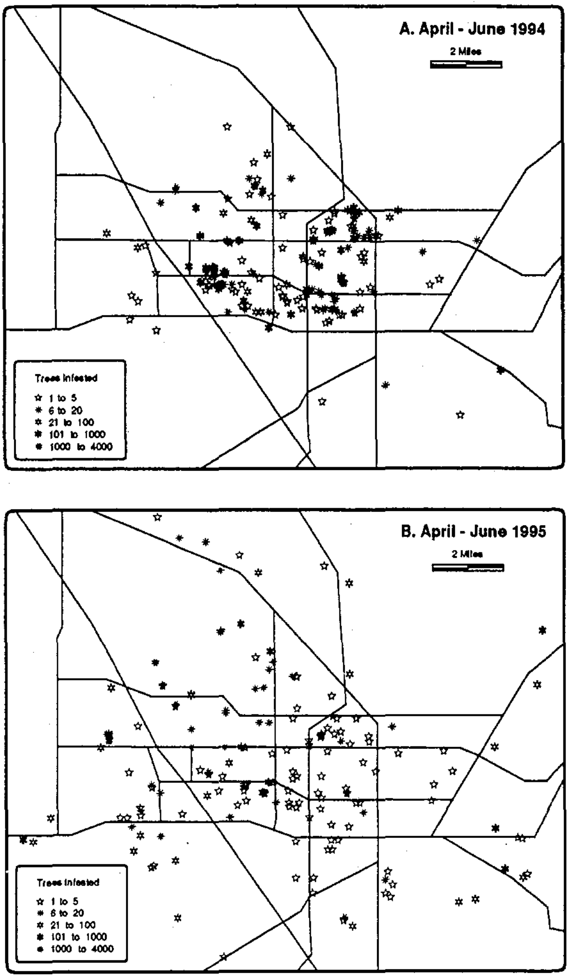

Figure 1. Comparison of SPB infestation size and location during the April–June periods of (a) 1994 and (b) 1995. The rapid detection and destruction of SPB brood clearly reduced the number and severity of infestation in the urban area, but failed to keep infestations from developing over a larger area.

In October 1994, 47 SPB Lindgren funnel traps baited with the beetle's attractant pheromone, frontalin, plus turpentine were established at

3.2 km (2 mi) intervals throughout and beyond the generally infested area. Perimeter traps were located from 3.2 to 12.7 km (2–5 mi) beyond any known infestation at the time. Results from the fall/winter trapping survey revealed that 96% of the traps caught SPB, reflecting a potential for new infestations virtually anywhere within the trapping grid. Somewhat surprisingly, all of the traps exhibited their highest weekly catches of SPB during December, when the vast majority of traps yielded beetles every week. The dramatic increase in catches during December coincided with unseasonably warm and dry weather, favorable to beetles and detrimental to tree resistance. In addition to trapping results, which indicated that beetles were widespread, existing infestations on the ground enlarged rapidly in December, suggesting a persistent epidemic.

Beginning in January and continuing through June 1995 (Figure 1) the outbreak progressed and worsened with regard to losses. By early July 1995, over 20,000 additional trees had been killed and infestations had expanded to the county boundaries (Figure 2b). Importantly, however, the relatively constant and consistent suppression efforts throughout the residential areas of northwest Gainesville appear to have successfully reduced losses in 1995. Comparing figures from April through June 1994 to those of 1995 (Figures 1a and 1b) reveals that fewer and smaller spots impacted residential areas despite an abundance of available host material. In addition, over 50% of all infested trees occurred on Florida Park Service lands, where management philosophy, stand history, topography, accessibility, and bureaucracy contributed to problems.

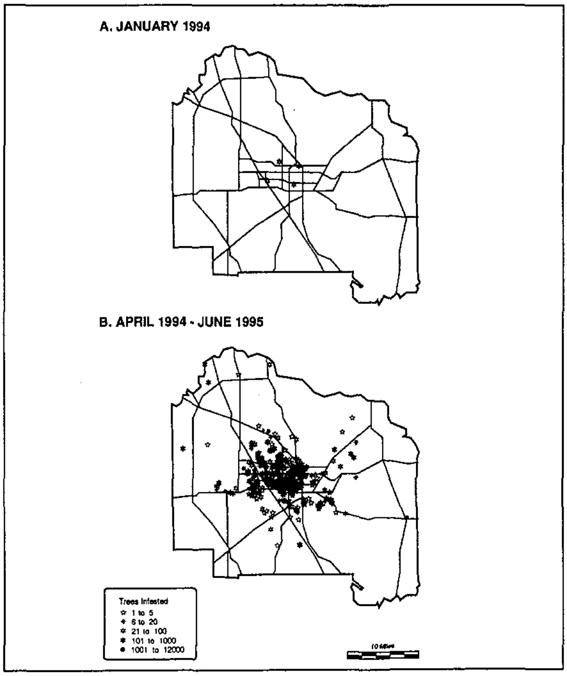

Figure 2. Location and relative size (number of infested trees) of active southern pine beetle (SPB) infestations in Alachua County, FL. (a) Approximate location of 4 active spots in January 1994, 3 months before discovery of outbreak. (b) Location of more than 600 properties affected during SPB outbreak.

The community combatted this "freak" outbreak aggressively, attempting to remove all infested trees. Because removals could not always be done in a timely manner, felled host material was often treated with the chemicals registered for this purpose—lindane, an organochloride insecticide, and chlorpyrifos, an organophosphate insecticide.

During the course of the Gainesville suppression program, the question was raised about the effectiveness of insecticides for killing the brood in beetle-infested trees. To investigate this question, 8 infested loblolly pines were felled and four 0.3 m (1 ft)-long sections cut from each stem. One bolt of each set was immediately dissected to determine the stage of brood development, 2 were sprayed with insecticide, and the fourth served as the unsprayed control. The latter 3 bolts were placed in special rearing cans and held in a well-ventilated rearing room for 1 month. At the conclusion of the experiment, the numbers and locations of beetles were recorded. Of the total number of beetles present, we assumed that only those that entered the collecting jars mounted 20 cm above the bottom of the rearing can were sufficiently healthy to disperse and infest new trees, the remainder being too weak to disperse.

The results presented in Table 1 clearly show that lindane and chlorpyrifos, when applied according to the label instructions, are highly effective. Mortality under the bark reduced emergence from 25% to 36% of the expected number. Of the beetles that did emerge, few made it from the bolt

Table 1. Effectiveness of two insecticides for remedial treatment of SPB-infested pines. (Beetles/ft², mean ± standard error.) Each mean is the average of eight 20-cm-long pine bolts treated during mid- to late stages of brood development.

Response	Control	Pesticide treatment: Chlorpyrifos 1%	Pesticide treatment: Lindane 0.5%
Beetles emerging	124.1 ± 18.8	45.3 ± 19.4	31.6 ± 10.6
% of control		36.5%	25.5%
Beetles flying	104.7 ± 18.8	1.6 ± 0.8	1.1 ± 0.7
% of control		1.5%	1.1%

into the collecting jar. Overall, insecticide reduced dispersing beetles by at least 98%. The data further indicate that the presence of emergence holes following an insecticide application should not be interpreted as treatment failure; the ability of the emerging beetle to disperse must be considered.

In addition to removing infested material, it was strongly recommended by the Florida Division of Forestry, in many cases, to treat uninfested trees with registered materials for protection, which include lindane and chlorpyrifos. Other chemicals are registered for use in horticultural protection of pines, such as carbaryl which is very effective in the west for protection against attack by western pine beetle (WPB) and mountain pine beetle (MPB), but not SPB (16). Fenitrothion is also registered, but has not proven as effective as lindane and no more effective than chlorpyrifos, but requires higher doses (reviewed in 7).

These pesticides are generally applied to the bole of the tree from approximately 12 m high to ground level, with high pressure hoses. Both chemicals are also recommended for BTB control, but spray cover is limited to a height of 2.5 m, which would not provide adequate protection from SPB or Ips infestation. For SPB, lindane provides protection for 3–6 months, while chlorpyrifos may need to be reapplied at 2–4 month intervals. We have observed mortality of natural enemies (Trogositidae) on trees 6 months after chlorpyrifos treatment while the tree was under attack by SPB.

The cost of preventive sprays in urban landscapes generally range between $17 and $25 per tree using lindane, whereas chlorpyrifos treatments vary between $36 to $50 per tree. Since neither material is species specific, both have undesirable nontarget effects that include killing natural enemies of bark beetles. The relatively long residual activity on nontarget organisms, and the potential for unwanted spray drift, runoff, or other nontarget pesticide movement raise concerns about environmental contamination.

Along with the routine use of lindane and chlorpyrifos, on a small-scale voluntary basis, 5 homeowners allowed us to treat their trees (73 trees) with 4-AA (as described above). In addition, 2 infestations in conventional pine stands were treated. Virtually all untreated trees in the vicinity of active SPB infestations were attacked. However, all 3 materials—lindane, chlorpyrifos, and 4-AA—provided good protection (>90%) from attack by SPB (Table 2). In these tests, 4-AA provided homeowners with an environmentally neutral alternative to chemical pesticide application for protection of high-risk pines to attack by

Table 2. 4-AA treatment results, Gainesville, FL, 6/28/95 to 6/10/95. No. sites treated: 7 (5 homesites, 2 forested); no. trees treated with 4-AA: 93 (73 homesites, 20 forested). Total percentage of 4–AA-treated trees attacked: 8.5%; no. verbenone-treated trees attacked by SPB: 15/22, 68%, no. untreated trees attacked by SPB: 9/13, 69%.

	No. treated	No. attacked	Adjacent untreated attacked
4-AA treated homesites			
homesite 1	9	0	11
homesite 2	19	1	39
homesite 3	14	2	16
homesite 4	16	0	8
homesite 5	15	3	9
% attacked		*8.2 ± 3%*	
4-AA treated forested sites			
forested 1	10	0	3
forested 2	10	2	0
% attacked		*10 ± 2%*	
Vervenone-treated forested sites			
forested 1	10	10	3
forested 2	12	5	0
% attacked		*68 ± 10%*	
Untreated (control) forested sites			
forested 1	5	5	0
forested 2	8	4	2
% attacked		*69 ± 13%*	

*Eight were treated with 50% recommended dose of Dursban 2E.

the SPB. Excluding labor, the per tree cost in the Gainesville test was around $30 for 3 months of protection.

The technique for using 4-AA included climbing ladders during initial setup, followed by refilling of vials about once per month, depending on weather conditions. Because protection is often a long-term proposition, slow release devices that can be installed without climbing and which last for 60–90 days are desirable. Work is ongoing to develop effective, efficient, and economical elution systems. A new long-lasting dispenser is currently being tested that eliminates the necessity of refilling vials and is completely encapsulated in a sealed, gel-filled vial.

Future Availability of 4-AA

4-AA shows great promise as a beetle repellent and offers exciting prospects for managing bark beetle infestations. Much developmental work and field testing remain to be done before it can become an alternative to insecticides for preventing SPB attacks on southern pines. A patent for use of 4-AA as a repellent for conifer-feeding bark beetles (scolytids) has been issued jointly to the Forest Service and Forest Products Lab at Mississippi State University (11). The Environmental Protection Agency (EPA) has granted an exemption from environmental use permit (EUP) requirements, thus allowing large-scale (up to 250 acres) testing of 4-AA. Further development of improved dispensers and licensing negotiations are underway. Thus, market development of this material is proceeding.

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Zusammenfassung. Eine der vielversprechensden Bereiche in der Borkenkäferforschung ist der Gebrauch von chemischen Abschreckungsmitteln (Semino-chemikalien), die von den Insekten auf ihren Wirtsbäumen produziert werden. Zusätzlich zu traditionellen Methoden, um den südlichen Kiefernkäfern in Gainesville, Florida zu bekämpfen, wurde in bewohnten Gebieten eine Semino-Chemikalie (4-allylanisole = 4-AA) sukzessiv getestet. 4-AA ist eine vom Wirt produzierte Zusammensetzung, die Abwehreigenschaften gegen viele Arten von Borkenkäfern auf Koniferen besitzt. Das massenhafte Auftreten von Käfern in Städten und die Aktionen, um den Schaden zu mildern werden hier diskutiert.