25

Use of Chemicals for Prevention and Control of Southern Pine Beetle Infestations

Ronald F. Billings

Manager, Forest Pest Management, Texas Forest Service,
College Station, TX 77840-7896

Keywords

bark beetles
Dendroctonus frontalis
insecticides
suppression
tree protection

Abstract

The southern pine beetle (SPB) is a major threat to pine forests in the Southeastern United States, Mexico, and Central America. In concert with one or more species of southern pine engraver beetles, SPB also may attack and kill pines in residential, recreational, or urban settings. Different control strategies and tactics have been used over the years to try to eliminate beetle problems or reduce resource losses during periodic outbreaks. Insecticides, once the principal means for treating southern pine beetle infestations in forest situations, are now used almost exclusively to protect individual high-value pines in urban settings. Reasons for discontinuation of large-scale insecticide use in forests in the early 1970s included the high cost of chemicals, questionable effectiveness on a landscape scale, and adverse impacts on the beetle's natural enemies. Although mechanical control methods (cut-and-remove and cut-and-leave) have since replaced chemical control in forest situations, there is still a need and demand for insecticides to prevent bark beetle attacks in residential or recreational areas. Currently, only insecticides containing the active ingredients bifenthrin and permethrin are registered and proven effective for prevention of bark beetles in the Southern United States, and application of these chemicals is limited to uninfested pines in residential or ornamental settings. Methods for applying these chemicals to standing trees for prevention of attacks by the southern pine bark beetle guild are discussed herein, together with safety precautions. Various systemic insecticides have recently been evaluated and found effective for preventing bark beetle attack in standing trees. Those containing the active ingredient emamectin benzoate or fipronil show the most promise, and EPA registration of these chemicals is expected. The advantages and disadvantages associated with the use of topical sprays and systemically injected insecticides to treat SPB populations or prevent the colonization of high-value trees also are discussed in this chapter.

25.1. INTRODUCTION

The southern pine beetle (*Dendroctonus frontalis* Zimmermann) (SPB), is a major bark beetle pest of pine forests throughout its range in the Southeastern United States, Mexico, and Central America (Thatcher and others 1980). In turn, this native pest has been the target of more sustained and aggressive direct control programs than any other bark beetle in the world (Billings 1980b). These control programs have been justified due to the economic, social, and ecological impact that periodic outbreaks of this insect are capable of causing to both commercial forests (Clark and Billings 2003, Redmond and Nettleton 1990) and high value pines in residential settings (Hayes and others 1996). A variety of strategies and tactics have been used over the years to address SPB outbreaks (Billings 1980b, Price and others 1998). This chapter describes the use of chemical insecticides in forest and urban situations for prevention and suppression of SPB.

25.2. EARLY DIRECT CONTROL STRATEGY AND TACTICS FOR SPB SUPPRESSION

Before the 1960s, foresters and pest managers knew little about the underlying causes of periodic SPB outbreaks and relationships between beetle attacks and host condition (Dixon and Osgood 1961, Thatcher 1960). In these early days, SPB was considered a beetle problem rather than a tree problem. With a limited knowledge of the insect, early attempts were aimed at eliminating the beetle when outbreaks were detected. At that time, direct control was the first and only line of defense for protecting valuable timber resources (Price and others 1998).

Early methods for killing bark beetles were varied and imaginative—rapid utilization of infested trees (i.e., salvage) and burning infested slabs, tops, and unmerchantable trees (St. George and Beal 1929); immersing infested logs in water (Hetrick 1949); exposing infested trees to solar heating (St. George and Beal 1929); and injecting poisonous chemicals into the sap stream of recently infested trees (Craighead and St. George 1938). Several of these methods proved inefficient, and most were impractical on an operational basis.

The search for more efficient means to kill beetle broods within trees led to the use of toxic chemical sprays. Orthodichlorobenzene in kerosene or fuel oil was successfully used on SPB-infested trees during outbreaks in the 1940s (Thatcher 1960). Following World War II, a new chlorinated hydrocarbon insecticide —benzene hexachloride (BHC)—became available and was first used in 1950 to address a SPB outbreak in East Texas (Billings 1980b). For the next 20 years throughout the South, the standard formulation for SPB control was 0.5 percent BHC in diesel or fuel oil; during summer months, an emulsion of 1 percent benzene hexachloride in water proved equally effective and reduced costs for operational applications (Bennett and Pickard 1966).

With BHC and its gamma isomer lindane as lethal weapons, pest control specialists at that time firmly believed that outbreaks could be suppressed and SPB problems solved by treating a sufficient number of infested trees to eliminate the beetle's pest status, if not the insect itself (Billings 1980b, Thatcher 1960).

The strategy in the 1950s and 1960s throughout the South was to eliminate the beetle population by applying insecticides to all infested trees in as many SPB infestations (called "spots") as possible during periodic outbreaks. Infested trees were identified during aerial surveys and subsequent ground evaluations. All trees with SPB brood or fresh attacks were felled, bucked into logs, and sprayed with BHC using hand-operated sprayers (Figure 25.1A). Prior to 1970, this was the most recommended method for suppression of SPB throughout the South (Dixon and Osgood 1961, Thatcher 1960).

State and Federal agencies, forest industries, and private landowners pursued this brute force strategy aggressively and with dedication. Chemical control had priority over salvage because of the belief at the time that "salvage contributes little or nothing to the control of the beetle population" (Texas Forest Service 1950). No SPB spot was too small to escape treatment if crews equipped with chainsaws and hand sprayers could locate it.

25.3. LIMITATIONS OF CHEMICAL CONTROLS IN FOREST SITUATIONS

Pest managers eventually recognized the limitations of the "kill the beetle" strategy and use of toxic chemicals as the primary tactic for SPB suppression in forest situations. Insecticide applications in commercial forests were expensive and time-consuming. Costs for 0.5 percent solution of BHC in fuel oil ranged from \$1 to \$10 per tree (Billings 1980b). Keep in mind that fuel oil sold for \$0.10-\$0.15 per gallon in the 1960s, a fraction of the costs at today's prices. Also, to be effective, chemical controls required careful, thorough treatment to ensure high beetle mortality (Anderson 1967). Infested trees had to be felled and bucked into logs, and each log rolled over so that all bark surfaces could be sprayed.

Perhaps more important, research findings from East Texas suggested that intensive use of chemical control was prolonging, rather than alleviating, the SPB outbreak by selectively

Figure 25.1—(A) Application of the insecticide benzene hexachloride in fuel oil for suppression of southern pine beetle infestations in the 1960s in East Texas (photograph by Max Ollieu, Texas Forest Service). (B) Application of Dursban® to SPB-infested tree in the 1990s, Sam Houston National Forest, Texas (photograph by Ron Billings, Texas Forest Service). Note differences in spray equipment and applicator protection in Figure (A), compared to that shown in Figure (B).

eliminating the principal predator of SPB, the clerid beetle *Thanasimus dubius* (Williamson and Vité 1971). These research findings, coupled with the increasing costs of application, resulted in the voluntary discontinuation of wide-scale chemical control for SPB in the South. By 1970, the BHC era had ended as abruptly as it had begun 2 decades earlier, and the search for new and more environmentally acceptable alternatives had begun (Billings 1980b).

In the late 1970s and early 1980s, two additional insecticides were tested and approved by the Environmental Protection Agency (EPA) for use against SPB: fenitrothion (Sumithion® or Pestroy®) (Billings 1987, Mizell and others 1981) and chlorpyrifos (Dursban®) (Brady and others 1980, Hastings and Coster 1981, Hastings and Jones 1976). These insecticides were used to protect high-value pines in residential areas and, to a limited extent, in forest situations (see Figure 25.1B). The high cost and logistical problems associated with forest applications limited their use for this purpose. More important, about that time, forest pest managers changed their tactics for direct control of SPB in favor of less costly and more environmentally friendly mechanical control methods. Due to environmental constraints, EPA eventually cancelled registration of these insecticides, and they are no longer available for bark beetle control. The registration for lindane was cancelled in the 1990s, despite support for its continued use for bark beetle prevention and control (Swain 1976).

25.4. CURRENT DIRECT CONTROL STRATEGY AND AVAILABLE TACTICS

The strategy for suppression of SPB in forest situations since 1970 has been to reduce resource losses by identifying and treating those SPB spots most likely to expand (Figure 25.2). These expanding infestations typically represent only about 30 percent of all SPB spots detected but account for 70 percent or more of the resource losses (Billings 1980b, Leuschner and others 1976). As a result, they are the primary targets of current direct control programs while cut-and-remove (salvage) (Texas Forest Service 1976) and cut-and-leave (Texas Forest Service 1975) have become the preferred control tactics in forest situations (Swain and Remion 1981).

Recommendation for use of these mechanical control tactics is based on a more comprehensive understanding of SPB biology, host relationships, and seasonal limitations in attack behavior (Billings 1980b, Payne 1980). Because of the proven effectiveness of mechanical control methods under operational conditions (Billings 1995, Clarke and Billings 2003, Redmond and Nettleton 1990), combined with their relatively low cost of application, these tactics have almost entirely replaced chemicals for direct control of multiple-tree SPB infestations (Billings 1980b, Price and others 1998). The rationale for this spot disruption strategy and how to apply the recommended mechanical control tactics are explained in detail in chapter 27.

Figure 25.2—Example of an expanding infestation of the southern pine beetle in East Texas, exhibiting the characteristic pattern of infested trees in various stages of foliage fade. (photograph by Ron Billings, Texas Forest Service)

25.5. SPB AND OTHER PINE BARK BEETLES IN URBAN SETTINGS

Chemical insecticides are still in demand to protect high-value pines from bark beetle attack. Pines in residential settings within the Southeastern United States may be infested by up to five bark beetle species. These include three species of pine engraver beetles (*Ips calligraphus*, *I. grandicollis*, and *I. avulsus*), the black turpentine beetle (BTB) (*Dendroctonus terebrans*), and SPB (Cameron 1987, Conner and Wilkinson 1983). Although the SPB has deservedly received more notoriety as a forest pest, the three species of engraver beetles and the BTB are more ubiquitous than SPB and typically are a more common cause of tree mortality in urban settings. A notable exception is the severe outbreak of SPB in Gainesville, Florida, in 1994-1995 (Hayes and others 1996). Losses of trees in residential or recreational sites (e.g., campgrounds) generally result in reduced shade, screening, and aesthetics; reductions in home property values, and costs associated with hazardous tree inspections and removal (Fettig and others 2009).

25.5.1. Beetle Interactions and Infestation Patterns in Individual Trees

A pine tree may be attacked and killed by a single bark beetle species, but more commonly, two or more species are involved. Each of the five bark beetles typically are found in certain portions of pine trees in the South (Figure 25.3). The black turpentine beetle, the largest of the five species, seldom attacks higher than 10 feet above the ground (Godbee and Franklin 1976). Its attacks can be recognized by the large, reddish masses of resin (pitch tubes) produced along the trunk of the tree. Each pitch tube is about the size of a 50-cent piece and marks the location where an adult BTB has attacked the tree (Figure 25.4). Low-density attacks by BTB may not kill the tree if no other bark beetle species are involved (Cameron 1987).

Of the three species of engraver beetles, the small southern pine engraver (*I. avulsus*) often limits its attacks to the tops and larger branches of stressed pine trees, creating I-shaped parent galleries between the bark and wood (Figure 25.3). If this is the only bark beetle present, the end result may be a topkill in which the lower limbs remain green and the tree survives (Figure 25.5).

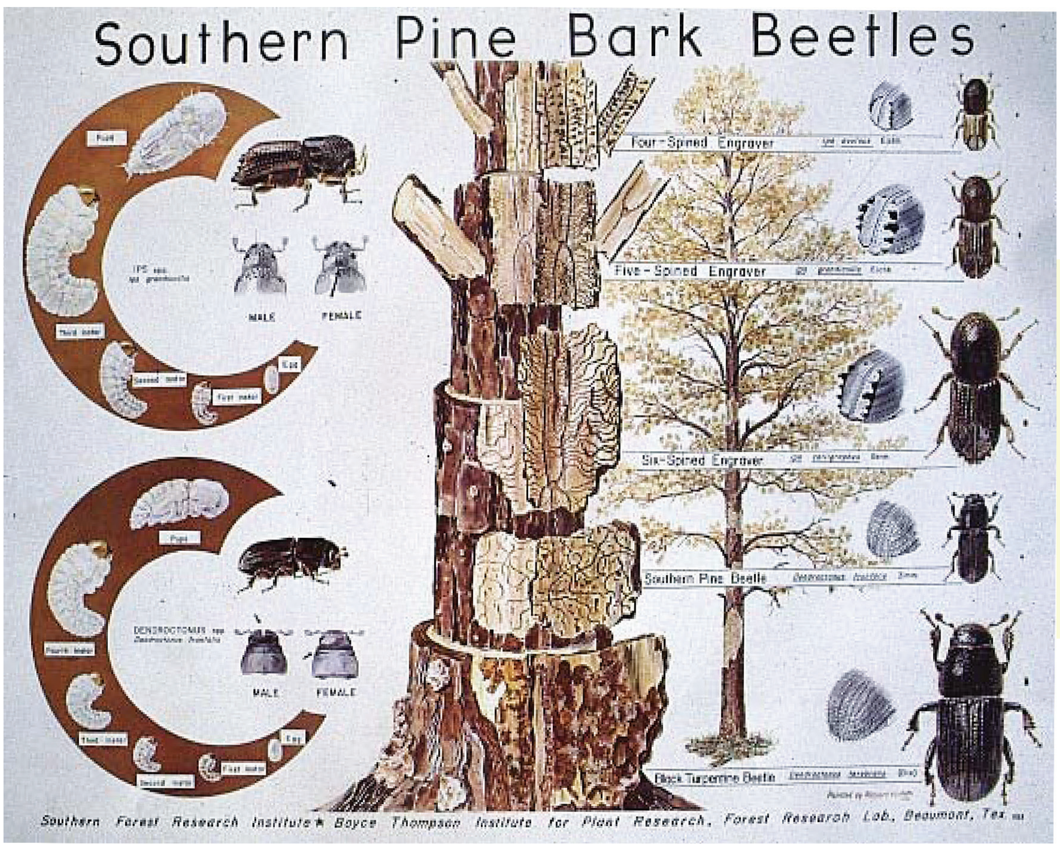

Figure 25.3—Illustration of the five species of southern pine bark beetles, typical position on an infested tree, and their characteristic gallery patterns. (painting by R. Kliefoth, Southern Forest Research Institute, Boyce Thompson Institute for Plant Research, Beaumont, Texas)

The six-spined engraver (*I. calligraphus*) and the eastern five-spined engraver (*I. grandicollis*) are common in the mid-bole region of bark beetle-infested pines, and they may share the tree with SPB, BTB, and the small southern pine engraver (Cameron 1987, Thatcher and others 1978). The parent galleries of engraver beetles are distinct from those made by adult SPB. Indeed, for the nonentomologist, it is easier and more reliable to distinguish SPB attacks from those of engraver beetles by examining the gallery patterns beneath the bark of infested trees rather than trying to identify the adult beetles themselves. Galleries of *I. grandicollis* and *I. calligraphus* are Y- or H-shaped, whereas those made by attacking SPB adults are S-shaped (Figure 25.3). Also, parent galleries of *Ips* beetles are usually maintained free of boring dust; in contrast, SPB parent galleries are packed with this sawdust-like material (Payne 1980).

Figure 25.4—Large pitch tubes characteristic of attacks of the black turpentine beetle on the lower trunk of a loblolly pine; also note coarse resin granules at base of tree. (photograph by Ron Billings, Texas Forest Service)

25.5.2. Symptoms of Bark Beetle Attack

Successful treatment of bark beetles with insecticides, whether for preventive or remedial control, depends on recognizing infested trees during early stages of bark beetle attack. The SPB and three species of engraver beetles have rapid life cycles, and the entire process of attack, colonization, brood development, and emergence may be as short as 25-35 days under favorable temperatures (Conner and Wilkinson 1983, Payne 1980). Thus, beetles may have completed their development and emerged from the infested tree by the time the crown begins to change color and beetle attack is noticeable from a distance. Often the bark beetle population may be found nearby in green-crowned pines.

The first symptoms of SPB or engraver beetle attacks to look for are pitch tubes on the surface of the bark and/or reddish boring dust at the base of the tree or in spider webs and on understory plants (Billings and Pase 1979a; Figure 25.6). These so-called Stage 1 trees will have green crowns, an inner bark-wood interface that is white similar to an uninfested tree, and no bark beetle galleries visible beneath the bark. If sufficient numbers of bark beetles attack, the tree dies rapidly due to the girdling effects of parent galleries and the blue stain fungi—carried by the attacking beetles—that invade and plug the water-conducting tissues of the tree. Once the tree is dead, adult beetles mate and the female lays eggs along the galleries constructed beneath the bark. The eggs soon develop into larvae, then pupae, and eventually into callow adults. Infested (Stage 2) trees supporting SPB broods are typically characterized by a green or fading crown (red crown in winter months), a bark-wood interface that is brown in color, and well-developed S-shaped galleries in the bark/wood interface (Figure 25.3, 25.6C).

Upon completing their development, bark beetles emerge by boring a circular hole through the bark, then fly in search of other trees to attack. The adults often infest adjacent pines in response to aggregation-inducing odors (pheromones) produced by other attacking bark beetles. The life cycle is then complete and immediately begins anew. Stage 3 trees, defined as those vacated by bark beetles, typically have red or bare crowns (although some may still be yellow), will have no bark beetle stages in or beneath the bark, and will have numerous round exit holes about the size of a pencil lead indicating where the beetles have emerged through the bark (Billings and Pase 1979a). Insecticide applications applied to Stage 3 trees will have no effect on bark beetle populations because the trees have been abandoned by the beetles.

25.6. INSECTICIDES FOR BARK BEETLE PREVENTION IN URBAN SETTINGS

The Federal government regulates pesticide use under the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA). FIFRA regulations require that all pesticide products be registered by the EPA prior to sale and/or use. Researchers have developed rigorous methods for evaluating the efficacy of insecticides for preventing SPB attacks (Berisford and others 1980) and used these methods to support EPA registration of several new chemicals in the 1980s, including chlorpyrifos (Dursban®) (Berisford and others 1982, Brady and others 1980, Hall and others 1982) and fenitrothion (Hastings and Coster

Figure 25.5—Top kill of loblolly pine, indicative of attacks by the small southern pine engraver, *Ips avulsus*. (photograph by Ron Billings, Texas Forest Service)

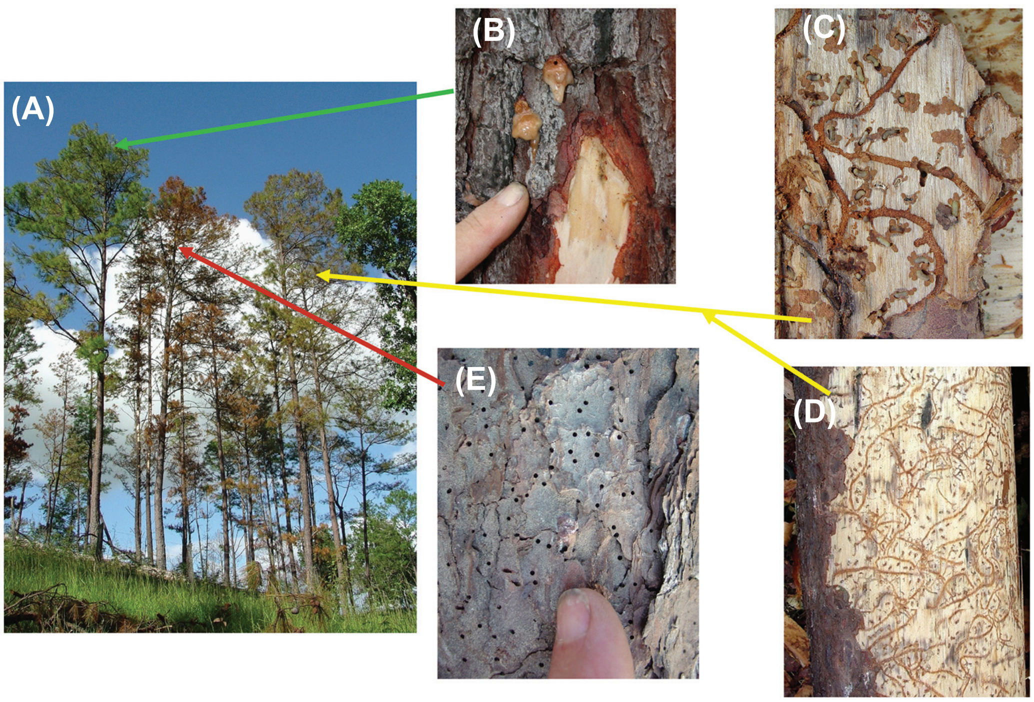

Figure 25.6—Crown color (A) and attack symptoms of a pine freshly attacked by the southern pine beetle (Stage 1) (B), an infested pine containing SPB brood (Stage 2) (C, D), and a tree vacated by SPB (Stage 3) (E) (photographs by Ron Billings, Texas Forest Service)

1981, Hastings and Jones 1976). Unfortunately, the number of insecticides registered for preventive use against bark beetles by the Environmental Protection Agency (EPA) has dwindled in recent years.

Lindane (BHC), chlorpyriphos, and fenitrothion (Hall and others 1982, Hastings and Coster 1981, Swain 1976), chemicals once used for bark beetle prevention and direct control, are no longer available. Carbaryl (Sevin®) is currently registered for bark beetle prevention and control, and frequently used to treat western conifers against bark beetle attack (DeGomez and others 2006; Fettig and others 2006a, 2006b; Gibson and Bennett 1985; Hastings and others 2001; Haverty and others 1985, 1998), but is not effective against SPB (Ragenovich and Coster 1974, Zhong and others 1994). Currently, ornamental pines in residential areas in the Southern United States may be sprayed with insecticides having the active ingredient bifenthrin or permethrin to prevent attack by SPB and related bark beetles. Chemicals containing 23 percent bifenthrin (sold under the trade name of Onyx®) and permethrin (Astro®, Dragnet®, Permethrin Pro®, or Permethrin Plus C® [Masterline®]) are currently registered and commercially available for bark beetle prevention.

For protection of high-value pines in residential areas from possible SPB infestation, a certified pesticide applicator should apply a spray mixture containing 1.0-2.0 pints of Onyx® insecticide (containing 23.4 percent bifenthrin) per 100 gallons (0.25-0.5 pounds active ingredient/100 gallons) of water to the trunk of the tree with a hydraulic sprayer in the spring of the year. Spray as high up the tree as possible, to at least halfway into the live crown, preferably prior to SPB attack. Do not apply more than 0.2 pounds active ingredient (12.8 fluid ounces) of this product to trees per acre. Repeat application may be necessary after 3-6 months or if probability of infestation is high. If Onyx® is unavailable, a registered insecticide containing permethrin (Astro®, Dragnet®, Permethrin Plus-C®, among others) may be substituted using application rates listed on the label. Consult your local State Extension or pest specialist or other qualified expert for more specific recommendations.

Permethrin Plus-C (Masterline) has proven effective for prevention of western pine beetle (*D. brevicomis*) attacking ponderosa pine (*Pinus ponderosa*) in California and mountain pine beetle (*D. ponderosae*) attacking lodgepole pine (*P. contorta*) in Montana for one field season (Fettig and others 2006a). This formulation of permethrin is rather novel because it contains methyl cellulose (i.e., plus–C). The process is thought to increase efficacy and stability by reducing drift, evaporation, and photo-chemical and biological degradation of the permethrin molecule (Fettig and others 2006a). This product has yet to be thoroughly tested for SPB prevention.

Note that Onyx®, manufactured by FMC Corporation, and the various permethrin products are not registered for use in forestry settings. Also, to prevent bark beetle attack on ornamental or other high-value pines, spray applications must be applied to point of runoff over the entire bole of standing trees (Cameron 1987) or, in the case of SPB, to just the upper half of the bole (Berisford and others 1982). This is difficult to do for trees much larger than about 40 feet tall. Nor are insecticides containing bifenthrin or permethrin registered for use as a cut-and-spray treatment for SPB suppression, as were lindane and chlorpyriphos (Dursban®). Rather, these chemicals are to be applied to standing, uninfested pines to prevent bark beetle attacks. Bifenthrin, the active ingredient in Onyx®, and permethrin, the active ingredient in Astro®, Dragnet®, and other brands, are broad-spectrum insecticides that will kill fish and a wide variety of insects, including bees and other beneficial species. Both chemicals may cause skin irritation and moderate eye irritation, and may be fatal if swallowed. Accordingly, homeowners should follow instructions on the label and take required safety precautions, described in section 25.8.

The safest approach is to hire a registered pesticide applicator or pest control operator (PCO) to make the application. Consult your local State Extension specialist, State Forest Service entomologist, or other qualified expert for specific recommendations.

25.7. INSECTICIDES FOR BARK BEETLE CONTROL IN URBAN SETTINGS

Insecticides are not recommended for application to bark beetle-infested trees in residential settings. Few insecticides are available for this purpose and none are permissible for use in forestry settings. Bark beetles in the South have rapid life cycles, and in most cases, the beetles will have emerged from infested trees before homeowners realize that the trees have been attacked. The best approach is to fell and remove all pines showing signs of bark beetle infestation (boring dust and pitch tubes in bark crevices, fading crowns). A registered insecticide should then be sprayed on uninfested, high-value pines nearby to prevent additional infestations (Cameron 1987, Thatcher and others 1978).

To be effective for remedial control, insecticides must be applied to pines in Stage 1 (fresh attacks) or Stage 2 (with brood). Unfortunately, as of early 2009, no insecticide is registered for this purpose in forest situations. Insecticides containing permethrin (Astro®, Dragnet®, Permethrin Pro®, and others) are available for use on ornamental pines but are of marginal effectiveness for control of SPBs. One botanical insecticide, sold under the trade name of Ornazin® 3 percent EC (AMVAC Chemical Corporation, Newport Beach, CA), is registered for pine bark beetle control on landscape trees. This insecticide contains the active ingredient azadirachtin, derived from the oil found in seeds of the neem tree (*Azadirachta indica*). It is an insect growth regulator that controls various insects in the larval, pupal, and nymphal stages by interrupting the molting process. Although pine bark beetles are listed on the Orazin® label, the efficacy of azadirachtin for SPB control remains to be demonstrated. Accordingly, until proven effective against bark beetles in general and SPB in particular, the author does not recommend this botanical insecticide for SPB control.

In most cases, trees already under attack by bark beetles other than BTB cannot be saved by use of chemical insecticides due to infection by blue stain fungi. If the goal is to reduce survival of beetles infesting ornamental pines, trees infested with SPB and/or *Ips* engraver beetles should be felled and cut into log sections, and the entire infested bole sprayed to the point of runoff (Cameron 1987). Such an approach to direct control, although needed during bark beetle outbreaks, is no longer available in forest situations. This discouraging status of chemical control for bark beetles will remain unchanged until an effective insecticide is developed and registered for this application.

25.8. SAFE APPLICATION OF PESTICIDES

If a homeowner must use pesticides to protect high-value pines from bark beetle attack, he/she should become acquainted with some general precautions to use them wisely and safely (http://ohioline.osu.edu/b504/b504_10.html).

1. Read the label. This is the first rule of safety in using any pesticide—read the label and follow the directions and precautions printed on it.
2. Store pesticides in closed, well-labeled containers out of the reach of children and pets. Do not store them under the sink, in the pantry, or in the medicine cabinet. Do not store them near food of any kind.
3. Store application equipment as you do pesticides—out of the reach of children or pets.
4. Do not save or reuse empty pesticide containers. Dispose of containers promptly as directed on the label.
5. Do not apply more pesticide than the label recommends. Overdosage is wasteful and may be dangerous.
6. Mix or prepare dusts or sprays outdoors or in a well-ventilated room.
7. In handling any pesticide, avoid contact with the skin. Do not get pesticide near your mouth, eyes, or nose.
8. If pesticide gets in your eyes, flush the eyes with water for five minutes; get medical attention.
9. Never smoke, eat, or drink while handling a pesticide. After finishing the work, wash exposed skin surfaces with soap and water.
10. If you spill pesticide on your clothing, launder the clothing before wearing it again.
11. If you become ill during or shortly after using a pesticide, call a physician immediately. From the container label, read to the physician the names of the active chemical ingredients; follow the instructions given for first-aid treatment.
12. Poison information centers are located throughout each state and are on call 24 hours a day. In an emergency, you could call the center closest to you but it

is preferable to let your doctor consult the center. Most telephone 911 systems can contact poison information centers directly.

25.9. POTENTIAL OF SYSTEMIC INSECTICIDES FOR SPB PREVENTION

Protection of individual trees from conifer bark beetles historically has involved topical applications of chemical insecticides to the entire bole of the tree using hydraulic sprayers. Even when available, insecticide spray applications have limitations. They are expensive, difficult to apply, effective for short periods (3-6 months), present a high risk for worker exposure and drift (Fettig and others 2008), and may be detrimental to natural enemies (Billings 1980b, Grosman and others 2002).

Accordingly, researchers have long been intrigued with systemic insecticides as an alternative. These largely water-soluble chemicals can be applied to the soil for absorption through the roots or by direct injection into the trunk. The chemicals are absorbed and transported throughout the sapwood and phloem tissues, and act to repel or kill insects that attempt to feed on or colonize the tree. One of the earliest approaches was to inject systemic chemicals into pines recently infested by SPB as a means to prevent brood development (Craighead and St. George 1938). In most cases, the treated trees died too rapidly to effectively take up the chemical, and this treatment was never used operationally.

In the late 1970s, Crisp, Richmond, and Shea (1979, unpublished data, in Billings 1980b) applied acephate (Orthene®) to foliage of loblolly pines prior to SPB attack at two different rates. The treatments were reported to reduce SPB larval survival but had no effect on eggs, pupae, callow, or parent adults. The investigators concluded that systemic insecticides will need to be more phloem-mobile, more toxic to all bark beetle life stages, and more persistent than acephate if this approach is to succeed.

Applications of fenitrothion (Pestroy®) to basal frills of SPB-infested trees showed promise for reducing SPB brood survival (Billings 1987), but never saw widespread use. Field trials using Mauget® injectors to deliver the insecticide metasystox-R (oxydementon methyl) have been conducted and determined to be ineffective for bark beetle prevention (Haverty and others 1996). A more recent study evaluated fenitrothion (Pestroy®) and a combination treatment of sodium N-methyldithiocarbamate (SMDC, Vapam®) plus dimethyl sulfoxide (DMSO) applied to bark hacks and dicrotophos (Bidrin®) applied by Mauget® injectors (Inject-a-cide - B®) to trees at the leading edge of SPB infestations (Dalusky and others 1990). Although none of the treatments prevented tree mortality, dicrotophos significantly reduced both egg gallery length and subsequent brood production. Because dicrotophos has a relatively high mammalian toxicity, it is not available to the general public.

Recently two different systemic chemicals—emamectin benzoate and fipronil—have been identified that show substantial promise for preventing bark beetle attacks. Emamectin benzoate (Syngenta Crop Protection), an avermectin derivative, has shown systemic activity in pine and is highly effective against pine wood nematode, *Bursaphelenchus xylophilis* (Takai and others 2000, 2003), and coneworm, *Dioryctria* spp. (Grosman and others 2002). Protection from a single injection has been demonstrated to last more than 3 years. Preliminary trials also suggest that this chemical has insecticidal activity against coleopteran pests, including the Asian longhorned beetle, *Anoplophora glabripennis* (Poland and others 2006). Fipronil (BASF Corporation), a new pheny pyrazole insecticide, also has systemic activity in pine and is highly effective in reducing damage from Nantucket pine tip moth, *Rhyacionia frustrana*, on young seedlings for greater than 12 months (D.M. Grosman, unpublished data).

In 2004 an injection trial was conducted in East Texas to evaluate the potential efficacy of several systemic insecticides for protection of loblolly pine against *Ips* engraver beetles, since no SPB infestations were present in Texas that year. The results with *Ips* bark beetles have shown that both emamectin benzoate and fipronil were highly effective in preventing both the successful colonization of treated bolts 3 and 5 months after tree injection and the mortality of standing trees (Grosman and Upton 2006). However, the difusion of fipronil throughout the tree appeared to be slower than that of emamectin benzoate and provided incomplete protection 4 weeks after injection. Three months following injection, however, the chemical had dispersed enough in the tree to provide full protection from bark beetle attack.

With these positive results, field trials with these systemic insecticides were extended to more aggressive *Dendroctonus* bark beetles to determine efficacy and duration of treatment effects. Data from 2006 and 2007 from Mississippi and Alabama conclusively showed that emamectin benzoate was effective in preventing successful attack by SPB. Fipronil also significantly reduced mortality of trees compared to check trees (Figure 25.7). Emamectin benzoate successfully prevented parent gallery construction, brood development, and emergence of both *Ips* engraver beetles and SPB from treated loblolly pines, whereas

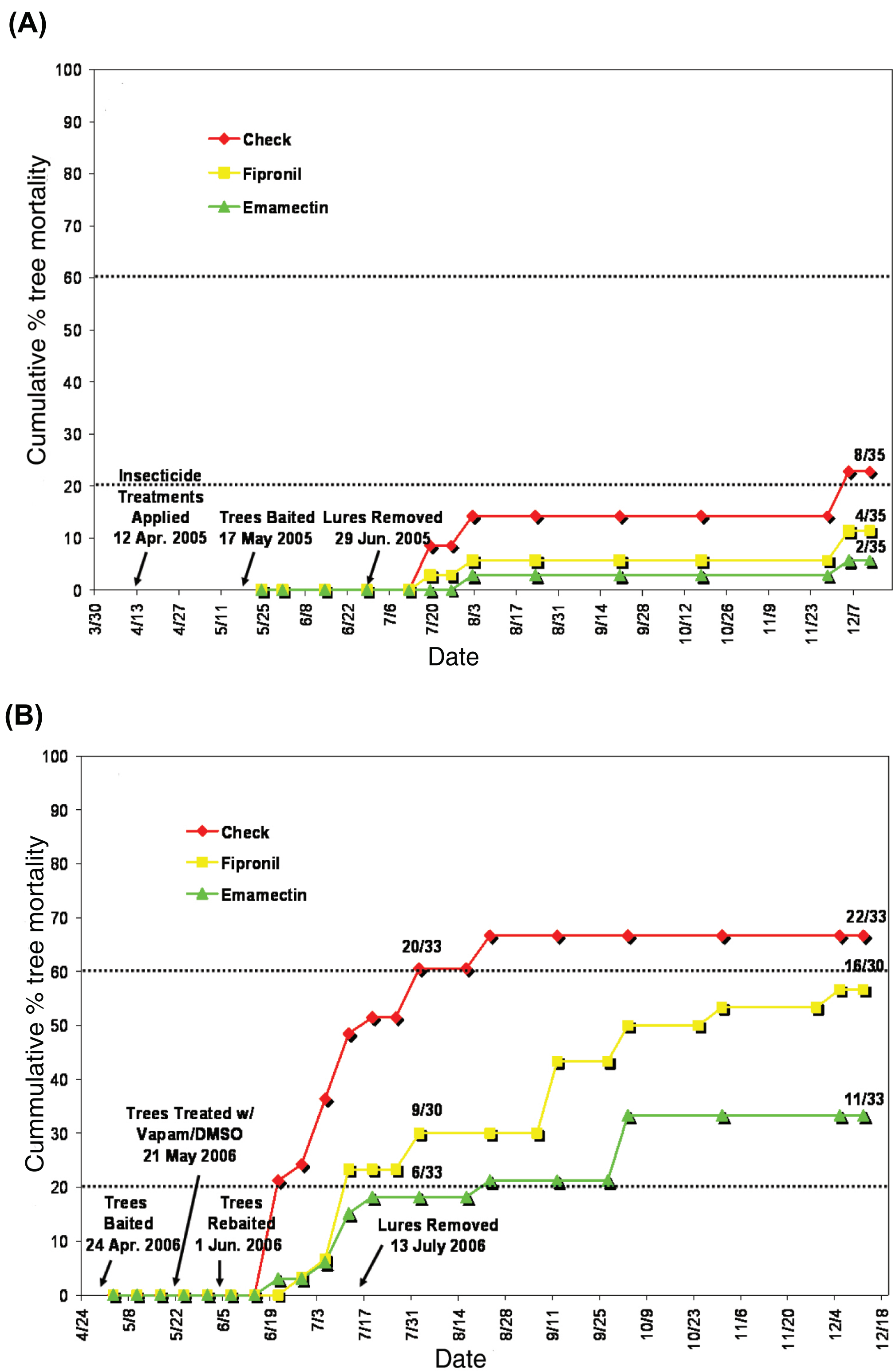

Figure 25.7—Cumulative first- (A) and second-year (B) mortality of emamectin benzoate- and fipronil-treated and untreated loblolly pine, *Pinus taeda* L., after attack by southern pine beetle, *Dendroctonus frontalis*, (2005) and *Ips* engraver beetles (2006), Chickasawhay Ranger District, DeSoto National Forest, Mississippi. The dashed line at 60 percent cumulative mortality is the level of tree mortality considered necessary for a valid test (Shea and others 1984); the dashed line at 20 percent cumulative mortality is the maximum allowable mortality for treatments to be considered efficacious.

Table 25.1—Effects of emamectin benzoate (EB) and fipronil (FIP) injection treatments on mean (± SEM) success of bark beetle adult attack, brood development and emergence, presence of blue stain fungi, and success of cerambycid larvae in logs taken from faded study trees in Mississippi and Alabama – 2006 (Grosman and others 2009)

				Ranking (Percent with:)					
Site	Treatment	N	No. of bark beetle *attacks per 1000 cm2*	Bark beetle galleries (Length > 2.5 cm) present	Bark beetle brood present	Bark beetle emergence holes present	Blue stain fungi present	No. of cerambycid *egg Niches per 1000 cm2*	No. of cerambycid *larval galleries per 1000 cm2*
			Ips Engraver Beetles						
	EB	11	9.3 + 1.5a[†]	0 + 0a	0 + 0a	0 + 0a	100 + 0a	22.8 + 4.5a	0.5 + 0.5a
MS	FIP	16	9.8 + 1.0a	22 + 4b	6 + 4a	6 + 4a	100 + 0a	20.3 + 1.9a	1.9 + 0.9a
	Check	22	9.5 + 0.7a	100 + 0c	100 + 0b	100 + 0b	100 + 0a	16.9 + 2.3a	11.3 + 0.7b
			Southern Pine Beetle						
	EB	7	11.0 + 1.8a	0 + 0a	0 + 0a	0 + 0a	100 + 0a	17.8 + 5.1b	0.4 + 0.4a
AL	FIP	12	11.8 + 1.8a	45 + 11b	46 + 11b	36 + 12b	100 + 0a	11.5 + 1.5a	4.8 + 1.3b
	Check	24	12.3 + 1.0a	100 + 0c	100 + 0c	100 + 0c	100 + 0a	8.9 + 0.8a	10.6 + 5.2c

[†] Means followed by the same letter in each column of the same site are not significantly different at the 5% level based on Fisher's Protected LSD (counts) or Kruskal-Wallis (ranked).

fipronil reduced brood success to a lesser extent (Table 25.1) (Grosman and others 2009). Although several emamectin benzoate and fipronil trees died, the primary cause was most likely the result of numerous inoculations of blue stain fungi by the numerous bark beetle adults that were induced with synthetic pheromones to attack the trees in these trials.

Imidacloprid and dinotefuran, both neonicotinoid compounds that were tested in the same trial, did not appear to have any marked effect against bark beetles (D.G. Grosman, Texas Forest Service, unpublished data). Additional trials to confirm the effectiveness of emamectin benzoate and fipronil against other species of destructive bark beetles and wood borers are currently under way.

It is conceivable that single injections of emamectin benzoate and fipronil may protect trees against bark beetles and wood borers for more than 1 year, as documented for these same chemicals used against other forest and seed orchard pests (Grosman and others 2002, Takai and others 2003). Duration trials using these chemicals for prevention of attacks by *Dendroctonus* or *Ips* bark beetles are needed to validate this hypothesis. Registration of emamectin benzoate and fipronil is currently being pursued with EPA.

25.10. CONCLUSIONS

The reduction or elimination of SPB populations using chemical insecticides was once the principal strategy for addressing periodic outbreaks of this pest throughout its range in the United States, Mexico, and Central America. During the 1950s and 1960s, benzene hexachloride mixed in fuel oil was used extensively to achieve this goal. The increasing cost of applying these chemicals in forest situations, adverse effects on the beetle's natural enemies, and the fact that SPB outbreaks persisted regardless of the level of suppression led to the discontinuation of this brute force approach by the early 1970s. Reducing resource losses by recognizing and treating expanding SPB infestations while they are still small has been the strategy used in recent decades. The primary tactics have been mechanical (cut-and-remove and cut-and-leave) rather than chemical.

There is still a need for chemical insecticides to prevent bark beetle attacks on high-value pines in residential areas, parks, and recreational sites. Unfortunately, most insecticides that have been tested and proven effective for this purpose in the past (e.g., lindane, chlorpyrifos, fenitrothion) are no longer registered for bark beetles. Only insecticides containing bifenthrin or permethrin are available for SPB prevention, and then only to protect trees in urban settings. But these chemicals must be applied as a topical spray, and their use is limited by all the disadvantages associated with such an application (need to cover entire bole of standing trees, possibility of spray drift and applicator exposure, short duration and need for repeated applications every 3-6 months, high cost, mortality of nontarget organisms). Also, bifenthrin, sold under the tradename Onyx®, is a restricted use pesticide that is to be applied only by certified pesticide applicators. Although bifenthrin has been shown to be efficacious for SPB prevention, whether insecticides containing permethrin are equally effective remains in question.

A promising alternative currently under development is use of systemic chemicals. Two active ingredients—emamectin benzoate and fipronil—have shown good efficacy for protecting standing trees from attacks by SPB, engraver beetles, and wood borers. Field trials have demonstrated that a single injection of either systemic insecticide may provide tree protection for 2 or more years. Use of systemic insecticides eliminates concerns with spray drift, threats to nontarget organisms, and for the most part, applicator exposure to the active ingredient. Hopefully, one or both of these chemicals will be registered for use for bark beetle prevention in the near future. It is anticipated that high costs will limit use of high-value pines in residential and recreational areas.