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Aerial Detection, Ground Evaluation, and Monitoring of the Southern Pine Beetle: State Perspectives

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Abstract

The southern pine beetle (SPB), is recognized as the most serious insect pest of southern pine forests. Outbreaks occur almost every year somewhere within its wide range, requiring intensive suppression efforts to minimize resource losses to Federal, State, and private forests. Effective management involves annual monitoring of SPB populations and aerial detection and ground evaluation of multiple-tree infestations during outbreaks. The 16 southern and northeastern States that face periodic SPB outbreaks have developed operational methods for detection and evaluation of new infestations and pending outbreaks of this destructive forest pest. Methods used by State forestry agencies for State and private forest lands often differ from those used on Federal forest lands and also vary significantly among States. This chapter describes the methodologies used by various States for conducting aerial detection flights and subsequent ground check evaluations for SPB. New technological developments, including geographical information systems, global positioning systems, digital sketchmapping systems, and coordinated Internet-based reporting systems, are being incorporated into traditional suppression operations to better manage this bark beetle pest. Also, a unique region-wide system for monitoring SPB populations and predicting infestation trends has been developed and implemented throughout the South. The first of its kind for any bark beetle species in the world, this system utilizes a network of pheromone traps deployed in early spring. Predictions of SPB activity to expect at the county, ranger district, and State level are made by comparing relative catches of SPB and those of a major SPB predator, the clerid *Thanasimus dubius*. Standardized monitoring, aerial detection, and ground evaluation protocols have become widely used by State forestry agencies and are considered essential components for the effective management of SPB.

17.1. INTRODUCTION

The southern pine beetle (*Dendroctonus frontalis* Zimmermann) (SPB), is considered the most destructive pest of southern pine forests (Branham and Thatcher 1985, Thatcher and others 1980). Outbreaks occur periodically throughout the range of its principal hosts, loblolly (*Pinus taeda*) and shortleaf pine (*P. echinata*). The SPB also infests other native pine species in Mexico (Cibrian Tovar and others 1995) and Central America (Vité and others 1975). During these outbreaks, which may last 3-4 years or longer (Price and others 1998), SPB typically creates an abundance of multiple-tree mortality centers, termed "spots" (Figure 17.1). Under favorable conditions, numerous small spots may converge if not controlled to impact thousands of acres (Figure 17.2) (Clarke and Billings 2003).

however, no SPB infestations have been reported in States west of the Mississippi River since 1998 (USDA Forest Service 2004). Due to periodic outbreaks and the impact they may have on commercial pine forests, the SPB has been the target of more extensive suppression efforts than any other bark beetle species in the world (Billings 1980b).

Detection and evaluation of infestations and monitoring of population trends are key components of an SPB pest management program (Billings 1980b, Clarke and Billings 2003, Thatcher and others 1982). State forestry agencies, responsible for detecting and monitoring bark beetle infestations on State and private forest lands, have developed methods that differ somewhat from those the USDA Forest Service uses on Federal lands. Methodologies for detection and monitoring

Figure 17.1—Example of an expanding SPB infestation characterized by infested trees in various stages of foliage fade. (photograph by Ron Billings, Texas Forest Service)

Since SPB has 3-10 generations per year (Payne 1980), outbreaks may develop rapidly, causing severe economic losses to Federal, State, and private forests. For example, in 2001 and 2002, the worst outbreak on record was recorded in the Southeastern United States More than 150,000 infestations were reported on Federal, State, and private ownerships in Alabama, Florida, Georgia, Kentucky, Mississippi, North Carolina, South Carolina, Tennessee, and Virginia. For reasons that remain unclear,

also will vary among the 16 States (Oklahoma, Arkansas, Texas, Louisiana, Mississippi, Tennessee, Kentucky, Alabama, Georgia, Virginia, Florida, South Carolina, North Carolina, Maryland, Delaware, and New Jersey) that routinely conduct these operations. Thus, aerial detection, ground evaluation, and monitoring procedures for SPB on State and private forest lands will be described separately in this chapter.

Figure 17.2—Example of a large area devastated by SPB: Indian Mounds Wilderness, Sabine National Forest, Sabine County, Texas, August 1993. (photograph by Ron Billings, Texas Forest Service)

17.2. UNIQUE CHARACTERISTICS OF SPB INFESTATIONS

Unlike other species of *Dendroctonus* in the Western United States and Canada (Fettig and others 2007), SPB may be capable of killing trees throughout the year in a large portion of its range. Adult beetles may emerge, fly, and infest host trees whenever minimum temperatures exceed 59 °F, the threshold for flight (Moser and Dell 1979a). However, SPB dispersal, reproductive capacity, and attack behavior, among other factors, are known to vary seasonally (Payne 1980, Texas Forest Service 1978, Thatcher and Pickard 1964). Detection and control programs are predicated on these seasonal differences. For example, detection records indicate that most multiple-tree SPB infestations or spots are initiated in the late spring or early summer and detected from May through August (Coulson and others 1972, Thatcher and Pickard 1964).

Adult SPB disperse from overwintering sites usually in March or April in Gulf Coastal States (later in northeastern portions of the insect's range) and seek out weakened trees to initiate attacks. Long-range dispersal in the spring coincides with the flowering of dogwood (*Cornus florida*) or production of loblolly pine pollen (Billings 1988). Many spots at this time of year are initiated when the beetles attack lightning-struck pines (Coulson and others 1983, Hodges and Pickard 1971) or trees weakened by drought stress, competition with other trees, or other factors that produce slow radial growth (Coster and Searcy 1981, Coulson and others 1974).

Healthy pines usually are capable of resisting initial SPB invasion by "pitching out" attacking beetles with a strong flow of oleoresin (Hodges and others 1979). To overcome a pine's defense mechanisms, initially attacking female SPB produce a potent aggregation pheromone, frontalin (Kinzer and others 1969), which combines with host odors from the tree to attract other SPB flying in the area (Coster and Johnson 1979a, Coster and others 1977a, Gara and Coster 1968). A weakened tree typically is unable to withstand the mass attack of SPB that results, and is rapidly killed. Once the pine's defense system is overcome, adult beetles colonize the initial tree while other SPB adults are induced to land on and attack adjacent pines. This switching behavior is triggered by different beetle-produced semiochemicals, in this case, verbenone and endo-brevicomin produced by male SPB (Gara 1967, Renwick and Vité 1969).

Attacking SPB introduce a blue stain fungus into the tree's sapwood, which helps to kill the tree. Once SPB colonization is complete, eggs are laid in the inner bark along characteristic S-shaped galleries (Figure 17.3) to establish a new generation of beetles (Payne 1980). Under favorable temperatures (70-85 °F), the eggs

Figure 17.3—Winding, S-shaped galleries beneath the bark of infested pines are characteristic of infestation by the SPB. (photograph by Ron Billings, Texas Forest Service)

develop into larvae, pupae, and then callow adults, emerging within 4-6 weeks after initial attack (Thatcher and Pickard 1967). Brood development and emergence may be prolonged by high or low temperature extremes (Beal 1933, Tran and others 2007). The foliage of the infested tree will eventually change color from green to yellow (fading) and then to red before eventually dropping from the tree (Doggett 1971). The signature produced in expanding SPB infestations by dead and dying pines in various stages of deterioration (Figure 17.1) is easily visible to aerial observers during summer months (Billings and Ward 1984, Ciesla and others 2008). By the time an infested pine's foliage has turned red or brown, the SPB will have completed development within the bark, emerged, and flown off in search of another pine to attack. The exception is the winter season, when red-crowned or bare trees may still harbor SPB brood (Billings and Kibbe 1978, Doggett 1971).

Presumably, a persistent, expanding SPB spot develops during the late spring if beetles continue to immigrate into the new infestation for at least 30 days or one SPB generation. By this time, the SPB brood will have completed development and begun to emerge from trees at the spot origin (the first trees infested). Newly emergent brood adults and reemergent parent beetles during summer months will tend to respond to pheromones produced on the periphery of the same infestation from which they emerged, attacking additional pines and creating the phenomenon known as "spot growth" (Gara 1967, Hedden and Billings 1979).

Once a large, expanding infestation becomes established, exposure of adult SPB to environmental hazards outside the tree is minimized and survival is maximized. The pine's defense systems (oleoresin exudation) may be rapidly and successfully overcome by the high concentrations of attacking beetles. Accordingly, even healthy pines capable of resisting the attacks of a few SPB are colonized in rapid succession as the spot expands (Cameron and Billings 1988, Hedden and Billings 1979). Operational records from East Texas have shown that only 25-30 percent of all detected SPB infestations enlarge for prolonged periods (Billings 1974, Leuschner and others 1976). Such spots are the target of direct control programs because they account for some 70 percent of timber losses (Billings 1980b, Thatcher and others 1982).

Spots in which the synchrony between pheromone production on the spot periphery and brood emergence from within the same spot is not maintained are destined to soon go inactive with no further enlargement (Cameron and Billings 1988, Hedden and Billings 1979). In this case, emerging beetles do not encounter aggregation pheromones and disperse (Gara

1967), often failing to establish new multiple-tree infestations once the preferred long-distance dispersal period (March through June) is over (Texas Forest Service 1978). Inactive spots can be recognized from the air during summer months by their small size and absence of trees with fading yellow foliage (Figure 17.4) (Billings 1979). Large infestations that exhibit no fading trees as a result of prolonged high temperatures, however, may contain sufficient SPB populations to resume spot growth processes when favorable temperatures return (Figure 17.5).

When ambient temperatures become more favorable for dispersal in the fall, a portion of the SPB population may leave established infestations upon emergence to initiate new

Figure 17.4—Example of an SPB infestation that is no longer active (e.g., lack of trees with fading crowns indicate that the beetles have abandoned this spot). (photograph by Ron Billings, Texas Forest Service)

Figure 17.5—Large or concentrated areas of infestation that show no recent SPB activity (e.g., no trees with fading crowns) due to hot, summer weather may experience renewed beetle activity when favorable weather conditions return. (photograph by Ron Billings, Texas Forest Service)

infestations nearby. Thus, during outbreaks, the SPB population typically passes the winter in scattered trees, in small, recently initiated spots, and/or in large infestations that remain uncontrolled (Texas Forest Service 1978, Thatcher and Pickard 1964). In contrast, when SPB populations are latent, it is common to observe few or no SPB-infested trees, a condition that may prevail for a decade or more (e.g., as in States west of the Mississippi River since 1998). Presumably, during these latent periods, a few SPB survive by inhabiting scattered trees colonized primarily by other members of the southern bark beetle guild, *Ips* spp. and/or the black turpentine beetle, *D. terebrans* (Payne 1980).

Given this unique attack behavior, the goal of both aerial observers and ground evaluation personnel during periodic SPB outbreaks has become to identify those SPB spots capable of causing extensive resource losses if not promptly controlled and distinguish them early in their development from infestations likely to soon go inactive. Accordingly, aerial detection and ground evaluation protocols unique to SPB have been developed over the years to achieve this goal.

17.3. AERIAL DETECTION OF SPB ON STATE AND PRIVATE FOREST LANDS

The detection of multiple-tree infestations likely to be caused by the SPB is the first step in suppression programs (Billings 1980b). Aerial detection (Billings and Ward 1984) is followed by on-the-ground (ground check) evaluations to identify or confirm the causal agent and determine the need for control (Billings and Pase 1979a). SPB infestations, particularly those that have the potential to expand over time, are then targeted for direct control (suppression) as a means to reduce further timber losses (Billings 1980b, Swain and Remion 1981).

The purpose of aerial detection is to identify and map the location of dead and dying groups of pine trees that show characteristic signs of being infested by SPB (Ciesla and others 2008, Thatcher and others 1982). An expanding SPB spot typically consists of five or more infested trees in various stages of foliage fade (see Figure 17.1). During summer and fall months, red-crowned pines (those from which SPB brood has emerged) will be visible from the air adjacent to trees with fading or yellow crowns (Billings and Doggett 1980, Ciesla and others 2008). The latter are likely to contain SPB broods in development (larvae, pupae, and/or new adults). Expanding infestations also will contain recently attacked pines usually situated near fading pines, but these trees will still have green crowns and be indistinguishable from uninfested trees to aerial observers. The presence of one or more pines with fading yellow crowns indicates SPB spots that are most likely to be in the process of expansion (Billings 1979).

17.3.1. Aircraft Used in Aerial Detection of SPB

A recent survey of southern pest management specialists conducted by the author reveals that State agencies use different types of aircraft to conduct SPB aerial detection operations. Certain State forestry agencies (Alabama, Arkansas, Florida, Georgia, Louisiana, Mississippi, New Jersey, North Carolina, and Virginia) own airplanes used for detection, while the other States contract private planes for this purpose. The State of Alabama contracts private planes to supplement its own aircraft when needed.

Typically, aircraft used for aerial detection are single-engine, high-winged aircraft that seat four persons, such as Cessna models 172, 182, 185, 206 or 207 (Figure 17.6). One observer, usually an agency forester or technician, is responsible for detecting spots visible out the right side of the plane, while a second observer records spots out the left side. When SPB populations are low, a single aerial observer and/or the pilot may record infestations. In many cases, pilots who fly aerial detection flights in search of wildfires also will report any suspected SPB infestations during fire season.

17.3.2. Preferred Seasons for Aerial Detection

SPB detection flights are generally flown during warm months, May through September, when multiple-tree SPB spots are most abundant and easy to identify from the air. The frequency of summer detection flights may vary from one every 1 or 2 weeks to one per year, depending on the State and the level of SPB activity. Fading pines are more difficult to detect during the spring and fall months, when hardwood tree crowns are coming into leaf or turning color, respectively. Thus, SPB detection flights are typically discontinued during these months. During the winter months, SPB populations tend to be more scattered, and the crowns of

Figure 17.6—Small, high-winged aircraft, such as this Cessna 182, are typically used for conducting aerial detection flights for SPB infestations. (photograph by Ron Billings, Texas Forest Service)

infested pines often turn from green to red without exhibiting fading foliage (Billings and Doggett 1980). A few States (Tennessee, Alabama, and North Carolina) routinely conduct winter detection flights to pinpoint large, overwintering SPB infestations during outbreak periods.

17.3.3. Flight Lines and Altitudes

To survey for SPB infestations, detection flights follow predetermined north-south or east-west flight lines over pine-forested areas, usually at an altitude of 1,000-2,000 feet aboveground. During SPB outbreaks, flight lines are generally spaced 1-5 miles apart and observers cover 100 percent of the area flown by recording SPB spots out to 0.5-2.5 miles from the plane (Aldrich and others 1958). In years when SPB populations are not expected to reach outbreak levels, State forestry agencies may fly 25-50 percent of the area by flying every second or fourth flight line. The total number of spots is then extrapolated from the data collected. In Arkansas, when SPB populations are at less than outbreak levels, detection flights follow even-numbered flight lines on the first flight and odd-numbered flight lines on the next flight scheduled 2-3 weeks later, so that 100 percent of the infested area is covered.

17.3.4. Flight Maps and Digital Sketchmapping Systems

Traditionally, suspected SPB spots have been plotted onto recent aerial photographs or topographical maps. With the advent of global positioning system (GPS) units, aerial detection procedures are becoming more sophisticated (Wainhouse 2005). Certain States (e.g., Georgia) locate the geographical position of SPB spots by flying directly over them in order to capture the coordinates with a GPS unit in the plane.

In recent years, Red Castle Resources, Inc., a private company, in cooperation with the USDA Forest Service, Forest Health Protection, has developed a digital sketchmapping system that has greatly aided aerial detection operations (see the Web site at http://redcastleresources.com/tech_eval_development/digital_aerial.html). The system integrates computer hardware, software, and assorted electronic components to provide a digital moving map display integrated with a GPS. Electronic maps or digital aerial photos are loaded into a laptop computer, and aerial observers plot suspected spots onto electronic map images using a touch-sensitive screen (see chapter 10).

A GPS unit installed in the plane provides the exact location of the plane throughout the flight, while an icon on the touchscreen shows the aerial observer where the plane is located on the electronic map. This technology greatly improves the accuracy of plotted spot locations. In most cases, two separate laptops and touch screens are installed in one plane to allow two aerial observers to plot SPB spots or other mortality centers independently. By the time the detection flight is completed, records of the newly detected spots are downloaded into a shapefile to be transferred to ground check crews. At present, only Arkansas, Delaware, and New Jersey use digital sketchmap systems for SPB detection, but all Southern States have plans to purchase and utilize this new technology in the near future, according to the recent survey of State pest management specialists.

17.3.5. Information Collected During Detection Flights

Information recorded during SPB detection flights varies among States. Certain States (Arkansas, Louisiana, Mississippi, and Delaware) only record the location of the spot while others (Tennessee, Alabama, Georgia, Florida, and South Carolina) also record an estimate of spot size based on number of red- and yellow-crowned trees. In Texas, Virginia, North Carolina, Maryland, and New Jersey, aerial observers assign each spot a ground check priority, in addition to recording location and estimated spot size (Billings and Ward 1984).

Spot Size Threshold and Spot Number

State agencies have set a threshold for spot detection, based on the number of pines with red and yellow crowns. This threshold usually varies from 5 (Arkansas, Delaware, Louisiana, Maryland, Mississippi, Oklahoma, and South Carolina) to 10 trees (Alabama, Georgia, Texas, and Virginia). Florida uses a threshold of 6 trees while North Carolina uses 2-3 trees, Tennessee 1-2 trees, and New Jersey 1-5 trees. Spots with less than 10 trees are difficult to detect if flight lines are spaced more than 1 mile apart (Aldrich and others 1958).

The 10-tree threshold was adopted in Texas in 1974, based on operational records that revealed that most SPB spots with less than 10 trees at detection were inactive upon subsequent ground check evaluation (Billings 1974). Small spots that are below this flight threshold are recorded on subsequent detection flights if they remain active and expand beyond 10 trees. Such detection thresholds are effective in reducing ground check work loads and serve to focus control operations on spots most likely to expand and cause unacceptable timber losses. With the exception of Mississippi, South Carolina, and Maryland, each State assigns a unique number to each SPB spot upon detection. This number identifies the spot throughout the season and is used to track specific ground check and control information in data management systems.

Assigning an Initial Spot Size

It is useful for aerial observers to assign an initial spot size to spots at the time of initial detection, since newly detected spots may vary greatly in number of infested trees and need for direct control. At this stage, the spot size estimate does not have to be precise. It is sufficient to place the spot in a broad category, based on estimated number of trees observed with fading and red crowns (e.g., 10-20, 21-50, 51-100, and > 100). Admittedly, currently infested trees are most likely to be ones with fading and green crowns. But infested trees with green crowns are indistinguishable from unattacked trees to aerial observers. Thus, the number of red-crowned and fading trees combined provides aerial observers the best estimate of the number of beetle-infested trees actually present in the spot (Billings and Ward 1984).

Assigning a Ground Check Priority

During severe outbreaks when several hundred new SPB spots may be detected in a single aerial detection flight, it is useful to assign each spot a ground check priority during the aerial detection phase. In Texas, for example, high priority is given to SPB spots having more yellow-crowned fading trees than red or bare trees, particularly those in dense, sawtimber stands (pines with diameters > 9 inches). In turn, low priority is given to spots with few yellow-crowned trees, those in sparsely stocked stands, particularly pulpwood stands (pines < 9 inches in diameter), or those located in mixed pine hardwood stands. Other spots are assigned a moderate priority for ground checking (Billings and Ward 1984).

Ground check crews should evaluate high-priority spots first, as these are most likely to expand and require control. Low-priority spots may not need to be evaluated on the ground, particularly when manpower and time are limited, as they often are during outbreaks. The status of these low-priority spots (e.g., if they are inactive or will eventually grow large) may be most efficiently updated during subsequent aerial detection flights. Small spots may be declared inactive from the air with no further need for control action if they are observed to no longer contain trees with fading yellow foliage (see Figure 17.4) (Billings 1979).

17.3.6. Scheduling Detection and Reevaluation Flights

The scheduling of SPB flights will depend on the season, level of SPB activity, current weather, availability of contract aircraft, and other factors (Billings and Doggett 1980). Flights should not be scheduled on cloudy or excessively windy days. Also, aerial observers should limit detection flights to no more than 4 hours/day, usually between 10am and 4pm, the time of day when aerial signatures are most visible (Ciesla and others 2008).

During mid- to late summer, it is recommended that all SPB spots that remain to be ground checked or controlled be given a unique symbol on flight maps and checked for recent activity during detection flights (Billings and Doggett 1980). Spots revisited by aerial observers that no longer contain trees with fading crowns may be listed as inactive, with no need for direct control (Billings 1979). Previously detected spots that initially were small (low priority for ground check) at first detection may be given a high priority for ground check if they have grown large in the interim.

17.3.7. Improving Aerial Detection Operations

Timely detection of SPB infestations while they are still small, combined with accurate plotting of their location on available aerial photos or maps, are key first steps in SPB suppression programs. Experienced aerial observers who are not colorblind or overly susceptible to airsickness are essential. Plotting an SPB spot in the wrong location or repeatedly reporting trees killed by casual agents other than SPB are actions of inexperienced aerial observers. Such actions will increase the workloads of ground crews and cause undue delays in suppression projects. Clearly, aerial observers should be trained to recognize the characteristic signature of SPB infestations and be able to distinguish them from those of other mortality agents (Billings and Ward 1984). Ciesla and others (2008) have developed an illustrated guide of aerial signatures characteristic of common mortality agents in forests of the Eastern United States. This guide should prove useful for training foresters and pest management technicians as aerial observers.

Digital sketchmapping technology promises to greatly increase the efficacy of SPB detection, once southern States have purchased the required equipment and trained their aerial observers to use it. With digital sketchmapping systems, the geographical locations of detected spots can be immediately downloaded as shapefiles into ground-based computers or field data loggers, accelerating the next step in SPB control operations, that of ground evaluation.

7.4. GROUND CHECK OPERATIONS

Once a suspected SPB infestation is detected, usually from the air, the next step in SPB control operations consists of ground evaluation or ground checking. The geographical location of an SPB spot, the actual level of SPB activity within the spot, the ability of SPB infestations to expand continuously, and the need for direct control may be different from that reported by aerial observers. Thus, to the extent possible, newly detected spots should be visited on the ground by trained foresters or technicians soon after detection.

17.4.1. Purpose of Ground Checking

The purpose of ground checking is multifold (Billings and Pase 1979a):

- To verify that SPB was indeed the causal agent
- To confirm or correct the geographical location of the spot given by the aerial observer
- To determine the potential for additional timber losses and identify the direction(s) of spot expansion (active heads)
- To establish a priority for control
- To identify the landowner
- To mark a buffer strip in the case of cut-and-remove or cut-and-leave control options

17.4.2. Ground Check Methods

Usually two trained State-agency foresters or technicians make up the ground check crew for safety reasons. Ground crews locate spots based on the geographical coordinates provided by aerial detection crews or position of the spot shown on aerial detection maps. Upon arriving at the spot, a ground check crew member will verify that SPB was the primary causal agent by observing the characteristic S-shaped parent galleries of SPB beneath the bark of infested trees (Figure 17.3). A pine with a fading yellow crown is the preferred candidate to inspect for SPB galleries because the bark is easy to remove with a hatchet or machete, and the parent galleries are plainly visible beneath the bark. In red-crowned trees, SPB galleries may be difficult to discern due to more extensive fungal growth and/or feeding by larvae of the pine sawyer, *Monochamus* spp. (Coleoptera: Cerambycidae).

Once SPB is confirmed as the causal agent, a hand-held GPS unit is used to verify or correct the geographical coordinates. Next, ground check crews should walk around the periphery of the spot to ascertain its relative size and to

Table 17.1—Symptoms associated with various stages of SPB-infested trees (from Billings and Pase 1979a)

Symptom	Stage 1 (fresh attacks)	Stage 2 (with SPB brood)	Stage 3 (vacated by SPB)
Foliage	Green	Green, fading to yellow before brood emerges	Red, needles falling, or bare
Pitch tubes	Soft, white, or light pink	White, hardened	Hard, yellow, crumble easily
Checkered beetles	Adults crawling on bark	Pink or red larvae about 1/2 inch long in SPB galleries	Larvae and pupae are purple; occur in pockets in outer bark
Bark	Tight, hard to remove	Loose, peels easily	Very loose, easy to remove
Color of wood surface	White, except near adult galleries	Light brown with blue or black areas	Dark brown to black
Exit holes on bark surface	None	Few, produced by re-emerging parent beetles	Numerous
Ambrosia beetle dust	None	White, localized areas at base of tree	Abundant at tree base, turns yellowish with age

determine if the spot contains more than one active head or direction of expansion.

Identifying Three Stages of SPB Attack

Ground crews should be able to identify three stages of SPB-infested trees in an expanding SPB infestation (Table 17.1). Stage 1 trees are those just coming under attack. These are pines with green crowns (Figure 17.7A) and fresh pitch tubes or boring dust in bark crevices (Figures 17.7B and C). The bark is attached tightly to the bole of the tree. Adults of the bark beetle predator *Thanasimus dubius*, family Cleridae, may be seen crawling on the outer bark of the tree (Figure 17.7D). When bark is removed, the inner bark and sapwood surface are white, as on a healthy tree (Figure 17.7E). Bark beetle galleries are not present or are less than 1 inch long.

Stage 2 trees are those with developing SPB brood (eggs, larvae, pupae, or new adults). These trees are characterized by having green or yellow fading crowns (Figure 17.8A) and well-developed S-shaped galleries beneath the bark (Figure 17.8B). Unlike with Stage 1 trees, no adult clerids will be present on the outer bark. The inner bark and surface of the sapwood will have turned light brown (Figure 17.8C), in contrast to the white color of the sapwood-phloem interface of Stage 1 trees (Figure 17.7E). There may be evidence of white sawdust accumulating at the base of Stage 2 trees, produced by attacking ambrosia beetles (Coleoptera : Platypodidae) that bore into the sapwood of beetle-killed pines. In most cases, the pitch tubes along the bole of Stage 2 trees will have hardened and turned yellowish. As SPB larvae mature, they move toward the bark surface, and observers must shave away thin layers of bark with an axe or machete to expose them or the pupae they become. The white pupae will soon transform to light brown callow adults, which will darken as they age (Figure 17.8D). Callow adults also can be found embedded in the bark of Stage 2 trees, until they emerge by boring a small circular hole in the outer bark and fly in search of another host tree.

In turn, Stage 3 trees are those infested pines from which SPB brood has completed development and emerged. Typically, these trees have red or brown-colored needles or bare crowns (Figure 17.9A). Numerous emergence holes or "shot holes" about the diameter of a pencil lead may be visible in the bark surface, signs that the SPB brood has abandoned the tree (Figure 17.9B). Ambrosia beetle dust is abundant at the base of Stage 3 trees (Figure 17.9C). The bark along the tree's bole is loose and easy to peel off, but the S-shaped SPB galleries may be largely obliterated by feeding larvae of sawyer beetles and other insects. The

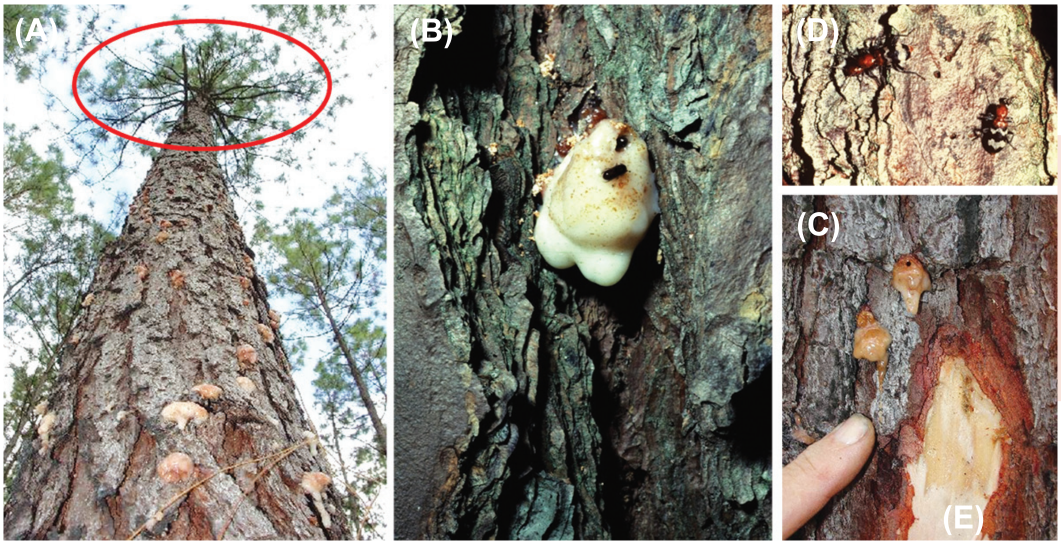

Figure 17.7—Symptoms of pines freshly attacked by SPBs (Stage 1) include (A) green crowns, (B, C) fresh pitch tubes in bark crevices, (D) adult clerid predators on bark, and (E) a white inner bark and sapwood surface.

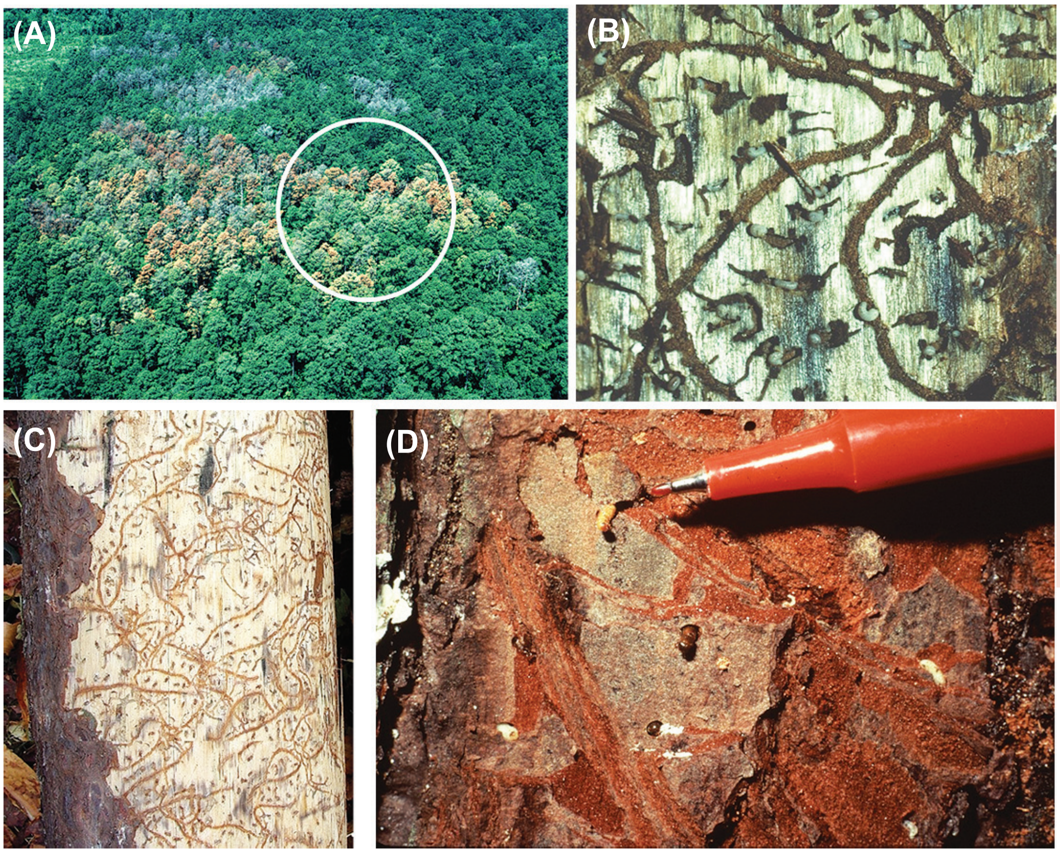

Figure 17.8—Symptoms of infested pines with SPB brood (Stage 2) include (A) green or fading crowns, (B) well-developed S-shaped parent galleries beneath the bark, (C) a brown-colored inner bark-wood interface, and (D) larvae, pupae or callow adults in or under the bark.

sapwood surface may be stained blue or black by blue stain fungi carried into the tree by the attacking bark beetles (Figure 17.9D). No SPB brood can be found within the bark of Stage 3 trees.

Spots that contain multiple trees in Stage 1 and Stage 2 are most likely to expand. Those that contain only trees in Stage 2 and Stage 3 still contain SPB brood but are unlikely to expand due to lack of a pheromone source produced only in Stage 1 trees. Spots with only Stage 3 trees are inactive, with no need for control. Particularly in late spring, ground crews may encounter spots containing primarily Stage 1 trees. This is indicative of a recently established spot. Whether such spots will eventually expand depends on several factors, principally the level of airborne SPB in the area and the initial spot size.

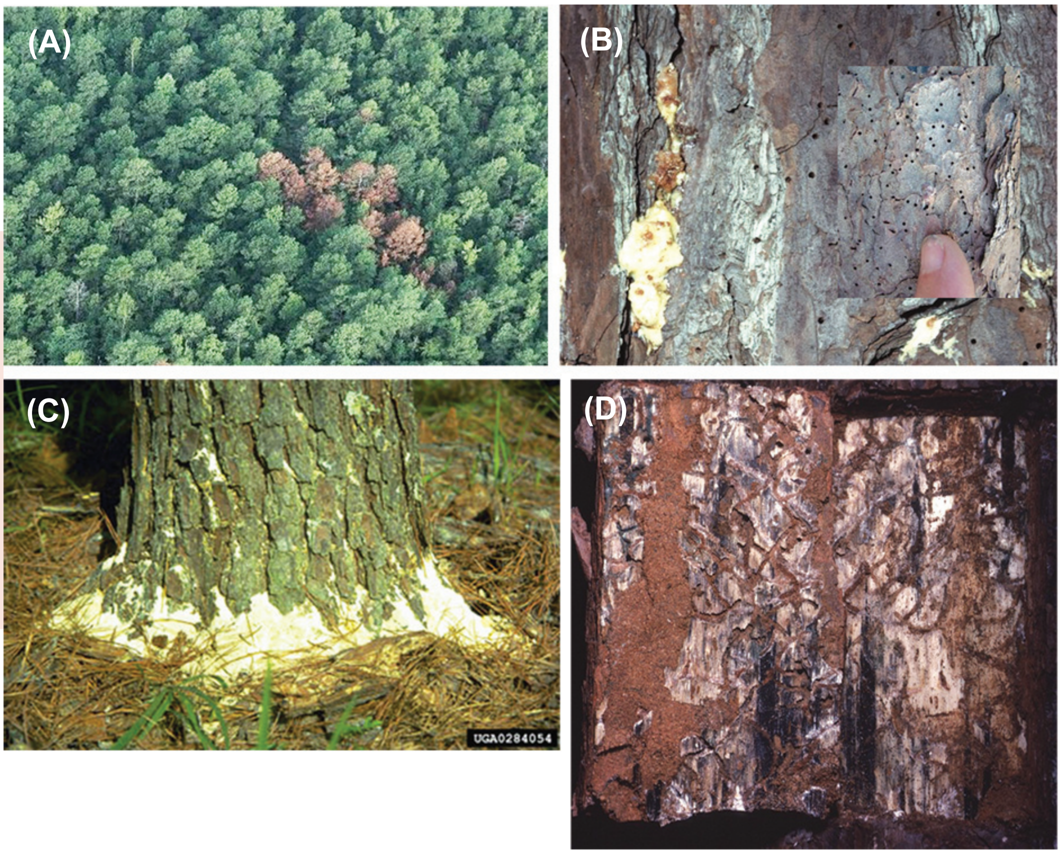

Figure 17.9—Symptoms of pines abandoned by SPB brood (Stage 3) include (A) trees with red or no foliage, (B) hardened pitch tubes with numerous exit holes on bark surface, (C) abundant white sawdust from ambrosia beetle dust at tree base, and (D) inner bark with sawyer galleries and blue stain masking SPB galleries.

Setting a Control Priority

Ground crews should determine the need for control and set a control priority at the time of ground check. As described in detail by Billings and Pase 1979a, the control priority is based on several factors (Table 17.2):

- The presence of Stage 1 trees, indicating a high probability for spot expansion
- The estimated number of infested trees
- Basal area of the stand at the active head
- Whether the stand contains pulpwood (average tree diameter at breast height < 9 inches) or sawtimber (average tree diameter > 9 inches)

Several predictive models have been developed to estimate tree losses to be expected in expanding SPB spots within 30-90 days if no direct control is applied (Billings and Hynum 1980, Reed and others 1981, Stephen and Lih 1985). These models may help pest managers make informed control decisions based on factors that can be easily measured in the field. They also may be useful to inform landowners about the extent and value of resources that are in jeopardy if direct control is delayed.

Marking a Buffer

The most recommended control measures for SPB infestations—cut-and-remove and cut-and-leave—require felling uninfested trees adjacent to Stage 1 trees to ensure that spot growth is halted. If direct control is likely to be applied to a spot shortly after the date of ground check, crews may mark the buffer strip during the ground check operation. Typically, the buffer is marked in a horseshoe-shaped pattern to encompass all Stage 1 trees and a few Stage 2 trees (Figure 17.10). Maximum width of the buffer will vary with the number of active trees in the spot and average tree height. In general, for most small to medium-sized spots (< 100 active trees), the buffer width is equal to the average height of the trees in the spot. Buffer widths will need to be expanded to control larger infestations (Billings 1980b).

The purpose of the buffer is to ensure that all SPB-infested trees are felled and pheromone production is disrupted in control operations. Because the SPB typically initiates attacks at mid-bole, early signs of beetle attack may be difficult to detect. The buffer provides a margin for error when identifying the trees under attack. Also, the buffer is essential to account for the fact that SPB spots may expand between the date of ground check and the date of control.

Table 17.2—Guide for setting SPB control priorities (May through October) (from Billings and Pase 1979a)

Key to spot growth	Your spot's classification	Risk-rating points
A. Stage 1 trees	Absent	0
(Fresh attacks)	Present	30
B. Stage 1 and 2 trees	1-10 trees	0
(Containing SPB brood)	11-20 trees	10
	21-50 trees	20
	More than 50 trees	40
C. Pine basal area (square feet/acre)	Less than 80 (low density)	0
(or stand density) at active	80-120 (medium density)	10
head or heads	More than 120 (high density)	20
D. Stand class by average	Pulpwood (9 inches or less)	0
d.b.h. (in inches)	Sawtimber (more than 9 inches)	10
	Total*	

* If total is 70-100, control priority = high

If total is 40-60, control priority = moderate

If total is 0-30, control priority = low

Indeed, if a delay of more than 1 week is anticipated between ground check and control operations, it is best to postpone marking the buffer until just before the control operation is begun. The final responsibility of the ground check crew is to flag a path back to the nearest road for subsequent visits by a control crew or to monitor the spot.

Landowner Notification

Identifying the landowner is an important step required only for spots on privately owned forest lands. Most State forestry agencies conduct ground checks of all spots on non-Federal lands following detection, then notify the appropriate landowner of the spot's occurrence and need for control. At least one State, Alabama, notifies landowners following the detection flight, leaving the ground check responsibilities and control decisions up to the landowner. All State agencies provide technical information to private landowners on identifying, evaluating, and controlling SPB infestations, as well as prevention guidelines.

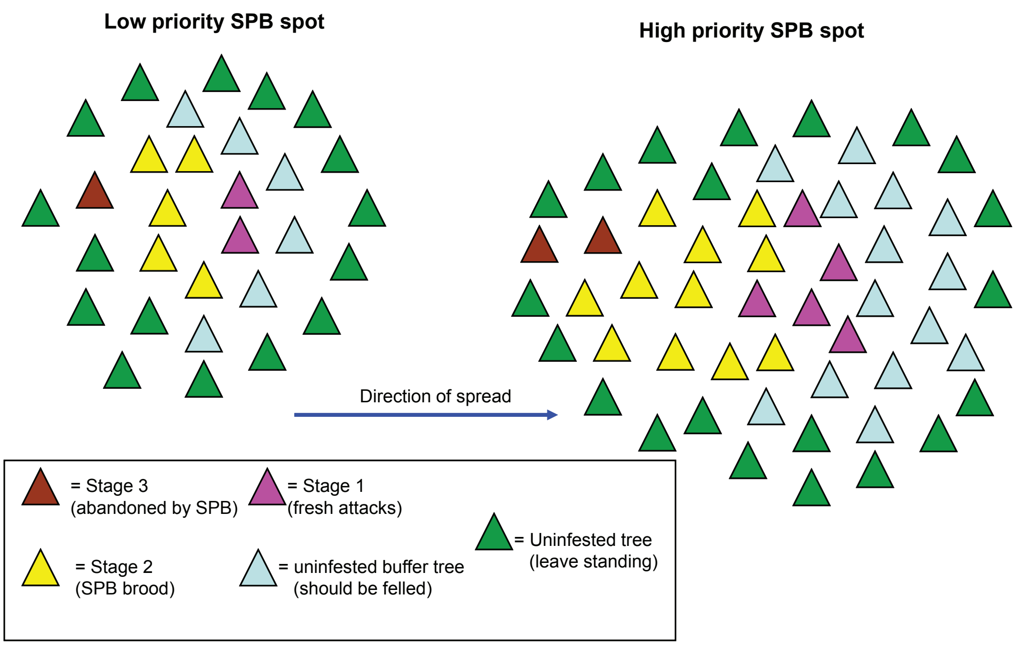

Figure 17.10—Diagram showing how to mark buffer strips for low- and high- priority SPB infestations (spots). All Stage 1 and Stage 2 trees, plus buffer trees, should be felled for cut-and-remove and cut-and-leave applications.

Recording SPB Operations Information

Each southern State has its unique methods for recording detection, and ground check and control information on SPB infestations during outbreaks. Some States maintain these records on Microsoft® Excel spreadsheets (Oklahoma, Arkansas, and Florida) while others (Alabama, Delaware, Georgia, New Jersey, South Carolina, and Texas) have developed electronic data management systems. The Texas Forest Service developed the first computer-based data management system for SPB, known as the SPB Operations Informational System (SPBOIS), in the early 1970s (Pase and Fagala 1979). This system served as a model for the Southern Pine Beetle Information System (SPBIS) later developed by the USDA Forest Service for National Forests (see http://www.fs.fed.us/r8/foresthealth/programs/spbis/spbis.shtml). Analysis of operational data from the Texas Forest Service SPBOIS has proven useful for identifying spot detection thresholds and other means to improve SPB control operations (Billings 1974).

To better coordinate and share information among State and Federal agencies on SPB infestations detected and controlled during outbreaks, the USDA Forest Service, Forest Health Technology Enterprise Team, in cooperation with State forestry agencies, is developing an Internet-based SPB information system (Anthony Courter, Softec Solutions, Fort Collins, CO, personal communication). Once developed, each southern State with SPB infestations will report detection and impact information into a single database via individual Web-based portals. This system will require that each State report a minimum of six standard variables, but will accommodate a wide variety of additional data variables to be chosen by each State. The six variables that are required from each State will be:

- Unique spot number
- Date of spot detection (month, day, year)
- Geographical location of the spot (county, latitude: longitude in decimal degrees)
- Final area affected (acres)
- Total volume of timber killed (cubic feet)
- Total value of trees affected (dollars)

Other variables are optional but may include additional aerial detection, and ground check and control information (e.g., spot size at detection, ground check priority, date of ground check, number of infested trees at ground check, mean tree diameter and stand basal area, landowner name and contact information, date of control, type of control, volume of pulpwood and sawtimber, and so on). Specific data, in addition to the six required variables, to be collected and recorded in the Southwide information system within a given State, will be determined by the State pest management specialist(s) in that State.

For the first time, standardized SPB operational information will be available across the South as it is collected by pest managers in up to 16 States, the national forests, and other public forest lands once this system is implemented. The new system will allow the USDA Forest Service and other stakeholders to monitor SPB activity and control programs across the South as the season progresses.

17.5. SPB MONITORING AND PREDICTION WITH PHEROMONE TRAPS

An operational system to forecast SPB infestation trends (increasing, static, declining) and relative population levels (high, moderate, low) has been developed and implemented throughout the range of this forest pest in the Southern and Eastern United States (Billings 1988, Billings and Upton, in press). The Texas Forest Service (TFS) developed the Southwide SPB Prediction System with inputs from Federal and State cooperators across the South. The system involves monitoring numbers of SPB and those of a major predator, the clerid beetle, *Thanasimus dubius,* using pheromone traps (Figure 17.11).

17.5.1. How to Predict SPB Infestation Trends

In general, from one to three multiple-funnel traps (Lindgren 1983) baited with the SPB aggregation pheromone, frontalin (Kinzer and others 1969), and host volatiles are placed in each county or National Forest Ranger District to be surveyed (Figure 17.11 A, B, C). Federal and State forest pest specialists in 16 States (Oklahoma, Arkansas, Texas, Louisiana, Mississippi, Alabama, Kentucky, Tennessee, Georgia, Virginia, Florida, South Carolina, North Carolina, Delaware, New Jersey, and Maryland) have participated annually in the region-wide prediction system, most for more

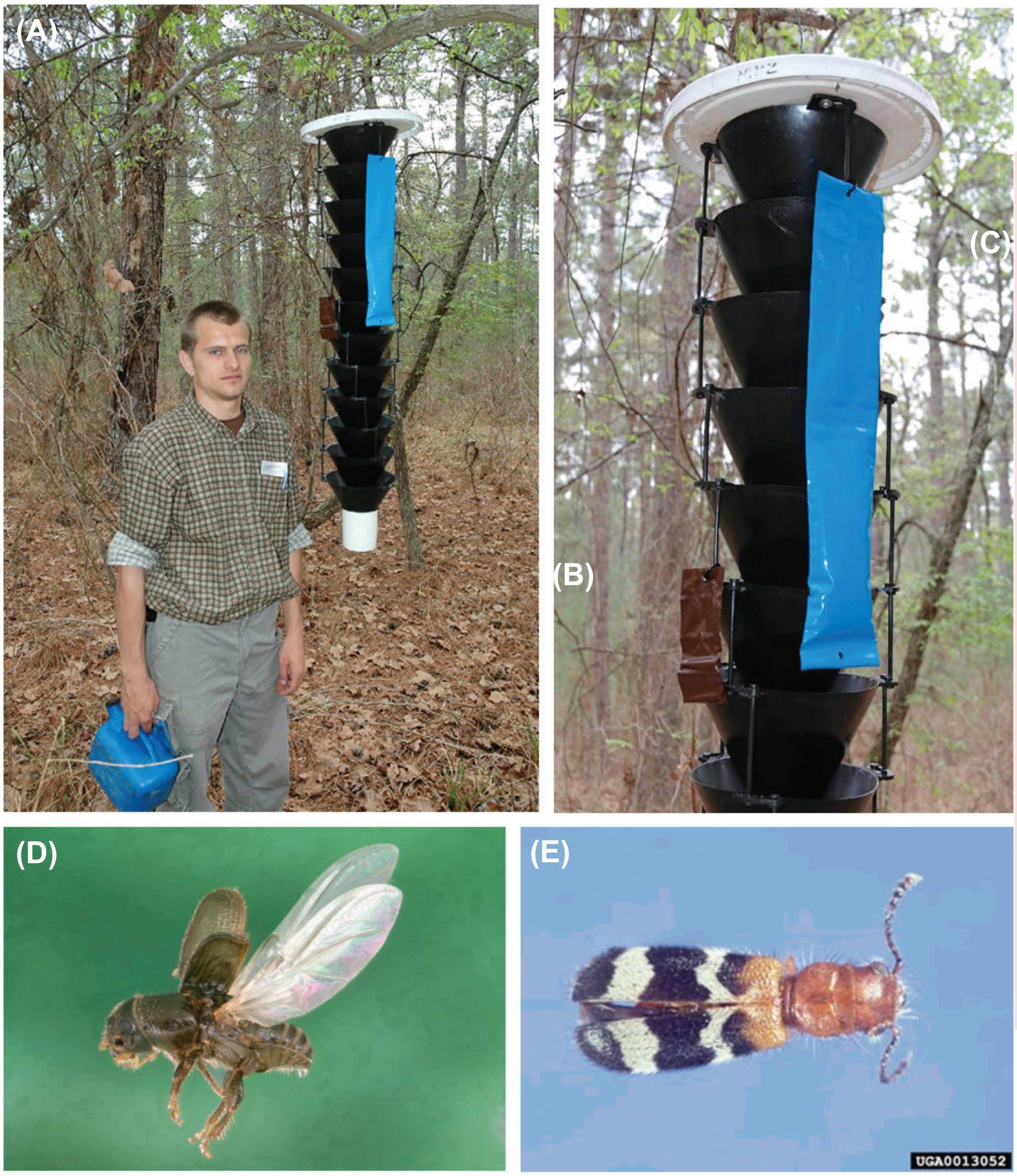

Figure 17.11—The Southern Pine Beetle Prediction System uses Lindgren funnel traps (A) placed in the field for 4 weeks starting when dogwoods bloom. The trap is baited with the SPB pheromone frontalin (B) and a dispenser of host odors (alpha- and beta-pinene) (C), an attractive bait combination that draws in flying adult SPB (D) and the clerid beetle, *Thanasimus dubius* (E), a major SPB predator. Both the number of SPB and number of clerids caught in traps are the variables used to forecast SPB infestation levels for the current year. (photographs (A), (B), (C) by Ron Billings, Texas Forest Service; photograph (D) by Erich G. Vallery, USDA Forest Service, www.forestryimages.org; photograph (E) by Gerald J. Lenhard, Louisiana State University, www.forestryimages.org)

than 2 decades. The traps are monitored for 4 consecutive weeks during the spring, beginning when dogwoods bloom. This seasonal event coincides with the long-range dispersal of SPB.

In 2007, the traditional host lure consisting of a rapid-release dispenser (amber glass bottle with wick) of steam-distilled loblolly pine turpentine was replaced with polyethylene bags of alpha-pinene (70 percent) and beta-pinene (30 percent). These commercially available host lures, in combination with synthetic frontalin, have proven equally effective for use in the SPB prediction survey (R. F. Billings, Forest Pest Management, Texas Forest Service, 301 Tarrow, Suite 364, College Station, TX 77840, unpublished data).

Responding insects are collected weekly for 4 consecutive weeks. Trap catch data—number of adult SPB (Figure 17.11D) and number of clerids (Figure 17.11E)—are sent to the Texas Forest Service for compiling and for making local, State, and regional predictions of SPB trends. The mean number of SPB/trap/day and the ratio of SPB to the total catch of SPB plus clerids (defined as percent SPB) in the current and previous year for the same trapping location are the variables used for predicting infestation trends and population levels for the remainder of the year. The SPB Prediction Chart (Figure 17.12) was developed and validated by comparing trap catch variables with actual detection records for each county, Ranger District, and State monitored. Upon completion of the annual survey, predictions are distributed to cooperators and are published on the Internet (Texas Forest Service Web page at http://texasforestservice.tamu.edu) for all to use, usually by the end of May.

17.5.2. Accuracy of the SPB Prediction System

An analysis of predicted and actual SPB infestation trends and population levels for participating States documents the accuracy of the prediction system (Billings and Upton, in press). From 1999 to 2005, the percent of correct predictions of SPB infestation levels averaged 82 percent for all States combined (range 71-100 percent); mean predictions for SPB population levels for States averaged 74 percent correct (range 43-100 percent). Despite system limitations, forest managers have come to depend on this early warning system for scheduling when and where to conduct aerial detection flights and to plan for suppression projects. This represents the first effective and validated prediction system for outbreaks of a bark beetle species anywhere in the world.

A recent survey of State forestry agencies shows that the SPB Prediction System has become the primary means of monitoring SPB populations during nonoutbreak years in three southern States—Arkansas, Texas, and Virginia. During years when SPB traps catch few or no SPB in spring surveys, the use of aerial detection flights may be greatly reduced or discontinued. In nine additional States—Oklahoma, Louisiana, Mississippi, Alabama, Georgia, Florida, South Carolina, Maryland, and Delaware—pheromone traps have become second only to aerial detection flights as the primary means to monitor SPB populations.

17.5.3. Extending SPB Monitoring into the Autumn

Based on the success of spring surveys to predict SPB infestation trends, the USDA Forest Service, Forest Health Protection, Region 8, is evaluating whether traps deployed

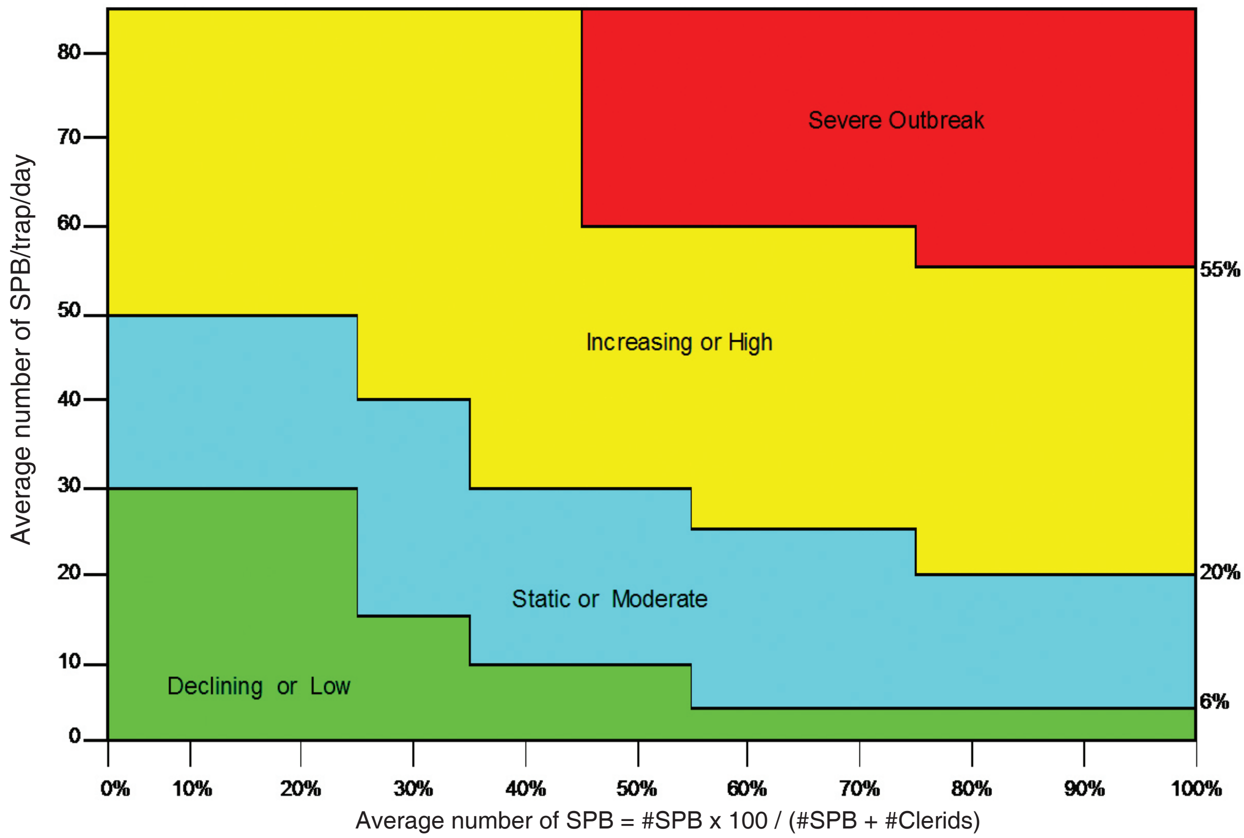

Figure 17.12—Southern pine beetle prediction chart, used to forecast SPB infestation trend and level for the current year, is derived by plotting the mean number of SPB/trap/day and percent SPB for the current year and comparing these data to that for the previous year (if available) for a given locality.

in November may be as effective as spring-deployed traps for prediction purposes (J.R. Meeker, USDA Forest Service, Forest Health Protection, 2500 Shreveport Road, Pineville, LA 71360). If so, fall surveys would provide even more lead time to prepare for pending SPB outbreaks. One limitation of fall surveys for predicting SPB infestation levels is that winter temperatures may play a critical role in determining SPB population trends the following spring (Ragenovich 1980, Tran and others 2007). By the same token, infestation trend predictions based on spring surveys may be rendered incorrect by adverse summer weather (excessively hot temperatures for prolonged periods) (Beal 1933). The long-term accuracy of fall predictions using pheromone traps remains to be determined.

17.6. SUMMARY

Monitoring SPB populations is a routine and essential phase of pest management for SPB, considered the most destructive pest of southern pine forests. Periodic detection flights over pine-forested landscapes in the South provide the primary means to detect new SPB infestations and pending outbreaks. Ground evaluation methods have been developed to provide pest managers with additional information on the status of SPB infestations detected from the air and the need for direct control. Methods for aerial detection and ground checking on State and private forest lands differ from those methods used on Federal lands, and also vary significantly among States. The goal in each case, however, is the same: to identify those SPB spots most likely to cause significant resource losses if not controlled and to facilitate subsequent control operations.

In recent decades, an effective system to predict SPB infestation trends and SPB population levels using pheromone traps has been developed and implemented to supplement aerial detection flights. This system is currently being implemented in 16 States through a network of traps deployed across the southern region each spring by State and Federal pest management specialists, providing another tool to better manage this destructive forest pest. Also, the feasibility of using pheromone traps deployed in the autumn to predict SPB infesation trends is being evaluated.

17.7. ACKNOWLEDGMENTS

Appreciation is extended to the State pest management specialists who contributed information on their States' specific methods for SPB detection and evaluation in the recent survey mentioned in this chapter. These specialists also voluntarily conduct the annual SPB prediction monitoring with pheromone traps in their respective States. These dedicated contributors are: Steve Mattox (Oklahoma Division of Forestry), James Northum (Arkansas Forestry Commission), William Upton (Texas Forest Service), Carlton Cobb (Louisiana Forestry Commission), Dr. Evan Nebeker (Mississippi Forestry Commission), Dana McReynolds (Alabama Forestry Commission), Clint Strohmeier (Tennessee Division of Forestry), James Johnson (Georgia Forestry Commission), Dr. Chris Asaro (Virginia Division of Forestry), Dr. Albert Mayfield (Florida Division of Forestry), Laurie Reid (South Carolina Forestry Commission), Rob Trickel (North Carolina Forestry Commission), Steve Tilley (Maryland Department of Agriculture), Glenn Gladders (Delaware Forest Service), and Jon Klischies (New Jersey Forest Service).