



# Implications of Population Phases on the Integrated Pest Management of the Southern Pine Beetle, *Dendroctonus frontalis*

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**ABSTRACT.** The southern pine beetle, *Dendroctonus frontalis* Zimmermann, has three population phases. In the latent phase, southern pine beetle-initiated infestations are absent, and southern pine beetle functions as a secondary bark beetle when present. The outbreak phase results when one or more multi-tree infestations are detected per 1,000 acres of susceptible host type, and the southern pine beetle acts as an aggressive primary colonizer. The intermediate phase consists of population levels between latent and outbreak. The characteristics of these three phases have management implications, and the integrated pest management (IPM) program for the southern pine beetle should be tailored for each phase. Recommendations for each phase are provided and discussed. Prevention and restoration are primary management concerns in the latent phase, whereas suppression takes precedence during an outbreak.

**Key Words:** southern pine beetle, population phases, *Dendroctonus frontalis*, management

The southern pine beetle, *Dendroctonus frontalis* Zimmermann, (Coleoptera: Curculionidae: Scolytinae), is a chronic insect pest within pine forests in the southeastern United States. Under favorable environmental and host conditions, it is an aggressive, primary bark beetle capable of killing large acreages of pines. Its principal range stretches from east Texas and Oklahoma to the east coast and north to southern New Jersey, and coincides with that of its primary hosts, shortleaf pine, *Pinus echinata* Mill. and loblolly pine, *P. taeda* L. (Clarke and Nowak 2009). Other typical host species are Virginia pine, *P. virginiana* Mill., sand pine, *P. clausa* (Chapm ex Engel.) Vasey ex Sarg., spruce pine, *P. glabra* Walter, pond pine, *P. serotina* Mich., and pitch pine, *P. rigida* Miller. During outbreaks, pine species usually less susceptible to the southern pine beetle also are attacked, including longleaf pine, *P. palustris* Mill., slash pine, *P. elliotii* Engelm., and eastern white pine, *P. strobus* L. Populations of the southern pine beetle also occur in Arizona, Mexico, and in Central America south to Nicaragua (Payne 1980). Southern pine beetles are a major cause of mortality of active cavity trees of the endangered red-cockaded woodpecker, *Picoides borealis* Vieillot (Conner and Rudolph 1995).

Southern pine beetle populations typically have been described as cyclic, with populations fluctuating between low, stable numbers and outbreak levels (Hain and McClelland 1979, Mawby et al. 1989). However, population levels in Texas, Arkansas, and Louisiana have remained extremely low since 1998. Bryant et al. (2006) recently suggested such area-wide population collapses represent a separate population phase, which they termed latent. The addition of this phase has prompted a reexamination of the IPM program for the southern pine beetle.

## Southern Pine Beetle Biology

Payne (1980) and Coulson (1980) provided a detailed overview of *D. frontalis* life history and population dynamics. Dispersal takes place in the spring, when temperatures are favorable for long-distance flight and prolonged adult survival. Initially, weakened trees with reduced resistance, such as lightning-struck pines, are attacked by dispersing pioneer beetles. The attacking beetles release aggregation pheromones, which combine with host tree volatiles to attract other *D. frontalis* of both sexes (Fig. 1). If sufficient populations are available, these pines can serve as 'epicenters' for new infestations (spots), and a pheromone-mediated shift of attacks to adjacent trees results in spot expansion (Gara and Coster 1968). Through mass attack, the beetles are able to overcome host resistance and kill otherwise healthy pines.

Southern pine beetles also inoculate the tree with a bluestain fungus [*Ophiostoma minus* (Hedge.) Syd. & P. Syd.] that can contribute to tree mortality (Fig. 2) (Coulson 1980). Infestations develop initially with a well-defined area of infestation growth known as a spot head (Fig. 3). *D. frontalis* may have 7–10 overlapping generations per year, and infestations can become self-sustaining, as most emerging and reemerging *D. frontalis* migrate to the spot head and participate in new attacks. During the hot summer months, beetle survival is limited outside of a host pine, and most beetles remain within or near the natal trees. As infestations grow, multiple areas with fresh *D. frontalis* attacks (spot heads) may develop, and eventually new trees may be attacked along the entire infestation perimeter where suitable hosts are present. All pines two inches or greater in diameter may be killed (Thatcher 1960). Spot proliferation, the development of new infestations near active or recently suppressed infestations, also occurs (Billings and Pase III 1979a, Fitzgerald et al. 1994). Some dispersal also takes place in the fall, when beetles may colonize isolated weakened trees. Beetles may overwinter within established infestations or in these isolated single trees.

As a result of this behavior, *D. frontalis* populations spend much of the year aggregated in infestations located within suitable host patches. These host patches within a susceptible pine type are characterized by a dominant pine overstory with minimal hardwoods (Kushmaul et al. 1979, Zhang and Zeide 1999) and a high pine basal area (Gara and Coster 1968, Hedden and Billings 1979).

The southern pine beetle is a member of a southern pine bark beetle guild that includes three species of pine engraver beetles: *Ips avulsus* (Eichoff), *I. grandicollis* (Eichoff), *I. calligraphus* (Germar); and the black turpentine beetle *D. terebrans* Olivier (Coulson et al. 1986). These species usually function as secondary pests, colonizing stressed or damaged hosts. Their populations rarely reach outbreak status (Flamm et al. 1988), but occasionally large areas are infested, particularly during periods of extended drought (St. George 1925, Thatcher 1960, Smith and Lee III 1972).

## Southern Pine Beetle Population Phases

Traditionally, southern pine beetle populations have been divided into two phases: outbreak (epidemic) and non-outbreak (endemic). Outbreak populations have been defined as one spot per 1,000 acres of suitable host type (Price et al. 1998). Non-outbreak populations have not been as well-defined in the literature. Between outbreaks, southern pine beetles may be exceedingly rare (Craighead 1925) or



**Fig. 1.** Southern pine beetle attacking in bark crevice, attempting to enter the tree despite host-produced resin. (Photo courtesy of Ron Billings).



**Fig. 2.** Characteristic S-shaped galleries of the southern pine beetle. The dark blue-black areas are inoculated with blue-stain fungi. (Photo courtesy of Ron Billings).

maintain small numbers of expanding infestations (Price et al. 1998). To better reflect actual population levels, Bryant et al. (2006) split non-outbreak populations into two phases. In the latent phase, multiple-tree *D. frontalis* infestations are rare or absent, whereas in the intermediate phase, infestations are present and detectable from the air, but their numbers fall below the outbreak threshold defined above. Intermediate was selected as the name for this phase as it is defined as falling between two extremes, and has been used to describe a phase of aggressive bark beetles (Berryman 1986). The term endemic was not used to avoid confusion with its other definition of native, and because it has been used previously to label population levels comparable to both the latent phase (Gold et al. 1979, Hain 1980) and to the combined latent and intermediate phases (Moore and Thatcher 1973, Payne et al. 1985, Mawby et al. 1989).

In addition to differences in number of infestations per area, other characteristics can be used to separate population phases (Table 1). During outbreaks, *D. frontalis* function as primary bark beetles. In the latent phase, southern pine beetles, when present, are secondary bark beetles, and may occupy only a small portion of the bole (Gold et al. 1979, Hain 1980, Moore and Thatcher 1973). Southern pine beetles may be primary or secondary attackers in the intermediate phase.

Infestation initiation and location also may vary by population phase. In the Coastal Plain, Hicks et al. (1981) and Porterfield and Rowell (1981) reported 45% and 42%, respectively, of infested stands during an outbreak had no evidence of disturbance. In contrast, Lorio (1984) found 81.8% of infestations during low *D. frontalis* population levels were associated with disturbances such as lightning, ice, logging, fire, or wind. When *D. frontalis* populations are low, most infestations develop in stands with high basal area, slow growth, and a large percentage of loblolly or shortleaf pine (Hain and McClelland 1979; Paine et al. 1985). As population numbers increase, the percentage of spots in stands considered as medium or low hazard for *D. frontalis* increases, although high-hazard stands still support the majority of infestations (Paine et al. 1985). Southern pine beetle outbreaks have been correlated with a low incidence of *O. minus*, although other staining fungi may be present (Bridges et al. 1985, Hofstetter et al. 2006).

Other differences in infestation and beetle behavior also occur between the phases (Table 1). The frequency of spot proliferation is influenced by the density of southern pine beetle spots (Billings and Pase III 1979a, Fitzgerald et al. 1994), and new infestations with no fading trees often have been discovered near established infestations



**Fig. 3.** Small southern pine beetle infestation with spot growth moving toward the upper left. Pines with fading foliage indicate the area of the spot head. (Photo courtesy of Ron Billings).

**Table 1.** Characteristics of southern pine beetle populations and infestations associated with three population phases

Southern pine beetle characteristic	Population phase		
	Latent	Intermediate	Outbreak
Spots per 1,000 acres susceptible host type	None	Between 0 and 1	One or greater
Colonizing status	Secondary	Primary or secondary	Usually primary
Infestation location	NA	High-hazard stands	Majority in high-hazard stands, some in medium- or low-hazard stands
Spot proliferation	NA	Rare	Common
Marginal hosts attacked	None	Rare	Occasional
Evident epicenter	NA	Usually	<80% of spots
Interchange between adjacent infestations	NA	Rare	Common when 1 or more spots occur w/in a host patch
Baited healthy pines attacked	None	<100% in 60 d	100% in 60 d
Bluestain fungus <i>Ophiostoma minus</i>	Unknown, likely similar to intermediate	High incidence	Low incidence

during outbreaks (S. C., personal observation). An increased incidence of spot proliferation in outbreaks also suggests that an interchange of beetles between neighboring infestations may be prevalent under outbreak conditions. Marginal hosts such as *P. strobus* and *Picea* spp. only are attacked when large infestations are active (Payne 1980) and are rarely successfully infested during the intermediate phase.

During several insecticide and trap tree studies, a trend in the speed and number of baited pines attacked and killed by *D. frontalis* during each phase has been observed in association with beetle population phases. In a test of the efficacy of 4-allylanisole (4-aa) for the protection of individual pines in Alabama, healthy loblolly pines were baited with frontaline and turpentine (Strom et al. 2004). On the Bankhead Ranger District, all baited pines not treated with 4-aa were attacked and killed within 30 d. Winston County, the site of the trial, was classified in Pye et al. (2008) as in outbreak, with 1.16 spots per 1,000 acres suitable host type. The other half of the study was conducted on the Oakmulgee Ranger District in Perry, Tuscaloosa, and Bibb Counties, which had 0.72, 0.77, and 0.83 spots per 1,000 acres, respectively, indicative of the intermediate phase, and just over 60% of the baited control trees were killed after 60 d.

In an insecticide injection trial on the Oakmulgee Ranger District in 2006, only eight of 33 baited control trees were killed after 60 d (Grosman et al. 2009). No infestations were reported on the Ranger District in 2006 in the U.S. Forest Service Southern Pine Beetle Information System (SPBIS) database, and only 66 infestations were recorded for the three-county area (Pye et al. 2008). In 2007, 18 of the

30 baited control trees were killed by *D. frontalis* within 60 d, with only 174 infestations reported in the area, well short of the 815 spots required for outbreak status. On the Chickasawhay Ranger District in Mississippi in 2005, only three of 35 baited control trees were killed within 60 d, and the District reported only 12 spots for the year. In a trap tree study conducted by the author from 2002 to 2009 during the latent phase in east Texas, none of the 25+ pines baited per year were attacked and killed by southern pine beetles. These results suggest that all baited pines readily are attacked during outbreaks, but only a portion typically succumb during the intermediate phase. No baited pines are successfully colonized during the latent phase.

### Integrated Pest Management Implications

Effective and efficient management strategies greatly reduce resource loss from *D. frontalis*. Clarke (2001) described an operational IPM program for *D. frontalis*. The primary components are prediction, detection, evaluation, suppression, and prevention. South-wide trapping surveys are conducted annually to predict southern pine beetle population levels and trends (Billings and Upton 2010). Lindgren funnel traps baited with frontaline, an attractant *D. frontalis* pheromone, and host terpenes are run for 4 wk each spring when *D. frontalis* disperse long distances (Fig. 4). The traps are deployed outside of active infestations. The numbers of *D. frontalis* and *Thanisimus dubius* (F.) (Coleoptera: Cleridae), a major *D. frontalis* predator, are counted. The mean number of *D. frontalis* per d and the ratio of *D. frontalis* to *T. dubius* are used to predict southern pine beetle popu-



**Fig. 4.** Lindgren funnel trap baited for southern pine beetle.

lation levels and if numbers are increasing, static, or declining. Aerial detection flights are conducted as needed from the late spring to fall to locate active infestations (Billings and Doggett 1980).

Prompt application of direct control methods, typically cut-and-remove and cut-and-leave, suppresses expanding infestations and greatly reduces tree loss (Clarke and Billings 2003). Cut-and-remove and cut-and-leave are the primary suppression treatments (Fig. 5) (Swain and Remion 1981). Both methods require the felling of a buffer of uninfested pines around the area of spot expansion. The purpose of the buffer is to account for delays in treatment application, interrupt pheromone dispersion near residual standing pines, ensure that all newly attacked trees are included in the treatment, and to



**Fig. 5.** Southern pine beetle infestation treated by cut-and-leave. (Photo courtesy of Roger Menard).

increase the distance between emerging beetles and uninfested pines. In the absence of suppression, expanding infestations may merge and grow quite large. Spot expansion can occur along the entire spot perimeter and marginal host species may be attacked and killed.

Numerous hazard rating systems have been developed to classify stand susceptibility to *D. frontalis* infestation (Mason et al. 1985). These systems often use pine species, pine basal area, stand age, landform, or other factors to identify the hazard as low, moderate, high, or extreme. Prevention programs are implemented to reduce the hazard and limit mortality when *D. frontalis* populations increase (Nowak et al. 2008).

The IPM program should be targeted to the current *D. frontalis* phase, the predicted phase, or both to maximize the efficient allocation of manpower and other resources. The following are recommendations for southern pine beetle IPM in each phase.

#### Latent Phase

Even though southern pine beetle populations are extremely low or locally extinct during the latent phase, the need for a southern pine beetle integrated management program remains.

**Prediction.** The spring survey still is necessary to document the absence of beetles and track long-term trends in clerid and southern pine beetle numbers. Survey results also provide a warning once southern pine beetle populations again become detectable. Additional trapping in the fall or winter could be advantageous in detecting population increases (Miller and Parresol 1992). The use of *endo-brevicom* in the late season surveys could be beneficial, as it is a potent attractant for *D. frontalis* when added to the standard southern pine beetle lures (Sullivan et al. 2007). Methods of correlating trap catches to southern pine beetle infestation levels the next year remain to be developed.

**Aerial Detection.** One or no aerial detection surveys are recommended, allowing resources to be directed to other forest health concerns. Forestry personnel on flights conducted for other purposes should record and report any suspected southern pine beetle infestations.

**Ground Evaluation.** Mortality of pines because of bark beetles will be caused primarily by *Ips* engraver beetles or the black turpentine beetle. Any large, concentrated area of pine mortality should be checked on the ground to ascertain the causal agent, with the exception of damage because of wildfire, which is easily recognizable from the air.



**Fig. 6.** A dense pine plantation rated as high hazard for southern pine beetle. (Photo courtesy of Erich Valley).

**Suppression.** Suppression activities are restricted to salvaging large areas of *Ips* bark beetle activity, potential hazard trees, or both. Forest managers should maintain a current list of loggers in anticipation of increased southern pine beetle populations.

**Prevention.** Management activities designed to reduce the susceptibility of forest stands would become the top priority of the IPM program. Overstocked, high-hazard pine stands should be thinned (Figs. 6 and 7), and areas with off-site, susceptible pines converted to site-compatible species (Belanger and Malac 1980, Nebeker et al. 1985). If the latent phase for *D. frontalis* coincides with known or expected outbreaks of *Ips* bark beetles, particularly during periods of extended drought and extreme high temperatures, care should be taken to limit damage to residual pines during thinning operations to prevent *Ips* infestation. Thinning operations also may be scheduled during cooler weather when *Ips* bark beetles are less active. Sites impacted by *D. frontalis* during previous outbreaks should be regenerated if adequate numbers of desired, site-appropriate seedlings and saplings are not present. Restricting the movement of currently infested material into the latent area would be advisable, and trees removed in suppres-

sion actions outside of the latent area should be processed at facilities within the area of general infestation when feasible.

An active prevention program during the latent phase also helps sustain local timber or biomass markets. If the latent phase is protracted, it is essential to maintain outlets for the materials generated from cut-and-remove operations once southern pine beetle populations return. Thinning operations also support the local logging community, ensuring that sufficient personnel and equipment will be readily available for suppression activities during the next outbreak.

In the absence of environmental conditions favorable for secondary bark beetles, such as drought, management practices that favor the maintenance of stable populations of southern pine beetle competitors and natural enemies could help prolong the latent phase of *D. frontalis*. For example, some logging slash from thinning operations for southern pine beetle prevention could be left on the ground as breeding sites for *Ips* spp. and wood borers (Fig. 8). These beetles would compete with dispersing *D. frontalis* searching for suitable host material such as lightning-struck pines (Flamm et al. 1993). The *Ips* beetles also would provide prey for *T. dubius* (Reeve et al. 2009),



**Fig. 7.** A recently thinned pine stand now rated as low hazard for southern pine beetle.



**Fig. 8.** Larva of a cerambycid wood borer which competes with the southern pine beetle for phloem resources. (Photo courtesy of Joe Pase).

helping maintain their population levels and their ability to rapidly respond to southern pine beetle infestations. The logging slash could be burned, chipped, or otherwise treated once the beetles had emerged if necessary for site restoration or fuel reduction. This concept has not been tested in the field, and should not be considered when southern pine beetle competitors currently are abundant. Research and economic analyses are required to examine the feasibility and necessity of this maintenance of southern pine beetle competitors.

**Other Considerations.** The latent phase provides an opportunity to ensure that all necessary environmental documentation or regulatory requirements for southern pine beetle suppression are current and in place. Training programs and tracking databases can be developed or improved. Forest landowner information should be updated and maintained in a GIS layer. Hazard rating maps should be updated to reflect current forest stand conditions. Southern pine beetle preparedness programs can be developed or revised based on the experience gained during the previous outbreak.

### Intermediate Phase

When southern pine beetle populations increase into the intermediate phase, the emphasis of the IPM program should switch from primarily prevention to a mix of silvicultural treatments and *D. frontalis* population reduction strategies. Preparations should begin for the potential onset of an outbreak.

**Prediction.** In addition to the spring survey, fall and winter trapping may help determine the population trends. The addition of *endobrevicomin* to the southern pine beetle trap lures would be beneficial, but the traps should be placed in hardwood inclusions within pine stands to prevent attacks on nearby pines.

**Aerial Detection.** Monthly aerial detection surveys may be needed from May-September, and aerial surveyors should be trained to use a Digital Aerial Sketch-mapping (DASM) system if available (Steiner 2011). This system allows users to plot infestation locations on a touchscreen, automatically assigning each spot a latitude and longitude. Other attributes for infestations can be entered as well, such as size estimates, ground-check priorities, and whether the infestation appears active. Pine timberland owners, including absentee ones, should be notified that southern pine beetle populations are increasing and instructed to survey their property routinely for infestations.

**Ground Evaluation.** Infestation coordinates and other data from the aerial surveys can be downloaded directly into handheld data loggers

or field computers equipped with GPS, and these devices are used to navigate to the infestations and collect spot data (Petty 2011). Each infestation must be assigned a unique spot number for tracking purposes. At the infestation, ground-checkers must verify that the southern pine beetle is the causal agent and determine if the infestation is active and likely to continue expansion. Data collected should include number of currently infested trees, number of newly attacked trees, and the number of spot heads and their direction of movement (Billings and Pase 1979b). Stand data may be collected, such as average tree diameter, pine and total basal area, and average tree height. Based on these spot and stand data, each spot is assigned a priority for control. The spot perimeter should be flagged and can be mapped as a shapefile. If possible, surveyors can designate a suppression method and immediately mark the infestation for treatment. Treatment choice is determined by spot size, access, market conditions, environmental regulations, and other factors. Cut-and-remove and cut-and-leave require a buffer, and the size of the buffer marked will depend on spot size, spot activity and predicted rate of expansion, forest stand conditions, and expected interval between marking and treatment implementation.

The utilization of a color-coded flagging system assists future ground-check and suppression activities. Specific color patterns are used to denote the access point into the infestation from a road, the spot perimeter, the location of fresh attacks, and the treatment area.

All data collected during aerial and ground surveys must be entered into a database. Infestation location can be entered as coordinates or as a shapefile. On National Forests, SPBIS functions as a southern pine beetle management database (Pecher 2011). Infestation activity can be tracked through time, ensuring that all spots are surveyed and suppressed in a timely manner. States and other large land management agencies may use their own databases. Subsequently, database records should be uploaded into the newly developed southern pine beetle Data Portal ([http://svinetfc12.fs.fed.us/SPB\\_DataPortal/](http://svinetfc12.fs.fed.us/SPB_DataPortal/)), which provides a consolidated picture of southern pine beetle activity throughout the southern and northeastern United States.

**Suppression.** All detected infestations with currently infested trees should be treated promptly to stop spot expansion and limit population growth. Cut-and-remove is the desired treatment for all accessible infestations. Vacated trees should be left standing to preserve natural enemy and competitor populations. Suppressed infestations should be



**Fig. 9.** A large southern pine beetle infestation in a mixed pine-hardwood stand. Many of the pines killed are hazards to homes, roads, and power lines. (Photo courtesy of Ron Billings).

monitored at least once within 2 wk posttreatment to check for breakouts. Once an infestation has been classified as inactive or suppressed, a polygon of the entire affected area should be collected and entered into the Data Portal. These shapefiles help determine the scope of the damage and assist in planning restoration actions.

Vité (1970) suggested baiting host trees as a method of area-wide southern pine beetle population manipulation. Solitary, uninfested pines could be baited with standard southern pine beetle lures plus *endo-brevicomin* in the fall, spring, or both to attract dispersing beetles. Once these trap trees become infested, they should be removed before the broods emerge. Pines scheduled for removal in thinning or other forest management actions also could be baited 1–7 d before being felled and removed. Though these trap tree techniques may have applicability during the intermediate phase, they have yet to be validated for their efficacy in southern pine beetle population reduction.

**Prevention.** Thinning and other operations that may result in tree damage would be restricted to the winter when southern pine beetles are less active. Sanitation, the removal of lightning-struck or other damaged pines, would be expedited to limit the number of potential infestation epicenters. The removal of small spots or individual infested trees in sawtimber stands during the late fall and winter should be emphasized, as these pines may sustain large southern pine beetle broods and fuel population growth in the spring (Thatcher and Pickard 1964, Lorio 1984).

**Other Considerations.** Land managers would need to maintain and update lists of available cut-and-remove and cut-and-leave operators that could be used if infestation suppression is required. Training sessions should be scheduled annually for all personnel involved in southern pine beetle detection, evaluation, and suppression. Trainees should become familiar with current integrated southern pine beetle management techniques as well as any guidelines or trigger points in their agency's preparedness plan.

### Outbreak Phase

During southern pine beetle outbreaks, a majority of available resources are targeted toward infestation detection, ground evaluation, and suppression. The goals of the IPM program become the reduction of total tree mortality and limiting impacts to other management concerns, such as red-cockaded woodpecker habitat or other valuable resources (e.g., recreation areas).

**Prediction.** Spring trapping surveys should be conducted. Pines near the survey traps should be examined each collection date for evidence of infestation, as spillover attacks can occur. If attacks on

nearby pines are observed, relocate the trap to an uninfested portion of the same stand or to a different stand and report the new infestation. The use of *endo-brevicomin* for fall surveys should be restricted to traps placed in hardwood areas 50–100 m from the nearest pine stand.

**Aerial Detection.** Detection flights may be needed as often as every 2 wk during the spring and summer. Aerial surveyors can load maps of previously detected infestations as a backdrop in their DASM system to prevent duplicate recording of spots. Once the data are downloaded and mapped, a notification system by e-mail or phone should be in place to alert landowners that infestations are on or near their property. Such a system requires up-to-date records of boundaries and ownership. If time permits, the pine forest within 100 m of active infestations should be surveyed for the presence of nascent satellite infestations without fading trees, particularly in high-hazard stands. A late-season flight is useful to reevaluate previously detected spots that remain uncontrolled, using the presence of fading (yellow-crowned) trees as evidence that a spot remains active (Billings 1979).

**Ground Evaluation.** Prioritization of infestations for ground-checking is essential during an outbreak. Most infestations should be evaluated within 3 d of detection. Infestations near high-value areas such as endangered species habitat should receive high priority. Infestations located in high-hazard stands also should be visited as quickly as possible. Database managers should conduct daily checks of their records to ensure that all detected infestations have been evaluated in a timely manner.

Data collection and infestation marking should proceed as described above for the intermediate phase. Larger-than-typical buffers may be required in outbreaks because of the rapid rate of spot expansion and delays caused by a shortage or heavy workload of suppression crews.

**Suppression.** Maintaining the prompt suppression of infestations is extremely important in minimizing the impacts of the outbreak, but it becomes problematic as resources become stretched. Any infestation with fresh attacks apparent during the initial ground-check should be scheduled for suppression. Given the large number of infestations developing during an outbreak, infestations need to be prioritized for suppression. Spots with large numbers of fresh attacks, in high-hazard stands, or both should receive high priority for suppression. Infestations near roads, buildings, power lines, campsites, or trails also should receive high priority and be treated while the beetles are still in the trees. Otherwise, dead trees after beetle emergence will pose a hazard and will be costly and dangerous to fell (Fig. 9). When possible, suppression efforts should be coordinated across all owner-

ships within high-hazard areas to treat all infestations and prevent spot proliferation. Spots with currently infested trees but no fresh attacks should be monitored, and such infestations should be revisited within 1–2 wk of the initial ground-check to ascertain if spot expansion has occurred.

Active infestations can add two or more trees per day during outbreaks, so timely suppression is imperative. An infestation tracking system such as the one developed in SPBIS should be used to ensure that all infestations are monitored and all expanding infestations are suppressed within 40 d of detection. If the 40-d interval cannot be met, land managers may need to recruit well-trained personnel from other areas to cope with the increased need for detection and suppression activities. The primary treatment tactic may switch to cut-and-leave to avoid the delays sometimes associated with cut-and-remove. Cut-and-leave treatments also should be used as markets become saturated with beetle-killed material. Trees felled in cut-and-leave treatments could be decked for future salvage if this process does not divert resources from other critical suppression activities. Trees vacated by southern pine beetles should not be felled, as they harbor natural enemies and competitors of southern pine beetles, plus sawyers need to concentrate their efforts on currently infested pines. All treated infestations should be monitored within 1–2 wk posttreatment to check for breakouts. Breakout treatments should be applied promptly to minimize additional tree loss and minimize buffer size. Collecting the shapefiles of the final affected area may be postponed until the winter if personnel are needed for ground-checking and infestation suppression.

**Prevention.** Prevention thinning would be curtailed, primarily because of the loss of outlets for the trees removed and the need for loggers for suppression activities. Restoration of affected areas could proceed in the winter.

Protection of high-value pines would be critical. Homeowners and recreation or park managers should consider treatment of their ornamental pines with labeled insecticides to prevent southern pine beetle infestation. Homeowners and businesses should be alerted to avoid pruning their pines while the outbreak is ongoing. As southern pine beetle-induced mortality of cavity trees is positively correlated with forest-wide infestation levels (Conner et al. 1998), wildlife managers routinely should check red-cockaded woodpecker cavity trees and other endangered species habitat for evidence of southern pine beetle infestation.

**Other Considerations.** An Incident Command System may be necessary to coordinate all management activities during an outbreak. City, state, and federal governments or agencies can declare the outbreak an emergency situation, which can help free up the resources necessary to combat the problem and may expedite suppression efforts. The public must be alerted to the severity of the outbreak to increase awareness and generate support for suppression. Public meetings should be scheduled to discuss the outbreak status, provide information on suppression strategies, and answer questions about southern pine beetle.

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