A Methodology for Assessing Annual Risk of Southern Pine Beetle Outbreaks Across the Southern Region Using Pheromone Traps

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Abstract

An operational system to forecast infestation trends (increasing, static, declining) and relative population levels (high, moderate, low) of the southern pine beetle (SPB), *Dendroctonus frontalis*, has been implemented in the Southern and Eastern United States. Numbers of dispersing SPB and those of a major predator (the clerid beetle, *Thanasimus dubius*) are monitored with multiple-funnel traps baited with the SPB aggregation pheromone frontalin and host volatiles. One to three traps are placed in each county or national forest ranger district to be surveyed for 4 consecutive weeks during the spring, to coincide with the long-range dispersal of SPB. The average number of SPB per trap per day and the ratio of SPB to total catch of SPB and clerids 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. An analysis of predicted and actual SPB infestation trends and population levels for 16 States and up to 19 consecutive years (1987-2005) documents the accuracy of the annual prediction system. From 1987 to 1998, predictions at the State level, validated by subsequent infestation detection records for the specific year, proved accurate 68 percent of the time (range 42 to 83 percent) for SPB infestation trend and 69 percent of the time (range 42 to 92 percent) for population level. From 1999 to 2005, the mean accuracy of predictions of SPB infestation trend improved to 82 percent for all States combined (range 71 to 100 percent); mean predictions for population level for States increased in accuracy to 74 percent (range 43 to 100 percent). Despite system limitations, forest managers have come to depend on this early warning system to predict pending outbreaks
or collapses of SPB populations. This represents the first effective and validated prediction system for outbreaks of a bark beetle species.

Keywords: Bark beetles, *Dendroctonus frontalis*, prediction, surveys, *Thanasimus dubius*.

Introduction

Forest managers and pest control specialists have long needed a reliable and practical early warning system to detect developing outbreaks of the southern pine beetle (SPB), *Dendroctonus frontalis* (Coleoptera: Curculionidae: Scolytinae), the most destructive forest pest of southern pine forests (Thatcher and others 1980). Because aerial surveys to detect SPB infestations do not become effective until late spring or summer (Billings and Doggett 1980), a more efficient system for monitoring SPB populations early in the season has value. Early detection of pending outbreaks gives forest pest managers valuable insight for scheduling detection flights and planning suppression programs.

In 1986, the Texas Forest Service began development of an operational system using pheromone-baited traps for predicting SPB infestation trends (increasing, static, declining) and population levels (high, moderate, low). In cooperation with State and Federal pest management specialists, the system was implemented throughout the South beginning in 1987 (Billings 1988, 1997). Validation and refinement of the system have been conducted periodically with use of year-end SPB infestation detection records. Here, we evaluate the accuracy of this prediction system, based on results from 16 States, most of which have now deployed the system for 20 consecutive years (1987-2006).

The southern pine beetle's range extends from New Jersey to Florida and west to Texas, coinciding with the distribution of its major hosts, loblolly (*Pinus taeda* L.) and shortleaf pine (*P. echinata* Mill.). SPB populations also are found from southern Arizona south to Nicaragua. Outbreaks of this insect tend to occur somewhere within its range every year, with peak populations occurring every 6 to 9 years in many Southern States (Price and others 1998).

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Figure 1—Small (A) and large (B) expanding southern pine beetle (SPB) infestations (spots) in east Texas, as seen from the air. Beetles emerging from the yellow-crowned host trees (faders) will tend to attack uninfested, green-crowned trees on the spot periphery in response to aggregation pheromones, leading to continuous spot growth during summer months.

The location and intensity of SPB outbreaks may vary greatly from year to year. Unlike most other destructive bark beetles of the genus *Dendroctonus*, SPB completes up to seven generations per year in Gulf Coastal States and infests host trees in distinct and predictable patterns that vary with the seasons. For example, most new multiple-tree SPB infestations (spots) are initiated during the spring, following long-range dispersal of overwintering beetle populations (Hedden and Billings 1979, Thatcher and Pickard 1964). In the late spring and summer, adult beetles tend to attack host trees on the periphery of the same spots from which they emerged (Gara 1967; Hedden and Billings 1977, 1979; Thatcher and Pickard 1964). This behavior leads to expansion of previously established spots, rather than the initiation of new ones. These expanding infestations (Figure 1) are easily recognized in summer detection flights by the presence of pines in various phases of crown discoloration (Billings and Doggett 1980). Emerging SPB adults tend to disperse again in the fall, redistributing the population among scattered single trees, nonexpanding spots, and established infestations prior to winter.

Materials and Methods

Standardized procedures for conducting the annual SPB prediction survey are available online at http://texasforestservice.tamu.edu/pdf/forest/pest/tutorial_for_predicting_spb.pdf. Basically, from one to three multiple-funnel traps (Lindgren 1983), available from Phero Tech, Inc., Delta, British Columbia, and other sources (e.g., Synergy Semiochemicals Corp., Burnaby, British Columbia, Canada) are placed in pine forests within a county or national forest ranger district in early spring. The traps consist of 12 funnels superimposed over a collection cup (Figure 2A) that is partially filled with soapy water. The number of counties or ranger districts surveyed differs from State to State, depending on availability of pest management personnel, supplies, travel distances, and other factors.

The survey is initiated when flowering dogwood (*Cornus florida* L.) begins to bloom or loblolly pine pollen appears. These physiological events coincide with the long-range dispersal of SPB (Billings, unpublished data). Each spring, when ambient temperatures consistently exceed 59 °F, (the flight threshold for SPB and its predators) (Moser
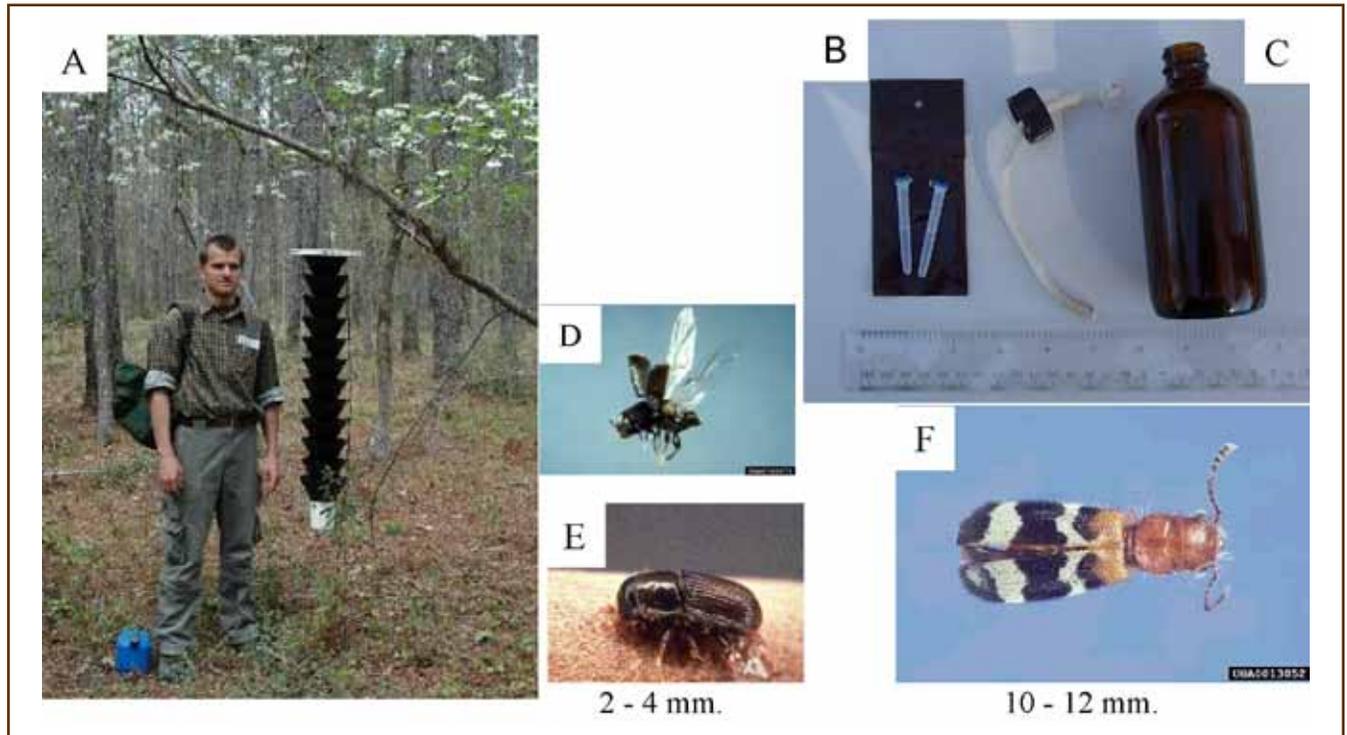
Figure 2—The Southern Pine Beetle Prediction System uses 12-funnel survey traps. The traps are (A) placed in the field for 4 weeks in the spring starting when dogwoods bloom. Each trap is baited with the SPB pheromone frontalin (B) and a bottle of steam-distilled pine turpentine (C), an attractive bait combination that draws in flying adult SPB (D) and the clerid beetle, *Thanasimus dubius* (F), a major SPB predator. Both the number of SPB (E) and number of clerids caught in traps are used to forecast SPB infestation levels for the current year. (Photos A-C by R. Billings; photo D by Erich G. Vallery, USDA Forest Service, Bugwood.org; photo E by Texas Agricultural Extension Service Archive, Texas A&M University, Bugwood.org; photo F by Gerald J. Lenhard, Bugwood.org)

and Dell 1979), populations of SPB disperse from overwintering sites in search of weakened pine trees in which they initiate new infestations (Billings and Kibbe 1978). Because of regional variations in climate, trapping usually occurs from early March to mid-April in the Gulf Coastal States and in April or May in States in the northern portions or mountain regions of the beetle's range. It is during this spring dispersal period that airborne populations of adult SPB and associated insects can be most effectively monitored with pheromone-baited traps for predictive purposes (Billings 1988).

Each trap is baited with a single pheromone packet containing two 400 microliter "bullet" capsules of racemic frontalin (Phero Tech, Inc., Delta, British Columbia) (Figure 2B), the SPB aggregation pheromone (Kinzer and others 1969, Payne and others 1978), and a rapid-release dispenser of steam-distilled southern pine turpentine (Billings 1985) (Figure 2C). From 1987 to 2005, the turpentine

dispenser consisted of a 250 ml amber Boston round bottle (Fisher Scientific Company, Pittsburgh, PA) with a cotton wick. Various brands of commercial-grade southern pine turpentine (Klean-strip™ (1987-1997), Star-tex™ (1998), and Hercules™ (1999-2006)) were used, depending on availability. These insect- and host-produced volatiles attract in-flight adult SPB (Figures 2D, E) as well as a major predator, the clerid beetle *Thanasimus dubius* (Coleoptera: Cleridae) (Figure 2F) (Billings and Cameron 1984, Moser and Dell 1980, Payne and others 1978, Vite and Williamson 1970). More than any other associated insect, *T. dubius* is believed to play a major role in the population dynamics of SPB (Moore 1972; Reeve and Turchin 2002; Thatcher and Pickard 1966; Turchin and others 1991, 1999).

Each trap is installed in a pine-forested area, preferably in stands having sawtimber trees (> 30 cm in diameter at breast height) with a sparse hardwood understory. The traps are purposely placed outside of SPB infestations to
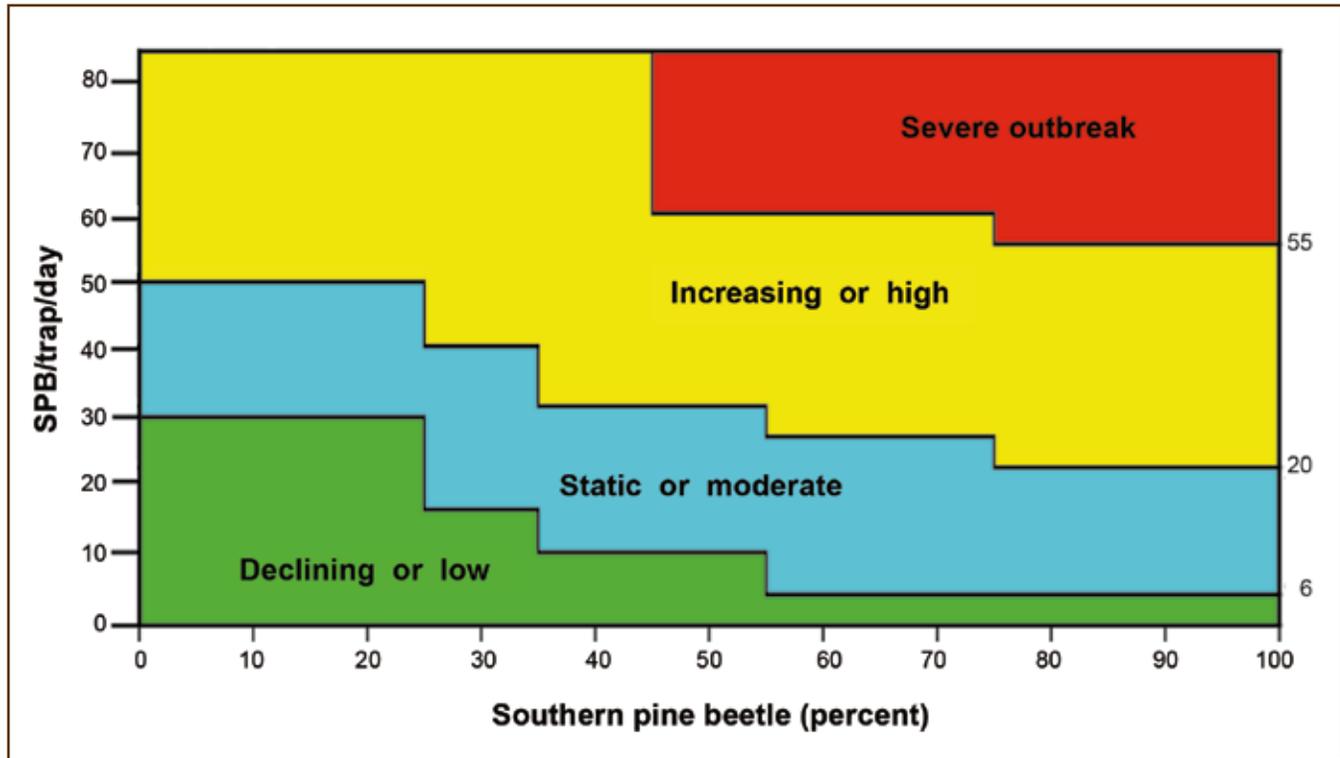
Figure 3—Southern pine beetle prediction chart. The prediction of SPB infestation trend and level for the current year is derived by plotting the mean number of SPB per trap per day and percent SPB for the current year and comparing these data to that for the previous year (if available) for a given locality. Percentage SPB = (No. SPB x 100)/(No. SPB + No. Clerids).

attract long-range dispersing SPB and its predators. Traps are suspended from a 3-m metal pole or from a cord strung between two hardwood trees, at least 10 m from any live pine (Figure 2A). If multiple traps are deployed in a county or ranger district, they should be at least 1 mi apart. The turpentine bottle is placed within the top funnel of the trap, and the frontalin packet is hung from a funnel stanchion near the middle of the trap.

Insects are collected from traps weekly for 4 consecutive weeks, and the numbers of adult SPB and clerids are counted and recorded. Upon completion of the survey, the data from each State and Federal cooperator are sent to the authors for compiling. With these data, the authors or cooperators or both make predictions of SPB infestation trend and relative population level for the current year, based on mean numbers of SPB per trap per day and percentage SPB. The latter is defined as the number of SPB x 100 percent divided by the combined number of SPB plus clerids caught per trap (Billings 1988). The data are

plotted onto the SPB prediction chart (Figure 3). This chart was developed and refined over the years by comparing the relationship between the two independent variables (SPB per trap per day and percentage SPB) and actual numbers of SPB spots detected in a given county or ranger district for the current year to ascertain SPB population level. Actual SPB infestation trend is obtained by comparing the number of spots reported in a given locality or State in the current year with the number reported for the same locality or State in the previous year.

Where trapping data are available for the previous year from the same county or ranger district (preferably from the same specific trap location), a comparison of mean SPB per trap per day and percentage SPB for the current year with that for the previous year provides further insight into the direction of infestation trends (increasing, static, or declining). In turn, the number of SPB spots detected in a given county, ranger district, or State in the previous year is useful for predicting population levels (high, moderate, or low) in

the current year. For purposes of this paper, the severe outbreak level shown in Figure 3 was considered the same as the increasing or high level. If no spots were detected in a given county the previous year, and few SPB are caught this year suggesting a declining trend, the prediction would be static or low (rather than declining or low, since infestation levels cannot decline below 0). Trap catch data for all individual counties or ranger districts monitored within a State are averaged to make SPB predictions at the State level. Once all the data are received and processed, the Southwide predictions at the local and State levels are sent to each cooperator and also are made available on the Texas Forest Service Web page (http://texasforestservice.tamu.edu).

The accuracy of State-level predictions made since 1987 are summarized in this paper. The Southwide SPB Prediction System was initiated in 1987 in 11 Southern States (Arkansas, Texas, Louisiana, Mississippi, Alabama, Georgia, Tennessee, Virginia, Florida, South Carolina, and North Carolina). Federal and State pest managers in several other States joined at a later date (Maryland in 1988, Oklahoma in 1996, Kentucky in 2000, Delaware in 2001, and New Jersey in 2002) and have participated ever since. Florida did not conduct SPB pheromone surveys from 1989 to 1994, but returned as a cooperator from 1995 to the present. At the end of each calendar year, SPB cooperators provide the authors with total numbers of SPB spots detected from aerial surveys in each county or ranger district monitored with pheromone traps, as well as for the entire State. These data are used to evaluate the accuracy of each year's predictions and provide valuable information for making predictions for the next year.

For purposes of the SPB Prediction System and to evaluate its accuracy, the following variables are defined:

Trend:

- Increasing = > 25-percent increase in total spots in a county, ranger district, or State from previous year.

- Static = ≤ 25-percent change in total spots from previous year.

- Declining = > 25-percent decrease in spots from the previous year.

Level:

- Low = < 0.40 spots per 1,000 acres of host type in a county, ranger district, or State during a given year.

- Moderate = 0.40-1.50 spots per 1,000 acres of host type.

- High = > 1.50 spots per 1,000 acres of host type.

- Severe outbreak = combined with increasing or high level for purposes of this paper.

Error:

- Minor = discrepancy between prediction and actual trend or population level was a single category (e.g., prediction was for static trend whereas actual trend was increasing; prediction was for low level whereas actual level was moderate, etc.).

- Major discrepancy between prediction and actual trend or level was two categories (e.g., prediction was for declining trend whereas actual trend was increasing or outbreak, prediction was for low population level whereas actual level was increasing or outbreak, etc.).

Host Type:

- Total acres of loblolly, shortleaf, and slash pine (*Pinus elliottii* Engelm.) from 1990 to 2000 Forest Inventory and Analysis data for a specific State, county, parish, or national forest ranger district.

Results

Actual SPB Infestation Levels: 1987 to 2005

Total numbers of SPB spots detected in 16 States in the Southeastern United States for the period 1987-2005 are shown in Figure 4. Infestation levels on a regional basis varied significantly by year from a high of >90,000 spots in 2002 to a low of <5,000 spots in 2005. During the 12-year interval from 1987 to 1998, at least one SPB outbreak cycle (increasing, peak, declining) occurred in every participating State. SPB populations reached peak levels in Arkansas in 1995; in Texas in 1989 and 1992; in Louisiana in 1992; in Mississippi in 1988, 1991, and 1995; in Alabama in 1992
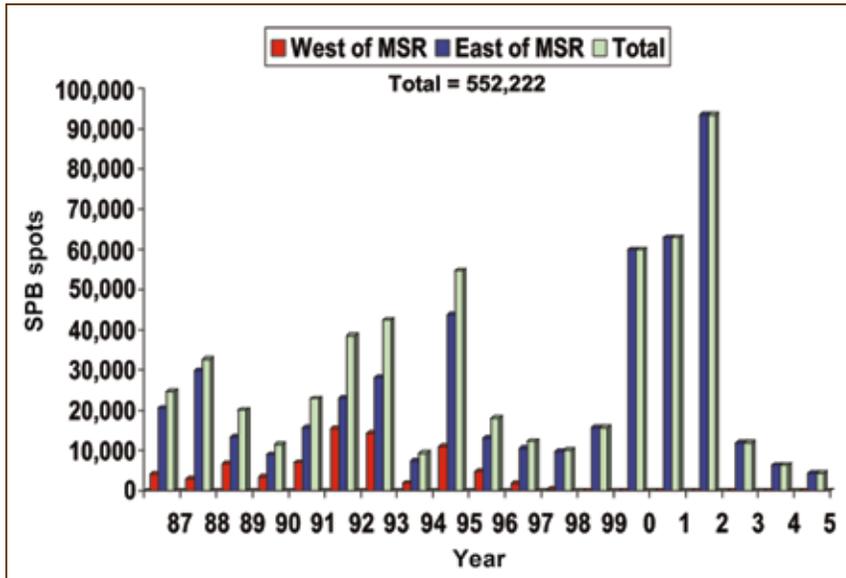
Figure 4—Total numbers of southern pine beetle infestations (spots) detected in 16 States for the period 1987-2005. This figure shows marked differences in infestation levels between those States located east and those located west of the Mississippi River (MSR).

and 1995; in Georgia in 1988; in Tennessee in 1988; in Virginia in 1993; in Florida in 1995 and 1997; in South Carolina in 1995; in North Carolina in 1995; and in Maryland in 1993. Interestingly, 9 of the 11 States that had participated in the system since 1987 reported SPB infestations in every year from 1987 to 1998. Only Florida and Maryland had at least 1 year with 0 SPB spots during this time.

From 1999 to 2005, SPB activity fluctuated widely across the South. SPB infestations totally disappeared west of the Mississippi River: Louisiana, Texas, Arkansas, and Oklahoma reported 0 spots for these years and few if any SPB were captured in pheromone traps during this 7-year period. In sharp contrast, the worst SPB outbreak on record within a single State occurred in South Carolina in 2002, when 67,127 SPB spots were detected (> 14 spots per 1,000 acres of host type). Peak populations occurred in Alabama and Virginia in 2000; in Kentucky, Tennessee, and Florida in 2001; and in Georgia, North Carolina, and New Jersey in 2002. Throughout this period, SPB trapping procedures were standardized with all cooperators using the same turpentine (Hercules™) and dispenser (amber bottle and wick). Also, in 1998 and again in 2002, the SPB prediction chart was slightly modified based on results of pheromone trapping and SPB detection records for the

period 1987–2001 [see Figure 3 versus the chart shown in Billings (1988)]. Accordingly, in certain cases, results for the period 1987–1998 were evaluated separately from those for the period 1999–2005 to determine whether accuracy of the prediction system has improved since 1999 following standardization of field trapping procedures and modifications to the SPB prediction chart.

Overall Prediction Accuracy at the State Level, Based on State Averages 1987–2005

Over the 19-year period (1987–2005), 245 State-level predictions of SPB infestation trend and population level were made by averaging the mean SPB per trap per day and percentage SPB for all locations monitored within each State for each year of participation in the Southwide survey. To determine overall accuracy of predictions at the State level, a 9 by 9 matrix was prepared to compare predicted versus actual infestation trends and population levels for every possible trend or level category (declining to low level, declining to moderate level, declining to high level, static at low level, static at moderate level, static at high level, increasing to low level, increasing to moderate level, increasing to high or outbreak level). Overall, the infestation trend and population level were both predicted accurately

Figure 5—Matrix showing accuracy of SPB trend predictions at the State level, based on 245 predictions over the 19-year period 1987–2005 in 16 States.

in 57 percent of the cases (140 of 245). The category of static or low was correctly predicted 85 percent of the time (45 of 53 cases) whereas the declining or low category was correctly predicted 73 percent of the time (60 of 82 cases). These two categories were the most common situations experienced across the South from 1987 to 2005, occurring in 55 percent of the total cases.

A 3 by 3 matrix was used to evaluate predicted and actual SPB trends alone (Figure 5). SPB infestations that increased by more than 25 percent from the previous year (increasing trend) occurred in 30 percent of the 245 cases and were correctly predicted 62 percent of the time. Those that declined by at least 25 percent from the previous year occurred in 43 percent of the cases and were correctly predicted 80 percent of the time. Static infestation trends (≤ 25 percent change from previous year) occurred in 27 percent of the cases and were correctly predicted 76 percent of the time.

A separate matrix was used for SPB population levels (Figure 6). Low SPB population levels occurred in 64 percent of the 245 cases and were correctly predicted 85 percent of the time. Moderate levels occurred in 26 percent

of the cases and were correctly predicted 54 percent of the time. In contrast, SPB populations reached high levels in 10 percent of the cases but were correctly predicted to do so only 32 percent of the time. However, 88 percent of those States that experienced high SPB infestation levels were predicted to have at least moderate levels. Major errors in both infestation trend and population level predictions occurred in only 3 percent of the cases. Major errors (those cases within red boxes in Figures 5 and 6) in trend predictions alone occurred in 11 percent of the cases (28 of 245 cases) whereas major errors in population level predictions alone occurred in only 2 percent of the cases (5 of 245 cases).

Accuracy of Predictions for Individual States, Based on State Averages: 1987–2005

Accuracy of SPB predictions at the State level for individual States for the period 1987–2005, determined by averaging data for all counties and ranger districts surveyed within the given State for a given year, is shown in Table 1. State-level trend predictions proved most accurate in Oklahoma, Texas, Mississippi, and Kentucky where accuracy exceeded 80

Figure 6—Matrix showing accuracy of SPB population level predictions at the State level, based on 245 predictions over the 19-year period 1987–2005 in 16 States.

Table 1—Accuracy of the SPB Prediction System by State: 1987–2005

State	Years Surveyed	Locations	Spots Detected	Correct Trend	Major Error Trend	Correct Level	Major Error Level
					--------------------------Percent--------------------------		
OK	9	15	0	89	0	100	0
AR	19	123	17,004	79	5	84	0
TX	19	357	27,236	89	11	89	5
LA	19	340	30,182	79	0	79	5
MS	19	156	44,123	84	11	53	11
AL	19	97	99,956	68	5	58	0
KY	6	17	5,137	83	17	67	0
GA	19	173	50,121	58	21	63	5
TN	19	79	46,301	68	26	53	5
VA	19	61	28,706	79	11	89	0
FL	13	240	6,957	69	15	77	0
SC	19	390	156,058	58	16	47	0
NC	19	160	37,831	68	21	68	0
MD	18	51	455	78	17	83	0
DE	5	5	3	60	0	100	0
NJ	4	21	637	50	25	50	0
Total	245	2,285	550,707				
Mean				72.4	12.6	72.5	1.9
±SE				2.96	2.17	4.39	0.82

Note: Based on State averages, with Locations column indicating counties, parishes, and National Forest Ranger Districts surveyed.

Table 2—Accuracy of the SPB Prediction System for 12 States from 1987 to 1998

State	Years Surveyed	Locations	Spots Detected	Correct Trend	Major Error Trend	Correct Level	Major Error Level
				----------Percent----------			
AR	12	65	17,004	67	8	75	0
TX	12	229	27,236	83	17	83	8
LA	12	181	30,182	75	0	67	8
MS	12	89	41,691	83	8	58	0
AL	12	52	47,193	67	8	42	0
GA	12	83	32,402	50	25	67	0
TN	12	39	12,710	58	17	58	8
VA	12	33	26,244	83	0	92	0
FL	6	69	1,632	67	17	83	0
SC	12	155	33,471	42	17	50	0
NC	12	70	25,978	67	25	67	0
MD	11	29	323	73	0	82	0
Total		1,094	296,066				
Mean				67.9	11.8	68.7	2.0
±SE				3.75	2.64	4.33	1.04

Note: Based on State averages, with Locations column indicating counties, parishes, and National Forest Ranger Districts surveyed.

percent. Accuracy of trend prediction was lowest for New Jersey (50 percent), South Carolina (58 percent), and Georgia (58 percent). Accuracy of predictions of SPB population level was greatest for Oklahoma (100 percent), Delaware (100 percent), Texas (89 percent), Virginia (89 percent), Arkansas (84 percent), and Maryland (83 percent). The least accurate predictions of population level were those for South Carolina (47 percent), New Jersey (50 percent), Tennessee (53 percent), and Mississippi (53 percent). Correct predictions for all States combined averaged 72.4 percent for trend and 72.5 percent for level. It should be noted that Oklahoma, Delaware, Kentucky, and New Jersey have participated in the annual survey for less than 10 years.

Accuracy of Predictions at the State Level: 1987–1998 versus 1999–2005

We summarized State-level predictions for 12 States for the periods 1987–1998 and 1999–2005. We then compared the summarized State-level predictions for these periods to ascertain whether prediction accuracy at the State level has improved in recent years as a result of system modifications described above. Tables 2 and 3 show that the accuracy of SPB trend predictions for these States combined increased

from 68 percent prior to 1999 to 82 percent in subsequent years. Prediction of population levels increased in accuracy to a lesser extent, from 69 percent to 74 percent. Trend predictions declined in accuracy during the last 7 years only in Virginia. The accuracy of predictions of population level declined slightly for Mississippi, Tennessee, Virginia, Florida, and South Carolina and increased in the other States surveyed.

Discussion and Conclusions

The Southwide SPB Prediction System has proven to be a practical and relatively reliable means to forecast SPB activity early in the season. Three traps per county, parish, or ranger district appear sufficient to predict SPB infestation trends and probable severity at the local level. By averaging trap catch data for all counties and ranger districts monitored in a given year (20 to 100 traps per State), a reasonably reliable prediction of SPB trend and level for a given State can be achieved. There is a distinct relationship between the numbers of both SPB and clerids caught in early-season traps and subsequent SPB infestation trends during the same year, providing further evidence that *Thanasimus dubius* populations are SPB-density dependent and

Table 3—Accuracy of the SPB Prediction System for 12 States from 1999 to 2005

State	Years Surveyed	Locations	Spots Detected	Correct Trend	Major Error Trend	Correct Level	Major Error Level
				---------------------------Percent------------------------			
AR	7	58	0	100	0	100	0
TX	7	133	0	100	0	100	0
LA	7	159	0	86	0	100	0
MS	7	64	2,432	86	14	43	29
AL	7	42	52,763	71	0	86	0
GA	7	85	17,719	71	14	57	14
TN	7	34	33,591	86	14	43	0
VA	7	28	3,048	71	14	86	0
FL	7	168	4,953	71	0	71	0
SC	7	233	122,587	86	14	43	0
NC	7	90	11,853	71	14	71	0
MD	7	22	10	86	0	86	0
Total		1,170	254,733				
Mean	7			82.1	7.0	73.8	3.6
±SE				3.18	2.11	6.54	2.59

Note: Based on State averages, with Locations column indicating counties, parishes, and National Forest Ranger Districts surveyed.

are likely to be a major regulating factor in SPB population dynamics, as suggested by Moore (1972) and Turchin and others (1991, 1999).

Declining SPB populations tend to be more consistently predicted than are increasing populations, presumably because SPB and clerid populations are distributed across the pine-forested landscape more uniformly following an outbreak than they are at the beginning of the outbreak. Nevertheless, since its implementation in 1987, the prediction system has been used by State and Federal pest management specialists and foresters as a basis for scheduling aerial detection flights and identifying the need for suppression projects. Knowing when endemic SPB populations are about to explode or outbreak populations are soon to collapse is valuable information for more effectively managing this major forest pest.

Although 16 States currently participate in the system, levels of participation and accuracy differ from State to State. One State (Louisiana) prefers to use a single trap per parish and distribute available traps among more parishes. Interestingly, this approach doesn't seem to have substantially affected the accuracy of State-level predictions (Tables 1, 2, 3). Presumably, surveying more locations or

using more traps per location or both will lead to more reliable predictions, particularly in the early stages of a developing SPB outbreak when beetle populations are more scattered.

Continual validation using end-of-the-year detection records has enabled refinement of the system over the years. The prediction chart (Figure 3) has been modified since 1987 to better define the dividing lines between increasing or high, static or moderate, and declining or low infestations as more data points (both trap catch data and corresponding infestation trends and population levels) became available. Single sources of pheromone and turpentine have been used by all cooperators since 1999. In 2006, the standard turpentine dispenser (amber bottle and wick) was replaced in many cases by a polyethylene bag of turpentine from the same source (Hercules™). Since 2006, the standard turpentine dispenser (amber bottle and wick) has been replaced by a polyethylene bag containing 200 gm of 75 percent alpha-pinene: 25 percent beta-pinene (Synergy Semiochemicals Corp., Burnaby, British Columbia, Canada). This new dispenser is more practical for field application and has been found to be equally effective in eluting host volatiles and attracting SPB and clerids.

As with any prediction system, the SPB prediction protocol has strengths and weaknesses. The strengths include its simplicity, practicality, and relative accuracy. Data from a few strategically placed traps in early spring provide forest pest managers with insight into SPB infestation trends and levels for the remainder of the year at both local and large geographical scales. Currently, the standardized system is being implemented annually in 16 States, providing a consistent means to monitor SPB populations throughout the range of this pest in the Southern and Eastern United States. Limitations include the following:

The process of installing and monitoring traps and counting beetles is tedious and time-consuming. Numerous field crews with varying levels of training and experience are involved in setting out and monitoring the traps and identifying the beetles captured, which influences the quality of the data.

Pheromone traps placed too close to host trees may initiate infestations and inflate trap catches, leading to erroneous predictions, although such high trap catches are eliminated from the prediction data prior to analysis when infested trees are reported adjacent to a trap or trap catches exceed ca. 1,200 SPB per trap.

Variations in climate among States means that trapping data from Northern States is often not available until early June, 1 or 2 months after the results from Gulf Coastal States are completed.

In certain years, atypical weather patterns may accelerate or delay emergence of overwintering SPB and clerid populations, leading to erroneous predictions. For example, in 1989, an SPB outbreak occurred in Texas but was not forecasted. In that year, beetles emerged in large numbers in late April and May, after survey traps had been removed from the field (Billings, unpublished data). Of course, SPB outbreaks may originate in counties or locations not monitored with pheromone traps, a potential problem in those States that survey a limited number of counties (e.g., Mississippi, Alabama) or a single locality within each county or parish (e.g., Louisiana) each year. Also, predictions made in the spring for increasing SPB populations will prove wrong if adverse summer temperatures or other unanticipated factors limit SPB population growth. And,

finally, maintaining a reliable source of steam-distilled southern pine turpentine has been a problem over the years. Despite these limitations, the system has been deemed a success. This is reflected in the fact that Federal and State cooperators continue to use it.

Nevertheless, improvements in the SPB Prediction System are continually being sought. For example, monitoring SPB and clerid populations in the fall months for predictive purposes using the same protocol is currently being tested. Since 2003, the national forests in Mississippi have been conducting fall pheromone trapping during the secondary dispersal phase of SPB. These studies, though limited, have yielded relatively accurate predictions similar to those generated from the following spring survey (James Meeker, U.S. Forest Service FHP, 2500 Shreveport Highway, Pineville, LA 71360, personal communication). If effective, fall trapping would provide forest managers with additional lead time to prepare for peak infestations in the summer. The accuracy of forecasts based on fall insect numbers, however, may be dependent on weather conditions the following winter. Severe winter conditions such as freezes, prolonged cold temperatures, etc., could curtail the growth of SPB populations that were increasing in the fall, for example. In turn, SPB populations that are in the process of declining following a severe summer may be identified several months earlier if pheromone traps are deployed in the fall. Additional fall trials are needed across the Southeastern United States over multiple years to fully evaluate this approach. Indeed, a combination of spring and fall trapping may prove most effective for tracking seasonal and annual SPB population shifts.

Recent field research has demonstrated significantly enhanced attraction of SPB to trap sites additionally baited with the pheromone (+)*endo*-brevicomin (B. Sullivan, personal communication, East Texas Forest Entomology Seminar, Fall 2005). This finding offers a potentially new and alternative means of improving the precision, accuracy, and timeliness of the system. A bonus of the current SPB Prediction System is the wealth of historical trap-catch data from across the Southern United States over a 20-year period, which can help researchers better understand SPB and clerid dynamics (Tran and others 2007). Finally,

incorporation of SPB predictions into area-wide hazard maps (Billings and Bryant 1983; Billings and others 1985; Billings and others, this volume; Cook and others 2007) may lead to the development of more effective SPB risk maps. This would provide yet another tool for more effectively managing SPB.

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