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Characteristics of bark beetle infestations in East Texas during a period of low southern pine beetle activity

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Characteristics of Bark Beetle[1] Infestations in East Texas During a Period of Low Southern Pine Beetle Activity

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Abstract

The species composition of southern pine bark beetle infestations was examined in east Texas in 1979. A total of 545 infestations were located in thirteen 18,000 acre survey blocks. *Ips* spp. were observed in 98.9 of the infestations, with black turpentine beetles, *Dendroctonus terebrans* Olivier, present in 42.4 % of the infestations. Southern pine beetles, *D. frontalis* Zimmermann, were only observed in 11 infestations (2.0%), and were less abundant than other bark beetle species in these infestations. Almost 80% of the infestations were associated with a recognizable pre-disposing factor (lightning, fire, etc.). Most infestations were small (less than six trees), though infestations associated with fire damage typically contained more than five infested trees. In the absence of an identified pre-disposing factor, infestations were frequently located in stands rated as high or moderate hazard for southern pine beetle.

Introduction

Bark beetles annually destroy more commercial timber in North America than any other causal agent. In the southeastern United States, this tree mortality is caused by a bark beetle guild (BBG) composed of five species: the southern pine beetle (SPB), *Dendroctonus frontalis* Zimmermann; the black turpentine beetle (BTB), *Dendroctonus terebrans* Olivier; and the engraver beetles *Ips avulsus* (Eichhoff), *Ips calligraphus* (Germar), and *Ips grandicollis* (Eichhoff) (Coulson et al. 1986).

The SPB is an aggressive pest capable of attacking and killing healthy pines (Payne 1980). Once female beetles locate and attack a susceptible host, they release aggregation pheromones. The pheromones, synergized by host odors, attract other SPB, both males and females, which mass attack the pine. If sufficient beetles respond, the attacks may soon switch to adjacent trees, and an expanding infestation (spot) may result. From spring through early fall, SPB populations are aggregated in these expanding spots.

Uncontrolled infestations may spread rapidly, affecting large acreages (Clarke and Billings 2003). Small SPB infestations lacking fresh attacks usually become inactive without killing additional trees (Hedden and Billings 1979). During the fall, many

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SPB adults disperse from summer infestations; by winter, the beetles inhabit scattered single trees or trees in older, active infestations (Billings 1979). *Ips* and BTB are usually considered secondary pests, and attacks are frequently limited to weakened and dying trees or downed timber and freshly-cut stumps (Thatcher 1960). *Ips* and BTB infestations are usually small and widely dispersed, seldom expanding beyond a few trees except during periods of severe drought or in areas severely affected by fire, storms, or similar disturbances.

SPB activity is cyclic, and populations fluctuate dramatically between periods of scarcity and periods of overwhelming abundance (Hain and McClelland 1979, Payne 1980). Some portion of the southeastern United States typically is in outbreak status each year (Price et al. 1998). In Texas, recent outbreaks have been on a 7-10 year cycle (Clarke et al. 2000). *Ips* and BTB populations usually remain at stable, low levels during most years. However, an *Ips* outbreak in Texas, Louisiana, Arkansas, and Oklahoma in 1956 resulted in the loss of 100,000 mbf (1 mbf = 1,000 board feet), while BTB killed an estimated 2,152 mbf in Texas and Louisiana in 1957-58 (Thatcher 1960). Remion (1971) reported estimated losses of 732 mbf and 151 cords due to the BTB outbreak on the Sand Hills State Forest, Florida in 1970.

All five species may be found colonizing the same tree (Thatcher 1960, Hain and McClelland 1979, Merkel 1981, Schowalter et al. 1981). During SPB epidemics, SPB are the first to attack, followed by the other pine bark beetles. As densities of the secondary bark beetles increase, attacks may coincide with those of SPB. When SPB populations are at low levels, their attacks may occur subsequent to *Ips* attack (Thatcher and Connor 1985), and resource availability may become a limiting factor (Moore and Thatcher 1973). Within a host, SPB generally occupies the main bole, with BTB infesting the lower portion of the bole. *Ips calligraphus* attacks often overlap with those of SPB and BTB, while *I. avulsus* and *I. grandicollis* are located in the upper bole and often infest branches (Birch and Svihra 1979, Paine et al. 1981).

The five species of the southern BBG usually colonize trees that are predisposed to attack by disturbances and conditions that either weaken or increase the attractiveness of the tree (Thatcher 1960, Wilkinson and Foltz 1982). Both natural and man-caused disturbances result in these conditions. Lightning-struck pines are an important resource for dispersing SPB (Coulson et al. 1999). Hodges and Pickard (1971) reported that 31% of SPB infestations (75% of August infestations) detected over a three- year period in south-central Louisiana were associated with lightning strikes. An estimated 40 to 60% of the *Ips* and BTB infestations detected in a south Georgia survey were associated with lightning damage (Wilkinson and Foltz 1982). Fires can also weaken and stress trees to the extent that they are susceptible to bark beetle infestation. Crown scorch, bole damage, and surface root damage may contribute to tree susceptibility and attractiveness (Thatcher 1960). Other naturally occurring disturbances that produce conditions favorable for BBG attack include windstorms, heavy rain (flooding), hail, and ice storms (Thatcher 1960, Lorio and Bennett 1974, Wilkinson and Foltz 1982).

Pathogenic organisms infecting southern pines often predispose a tree to attack. Wilkinson and Foltz (1982) reported that fusiform rust, *Cronartium quercuum* (Berk.) Miyabe ey shirai F. sp. *fusiforme*, can cause damage that may lead to *Ips* infestations. Root diseases also are frequently associated with bark beetle infestations. Bradford and Skelly (1976) reported that endemic infections of annosus root disease, *Heterobasidion annosum* (Fr.) Bref., predisposed pines to SPB attack. Littleleaf disease, associated with infections of *Phytophthora cinnamomi* Rand., on shortleaf pine, *Pinus echinata* Mill., has been recognized as a major factor related to SPB infestations in the Georgia Piedmont (Belanger et al. 1977).

The operation of heavy equipment (i.e., bulldozers, backhoes, skidders, tractors, and graders) in forested areas frequently predisposes trees to bark beetle attack by physically damaging roots and boles, and/or compacting soil (Thatcher 1960, Merkel 1981, Wilkinson and Foltz 1982). Historically, BTB has been a major pest problem in southern pine stands that have been selectively harvested or thinned, as freshly-cut stumps are frequently colonized (Merkel 1981). *Ips* also may become a problem in mature stands following summer thinning (Mason 1969).

Predisposed trees attacked by bark beetles may serve as epicenters for SPB infestations when they are located in suitable stands (Coulson et al. 1999, Clarke et al. 2000). Highly susceptible stands for SPB have high pine basal areas and a strong component of overstory loblolly or shortleaf pine with minimal hardwoods (Gara and Coster 1968, Hedden and Billings 1979, Kushmaul et al. 1979, Zhang and Zeide 1999). Hazard rating systems for SPB were developed in east Texas by Hicks et al. (1981a) and Mason et al. (1981). These systems categorize the hazard of stands based on pine basal area, average tree height, and landform, with dense stands in low-lying areas being the most susceptible. Infestations initiated in stands with a basal area of 70 ft^2/ac or less rarely expand beyond 5 trees (Nebeker and Hodges 1985).

East Texas experienced a long SPB outbreak from 1972-1977, peaking in 1976 (Clarke et al. 2000). By 1978, populations had returned to low levels and few SPB infestations were detected (Price et al. 1998). The objectives of this study were to examine the species composition, pre-disposing factors, and stand attributes of bark beetle infestations in east Texas in 1979, a period of low SPB activity.

Materials and Methods

The study was conducted in portions of Montgomery, Liberty, Hardin, Jasper, Tyler, Polk, Angelina, Sabine, Nacogdoches, and Cherokee counties of east Texas, located on the Western Gulf Coastal Plain. Ten randomly-selected 18,000 acre Texas Forest Service grid-blocks, as described by Mathews (1978), plus three additional 18,000 acre grid-blocks characterized by recent high SPB activity were selected (Fig. 1). The predominant tree species in most of the study blocks were loblolly pine, *Pinus taeda* L., and shortleaf pine, *P. echinata* Mill. The Wolf Hill and Zavalla blocks contained considerable acreages of longleaf pine, *P. palustris* Mill. Plantations of slash pine, *P. elliottii* Engelm., although located throughout the study area, were predominately in the southeastern grid-blocks, particularly in the Spurger block.

Suspected beetle infestations were plotted using color infrared aerial photographs of the study area taken on 14 September 1979 by Wallace Aerial Survey, Houston, Texas. The photographic survey specifications were 1:12,000 scale factor, 60% endlap and 30% sidelap stereo coverage, north/south oriented flightlines, minus-blue filter (yellow #13), and 9 in. x 9 in. positive transparencies. Photographs were prepared for interpretation by filing individual frames by sample block and flightline, delineating the effective area of interpretation, and generating photo index maps on 1:24,000 USGS orthophotoquad maps and 1:63,360 Texas Forest Service grid maps.

Extensive photo-interpretation training exercises were conducted in the Martinsville sample block (Fig. 1). An Old Delft scanning mirror stereoscope, featuring 10X zoom magnification, was used in the photo-interpretation. Suspected infestations were marked on clear acetate overlays and plotted on photo index maps. All apparent infestations (dead or dying pine trees) were visited on the ground to establish color or shape characteristics for bark beetle-infested trees. Infested trees with necrotic foliage (i.e., redtops) appeared yellow to yellow-green on the color infrared photography. Infested trees with yellow or fading foliage appeared beige. Apparently healthy pines were magenta or purple. Infestations in all grid-blocks were identified and labeled by spot and photo frame number. The estimated number of attacked trees with fading and red foliage was recorded.

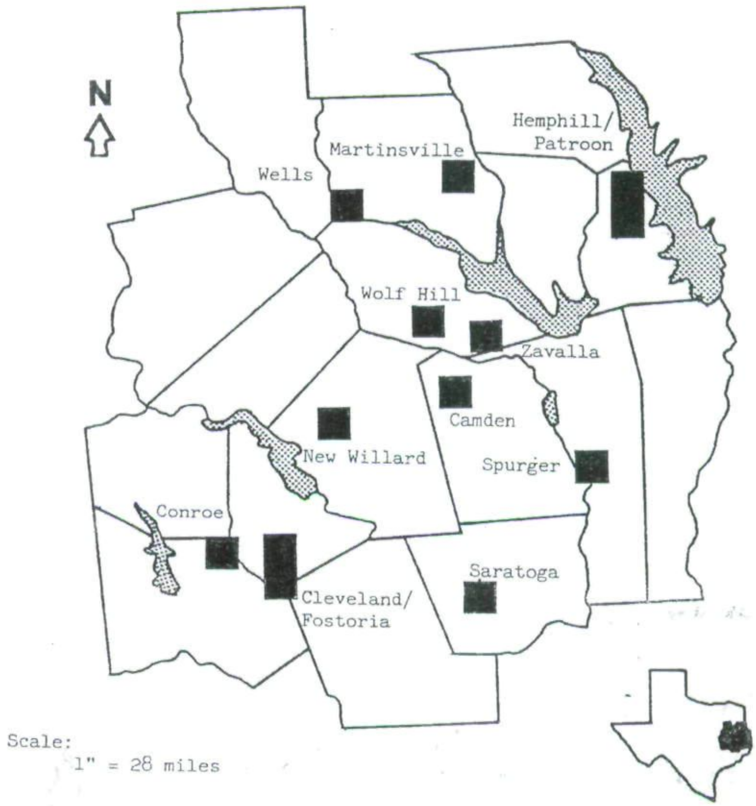

Fig. 1. Location of survey blocks in east Texas for the southern pine bark beetle study, 1979.

Approximately 90% of the apparent infestations were examined on the ground during the subsequent fall and winter. The inner bark of all attacked trees at or below breast height (1.3 m above ground) was examined for evidence of bark beetle infestation. The middle and upper tree bole also were examined for signs indicating the presence of *Ips* or SPB, as galleries frequently were visible on exposed portions of the wood surface. Dislodged bark pieces, scattered around the base of attacked trees, also were examined for characteristic egg gallery patterns. I-, H- or Y-shaped galleries indicated *Ips* activity; S-shaped galleries provided evidence of SPB colonization. A 3.2 m climbing ladder was used to access the bark higher on the bole when the beetle species attacking the tree could not be identified from the ground. Several trees were felled for complete examination.

Data collected during this phase of the survey included bark beetle species present (*Ips* spp., BTB, or SPB) and total tree mortality (TTM). Pine basal area (PBA) at the point of infestation, tree height (TH) and landform (LF) were coded into broad classes adapted from Mason et al. (1981) in their Texas SPB Hazard Rating System (Table 1). This hazard rating system was used to calculate the SPB hazard of the site for each infestation: low, moderate, or high.

Table 1. Site Factors and Classes Recorded for Bark Beetle Infestations in East Texas, 1979 (Adapted from Mason et al 1981).

Factor	Classes
Pine Basal Area (PBA)	≤ 40 sq ft/ac
	41 – 80 sq ft/ac
	81 – 120 sq ft/ac
	>120 sq ft/ac
Tree Height (TH)	≤ 50 ft
	51 – 75 ft
	76 - 100 ft
	> 100 ft
Landform (LF)	ridge
	side slope
	bottom land

Predisposing factors were categorized into five classes: no apparent predisposition (NAP), lighting strike (LS), logging damage (LD), fire damage (FD), or other disturbances (OD). Logging damage included tree base and bole scars, slash piled near or adjacent to residual trees, and/or root damage and compaction as a result of logging activities. Fire damage included crown scorch and recent fire scars. Other disturbances included root diseases, wind throw, root disturbance from erosion or construction not related to logging, flooding, chemical contamination, and other recognizable disturbances.

Data analyses were made using the Statistical Package for Social Sciences (SPSS) (Nie et al, 1975). Additional coded variables generated in the SPSS command program were infestation size class (ISC) and predisposing factor present or absent (PRE). The number of infestations, total tree mortality, and mean infestation size were compiled for each factor by bark beetle group. Cross-tabulations were generated for PRE by ISC and subjected to Chi-square contingency tests to determine if infestation size was independent of stand disturbance. Similar analyses were conducted for PRE by HAZ, PBA, TH, and LF to test whether bark beetle infestations in undisturbed stands were randomly distributed and not associated with factors that reflect stand stress. In these analyses, the LF categories ridge and side slope were combined, as were the TH categories 76-100 and > 100 ft (Table 1).

Results

Ips spp. were the predominant bark beetle group, and were observed in 539 of 545 (98.9%) bark beetle infestations and 99.3% of attacked trees (Figure 2). *Ips calligraphus* was the predominant species in most infestations, generally occupying the lower and middle portions of the bole. *Ips avulsus* was found in the upper bole, crown and branches, with *I. grandicollis* sometimes replacing *I. calligraphus* in the mid-bole. *Ips grandicollis* and *I. avulsus* occasionally were observed alone, particularly in suppressed and immature trees and in windthrown trees. The second most frequently observed group, BTB, was found in 42.4% of the infestations and 50.6% of the attacked trees. Four infestations consisted of BTB alone. SPB represented only a minor component of the bark beetle complex, and all infestations with SPB also contained evidence of *Ips*, BTB, or both. The 11 infestations containing SPB involved only 26 infested trees (Fig. 2).

Infestations were subdivided into two groups: 1) *Ips* were the only bark beetles detected; and 2) all other bark beetle combinations. *Ips*-only infestations were generally smaller than infestations that included *Dendroctonus* spp., with a mean of 3.2 attacked trees per infestation, and 65.5 % consisted of only one tree (Table 2). Though 58% of the infestations were classified as containing only *Ips*, only 49% of the total bark beetle pine mortality was found in these infestations. Infestations including *Dendroctonus* spp. averaged 4.4 trees per infestation, accounting for 50% of the total pine mortality, and 150 of the 235 infestations contained two or more trees. A majority of these infestations consisted of *Ips* and BTB only (Figure 2). BTB were located in the base of the tree, up to about 3 m. BTB attacks also were frequently observed in otherwise unattacked trees on the periphery of BC infestations. Many of these trees initially survived, but return visits revealed some were later attacked by *Ips* spp. and killed.

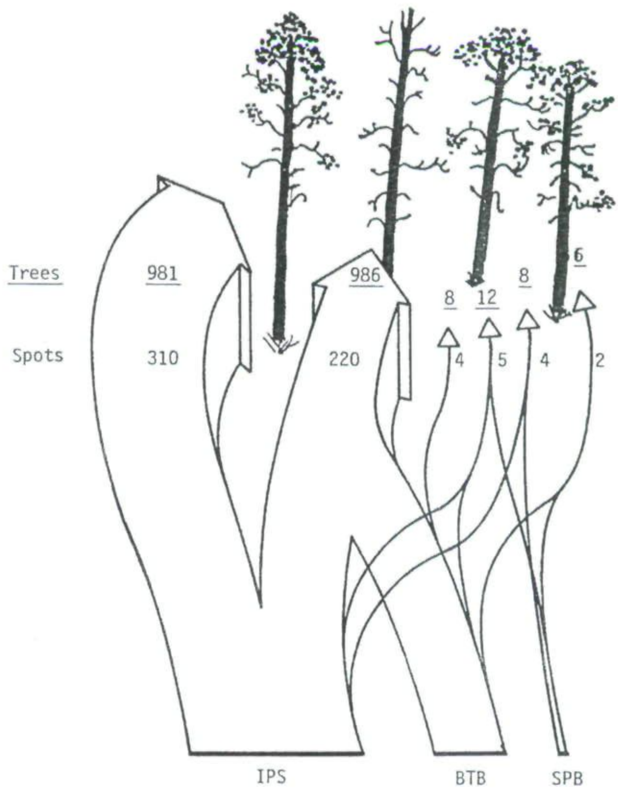

Fig. 2. Composition of southern pine bark beetle infestations (spots) and pine mortality (trees) observed in survey blocks in east Texas, September 1979.

A large percentage of the BBG infestations occurred on side slopes (86.8%), with 12.2% in bottoms and 1% on ridges. Just under half (49.2%) were in stands with a pine basal area greater than 80 ft^2/ac, but these included 65.8% of the infested trees. Only 5.7% of infestations were in stands with a mean tree height of 50 ft or less, with 57.2% and 37.1 % in stands with tree height of 51-75 ft and >75 ft, respectively. Using the SPB hazard rating, 49.7% of the infestations were in stands classified as low hazard for SPB and 40.7% were in stands classified as moderate hazard (Mason et al. 1981). Though only 9.5% of infestations were in high hazard stands, these spots accounted for 23.2% of the total tree mortality. Low and moderate hazard stands had 38.1 and 38.7% of the tree mortality, respectively.

Apparent predisposing disturbances were associated with 79.4% of the bark beetle infestations observed in the study (Table 2). Though 12.5% of infestations associated with a predisposing factor included more than five trees, compared to only 8.0% with no apparent predisposition, a chi-square test indicated that final infestation size was not significantly contingent on the presence of predisposition (X^2=2.5, df=2, P=0.29).

Lightning strike, observed in 55.8% of the infestations, was the most prevalent disturbance predisposing southern pines to bark beetle attack. Resulting infestations frequently contained only one or two attacked trees and represented 33% of the total tree mortality. The ultimate size of infestations initiated by lightning strikes was influenced by the bark beetle complex involved in the attacks. Seventy-seven percent of the single-tree infestations associated with lightning strikes contained only *Ips* spp. Over 65% of the lightning strike-associated infestations with more than 5 trees included species other than *Ips*. Approximately 68% of the *Ips*-only infestations involved only one tree, whereas only 33% of other infestations included only one tree.

Table 2. Number of Bark Beetle Infestations by Predisposing Factor, Beetle Group, and Infestation Size Class in East Texas, 1979.

Predisposing Factor[a]	Bark beetle group[b]	Infestation Size Class (number of trees) 1	2-5	>5	Total
NP	IO	43	19	4	66
	BC	18	24	4	46
LS	IO	126	50	8	184
	BC	42	63	15	120
LD	IO	22	11	2	35
	BC	8	22	14	44
FD	IO	3	1	6	10
	BC	3	3	6	12
OD	IO	9	4	2	15
	BC	4	7	2	13
Total infestations		277	204	63	545

[a]NP=no predisposing factor; LS= lightning strike; LD=logging damage; FD=fire damage; OD=other damage.
[b]IO=*Ips* spp. only; BC=all other bark beetle combinations.

Fire damage contributed to only 4.0% of the infestations, but these infestations accounted for approximately 30% of the total pine mortality. Infestations predisposed by FD frequently included more than five trees, and almost 73% of the FD-associated infestations included more than one tree (Table 2). Logging damage was associated with

14.5% of the infestations. *Ips*-only infestations associated with LD generally were limited to one tree, while other infestations usually contained two or more trees.

A contingency analysis of the cross-tabulations for interactions between PRE and SPB hazard class indicated that these two variables were not independent (X^2=10.7, df=2, P<0.01). A higher percentage of infestations with no apparent predisposition occurred in stands rated as moderate or high SPB hazard (51.8% and 12.5%, respectively) than did infestations with a predisposing factor present (37.9% and 8.8%). In contingency analyses of PRE with the individual factors used in the hazard classification, only the PRE-PBA interaction was significant (X^2=8.7, df=3, P<0.03). Less than half (46.0%) of infestations with a predisposing factor were in stands with PBA>80 ft^2/ac, versus 60.7% of infestations with no predisposition. The contingencies for tree height and landform by PRE were not significant.

The distribution of infestations varied among study blocks (Table 3). Though most infestations were small, several large infestations associated with FD and LD occurred in the Cleveland/Fostoria block, and the largest number of infestations and attacked trees were in this block. The Spurger block had extensive hardwood areas adjacent to the Neches River, and few infestations were detected. One large infestation in this block was associated with an incidence of fusiform rust infection. Larger infestations associated with FD also were located in the Wolf Hill block.

Table 3. Number of Spots and Attacked Trees for all *Ips* Spp., Black Turpentine Beetle (BTB), and/or Southern Pine Beetle (SPB) Infestations by Study Blocks in East Texas in 1979.

	Total		*Ips* only		*Ips*/BTB[a]		SPB[b]	
Study block	Spots	Trees	Spots	Trees	Spots	Trees	Spots	Trees
Conroe	66	224	30	44	34	174	2	6
Cleveland/Fostoria	74	706	48	344	24	356	2	6
Saratoga	24	72	18	63	5	8	1	1
New Willard	40	92	21	20	16	63	3	9
Camden	44	125	14	19	30	106	0	0
Spurger	4	39	3	37	1	2	0	0
Wolf Hill	47	167	25	118	19	45	3	4
Zavalla	57	110	34	49	23	61	0	0
Wells	64	158	36	97	28	61	0	0
Martinsville	57	123	38	83	19	40	0	0
Hemphill/Patroon	68	185	43	107	25	78	0	0

[a]*Ips*/BTB: *Ips* plus BTB or BTB only.
[b]SPB: Infestations with some SPB.

Eight of the infestations that included SPB occurred in the southern study blocks. The other three were in the Wolf Hill block, which sustained considerable tree mortality during the previous SPB outbreak. The two SPB infestations located in the Cleveland/Fostoria block occurred on the Sam Houston National Forest and were within 100 m of each other.

Discussion

Though *Ips* beetles and BTB were the most prevalent bark beetles, the frequency and size of the infestations did not appear to constitute an outbreak. These secondary bark beetles can cause widespread losses (Thatcher 1960, Smith and Lee 1972), but most of the 1979 infestations were small. The absence of widespread tree stress caused by factors such as drought may have contributed to the low level of infestation. In addition, the small percentage of infestations that contained SPB and the low number of infested trees in these infestations provided little opportunity for SPB population growth.

In 1979, SPB numbers in east Texas had declined rapidly to historically low levels. The number of SPB infestations reported fell from 4,333 in 1977 to only two in 1979 (Clarke et al. 2000). The cause of the collapse of SPB populations was unclear. Moore (1979) collected more *Ips* beetles than SPB in one of three infestations trapped in east Texas in 1977, the only one of the three that had been initiated the previous year. Competition among bark beetles and other competitors for hosts has been suggested as a factor in SPB outbreak declines (Clarke et al. 2000, Dodds et al. 2001). Within a tree, SPB may have difficulty competing with *Ips* beetles and wood borers such as *Monochamus* spp. (Hain and Alya 1985). Hennier (1983) theorized that the arrival of *Monochamus* near the time of SPB attack would severely impact SPB brood production. Gold et al. (1980) also suggested that endemic populations may be limited by resource availability. SPB did not appear constrained by host availability in Texas, as numerous, highly susceptible pine stands were still evident in 1979 as well as during the decline of a SPB outbreak in 1994 (Clarke and Billings 2003).

Traditionally, SPB population levels have been classified as either outbreak or endemic. Outbreak levels have been defined as one SPB infestation per 1000 acres of susceptible host type (Price et al. 1998). Endemic has been the term used for any lower incidence level. In Texas since 1958, SPB-initiated infestations had always been observed in these non-outbreak years, and no fewer than 100 SPB infestations had been reported annually from 1958-1978. The scarcity of SPB observed in 1979, with SPB rarely present in any bark beetle infestations, was different than from other "endemic" years in Texas. To help differentiate between these two non-outbreak levels, we propose the term "latent" for extremely low SPB populations. Latent SPB populations compose a minor component of the overall BBG area-wide populations and are absent from most BBG infestations. Latent SPB generally must rely on other bark beetles to attack and colonize host trees. Gold et al. (1980) stated that SPB may take 2-3 weeks to begin colonizing trees initially attacked by *Ips* beetles. In these instances, SPB may be restricted to only a few feet of the bole (Moore and Thatcher 1973). Hain and Alya (1985) found that though SPB can survive in *Ips* infested trees, their numbers will be maintained at low levels.

The high number of BBG infestations associated with an identifiable pre-disposing factor in this study mirrored the findings of Lorio (1984) in which 81.8% of endemic SPB infestations in Louisiana involved some type of disturbance. These results indicate that low level populations of SPB or other bark beetles in the southeastern U.S. rely heavily on pre-disposing factors to create hosts that can be successfully colonized. Only 55% and 58% of epidemic SPB infestations were associated with an identified pre-disposing condition in east Texas and across the Gulf Coastal Plain, respectively (Hicks et al. 1981b, Porterfield and Rowell 1981). Outbreak densities of SPB are normally distributed across all hazard classifications (Mason et al. 1981).

SPB-initiated infestations, whether during outbreak or other periods, are larger on average than spots initiated by other bark beetles. Porterfield and Rowell (1981), summarizing epidemic SPB activity across the Gulf Coastal Plain, reported that only 32% of SPB infestations contained 10 or fewer trees. Lorio (1984) examined SPB infestations under endemic conditions over a three-year period in Louisiana, and approximately half of the infestations contained 10 or more trees. In our study, in which SPB was not the primary bark beetle, only 11.8% of the infestations had six or more dead trees (Table 2).

The site and stand conditions of BBG infested areas in 1979 differed from those for SPB-dominated populations. SPB infestations in east Texas in the outbreak years from 1974-1977 were predominantly located in bottomlands or on the moist, flat uplands just above the bottomlands (Hicks et al.1981b), not on side slopes. In addition, the mean PBA of SPB infestations was 122 ft^2/ac. Approximately half of the bark beetle infestations in our study were in stands with a PBA under 80 ft^2/ac. However, when an identifiable pre-disposing disturbance was absent, BBG infestations were not randomly distributed. These infestations often were associated with factors that reflect stand stress, e.g. high pine basal area, indicating inter-tree competition acts as a pre-disposing factor as well. BBG infestations located in such stands also tended to be larger, as infestations in lower hazard stands may not expand.

The causes of the resurgence of latent SPB populations to outbreak status in 1984 (Clarke et al. 2000) are unknown. Climatic factors may have been involved (Kroll and Reeves 1978), as could an increase in the number of refuge trees. Trees struck by lightning and pines killed by other bark beetles may serve as reservoirs for latent SPB populations (Thatcher and Pickard 1967, Lorio and Yandle 1969). Removal or treatment of these trees could retard the increase and spread of SPB and delay the incidence of outbreaks. Lorio (1984) suggested that endemic SPB infestations in sawtimber stands should receive high priority for suppression, and this recommendation should be expanded to include BBG infestations, which may or may not contain latent SPB. Thinning to reduce PBA and SPB hazard is recommended for periods of low SPB density, when SPB suppression actions are minimal. These treatments, if implemented carefully, should also reduce the frequency and size of all BBG infestations. Recommendations for thinnings to reduce pest incidence are given in Hedden (1978) and Nebeker et al. (1985). Care must be taken to minimize any damage that predisposes the residual trees to bark beetle attack, as these pines could help support latent SPB populations.

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