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SOUTHERN PINE BEETLE

A Review of Present Knowledge

by

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The southern pine beetle, Dendroctonus frontalis Zimm., is one of the most destructive insects of pine in the South and has been recognized as such since investigations by Hopkins (1899). Outbreaks of this native insect have occurred at irregular intervals since the 1890's. Most reports indicate only the general area affected by outbreaks; others indicate the size in acres or square miles (Hopkins, 1903; Craighead, 1925; St. George, 1930; Cary, 1932; Hetrick, 1941; Southern Forest Experiment Station, 1957, 1959). Estimates of losses from individual outbreaks range from 1,200 MBF to 200,000 MBF (Anonymous, 1924; Lee, 1954b; Southern Forest Experiment Station, 1955a, 1955b, 1958). In an outbreak in the Southeast from 1952-1955 an estimated 53,200 MBF of sawtimber plus 138,600 cords of poletimber were lost (Merkel and Kowal, 1956). Blue stain introduced by the beetle degrades the wood and causes additional economic losses even when dead trees can be salvaged. Furthermore, the dead pines which cannot be salvaged create a fire hazard and are usually replaced by slow growing, undesirable hardwoods. In most cases stands become less productive and decline in commercial value.

Although this insect has been studied rather intensively and its general life history is known, its behavior and relationship to the environment and the factors contributing to epidemics are poorly understood. Outbreaks frequently occur without apparent warning, yet populations may disappear as quickly as they appeared. Research is needed to determine the factors contributing to the rise and decline of populations. The present review attempts to bring together pertinent data as an aid to future research.

DISTRIBUTION

The range of the southern pine beetle extends from southern Pennsylvania to southern Missouri, south to the Gulf and east to the Atlantic seaboard. It occurs in extensive areas of eastern Oklahoma and Texas (Chamberlin, 1939). Hopkins (1899, 1909a) recorded it from the District of Columbia, Pennsylvania, Maryland, Virginia, West Virginia, North Carolina, South Carolina, Tennessee, Georgia, Florida, Alabama, Mississippi, Louisiana, Arkansas, Oklahoma, and Texas. Specimens have also been collected from southeastern Kentucky by personnel of the Southeastern Forest Experiment Station. St. George and Beal (1929) reported that outbreaks occurred periodically in Delaware and that the beetle was known to occur in the southernmost portions of New Jersey, Ohio, Indiana, Illinois, and Missouri (fig. 1).

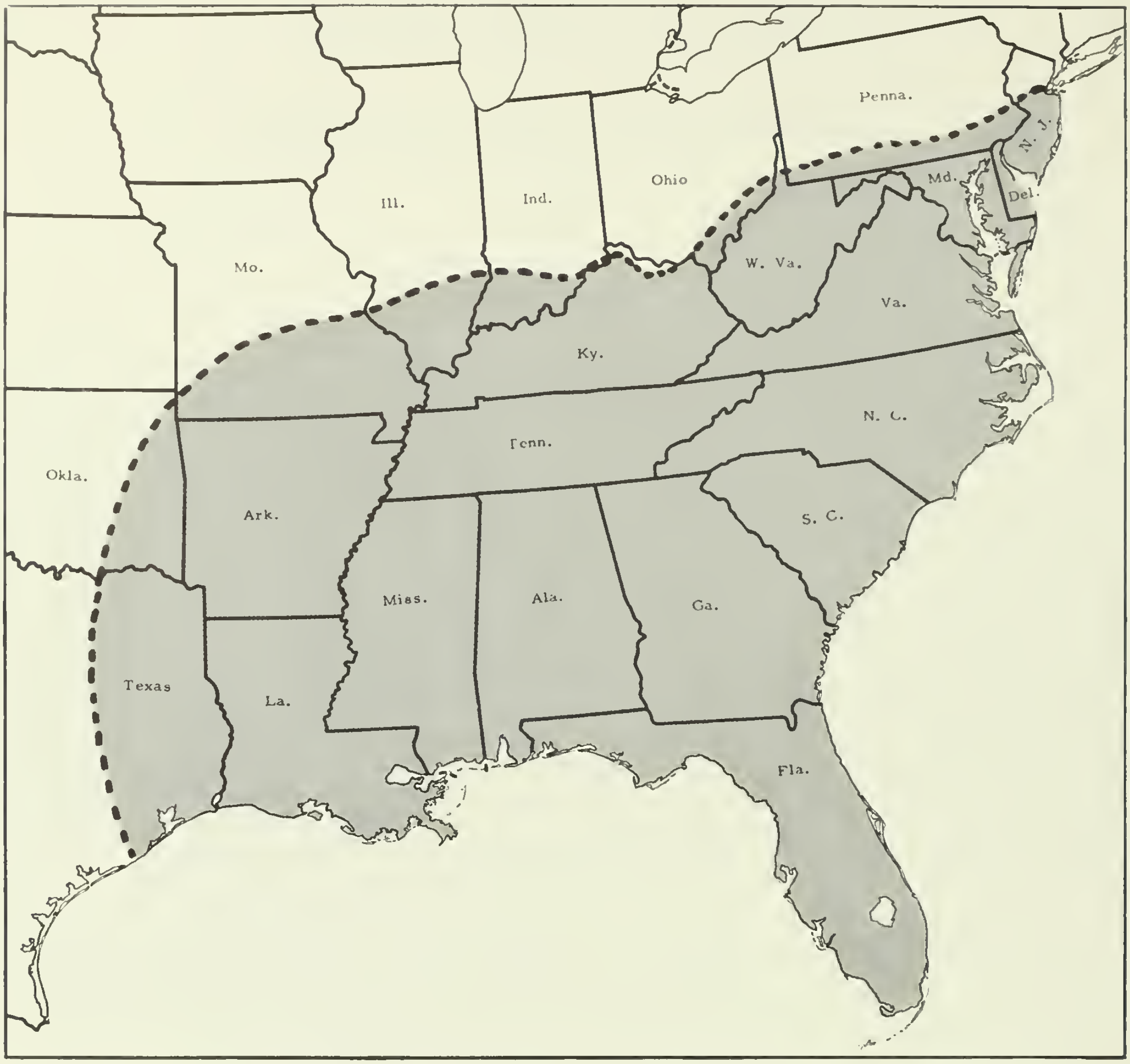

Figure 1.--Distribution of the southern pine beetle in the United States.

HOSTS

St. George and Beal (1929) reported that the southern pine beetle attacked and killed pines of all species occurring within its range, and that it was especially destructive to loblolly and shortleaf pines. The following hosts were recorded by Hopkins (1909a): shortleaf pine, *Pinus echinata* Mill.; pitch pine, *P. rigida* Mill.; loblolly pine, *P. taeda* L.; Virginia pine, *P. virginiana* Mill.; Table-Mountain pine, *P. pungens* Lamb.; eastern white pine, *P. strobus* L.; longleaf pine, *P. palustris* Mill.; spruce pine, *P. glabra* Walt.; red spruce, *Picea rubens* Sarg.; and Norway spruce, *P. abies* (L.) Karst. Wyman (1924) recorded slash pine, *P. elliottii* Engelm., as being attacked. Personnel of the Southeastern Station have also observed the beetle killing Japanese red pine, *P. densiflora* Sieb. and Zucc., and red pine, *P. resinosa* Ait., in plantations in western North Carolina and pond pine, *P. serotina* Michx., on the coast of North Carolina.

DESCRIPTION OF STAGES

The southern pine beetle was originally described by Zimmerman (1868). The description that follows is intended only to acquaint the reader with the general appearance of the insect in its different stages; most taxonomic details have been omitted. A number of authors have presented detailed descriptions of its life stages (Hopkins, 1899, 1909a; Blackman, 1922; Chamberlin, 1939; and Fronk, 1947).

The adult southern pine beetle is a slender, cylindrical insect, 2.2 to 4.2 mm. long, brown to black in color. The front of the head has a longitudinal groove with elevations on each side. The elytral declivity is convex. The female may be distinguished from the male by the presence of a transverse elevation on the anterior portion of the pronotum (Blatchley and Leng, 1916).

The egg is oblong to oval, pearly white in color, 1.5 mm. long and 1 mm. wide. Upon emerging, the small, wrinkled, legless, grublike larva is approximately 2 mm. long. Its head capsule is reddish brown. The full grown larva is approximately 5 mm. long. Head capsule measurements indicate that there are four larval instars (Fronk, 1947). The mature larva migrates to the outer bark and constructs a pupal cell in which it transforms to the pupal stage. The white fragile pupa is 3 to 4.2 mm. in length and is distinguished by its large head and prothorax which closely resemble those of the adult. The pupa molts to a soft, whitish adult beetle which soon hardens and changes in color to a reddish brown and then to a dark brown or black.

BIOLOGY AND ECOLOGY

Life History

The details of the life history of the southern pine beetle were originally reported by Hopkins (1899, 1909b). The number of generations of the beetle per year varies principally with climatic conditions and they are difficult to follow because of their complex overlapping and because attacks appear to be continuous during favorable weather. Hopkins (1899, 1909b) found there were two to three complete generations in West Virginia; there may be four or a partial fifth generation at the lower elevations and more southern localities of that area. Other studies conducted in North Carolina and Virginia resulted in similar findings (Fronk, 1947; St. George and Beal, 1929).[1/][2/][3/] The number of generations that occur in the southern part of the beetle's range is not definitely known (fig. 2).

1/ Beal, J. A., and St. George, R. A. Progress report on the southern pine beetle. Summary of observations and experiments. U. S. Bur. Ent. Plant Quar., Div. Forest Insect Invest., Asheville, N. C. 1926. (Typewritten, 35 pp.)

2/ Craighead, F. C., and St. George, R. A. Progress report on forest insect investigations conducted at Asheville, N. C., April to October, 1925. U. S. Bur. Ent. Plant Quar., Div. Forest Insect Invest., Asheville, N. C. 1925. (Typewritten, 40 pp.)

3/ MacAndrews, A. H. The biology of the southern pine beetle. Syracuse University. 1926. (Unpublished thesis, 103 pp.)

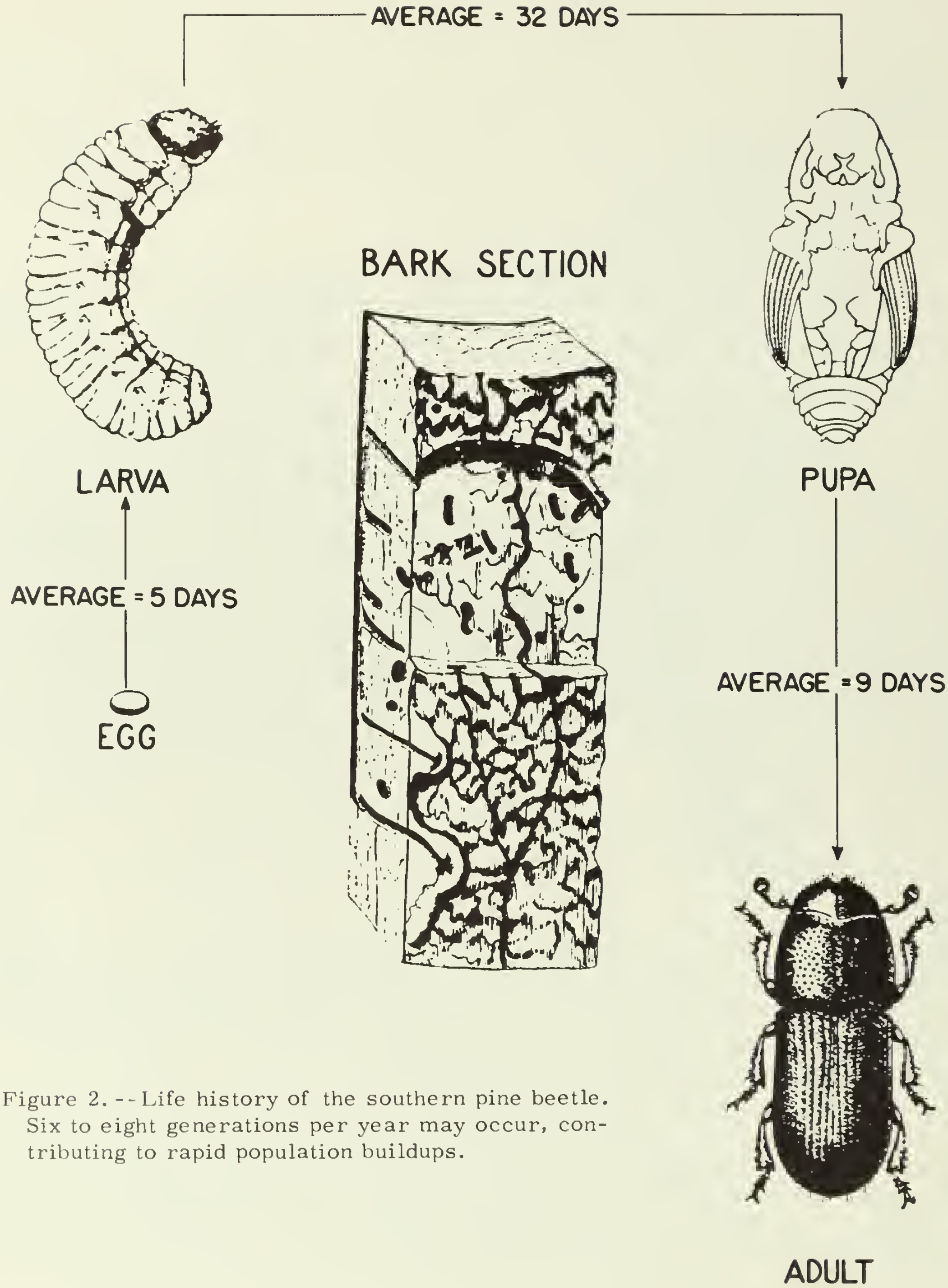

Figure 2.--Life history of the southern pine beetle. Six to eight generations per year may occur, contributing to rapid population buildups.

The beetle passes the winter in all stages of development, and emergence varies with the overwintering stage and climatic conditions. In the southern Appalachians the more mature individuals emerge about the middle of April; the remaining stages may continue to emerge through the greater part of June (fig. 3).

Figure 3.--Emergence holes of the southern pine beetle in the bark of pine.

MacAndrews (see footnote 3) stated that the "old parent adults emerge a week to ten days or more before their offspring. They usually leave the tree when the broods are in the larval stages.... While some of the adults emerge at once, others may construct a short feeding gallery, away from the pupal cell, before finally emerging." Each adult makes its own exit hole.

Emerging adults of most generations exhibit no set pattern of attack; they may attack nearby uninfested trees or migrate a considerable distance from the trees in which they developed. Hopkins (1899) reported that upon emergence in the spring, hibernating beetles "...evidently do not attack the healthy, living trees, but excavate their brood galleries in the living bark of trees injured but not killed by the attack of late broods the previous fall." Generally they attack the middle and upper trunk first; as attacks progress they may extend to within five feet or less of the ground. Trees from the smaller diameters to the largest are attacked and killed. In "hot spots" and areas where preferred material is scarce, trees as small as three-quarters of an inch d.b.h. have been killed.

When initial attacks occur on apparently healthy pine trees, a profuse flow of sap usually takes place at the point of entry. The adults not "pitched out" extend the gallery laterally through the outer and middle layers of bark for some distance (one or two inches) before the inner layer is penetrated (Hopkins, 1899). If the flow of sap is moderate, the beetles bore directly to the wood and construct their galleries through the inner bark. MacAndrews (see footnote 3) reported that "the female bores directly into the cambium and at once constructs a small nuptial chamber." This chamber is approximately 5 mm. long and 3 mm. wide. The beetles are monogamous and usually only one male and one female are found in each gallery. After fertilization the female begins construction of the winding S-shaped gallery. Galleries vary in length from 2 to 12 inches (fig. 4). Craighead and St. George (see footnote 2) observed that parent adults extended the egg galleries about an inch a day. Eggs are laid singly in niches at irregular intervals along the sides of the galleries. Fronk (1947) reported the average time for hatching as 5.5 days. MacAndrews (see footnote 3) stated that: "Some of the beetles expended their energy in laying eggs and constructed short galleries. Others concentrated on gallery construction and laid comparatively few eggs. The daily rate of [gallery] growth also varies with the condition of the cambium. When a copious flow of resin was present, the gallery construction slowed up considerably."

The larvae mine away from the egg gallery at right angles and their galleries are often concealed by the phloem. The larval gallery is usually short and narrow; at the end is an oval-shaped feeding area which is later extended into the dry outer bark where pupal cells are constructed. Larval mines vary from 5 to 20 mm. in length, with the average being 10 mm.[4/] If the bark dries too rapidly, the larvae will continue to bore for some distance through the inner portion of the bark without increasing in size (Holst, 1937; Hopkins, 1909a). Fronk (1947) reported that there were four larval

4/ Lee, R. E. A study of the southern pine beetle in epidemic status. U. S. Forest Serv. South. Forest Expt. Sta. 1955. (Office Rpt., 13 pp.)

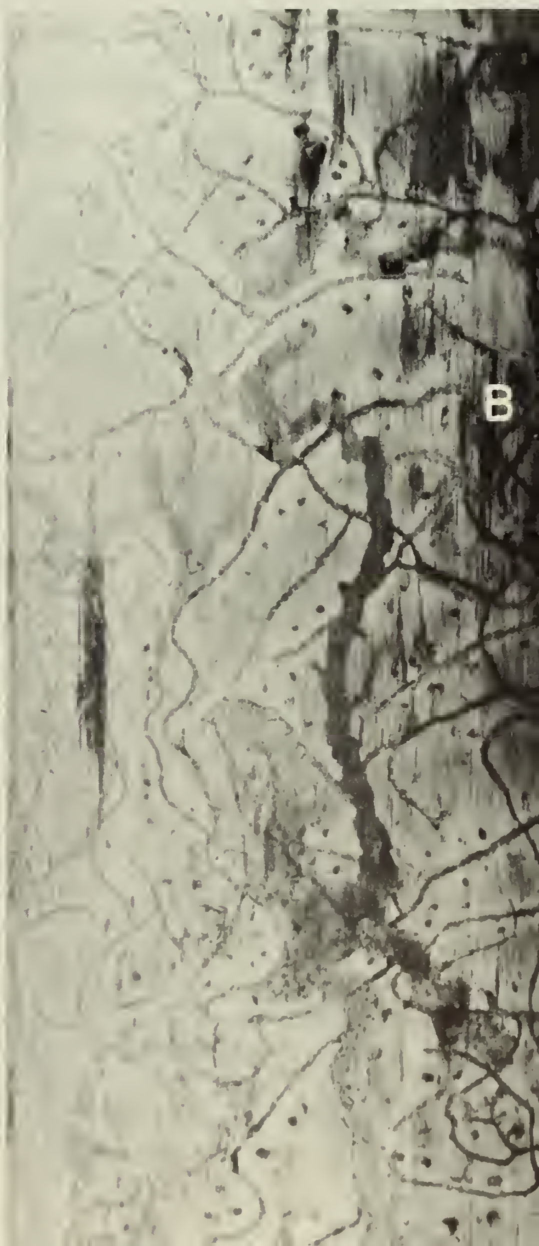

Figure 4.--A, S-shaped adult galleries and small larval galleries in the inner bark of pine. B, Southern pine beetle galleries etched on the surface of wood of pitch pine. The large galleries packed with boring dust are those of a wood borer, Monochamus sp.

instars and that on the average 32 days were spent in the larval stage. He found the average pupal period to be 9.4 days and the average time from egg to adult to be 47 days with a minimum of 40 and a maximum of 54 days. Other workers have reported similar results (Hopkins, 1899; see also footnote 3). St. George and Beal (1929) found that under favorable conditions a brood can develop from egg to adult in 30 to 40 days.

The southern pine beetle has a great potential for increase from generation to generation and from season to season. On the basis of averages of counts of beetles attacking per square foot and beetles emerging per square foot, MacAndrews (see footnote 3) reported an increase of 800 percent. Craighead et al. (1927) reported an average potential increase of 850 percent and that an increase of 1,000 percent may well be possible. Emergence was reduced in small, thin-barked trees (see footnotes 2 and 3). The tremendous capacity of the beetle to multiply explains why sudden changes from endemic to epidemic populations may occur when conditions become favorable for the insect. Just what these conditions are and how they influence the biology of the beetle in its relationship to the environment is not known.

Characteristics of attack.--Characteristics of injury to trees and changes in foliage following attack have been reported by several authors (Hopkins, 1899, 1909b; St. George and Beal, 1929; see also footnotes 2 and 3). The first external evidences of attack are the presence of pitch tubes on the middle to upper trunks and reddish boring dust along the upper trunks and in loose bark at the bases of the trees. If attack is sufficient to kill trees, a series of changes take place in the foliage as the attack progresses. During the summer, about two weeks after attack, the needles appear faded and yellowish; in about a month they appear sorrel to reddish brown; and in another month the foliage is shed (fig. 5). By the time the needles are reddish brown, all bark except at the base of the tree is dead, but the base of the tree may remain alive for weeks or months after the top is dead. Craighead and St. George (see footnote 2) stated that the yellow to sorrel stage of the needles coincided with the emergence of the brood. By the time the needles are reddish brown, practically all the broods have emerged (Hopkins, 1909b). MacAndrews (see footnote 3) found that the old needles at the base of the crown were the first to change color, followed in succession by the old needles at the top of the crown, the new needles at the base, and the new needles at the top. When the bark is removed, the S-shaped galleries of the beetle can be seen on the inner bark and outer surface of the wood (Hopkins, 1909b; St. George and Beal, 1929).

The rapid dying of attacked trees is associated with penetration of blue stain, Ceratocystis minor Hedgc., introduced by beetles. The tree dries out quickly, phloem is destroyed, and the foliage begins to fade in about three weeks. In the absence of blue stain, mortality may be delayed considerably. Craighead and St. George (1940) noted that a group of shortleaf pines attacked in the fall showed no indication of fading until the following spring. In this case relatively few beetles reached the xylem and interference with conduction by the fungus was delayed. As a result the affected trees were able to survive over the winter and did not fade until spring.

Figure 5.--A large stand of pine killed by the southern pine beetle in Tennessee. A few live pines are scattered through this once dense stand.

Phenological observations by St. George and Beal (1929) indicated that the more mature beetles began to emerge in the spring about the time eastern redbud, Cercis canadensis L., bloomed and that later ones continued to emerge until midsummer when the blackberries began to ripen. MacAndrews (see footnote 3) correlated the emergence of the first generation with the blossoming of the flame-colored azalea, Rhododendron calendulaceum (Michx.) Torr.; the second with the blossoming of mountain-laurel, Kalmia latifolia L.; and emergence of the third generation with blossoming of sourwood, Oxydendrum arboreum (L.) DC.

Flight habits.--Little intensive research has been done on the flight habits of the southern pine beetle, and there are many conflicting observations and opinions on the subject. A great deal of research is needed on flight behavior in relation to migration and attack of trees. Hopkins (1899, 1909b) believed that, since southern pine beetles were found in electric light globes and were otherwise attracted to light, the species flew at night as well as during the day. In contrast, MacAndrews (see footnote 3) failed to attract beetles to a lamp in an epidemic area even though many other species of bark beetles and cerambycids were attracted.

Upon emergence beetles fly to other living trees or sometimes to freshly cut logs (St. George and Beal, 1929). Balch[5] noted that upon emergence beetles flew above the trees toward light, and that when in the open their direction seemed to be determined by the direction of the wind. Hopkins (1899) reported that from the character of attack at certain times it appeared that great migrating swarms occurred which ascended high into the air and were evidently carried long distances by strong winds and storms. This was indicated by the fact that the first groups of trees that died in a newly invaded locality were usually on high slopes where the swarm would come into contact with the timber. At the conclusion of such flights great numbers of beetles were observed to congregate under the loose bark flakes of healthy trees before simultaneous entrance into the inner bark (Hopkins, 1909b).

A peculiar habit of the beetle is that of migrating from one group of brood trees to another group of trees some distance away, instead of continuing their attack on the trees immediately surrounding those from which they emerge (Hopkins, 1899).

Speers (1956) used radioisotopes in an attempt to learn more about the flight habits of the beetle. Improvement of new techniques such as this may be profitable in studies of migration and dispersal of insects.

Beetle breeding in felled logs and weakened trees.--Hopkins (1909b) stated that the southern pine beetle would breed in injured and felled trees, but specific instances of such attacks were not cited. The first report of the beetle successfully completing a generation in felled logs was made by MacAndrews (see footnote 3). Craighead and St. George (see footnote 2) also observed the beetle attacking felled logs. St. George and Beal[6] reported that when occurring in small numbers the beetle is found breeding in weakened and dying trees. The beetle is also associated with secondary species of insects and will attack recently felled logs and slash down to a diameter limit of about four inches, preferring the sides and bottoms of such material. They also reported that the beetle was capable of building up to epidemic proportions in felled logs and slash in a single season after being reduced to a minimum by low winter temperatures.

However, Craighead *et al.* (1927) summed up the early findings on the importance of such material in causing outbreaks by saying that "...the infrequency with which the southern pine beetle attacks slash, cull logs, or wind-blown trees immediately eliminates it as an argument for the disposal of such material." Later, St. George and Huckenpahler[7] visited many areas where summer-cutting had been carried out, and in only one case was an attack attributed to population buildup in cuttings. These observations indi-

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5/ Balch, R. E. The influence of the southern pine beetle on forest composition in western North Carolina. Syracuse University. 1928. (Unpublished thesis, 33 pp.)

6/ St. George, R. A., and Beal, J. A. Progress report on studies on the southern pine beetle (*Dendroctonus frontalis* Zimm.). U. S. Bur. Ent. Plant Quar., Div. Forest Insect Invest., Asheville, N. C. 1927. (Typewritten, 40 pp.)

7/ St. George, R. A., and Huckenpahler, B. J. Insects in relation to cutting of pines in emergency conservation work in the southeastern United States. U. S. Bur. Ent. Plant Quar., Div. Forest Insect Invest., Asheville, N. C. 1934. (Typewritten, 14 pp.)

cate that the danger of attracting the southern pine beetle by cutting pines in midsummer is not as great as formerly believed.

Although the beetle will occasionally attack felled logs and slash, these materials apparently do not play an important role in the epidemiology of the insect.

Factors Predisposing Stands to Attack

Many factors may predispose trees and stands to attack by the southern pine beetle and contribute to the development of epidemics. Such factors as drought, rainfall deficiencies, rainfall excesses, fire, lightning, or mechanical injury to trees are complex in themselves and in their interrelationships, and their individual effects in relation to beetle outbreaks cannot be readily separated.

Drought and rainfall deficiencies.--Drought and rainfall deficiencies have long been recognized as factors contributing to outbreaks of the southern pine beetle (Wyman, 1924; Craighead, 1925; St. George, 1930, 1931; Knull, 1934; Hetrick, 1949; and Merkel, 1956; see also footnotes 2, 3, 4, and 8). Craighead and St. George (footnote 2) indicated that drought played an important part in inducing attack and that changes in trees as a result of drought also affected brood development. Knull (1934) stated that drought weakened trees and made them more susceptible to attack. After comparing southern pine beetle outbreaks, Lee (footnote 4) reported: "Mounting evidence indicates that when the beetle is on the incline, the most susceptible hosts are drought-weakened pines, and it is suggested that these trees may even be on soils so depleted of moisture that the permanent wilting point has been reached."

Wyman (1924) observed deficiencies in rainfall preceding an outbreak that was subsequently curtailed by excesses in precipitation. St. George and Beal (footnote 8) considered deficiencies in rainfall during July and August of one inch or more as contributing to outbreaks. They stated that under such conditions the trees were in a weakened condition and easily overcome by the beetles.

After comparing outbreaks with precipitation records, Craighead (1925) concluded, that with two exceptions, every southern pine beetle outbreak on record occurred during periods of rainfall deficiency. This suggested an intimate relationship between epidemics and drought periods. He felt that late summer and fall deficiencies were more important in producing outbreaks than those in other seasons. In contrast to this, Merkel (1956) stated that there was not sufficient evidence to show that droughts in late summer and early fall were more conducive to outbreaks than rainfall deficiencies at other times of the year. Further, "...close analysis of weather data indicates that winter, spring, and early summer droughts, or accumulated precipitation deficiencies early in the growing season, contribute to the development of outbreaks, which may not show up until late summer or fall."

8/ St. George, R. A., and Beal, J. A. Report on the southern pine beetle outbreak located at Hot Springs, N. C., and vicinity. U. S. Bur. Ent. Plant Quar., Div. Forest Insect Invest., Asheville, N. C. 1929. (Typewritten, 8 pp.)

The collapse of outbreaks has often been associated with excesses of rainfall (Wyman, 1924; Craighead, 1925). Craighead stated that "...heavy precipitation during periods of attack and brood development seems to be most effective in control by killing the beetles and young larvae beneath the bark of attacked trees." On the other hand, Hetrick (1949) reported: "Excess of precipitation as well as deficiencies of rainfall may contribute to outbreaks of the southern pine beetle. Damage to root systems of pine trees contributes more attractiveness to bark beetles than damage to trunks of trees."

As indicated, there appears to be no doubt that drought is associated with outbreaks of the southern pine beetle. Rainfall deficiencies have been noted preceding most outbreaks. It appears that winter, spring, and early summer deficiencies may be just as important as late summer and early fall deficiencies. Other factors may also be involved, however, because outbreaks have been known to collapse while favorable drought conditions have persisted. Some outbreaks have also occurred in the absence of droughts--even after periods of excess rainfall--and it is possible that copious and prolonged rainfall may damage root systems of trees and thus create favorable conditions.

Fire and lightning.--Observations indicate that fires have a direct influence in inducing beetle attacks (St. George and Beal, 1929). Knull (1934) observed that trees suffering from the ravages of fire and lightning appeared to suffer severely and seemed to be responsible for isolated infestations. The significance of the attack by the beetle in fire-killed timber is often more difficult to determine than for some other insects (St. George, 1928). Beal and St. George (see footnote 1) found it difficult to assess the influence of the beetle in the case of fire-damaged trees because mortality was due in part to the weakened condition of the trees. They concluded that fire was probably a much more important factor than insects in the removal of trees from the stand.

Craighead and St. George (1928) reported the southern pine beetle concentrating on a burned area apparently as a result of fire. Ips beetles, ambrosia beetles, and pine sawyers were also present, but only the southern pine beetle played an important part in tree killing. Most trees were killed as a result of fire and attack, not by insect attack alone; however, in practically all cases, mortality to trees five inches in diameter and over (trees also classed as dominants) was from the work of the southern pine beetle alone.

A heavy attack by the beetle was noted in standing pines whose tops had been completely burned off. Brood mortality was high and was attributed to increased water content of the stem because of complete defoliation. St. George and Beal (see footnote 6) concluded that severely burned trees which have lost their foliage do not furnish an ideal breeding site for the southern pine beetle, but instead serve as a check on its development. This condition should not be confused with conditions existing on less severely burned trees which have retained their foliage. Such trees were observed to contain heavy broods.

Most researchers who have worked with the beetle in the field have observed it attacking lightning-struck pine trees (fig. 6), but the exact nature of the attraction is unknown. Wind-thrown and lightning-struck trees have appeared to act as attractants in drought-affected areas, and in one instance 21 trees struck by lightning were subsequently attacked by the southern pine beetle (St. George, 1930). From 2 to 10 surrounding pines were also attacked and killed as a result of the attraction. St. George and Beal (see footnote 8) observed a large lightning-struck pine in the center of an infested area. The tree was heavily attacked and appeared to serve as a focal point for the start of the infestation.

Susceptibility of Individual Trees

Phloem moisture content.--Beal and St. George (see footnote 1) studied normal and drought-affected trees in order to detect differences in moisture relations. They found that the moisture content of the wood and phloem at all levels of the trunk and of the leaves was less in drought trees than check

Figure 6.--Lightning struck trees are attractive to beetles and may serve as foci for the initiation of southern pine beetle infestations.

trees. Moisture content is also altered by beetle attack. Following attack, the wood dries rapidly and an increase in moisture occurs at the base of the tree. "The wood of normal trees shows an increasing percentage from base to top. A gradual change to reverse condition begins after attack. This reversal is due to a more rapid drying out at the top and a delayed increasing water content at the base."

Several workers have pruned, topped, and watered trees in attempts to discover the effects of increased phloem moisture content on brood development (see footnotes 1, 2, 3, and 6). Although the results have varied greatly, brood emergence has been reduced in many cases. Transpiration reduction caused by pruning and topping probably accounts for the maintenance of phloem moisture content in such trees (see footnote 3). St. George (1931) observed that an abnormally moist condition of the inner bark, probably caused by lessened transpiration during the winter, may have been responsible for the death of the overwintering brood. St. George and Beal (see footnote 6) reported that artificial watering did not result in a direct reduction of the brood, but it appeared to prevent attack on some trees and reduced the brood in the basal portions of others.

It would appear that the moisture content of the bark and phloem, especially the phloem, is a critical factor which affects the survival of broods of the southern pine beetle. The phloem moisture conditions are also modified by the attacks of the beetles themselves. The subject of moisture content in trees, as associated with beetle outbreaks, must be studied intensely in the effort to determine the reasons for the rise and fall of beetle populations and the occurrence of epidemics.

Forest Composition and Stand Susceptibility

Balch (see footnote 5) studied the influence of the southern pine beetle on forest composition and found that in destroying thrifty stands of pure pine the beetle brought about replacement by mixed stands consisting largely of less valuable, slower growing species. The composition of future stands was predicted from estimates of advance reproduction. Such stands, it was thought, would consist of two age classes. The upper story would be composed of scattered pine and oak and the lower story would consist of 30 percent pine, 12 percent desirable hardwoods, and 58 percent undesirable hardwoods. The only possible advantage of such types of stands is that they would be fairly immune to southern pine beetle attacks.

Hoffman and Anderson (1945) found that pure pine stands were more susceptible to attack than mixed pine-hardwood stands. The openings resulting from bark beetle attacks did not revert to pure pine but were taken over by mixed pine-hardwood stands. The pines in such stands were those which had not succumbed to beetle attack. Little pine reproduction became established after the larger trees had died. On small areas better than three-quarters of the pine six inches d.b.h. and over were attacked and killed; the smaller trees were less subject to attack (fig. 7).

Figure 7.--Pine stand killed by the southern pine beetle showing advance pine and hardwood reproduction that will replace this formerly pure pine stand.

Lee (see footnote 4) compared southern pine beetle outbreaks in several states to determine whether similarities or differences in the environments might be found which could be used as indications of host susceptibility. The beetle was found to attack pines under a wide variety of conditions and did best in dense stands. There was great variation in the age and size of trees attacked; young, apparently thrifty stands were by no means immune. Osgood[9] studied site and stand characteristics in many infested areas of the southern Appalachians. The beetle attacked pure stands growing under average field conditions. Based upon the factors measured, most pine stands found in this area were in poor condition.

Rearing Methods and Attempts to Induce Attack

As previously indicated, the southern pine beetle is characterized by violent fluctuations in populations. In order to conduct controlled biological and ecological studies, it is necessary to have a continuous supply of the beetles available. It has been impossible to conduct such studies because no satisfactory method for rearing the beetles has been found. Attempts to rear large numbers of beetles by inducing attack on standing trees and caged logs have produced varying results that have not been consistently successful.

Beal and St. George (see footnote 2) were unsuccessful in inducing attacks "...until the bark containing the beetles was caged with the material on which attack was desired." Several attacks were induced by this method on caged logs and in a standing tree, and further experiments conducted the following year (St. George and Beal, 1929) were so successful that it was assumed attacks could be induced whenever desired; however, no additional experiments were conducted. Caird (1935) was able to induce attacks on standing trees by similar methods. Attacks also occurred on trees adjacent to an infested caged bolt (fig. 8).

Recent efforts to rear the beetle under artificial conditions have met with little success. The application of electrical shock to bolts and the introduction of blue stain fungi before exposure to attack were unsuccessful.[10] Osgood and Carter[11] tried the following treatments with little success: (1) mechanical injury to standing trees; (2) caging infested bark on standing trees; (3) caging infested bolts on trees; (4) caging infested bark and phloem with uninfested bolts (ends waxed); (5) caging infested bark and phloem with uninfested scorched bolts; (6) caging infested bark and phloem with uninfested mechanically injured bolts; (7) caging infested bark and phloem with uninfested bolts treated with sulfuric or acetic acid; and (8) caging infested bark on uninfested bolts. It appeared that the high moisture contents of the wood and inner bark of bolts were unfavorable for the development of the early larval stages.

9/ Osgood, E. A. A study of site and stand characteristics of southern pine beetle infestations. U. S. Forest Serv. Southeast. Forest Expt. Sta. 1958. (Office Rpt., 5 pp.)

10/ Smith, V. K., Jr. Techniques used in attempts to rear Dendroctonus frontalis. U. S. Forest Serv. South. Forest Expt. Sta. 1954. (Typewritten, 18 pp.)

11/ Osgood, E. A., and Carter, W. A. Techniques used in preliminary attempts to rear southern pine beetle, Dendroctonus frontalis Zimm. U. S. Forest Serv. Southeast. Forest Expt. Sta. 1958. (Office Rpt., 10 pp.)

Figure 8.--Two attempts to induce beetle attack on pines. In A, a shortleaf pine was caged with sections of infested bark. Tagged trees are ones on which subsequent attack was induced. In B, an infested bolt was caged and placed in the midst of a beetle-free stand in an effort to attract beetles to the area.

ASSOCIATION OF THE BEETLE WITH TREE-KILLING FUNGI

The relationship of the southern pine beetle to fungi has been studied intensively. Most of the work has been concerned with the blue stain fungi. Craighead (1928) noted that complete girdling of the cambium and phloem by the beetle was not entirely responsible for the rapid death of the trees, and he pointed out that blue stain probably hastened their death. Craighead and St. George (see footnote 2) reported that heavily blue-stained trees were notably drier than unaffected trees. In cross sections, blue-stained portions were relatively dry, but the adjacent, unstained wood was saturated. Later studies indicated that there was a relationship between moisture content of the stems and the development of blue stains (see footnote 6). The blue stain developed best under conditions of decreased moisture and increased air supply. Beetle development and blue stain development apparently proceeded together. Dendroctonus frontalis was always accompanied by blue stain fungi, and when the brood failed to develop the fungus also failed.

Ceratocystis minor is the blue-staining fungus specifically associated with the southern pine beetle. Rumbold (1931) originally described it as Ceratostomella pini Munch. when she also described its various stages. Nelson and Beal (1929) showed that the southern pine beetle was a factor in the spread of the fungus. Of 218 zones of blue stain in shortleaf pine attacked by the beetle, 97 percent were found to be directly associated with the entrance holes of the beetle. Death of the trees was considered the result of the combination of mechanical injury caused by the beetle and the action of the blue stain fungus. They further stated: "Bluestain in southern pines, except in association with beetle attack, is uncommon, although it occasionally is found in pines which have been severely wounded, such as dry faces of turpentined trees." Additional inoculation experiments with blue stain fungi further demonstrated that it could kill pines (Nelson, 1934). If the entire cross section became stained, death invariably resulted. Because the fungus brought about a reduction in water content in uninfested trees favorable for brood development, it was believed that C. minor was probably indispensable to the southern pine beetle. Subsequent laboratory experiments, however, showed that the yeasts and blue stain fungi generally found in association with the insect were not essential for the development of adults from the egg (Holst, 1937). This was supported by the fact that beetles developed successfully from sterilized eggs. Hetrick (1949) reported that the fungus does not always accompany the southern pine beetle and that the beetle can infest trees and develop healthy broods in its absence. Although these two organisms may develop independently, it is doubtful whether either could be very successful in the absence of the other. This is a symbiotic relationship where the presence of the beetle is essential to the optimum development of the fungus and vice versa.

Bramble and Holst (1935, 1940) have reported that a number of fungi and yeasts are introduced into pines by Dendroctonus frontalis. An unnamed basidiomycete and C. minor were reported as capable of killing trees upon inoculation if the inoculation points encircled the stems of the trees. They further found: "Fungus infection of the sapwood which followed infestation of living pines by Dendroctonus frontalis was not a simple infection by a single fungus but a complex invasion accomplished within a short period by a number of fungi." Contrary to what had been expected, the most prominent invader of the outer sapwood immediately following attack was not C. minor. In the early stages it was accompanied and even preceded by other fungi. The most prominent early invaders were Dacryomyces sp. and Pichia pini (Holst) Phaff. However, in later stages C. minor rapidly penetrated the inner growth rings and appeared to take the lead in further penetrations of the sapwood. These observations were substantiated by inoculations that showed that Dacryomyces sp. and P. pini alone could penetrate only a short distance into the sapwood of healthy trees. The infected tissue was confined to the external area affected by the removal of bark. In contrast, C. minor alone was able to penetrate to the center of inoculated stems of healthy trees. It was concluded that none of the fungi played more than an assisting role in killing trees, because even C. minor required wounds of considerable tangential extent before it could seriously damage a healthy stem. The fungi just mentioned are considered primary; others isolated were secondary and not involved in the death of trees.

Chiefly, fungi accompanying beetle attacks stop conduction and bring about the death of trees more rapidly than could be accomplished by the mechanical injury caused by the beetle alone (Bramble and Holst, 1940). Following the stoppage of conduction there is a reduction of the water content of the stem because of water withdrawal by the transpiring crown and the inability of the water to pass through the infected stem from the roots.

Caird (1935) reported that the role of Ceratocystis minor and related fungi appears to be an acceleration of the drying of the tree bole. After beetle attack, drying takes place in the outer rings (the outer rings failed to conduct dye solutions) and various fungi enter the wood. The capacity for conduction is lost first by the outer rings and proceeds progressively toward the center. As this condition advances toward the center of the tree, the water supply to the leaves is cut off and they die (fig. 9). Failure of the outer rings to conduct is intimately associated with the drying of the wood. The failure of the wood to conduct dye solutions was also associated with the penetration of the wood by fungi. C. minor and an unidentified fungus were the only fungi capable of penetrating deeply into the wood during the early stages of attack. Inoculations showed that C. minor growing alone was capable of killing trees. The unidentified fungus was not tested.

Craighead and St. George (1940) observed that pines lightly attacked in the fall by the beetle and from which no brood emerged the following spring received sufficient inoculation of the blue stain fungus to cause the death of the trees the following spring.

Optimum development of C. minor and perhaps other fungi does not occur unless the southern pine beetle is present. It is also probable that rapid increases in beetle populations are made possible by the action of these fungi in creating a more favorable environment for insect development. This symbiotic relationship may, in part, explain the sudden appearance of infestations where formerly the beetle could not be found.

Hetrick (1949) reported trees infested with southern pine beetle and with rhizomorphs of the mushroom root rot, Armillaria mellea (Vahl.). This root rot fungus apparently weakened the tree before beetle attack.

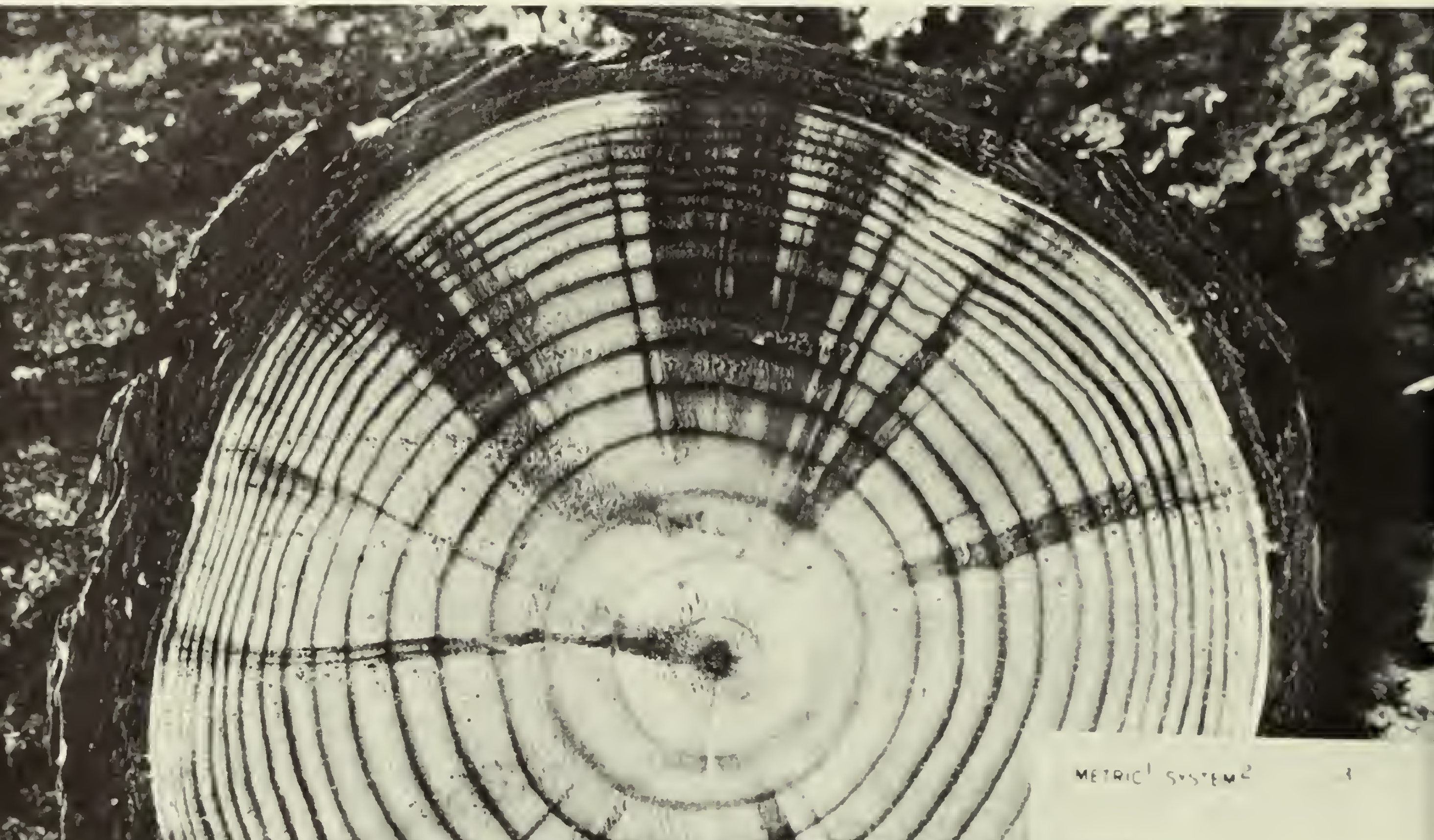

Figure 9.--Cross-section of pine killed by the southern pine beetle showing blue stain extending from beetle entrance holes to the heartwood.

Predators

Several insect predators have been observed attacking the southern pine beetle:

Insect predators of the southern pine beetle

Predator family and species	Stage attacked
Anthorcoridae	
Lyctocoris elongatus (Reuter)	Nymphs and adults feed on eggs and larvae
Scolopscelis flavicornis (Reuter)	Nymphs and adults feed on eggs and larvae
Cleridae	
Enoclerus quadriguttatus Oliv.	
Priocera castanea (Newman)	
Thanasimus dubius (F.)	Larvae feed on larvae, adults on adults
Ostomidae	
Temnochila virescens (F.)	Larvae feed on larvae and pupae, adults on adults
Tenebrionidae	
Hypophloeus cavus Lec.	
Hypophloeus parallelus Melsh.	
Tenebroides collaris (Strum.)	Larvae feed on larvae and pupae, adults on adults
Dolichopodidae	
Medetera sp.	

Fronk (1947) found that the beetles *Tenebroides collaris* (Strum.), *Temnochila virescens* (F.), and *Thanasimus dubius* (F.) were very active; the larvae feed on larvae and pupae of *Dendroctonus frontalis*, and the adult predators feed on adults. One larva of *T. dubius* was observed feeding on 96 larvae of the southern pine beetle before it pupated. Fiske (1908) observed that it was not uncommon to find beetle-infested trees in which the brood had been almost entirely destroyed by this predator.

The nymphs and adults of two anthrocorids, *Lyctocoris elongatus* (Reuter) and *Scolopscelis flavicornis* (Reuter), are active feeders on the eggs and larvae of the southern pine beetle (Fronk, 1947). *Medetera* sp. (Dolichopodidae), when present in sufficient numbers, has been reported capable of reducing beetle populations slightly (Fiske, 1908). Several other species, including the clerids *Enoclerus quadriguttatus* Oliv. (Chamberlin, 1939) and *Priocera castanea* (Newman) (Boving and Champlain, 1921), have been observed preying on the southern pine beetle. The tenebrionids

Hypophloeus cavus Lec. and H. parallelus Melsh. have been observed in brood galleries and pine bark (Hopkins, 1899).

In 1892 Hopkins (1899) released 2,200 specimens of Thanasimus formicarius L., the European bark beetle destroyer, in West Virginia. These clerids were collected in Germany for the express purpose of combating the southern pine beetle, and marked the first importation of natural enemies into the United States to combat destructive forest insects. Unfortunately, the host population collapsed before these insects could become established, and no field recoveries have ever been made.

Fronk (1947) found that: "Six different species of mites were associated with D. frontalis under the bark. Dendrolaelaps sp. (Laelaptidae) appears to be a new species and is the first record from this country. Histogaster carpio K. (Acaridae) and Parasitus sp. (Parasitidae) were observed feeding on the larvae of D. frontalis. Zerocoseius sp. (Laelaptidae) and Oribatoidae mites were present, but their relationship is unknown. Uropoda sp. was probably the most numerous of the mites. Although this mite is not parasitic on the southern pine beetle, it may hinder its dispersion by its phoresitic attacks."

About 80 percent of the beetles that emerged from eggs in an insectary had Uropoda sp. or their hairlike pedicels attached. Hetrick (1940) stated: "Mites were found on the bodies of 17 percent of the new adults of the overwintering brood and on 62 percent of those of the first brood of Dendroctonus frontalis emerging in the insectary, but no information was obtained on their importance in the field. Specimens were determined by H. E. Ewing, Entomologist of the United States National Museum as follows: two species of the family Parasitidae; one of the family Uropinae; one of the family Dameosmidae; and one of the family Cheltidae, genus Cheltia."

Woodpeckers have been observed to strip the bark from trees infested with the southern pine beetle (Hopkins, 1899; St. George, 1931; see also footnotes 1 and 8). In one infestation woodpeckers were noted working on 7.6 percent of the infested trees (see footnote 8) and have been reported as reducing broods to one-third to one-fourth of their original number (see footnote 1). St. George (1931) reported that hairy woodpeckers stripped bark from infested trees except where adult beetles had largely emerged. In stripping the bark they were responsible for killing many more beetles than they consumed because large numbers of the larvae were exposed to the cold. It has been reported 12/ that 77 percent of the southern pine beetle larvae in the dry outer bark of trees attacked by woodpeckers were killed by low temperatures, while only 44 percent of such larvae were killed in trees not attacked by woodpeckers. It seems unlikely that woodpeckers are very effective in reducing epidemics of the southern pine beetle, but they are probably quite effective in reducing the beetle in the endemic state and preventing populations from building up (fig. 10).

12/ Southeastern Forest Experiment Station. Semi-annual progress report, July-December 1957. (Unpublished, pp. D14-16.)

Figure 10.--Woodpecker feeding signs on pine infested with the southern pine beetle.

The relationship of secondary insects to the southern pine beetle is poorly understood. With the exception of such cerambycids as Monochamus titillator (F.), Acanthocinus nodosus (F.), and Xylotrechus sagittatus (Germ.), known to be competitors for food (see footnotes 1 and 3), most other insects are reported only as associates of the southern pine beetle (Craighead, 1950; see also footnotes 2 and 3). Hopkins (1899) reported great numbers of beetles killed by Monochamus spp., but Beal and St. George (see footnote 1) found Monochamus larvae nowhere numerous enough to destroy more than half the brood. MacAndrews (see footnote 3) pointed out that the relationship between cerambycid larvae and southern pine beetle mortality is more complicated than appears on the surface. He stated: "If *frontalis* brood development begins before or immediately after oviposition by cerambycids the brood mortality of *frontalis* is not increased in thick barked trees." If they fail to get a start, considerable mortality results, regardless of bark thickness. When the bark was less than three-quarters of an inch thick, most of the pupae were destroyed; only those in the outer bark escaped.

Parasites

Hopkins (1899), Fiske (1908), Muesebeck (1938), Hetrick (1940), and Chamberlin (1939) have studied the insect parasites of the southern pine beetle.

Insect parasites of the southern pine beetle

Parasite family and species	Stage parasitized
Braconidae	
Bracon pissodis Ashm.	Larva and pupa
Coeloides pissodis (Ashm.)	
Compylonerus (*Bracon*) *mavoritus* (Cress.)	
Dendrosoter sulcatus Mues.	
Doryctes sp.	
Ecphylus (*Sactopsus*) *schwarzii* Ashm.	Larva
Spathius canadensis Ashm.	
Eulophidae	
Tetrastichus thanasimi Ashm.	On *Thanasimus dubius*
Pteromalidae	
Cecidostiba dendroctoni Ashm.	
Heydenia unica C. and D.	
Roptrocerus (*Pachyceras*) *eccoptogastri* Ratz.	
Torymidae	
Liondontomerus (*Lochites*) sp.	
Stratiomyidae	
Microchrysa polita (L.)	Larva
Tachinidae	
Tachina sp.	On *Thanasimus dubius*

Fiske (1908) stated: "It is only in rare instances that all the individuals of a brood of wood or bark borers are equally exposed to the attack of any one parasite, and a proportion will almost always escape." He studied the southern pine beetle and found striking differences in the proportion of parasitized individuals in different trees and at various heights in the same tree. In the tops of large trees or in small trees with thin bark, braconid parasites attacked 45 percent of the larvae; lower down on the same trees (in the case of large trees) these parasites were seldom present. Such conditions become more important when different host trees and parasite species are involved and have a great influence upon the effectiveness of parasites.

Furthermore, although hyperparasites may not greatly reduce the effectiveness of primary parasites, various predators undoubtedly do since at times they will attack both parasites and hosts with like freedom. When a predatory species such as Thanasimus dubius becomes as numerous as it often does in trees infested with the southern pine beetle, a great many parasites will be destroyed along with the bark beetles.

Hetrick (1940) reared the following species (listed in order of importance) from Dendroctonus frontalis: Coeloides pissodis Ashm.; Cecidostiba dendroctoni Ashm.; Spathius canadensis Ashm.; Heydenia unica C. and D.; Roptrocerus eccoptogostri Ratz.; and Dendrosoter sulcatus Mues. He found that parasitism of the overwintering brood was 0.39 percent and that of the first brood was 10 percent.

Fronk (1947) reported that Microchrysa polita (L.), a stratiomyid, is parasitic in the larval stage. The most abundant parasites were Coeloides pissodis and Cecidostiba dendroctoni. These parasites were present throughout the year and undoubtedly contributed to the reduction of the southern pine beetle.

Nematodes and Pathogenic Organisms

Several nematodes attack the southern pine beetle and Hetrick (1940) reported that two were associated with the beetle. One, belonging to the genus Anguillonema, was a true endoparasite; the other, belonging to the genus Aphlenchoides, appears to be only an associate. The larvae of this nematode attach themselves beneath the elytra of adult beetles, apparently for transport. Massey (1957) recovered parasitic females of Aphelenchulus barberus n. sp. from the southern pine beetle; the males were not parasitic.

Anguillonema sp. has been reported as infesting a large portion of the adult beetles and as being responsible for heavy mortality to broods of the beetle (Hetrick, 1940). This endoparasitic nematode, together with an entomophagous fungus of the genus Beauveria, was considered largely responsible for the collapse of a bark beetle epidemic in Virginia (Hetrick, 1941).

The role of diseases in the regulation of the southern pine beetle populations is largely unknown. No bacteria or viruses have been reported as attacking the beetle; however, two fungi have been found to be associated with the insect. In a recent report (Southern Forest Experiment Station, 1955b) on an instance of natural control in Alabama, a white fungus was found associated with dead bark beetles. This may be the same fungus discovered by Hopkins (1899) and later identified as Cylindricola dendroctoni Peck. Harrar and Ellis (1940) isolated a species of Beauveria and demonstrated its pathogenicity to Dendroctonus larvae, and Harrar and Martland (1940) have demonstrated the mode of infection, action within the host, and methods of fructification of this pathogen.

Temperature Effects

It appears that climatic factors are more efficient than biological agents in the regulation of populations. It has been shown that low temperatures are capable of killing a large portion of the overwintering brood (Beal, 1927, 1933; see also footnotes 6 and 13). Hopkins (1899) reported that an outbreak in West Virginia subsided suddenly because of climatic conditions and the action of one or more diseases. From what is now known, it is probable that low temperature alone caused the sudden collapse of the outbreak. In North Carolina, outbreaks following a succession of mild winters have been terminated by cold winters (Beal, 1933). It has been concluded that mild winters and soil moisture deficiencies are important factors contributing to outbreaks in the southern Appalachians (Merkel, 1956).

At air temperatures of 10° F., larvae in the inner bark suffered 100-percent mortality, but no mortality occurred to those occupying the outer bark (Beal, 1933; see also footnote 6). Differences in mortality between larvae occupying the inner bark and outer bark appear to be related to moisture content. The moisture content of the inner bark (phloem) was much higher than in the outer bark and caused the high mortality of larvae occupying the inner bark (Beal, 1933; see also footnote 6). Osgood (see footnote 13) found mortality in the outer bark to vary with bark thickness. At times he found considerable survival of small larvae in the inner bark and attributed this to lower phloem moisture content.

In field observations, Beal (1933) found that some pupae died at 0° F. and adult mortality was heavy. At -5° F., 100-percent mortality occurred to larvae and adults in the outer bark, and pupal mortality was 90 percent. St. George and Beal (see footnote 6) reported complete brood mortality at temperatures between 0° F. and -5° F. No mortality occurred to the egg stage at these temperatures. In laboratory experiments, Fronk (1947) found that 100-percent mortality occurred to all stages (including the egg) maintained for longer than one week at 0° F. Some eggs hatched successfully after an exposure of no longer than one week, but all larvae died. Beal (1933) stated that in spite of the resistance of the eggs, the small number of broods which overwintered in that stage eliminated the likelihood of the survival of large numbers of eggs. Occasionally broods were unaffected by low winter temperatures, particularly those found in a narrow strip of bark on the bottom of logs lying on the ground. Thin-barked, second-growth pines offered little protection to hibernating larvae because low temperatures for short periods were almost as effective as those of longer duration.

High summer temperatures are not a natural limiting factor; however, in felled logs exposed to the sun during the summer months, subcortical temperatures as high as 112° F. occurred when the air temperature was between 70° and 80° F. and resulted in complete brood mortality (Beal, 1933). Some mortality of larvae and pupae began to occur at 100° F.

13/ Osgood, E. A. Mortality of the southern pine beetle due to low temperatures in the southern Appalachians. U. S. Forest Serv. Southeast. Forest Expt. Sta., Asheville, N. C. 1958. (Office Rpt., 13 pp.)

APPLIED CONTROL METHODS

Earliest methods of controlling the southern pine beetle included: (1) burning the infested bark; (2) converting the material into lumber and burning the slabs; or (3) placing unbarked logs in water (Hopkins, 1909b). It is necessary to burn the bark because larvae, pupae, and adults are concealed in it. Felling and limbing infested trees and exposing them to direct sunlight has also been recommended (St. George and Beal, 1929). More recently, Hetrick (1949) recommended that infested bark be dumped into ponds or sluggish streams. Since no adults emerge when the bark is placed in water, a considerable population reduction may be accomplished.

Much work has been conducted on the introduction of chemicals into the sap stream of standing trees (Craighead and St. George, 1930, 1938; see also footnotes 1 and 6). Workers were concerned primarily with killing the beetles to prevent their spread, and not with saving the trees. The most serious difficulty encountered was the stoppage of conduction and the subsequent interference with the movement of chemicals through the tree caused by the development of blue stain (fig. 11). Craighead and St. George (1938) stated: "...with the southern pine beetle in shortleaf pine in the South, these blue stains will permeate the outer layers of sapwood within 5 to 7 days after attack, and it is rarely if ever possible to obtain effective distribution of the chemical or destruction of the bark beetle unless the trees are treated within this time. This limits the usefulness of this method in the Southeast--in fact makes it really impractical for forest work."

In recent years toxic oil sprays which penetrate and kill the beetles in the bark have been used. Workers at the Southern Forest Experiment Station tested a number of formulations of benzene hexachloride (BHC), orthodichlorobenzene, trichlorobenzene, chlordane, and DDT against the beetle.[14] Best kill was obtained with 0.5 percent gamma BHC in fuel oil and good results were obtained with 0.25 percent gamma BHC in oil (fig. 12). These formulations were recommended and applied in large-scale beetle control projects. Other formulations gave unsatisfactory control or were considered too expensive for use in forest spraying.

Speers et al. (1955) found that benzene hexachloride was more effective than orthodichlorobenzene or ethylene dibromide in controlling the beetle. Trees were treated with 0.5 percent gamma BHC in fuel oil; orthodichlorobenzene, one part to five parts fuel oil; and ethylene dibromide, three pounds in five gallons of fuel oil. Counts of emergence holes indicated that BHC gave 89 percent control and that orthodichlorobenzene and ethylene dibromide gave 77 percent control. More than 99 percent of the beetles which emerged from logs treated with BHC died within three days. Beetles emerging from logs treated with orthodichlorobenzene and ethylene dibromide lived as long as those emerging from the untreated trees. Procedures currently recommended for control of the beetle through the use of toxic oil sprays may be found in an illustrated booklet by McCambridge and Rossoll (1957).

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[14] Southern Forest Experiment Station. Quarterly Rpt. (Oct.-Dec.). 1950.

Figure 11.--Equipment used to inject chemicals into the sap stream of pines to control the southern pine beetle.

Figure 12.--Spraying logs with benzene hexachloride to control the southern pine beetle.

SURVEYS

Aerial sketch mapping is the most economical method of detecting and appraising timber losses caused by the southern pine beetle; this method as used in Texas and Mississippi has been described by Heller et al. (1955). Studies were conducted in the southern Appalachians to determine how accurately southern pine beetle infestations could be mapped from the air (Aldrich et al. 1958; Southeastern Forest Experiment Station, 1957). If single trees and infestations of 2 to 5 trees are to be mapped, the observation strips should be limited to one-half mile. When small infestations are not plotted, mile-wide strips are adequate. Flights should be made at altitudes of 1,000 feet and at speeds no greater than 100 miles per hour.

Coyne et al. (1954) compared the accuracy and cost of aerial sketch mapping, black and white aerial photos, the operation recorder, and color aerial photos. Aerial sketch mapping was the least expensive, followed by black and white photos, the operation recorder, and color photos. For detecting insect damage, color film has proved more accurate than panchromatic with a red filter (Heller et al., 1959). Color photography would be most useful when the location of infested trees had to be mapped with a high degree of accuracy.

Lee (1954a) developed a unique method of locating the beetle at low population levels. Logs were examined for evidence of attack on skidways in log concentration yards of large lumber companies. These logs are so marked that they can be traced to their area of growth. By this method hundreds of suspect logs from many areas may be examined in a short time.

SUMMARY

Although considerable work has been done with the southern pine beetle, factors regulating beetle populations are poorly understood. Little is known of the basic physiology or ecology of the insect, or how changes within the host tree affect survival. The role of attractants and repellents in the selection of host trees is unknown, nor is it known whether toxic substances in the host are responsible for the failure of attacks and survival of the broods within the trees.

Studies have been conducted only under epidemic conditions; indeed, it is extremely difficult to detect the insect at endemic levels. Long-term studies have not followed the insect through endemic and epidemic periods. New aerial survey methods are being developed to locate insect populations. Environmental factors have not been carefully analyzed and compared under endemic and epidemic conditions; minor changes may prove very important to population increase or decrease. Rearing methods have met with indifferent success and failure to develop adequate rearing techniques has impeded both physiological and ecological studies in the laboratory and in the field.

Efficient chemical control methods have been worked out for the southern pine beetle, but such methods are only temporary remedies. They are stopgap measures and do not get at the basic problem.

The problem is to develop resistant trees and to regulate conditions so that the beetle populations are not able to reach outbreak proportions. Only through the development of satisfactory silvicultural controls can we eliminate costly temporary chemical control measures. In order to develop such controls basic studies must be started, and studies of the effects of stand composition as well as insect and tree physiology and ecology must be undertaken.

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