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Biology and Control of the Engelmann Spruce Beetle in Colorado

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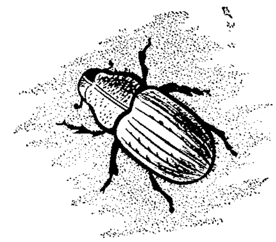

By C. L. MASSEY and N. D. WYGANT, *entomologists, Rocky Mountain Forest and Range Experiment Station, Forest Service*

INTRODUCTION

THE ENGELMANN SPRUCE BEETLE (*Dendroctonus engelmanni* Hopk.) is the most serious pest of Engelmann spruce forests in the United States. From time to time epidemics of the insect have destroyed this spruce over large areas, especially in the Rocky Mountain region (fig. 1). Damage by the beetle was reported as early as 1898, when Sudworth (*4, p. 137*)[1a] reported that 10 to 25 percent of the spruce on the White River National Forest, Colo., had been destroyed, supposedly by climatic factors. The timber he observed was later examined by entomologists and the death of the trees was attributed to the Engelmann spruce beetle. The species was described by Hopkins in 1909 (*1*). He reported that approximately 90 percent of the spruce in the White Mountains of the Lincoln National Forest in New Mexico was killed by the insect, and found evidence of beetle damage that had occurred 50 years earlier on the Pike National Forest in Colorado (*2*).

From 1939 to 1951 the beetles destroyed 4.3 billion board-feet of timber in western Colorado—3.8 billion board-feet of Engelmann spruce and 500 million board-feet of lodgepole pine. This infestation was directly correlated with large numbers of trees that were blown down by a severe windstorm on June 20, 1939. Some of the roots were still covered and functioning; others were completely severed. In many of the trees the bole was left standing with the crown blown off by the wind or broken off by falling trees. Apparently the beetles were present in endemic numbers and attacked the wind-damaged trees. By the summer of 1941 tremendous beetle populations had developed. The adults emerging from the wind-fallen and wind-broken trees attacked standing green trees in the surrounding area.

It was realized at the beginning of this outbreak that studies were needed to determine the life history and habits of the beetle, so that practical control measures could be developed. Funds were made

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[1] This study was made in the Division of Forest Insect Investigations, of the former Bureau of Entomology and Plant Quarantine, in cooperation with the Colorado Agricultural and Mechanical College. That Division has recently been transferred to the Forest Service. G. R. Struble made some of the studies on the life history and habits of this beetle.

[1a] Italic numbers in parentheses refer to Literature Cited, p. 35.

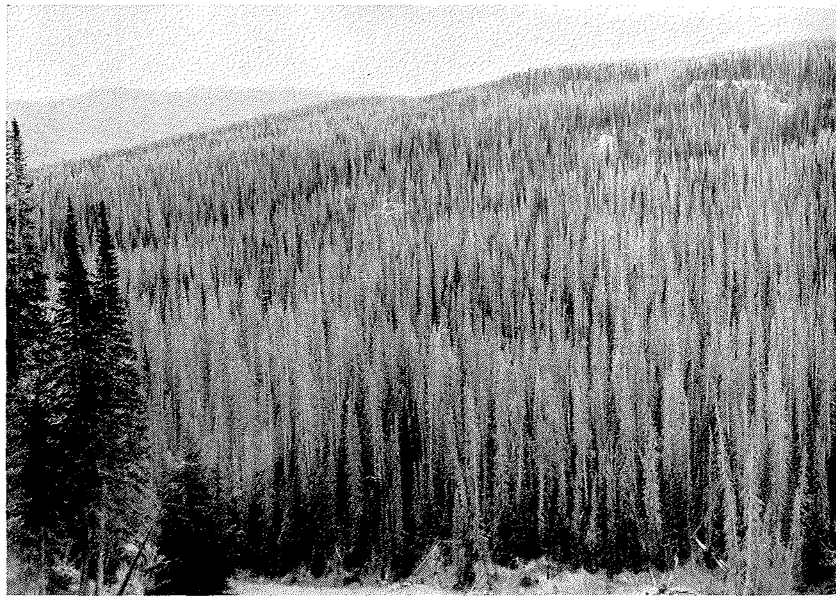

FIGURE 1.—Stand of Engelmann spruce killed by the Engelmann spruce beetle, White River National Forest, Colo.

available in 1944, and studies were started that year in Colorado on the White River and the Grand Mesa National Forests. By 1948 the beetle had killed most of the host material on these two forests and the studies, of necessity, were moved to Rabbit Ears Pass on the Routt National Forest. The information obtained during the course of the studies was used extensively in control work that was begun in 1950 and continued through 1952.

This circular contains the complete information on the results of these studies, including the work on chemical control reported by Massey, Chisholm, and Wygant (*3*).

DISTRIBUTION

The Engelmann spruce beetle probably occurs over the entire range of Engelmann spruce. It has been collected from northern British Columbia and Alberta to southern Arizona and New Mexico, and from the Siskiyou Mountains of Oregon to the Black Hills of South Dakota. Its probable distribution is illustrated in figure 2.

HOSTS

The hosts of the Engelmann spruce beetle are Engelmann spruce (*Picea engelmannii* Parry), blue spruce (*P. pungens* Englm.), white spruce (*P. glauca* (Moench.) Voss), and lodgepole pine (*Pinus contorta* Dougl.). As the name implies, its chief host is Engelmann spruce. Although the beetle will attack blue spruce, this tree, growing as it does along streams and in very small stands, does not lend

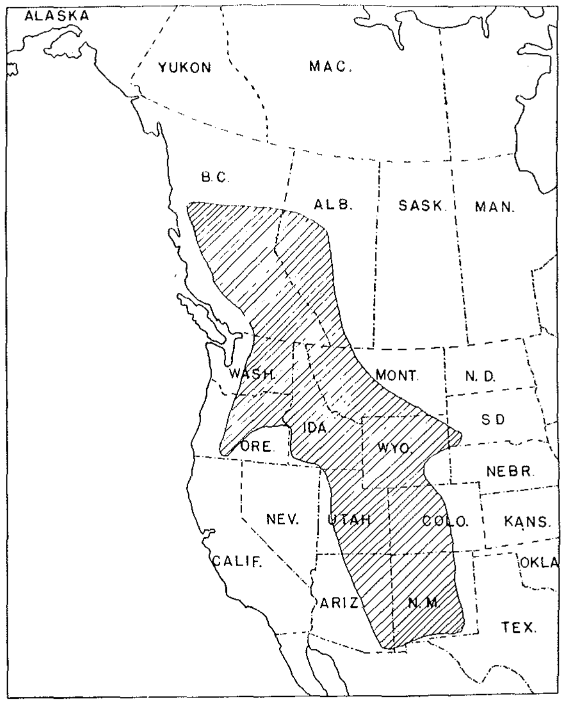

FIGURE 2.—Distribution of the Engelmann spruce beetle in western North America.

itself to extensive infestations. In mixed stands of Engelmann spruce and lodgepole pine and under epidemic conditions, the latter species is attacked extensively by the insect. Large numbers of the adults may enter trees of this species, but the galleries they make are not typical and few, if any, broods are produced.

DESCRIPTION OF STAGES

The life stages of the Engelmann spruce beetle are shown in figure 3.

The eggs of the Engelmann spruce beetle are oblong, pearly white, and shine when exposed to the light. They are 0.75–1 mm. long.

The larva is a stout, cylindrical, legless grub. The body is covered with many transverse folds and wrinkles. When full grown it is 6–7 mm. long.

The pupa is creamy white. The wings, legs, and antennae of the adult are visible through the pupal skin, and when nearly mature the light-brown color of the callow adult becomes apparent.

Hopkins (*1, p. 130*) described the adult insect as follows:

Female: Length 6.2 mm., black. Head with front convex, faint median and posterior impression and faint anterior line. Elytral declivity with striae not deeply impressed; punctures of pronotum distinctly irregular; posterior half of pro-episternal area not punctured; punctures of prothorax and elytra rather coarse; striae moderately impressed; interspaces moderately convex and

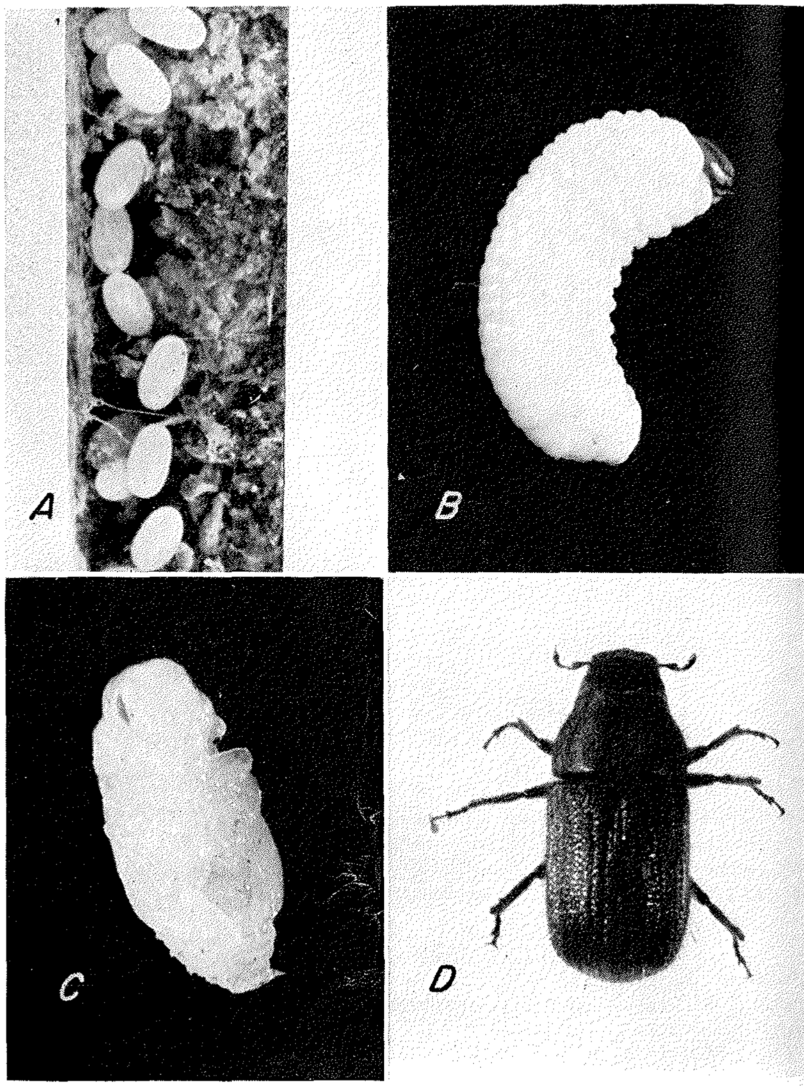

FIGURE 3.—Engelmann spruce beetle: *A*, Eggs; *B*, larva; *C*, pupa; *D*, adult. Eggs ×10; others ×7.5.

scarcely rugose except on dorsal area. Secondary sexual characteristics. Declivity convex; striae rather distinctly but not deeply impressed; punctures distinct; interspaces with rows of granules. Male: Length 5.5 mm. Front without anterior line. Elytra with striae less distinctly impressed and interspaces less convex than in female. Declivity convex with striae and strial punctures obscure; interspaces flat, shining, finely but distinctly punctured and without granules except on vertex.

Variations: The length varies from 5 to 7 mm. with the average at about 6.5 mm. The color ranges from uniform light to dark red and black, to black head, thorax, and abdomen, and red elytra. The sculpture and vestiture of the epistoma vary as usual, with the greatest variation in size, color, and punctures.

TAXONOMIC RELATIONSHIPS

The Engelmann spruce beetle is closely related to the eastern spruce beetle (*Dendroctonus piceaperda* Hopk.), the Alaska spruce beetle (*D. borealis* Hopk.), and the Sitka spruce beetle (*D. obesus* (Mann.)). Their taxonomic differences are in the characteristics of the pronotum and the sculpture of the elytra. All beetles are about the same size. Differences are hardly perceptible when single specimens are compared; it is only when large groups of each species are examined that they can be noted.

METHODS OF STUDY

General observations were made on the various phases of the life history from 1944 through 1951. In addition, special studies were conducted on the biology and control of the beetle.

To determine the period of emergence and its duration, and to obtain information as to the parasites, predators, and associates of the Engelmann spruce beetle, cages were placed on trees infested the previous year and also on trees immediately after attack (fig. 4). Collections were made from all cages once a week during the summer months.

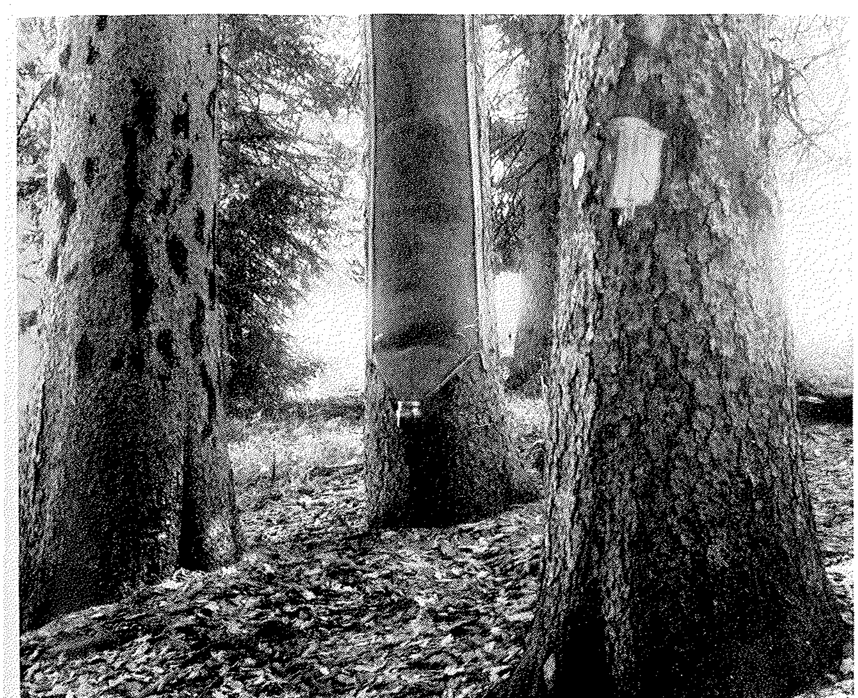

FIGURE 4.—Tree cages used in studies on the life history and habits of the Engelmann spruce beetle.

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To determine the period of attack, sample plots were established in various parts of the spruce study area. The plots were cruised weekly; each newly attacked tree was blazed and numbered, and its diameter at breast height and height were recorded.

To ascertain the rate of brood development, individual galleries were opened at weekly intervals on a given number of trees, from the time they were attacked until the end of the developmental season. Air temperatures at breast height were recorded on a thermograph in the study area.

To determine the effectiveness of DDT and BHC emulsions on the broods treated infested logs together with green uninfested logs were covered with box cages, the green logs acting as attractants to emerging beetles (fig. 5).

Insecticide studies were made in the laboratory and in the field. In the laboratory, infested log sections were treated with various chemicals. In the field, chemicals were applied to standing trees and log sections. Applications in the laboratory were made with a tank-type pressure sprayer equipped with a pressure valve to regulate the rate of application. The nozzle used delivered a fine fan-shaped spray. The log sections were revolved on a turntable while being sprayed. In the field applications were made with similar equipment, although most of the sprayers were equipped with a No. 6 solid-

FIGURE 5.—Cages used in control studies on the Engelmann spruce beetle.

stream nozzle. In all treatments the insecticides were applied until they started to drip from the treated surface.

The log sections and trees were sampled for mortality usually 2 to 3 weeks after the insecticide was applied. All dead and live insects were counted in the sample area, which was either 1/4 or 1/2 square foot.

LIFE HISTORY

Attack Period

In 1944, 1945, and 1946 the dates on which the first attacks occurred varied 3 to 6 weeks and the last attacks 3 days to 2 weeks, as shown in table 1.

TABLE 1.—*Number of trees attacked by Engelmann spruce beetles, on the White River National Forest, on different dates, 1944–46*

Date of examination	Plot 1	Plot 2	Plot 3[1]	Total	Date of examination	Plot 1	Plot 2	Plot 3[1]	Total
1944					*1945*—Con.				
July 4	4	0	------	4	July 30	8	32	5	45
12	3	10	------	13	Aug. 6	3	4	0	7
18	3	19	------	22	13	2	0	0	2
28	1	3	51	55					
Aug. 2	0	13	19	32	*1946*				
8	0	0	0	0	June 26	12	44	34	[2] 90
22	0	0	0	0	July 3	34	11	59	104
					9	31	8	33	72
1945					16	12	3	27	42
July 10	0	11	0	11	24	2	1	3	6
16	3	35	8	46	30	5	1	0	6
23	7	37	12	56					

[1] Established on July 28, 1944. Attacks recorded on that date could have occurred before that time.

[2] Trees attacked over 3-week period.

Seasonal temperatures vary tremendously at the elevations where Engelmann spruce grows. The early attack in 1946 can be attributed to the early spring in the area; in that season the snow had gone by June 1. In 1944 and 1945 snow was present in drifts as deep as 3 feet on July 1.

Emergence of New and Hibernating Adults

To determine the time of emergence of adult beetles, parts of several trees in the infested area were caged. The cages consisted of No. 16 mesh screening and varied in size from 2 feet long by 1 foot wide to 10 feet long by 1½ feet wide. Strips of bark approximately 2 inches wide were peeled from the tree, and the edges of the wire were fastened against the wood with box strapping and lathing (fig. 4). The lower edge of the screening was funnel-shaped, opening into a pint Mason jar.

Cages were placed on trees attacked in 1944 and 1945. A total of 24 cages were attached, covering 186 square feet of bark. Emergence of adult beetles in these cages was recorded for 2 years on the trees attacked in 1944 and 1 year on those attacked in 1945 (table 2).

TABLE 2.—*Number of Engelmann spruce beetles emerging in cages on trees attacked in 1944 and 1945, White River National Forest*

Date of collection	From 1944 attack		From 1945 attack—1946	Total
	1945	1946		
June 19		2,742		2,742
June 26		905		905
July 3		1,417		1,417
July 9		981		981
July 16	29	117		146
July 24	37	38	201	276
July 30	20	10	583	613
Aug. 6	65	17	856	938
Aug. 13	97	18	753	868
Aug. 20	284	31	723	1,038
Aug. 28	522	8	183	713
Sept. 4	455	5	357	817
Sept. 10	1,283	39	368	1,690
Sept. 17	1,319	8	619	1,946
Sept. 25	592	18	204	814
Sept. 28	187			187
Oct. 19	907			907
Total	5,797	6,354	4,847	16,998

Emergence of the beetles takes place in two distinct periods, in June and July and in August and September.

Many of the beetles that emerge during August and September, instead of attacking green trees in the surrounding area, go to the bases of the trees where they overwinter (fig. 6).[2] They re-emerge in June and July. The Engelmann spruce beetle appears to be the only species of *Dendroctonus* that goes into hibernation.

Early observations seemed to indicate that the insects hibernate in the same tree in which they develop. As a check on these observations, the bark of several infested trees was peeled from the ground line to a height of 3 feet on the bole, and also from the root crown down to the mineral soil. Hibernating beetles gathered in large numbers above the stripped area (fig. 7). Further checks were made by cutting several trees attacked in 1944 before emergence began in 1945. When the stumps of these trees were examined late in September, only a few hibernating beetles were found. Subsequent observations showed that an adult, upon emerging, crawls or falls to the base of the tree and either forms a feeding gallery or enters a hole to a feeding gallery made by another hibernating adult (fig. 8).

[2] This habit was first determined by G. R. Struble on the Grand Mesa National Forest in 1944.

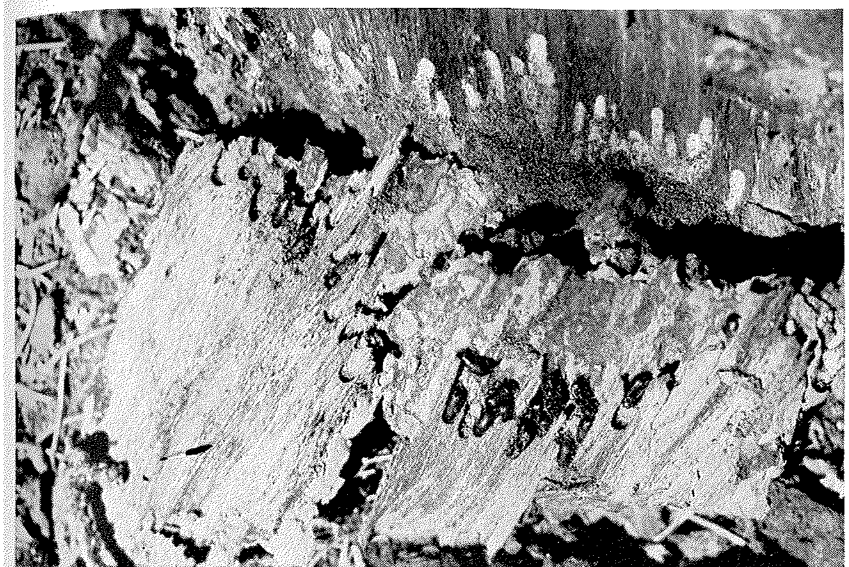

FIGURE 6.—Hibernating adults of the Engelmann spruce beetle in bark peeled from the base of an infested tree.

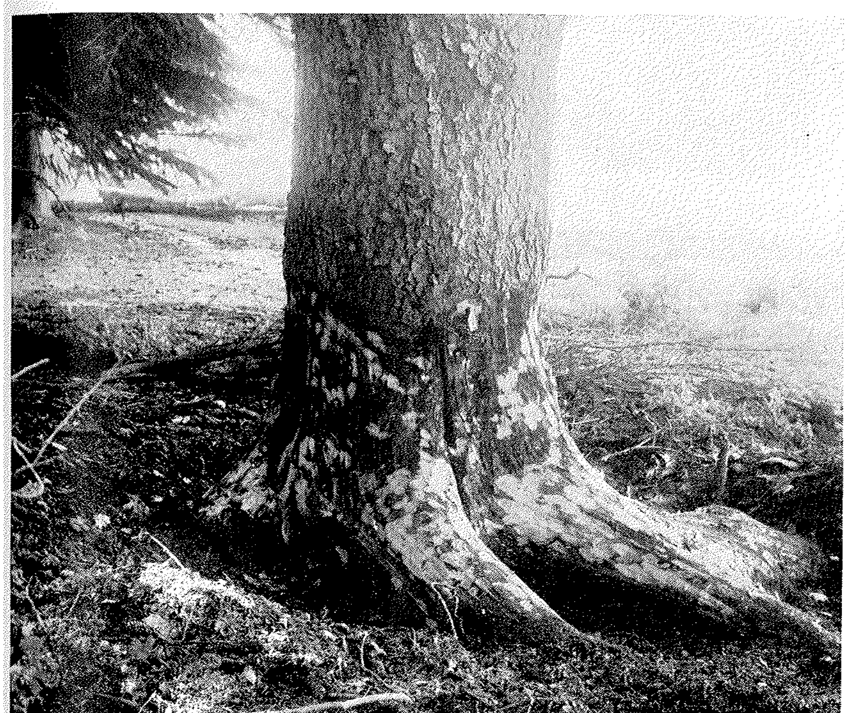

FIGURE 7.—Base of Engelmann spruce tree from which bark was stripped to force the beetles to hibernate in the upper part of the stem.

FIGURE 8.—Galleries of hibernating Engelmann spruce beetles in the base of infested tree. Feeding galleries radiate from a single entrance hole.

To determine the number of adults that hibernate in a given area of bark and the number that use the same entrance hole, two pieces of bark, each covering ½ square foot, were taken at the root crown of several infested trees, and the beetles and entrance holes were counted. A maximum of 305 beetles were taken from a square foot of bark; the average was 200. Approximately 14 beetles used the same entrance hole.

Beetles that pass their first winter as larvae go through the second winter as adults. Hibernation in the base is not habitual, even with beetles that require 2 years to complete their life history. About half the beetles in a given tree pass the second winter in the spot where they became adults.

To determine whether beetles must pass one winter in the adult stage before they attain sexual maturity, adult beetles that had recently emerged and those that had hibernated for one winter were caged separately with green logs. Only a few attacks were found on the logs caged with newly emerged adults, but many were found on the logs caged with hibernating adults.

Emergence of the beetles to hiberate in the base begins about the latter part of July and extends through September. In 1944 the peak of this emergence occurred the last week in August, and in 1945 the second week in September. In 1946 there were two peaks of emergence, the first week in August and the second week in September. However, emergence from most of the trees attacked in 1945 and caged in 1946 was not completed until July of 1947.

At low elevations and on warm sites, the Engelmann spruce beetles may complete their life cycle in 1 year. However, they usually go into the winter as new adults and re-emerge to attack the following June and July. Table 3 shows the 1947 emergence of beetles that completed their life cycle in 1 year on trees attacked in 1946.

TABLE 3.—*Number of Engelmann spruce beetles collected in 1947 in cages on trees attacked in 1946, White River National Forest*

Date collected	Cage 1	Cage 2	Total	Date collected	Cage 1	Cage 2	Total
June 21	149	29	178	Aug. 8	6	11	17
July 3	64	7	71	15	3	14	17
10	115	62	187	22	5	23	28
17	239	256	495	29	10	15	25
24	121	124	245	Sept. 5	6	34	40
31	32	43	75				

Emergence was at a peak during the middle 2 weeks of July. It was during the same period that the peak of attack occurred in the field.

Field studies also show that emergence may continue as long as 3 years after the initial attack. A few beetles emerged in June and July of 1947 from trees attacked in 1944.

Cages were placed over 145 square feet of bark surface on 15 infested trees. After the enclosed broods had matured and emerged, the cages were removed and counts made of the number of brood galleries and the total number of beetles that had emerged. Records were also obtained of the total number of holes present in the caged area of bark, including those made by both the parent beetles and the ensuing brood. The data revealed that from each successful attack (one producing a brood) 18 beetles had emerged and that an average of 7 beetles had emerged from a single hole (table 4).

Parent Adult Emergence

Experiments were conducted on the White River National Forest to determine the number of adults that re-emerge the same season that they attack. In 1944 a total of 12 square feet of bark on six trees was caged in the same manner as for the emergence studies. The trees were infested at the rate of seven successful attacks per square foot. The cages were 2 feet long and 1 foot wide. The adults that re-emerged into the cages were collected at weekly intervals. A total of 166 was collected that year, as follows:

Tree No.:	*Males*	*Females*
1	7	5
2	15	24
3	15	18
4	11	16
5	13	18
6	7	17
Total	68	98

On the basis of two beetles per attack, the number of re-emerging adults approached 100 percent, of which 59 percent were females.

To determine if the re-emerging adults would re-attack, an experiment was carried on in 1945 in which three recently attacked logs were placed in box-type cages with three green logs. The logs were located at an elevation approximately 2,000 feet lower than the area of infestation, where developmental temperatures prevail for a longer period. Although a large percentage of the adults emerged, all did not immediately re-attack; many hibernated and attacked in June or July of the following year. A total of 163 adults hibernated in the bases of the infested logs, 61 hibernated in the bases of the green logs, 40 remained in egg galleries in the infested logs, and 60 were in egg galleries in the green logs. Forty-six egg galleries were made in the green logs. Therefore, on the basis of 2 beetles per gal-

TABLE 4.—*Parent galleries and emergence of progeny of Engelmann spruce beetles from cages on trees on the White River National Forest*

Cage	Beetles	Parent galleries		Progeny emergence	
		Number	Beetles per gallery	Number of holes	Beetles per hole
	Number		*Number*		*Number*
A	1,194	72	16.5	128	9.3
B	1,628	56	29.7	247	6.6
C	1,078	45	24.0	112	9.6
D	509	32	15.9	189	2.7
E	920	32	28.8	198	4.6
F	920	43	21.4	103	8.9
G	848	27	31.4	226	3.7
H	1,754	78	22.5	143	12.3
I	851	49	17.4	76	11.2
J	623	81	7.7	129	4.8
K	294	71	4.1	165	1.8
L	819	68	12.0	116	7.1
M	1,338	101	13.2	149	9.0
N	1,673	31	54.0	115	14.6
KL upper	125	42	3.0	30	4.2
KL lower	498	30	16.6	23	21.6

lery, 32 of the beetles had re-emerged a second time to attack. Whether this would have resulted if the experiments had been conducted at the elevation of the original area of attack is not known. However, it is reasonable to assume that a smaller percentage would have re-attacked the same year because of the differences in temperatures at the two elevations. The results of this experiment suggest that the life span of this insect may be 3 years or longer.

DESCRIPTION OF GALLERIES AND CHARACTERISTICS OF INFESTED TREES

When the Engelmann spruce beetle enters the tree, it constructs an egg gallery in the bole (fig. 9), mostly in phloem, but the gallery grooves the wood slightly. It is short and wide and usually extends up the bole. There is a small crook at the base of the gallery, turning either to the right or to the left; at times it is nearly absent. The base of the gallery is usually filled with pitch mixed with boring dust. As the beetles extend their tunnels, they make ventilation holes through the bark. At various intervals along the galleries they also construct niches about the length of their body into the wood, into opposite sides of the gallery, or out into the bark. It is in these niches that the beetles turn around. A characteristic Y occurs at the end of many of the galleries. Eggs are not laid in the arms of the Y. Possibly the male beetle makes one arm and the female the other. Of 218 galleries measured at various heights on 11 trees, the maximum length was 9 inches, the mean 5 inches, and the minimum 2.5 inches.

In 1944 the number of galleries made in 1 square foot of bark surface ranged from 0 to 24, with an average of 6. Between heights of 1 to 15 feet and 16 to 30 feet there were 8 and 5 per square foot, respectively. The greatest number occurred on the first 5 feet of the bole with numbers diminishing progressively up the stem. In 1946 an average of 9 galleries were made per square foot. This increase may be attributed to a general increase in the population.

Trees infested by the Engelmann spruce beetle are often difficult to detect. The needles turn a greenish yellow and fall after about a year. The characteristic red-top effect of pines infested with other species of *Dendroctonus* is absent. At times needles may remain green until the fall of the second year. Unless the trees build up a considerable resistance to the beetles, few or no pitch tubes are present.

Infested trees usually have red boring dust around their bases. At times, however, the dust is not noticeable and the bole must be examined for emergence or ventilation holes.

The Engelmann spruce beetle prefers the large, more mature trees as host material. As the large trees become depleted and as the beetle population becomes excessively abundant, the insects progressively attack the smaller diameter classes until trees as small as 2 inches diameter at breast height are infested. This was clearly shown in 1946 in a survey of trees killed prior to that year on the White River National Forest. Of the trees 36 to 38 inches in diameter 75 percent had been killed by 1943. The average diameter of the

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FIGURE 9.—Egg galleries of the Engelmann spruce beetle.

trees killed in 1940–44 was 21 inches; of those killed in 1945 and 1946, it was 17 and 15 inches; and of those still living at the end of 1946 it was 13.5 inches.

Trees successfully attacked by the beetle were infested to an average height of 33 feet. The maximum height on 100 trees was 56 feet, the minimum, 16 feet. The average noninfested length above the highest point of infestation was 54 feet, with a maximum of 85 feet and a minimum of 24 feet. The average diameter of the trees at the highest point of infestation was 19 inches.

The height to which trees were infested on the White River National Forest varied directly with the increase in diameter at breast height. On trees with average diameters of 16 to 20 inches, 21 to 24 inches, 25 to 28 inches, and 29 to 32 inches, the respective heights of infestation were 28, 31, 35, and 39 feet.

Studies made on the Routt National Forest revealed that the height of infestation on trees in the smaller diameter classes followed the same general pattern (table 5).

TABLE 5.—*Height of Engelmann spruce beetle infestation in trees in various diameter classes, Routt National Forest*

Diameter class (inches)	Samples	Height of infestation
	Number	*Feet*
4 to 6	5	14
6 to 8	15	13
8 to 10	30	18
10 to 12	31	26
12 to 14	20	24
14 to 16	14	29
16 to 18	7	34

A characteristic blue stain is found in all trees infested by the Engelmann spruce beetle. It is a light grayish blue and is slow in developing. The ends of infested logs develop a fuzzy appearance caused by the protrusion of the mycelia of the staining fungus. This growth differs considerably in color from the regular blue staining of the wood in that it is almost black. When growth is heavy, it may have a downy appearance much the same as mildew.

Isolations from samples of the wood and bark yielded pure cultures of *Leptographium* sp.[3] From preliminary isolations it was concluded that the Engelmann spruce beetle has an associated blue-stain fungus similar to the fungus associated with the eastern spruce beetle.

DEVELOPMENT OF THE BROOD

Eggs

The eggs are laid at the sides of the galleries in groups arranged in alternate rows from side to side. The number of groups per gallery usually varies with the length of the gallery; most of them have 3 to 4 rows, although galleries with 2 and 5 rows are common. The average length of the egg group, on the basis of 134 measurements, was 1.4 inches. The maximum length was 3.3 inches, and the minimum 0.5 inch.

Eggs were counted in 136 galleries, which totaled 668 inches in length. The maximum number of eggs was 144, found in a gallery that was 6.1 inches long. The average number of eggs per inch of

[3] Made by Ross Davidson, Division of Forest Pathology, Bureau of Plant Industry, Soils, and Agricultural Engineering.

gallery length was 20.5. In arriving at this figure, 1 inch was subtracted from the total length of each gallery to compensate for the lower portion of the crook, in which no eggs were laid. From 3 to 4 weeks are necessary for the eggs to hatch.

Larvae

Upon hatching, the larvae feed in groups at right angles to the egg gallery until they are approximately one-third grown. They then form separate feeding galleries, which more or less wind throughout the phloem (fig. 10).

FIGURE 10.—Egg and larval galleries of the Engelmann spruce beetle in bark of infested tree.

The rate of larval development is dependent upon various interrelated factors. Southern exposures are warmer than northern exposures and, as a result, larvae infesting the south side of trees develop most rapidly. Time of attack also affects the rate of development. Larvae in trees infested early in June are usually full grown by September 1. By October many of them have developed into pupae and callow adults.

Seasonal temperatures are also important. During the summer of 1945 temperatures generally were subnormal, so that many larvae entered the winter one-third to two-thirds grown. The year 1946 was characterized by an early spring, and summer temperatures were about normal. As a result, many larvae developed into pupae and callow adults by the middle of September.

Trees infested with the Engelmann spruce beetle contain many more larvae per square foot than trees infested with other species of *Dendroctonus*. In 1944 populations ranged from 66 to 542 per square foot and averaged 316. Brood was most abundant in the lower 5 feet and least abundant in the upper 5 feet of infested bark. The average brood per square foot ranged from 361 in the first 5 feet to 215 in the last 5 feet of the infested stem. The great number of larvae in the lower portion of the tree is a direct result of the large number of egg galleries in that area. This occurred despite the fact that more larvae per gallery were found in the upper portion of the stem. The lower 15 feet of the stem had an average of 7.6 galleries per square foot and an average of 45.3 larvae per gallery. There were only 4.8 galleries per square foot at heights from 16 to 30 feet; however, they contained 61.5 larvae per gallery.

Population counts made in 1946 showed nearly the same number of larvae as in 1944—the mean numbers per square foot being 309 and 316, respectively.

Populations per square foot varied with the diameter of the trees, ranging from 236 larvae per square foot in trees 12 to 16 inches in diameter at breast height (d. b. h.) to 361 in trees 22 to 26 inches d. b. h.

Pupae

Full-grown larvae construct cells in which to pupate. Many of them are formed entirely within the bark; others, between the bark and the wood (fig. 11).

The time required by pupae to develop into callow adults is dependent upon the temperatures during pupation. Late in the spring and in the summer months, 10 to 15 days are required for the transformation into adults. However, if the insects enter the winter in the pupal stage, several months may be required. Some individuals go into the winter as pupae and transform into adults by the following spring.

NATURAL MORTALITY

Emergence records from 110 square feet of bark surface indicate that approximately 75 percent of the brood dies—half of them after the larvae are half grown and before the adults emerge. This mortality figure was obtained by comparing the average number of such

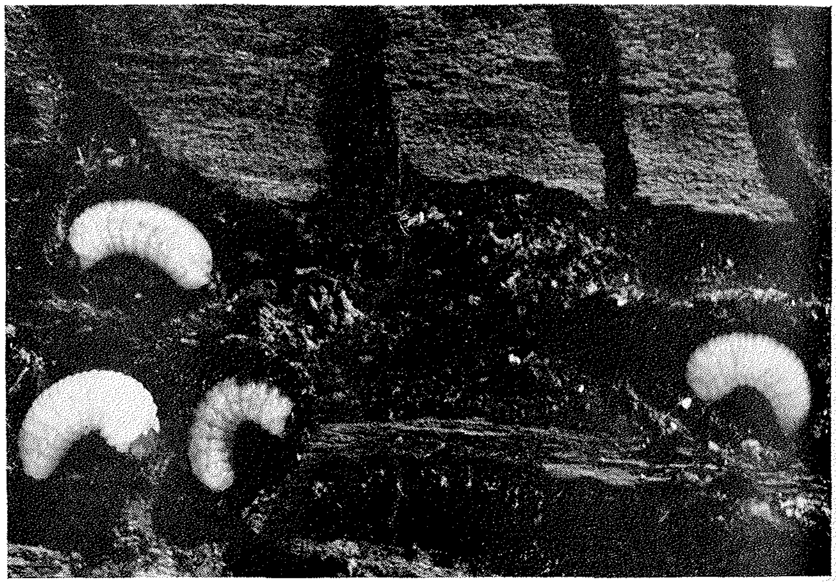

FIGURE 11.—Pupal cells formed in the bark by mature larvae of the Engelmann spruce beetle.

larvae per square foot (316) with the number of emerging adults (150). The heavy mortality may have been due to parasites, predators, and low temperatures.

PREDATORS AND PARASITES

Woodpeckers

Woodpeckers are the most important predators of the Engelmann spruce beetle. In some areas they have destroyed as much as 75 percent of the beetle population.

Three species are abundant in infestations in Colorado—the Alpine three-toed, the Rocky Mountain hairy, and the downy. The hairy and the three-toed, in pairs, work over trees infested with the Engelmann spruce beetle—at least during the summer months. Each pair confines its activities to a small area of an infested stand. In fact, one pair worked a group of only 7 or 8 trees for several weeks. Many trees are completely stripped of bark by the birds and the mortality of the brood in these trees approaches 100 percent (fig. 12). In trees moderately worked by woodpeckers there was a large reduction in beetle populations. This is due partly to feeding of the birds and partly to the drying of the bark. Population counts were made on numerous trees on which woodpecker work varied from slight to heavy (table 6).

The data indicate that a slight amount of woodpecker work reduced the population by nearly half, but in trees heavily worked by the birds the beetles were almost completely destroyed.

FIGURE 12.—Tree from which the bark has been stripped by woodpeckers to feed upon the larvae of the Engelmann spruce beetle.

During the summer of 1947 a study was initiated on the White River National Forest and on the Grand Mesa National Forest to determine the food habits of the birds.[4] A total of 135 woodpeckers and sapsuckers were collected. The stomachs were removed and preserved in formaldehyde. They were then examined in the laboratory for food content.

To determine also whether the birds fly from one area to another during a day's feeding, individuals were collected in areas heavily

[4] Acknowledgment is made to Johnson A. Neff, of the United States Fish and Wildlife Service, for assistance in the formation of the woodpecker study.

TABLE 6.—*Reduction in Engelmann spruce beetles caused by the feeding of woodpeckers*

Woodpecker feeding	Samples	Adults per square foot	Reduction
	Number	*Number*	*Percent*
None	37	162	0
Slight	10	90	44
Moderate	38	41	75
Heavy	20	4	98

infested with bark beetles, in areas only slightly infested, and in areas containing no Engelmann spruce beetles. The collections were made in a small part of the forest area. Only a few birds were collected where there were no spruce beetles, although the birds were numerous in slightly infested areas, and abundant in heavily infested areas.

The presence of the beetles in the stomach contents of the birds decreased sharply when feeding occurred outside heavily infested areas. Only a few were taken from birds collected in the slightly infested areas and none from those collected where no infestation was known. For the most part the food content consisted of other wood-infesting insects, such as carpenter ants and larvae of the Cerambycidae.

During the summer months the birds consumed more adults than other stages of the beetle. A total of 2,387 adults were taken from the stomachs of 115 birds collected from July through the middle of September, or an average of 20.70 beetles per stomach. The stomachs also contained a total of 498 larvae that were definitely known to be those of the Engelmann spruce beetle, or an average of 4.33 per stomach.

The number of adult beetles consumed per month by the birds varied considerably. In July the collections averaged 11.82 beetles per stomach; in August 29.11, and in September 13.15. The same variation existed as to the number of larvae consumed; in July, there were 2.57 larvae per stomach, in August 1.35, and in September 12.42. The cause of this variation probably lies in the fact that adult beetles are more readily obtainable during the early and middle part of August, when the beetles leave the bole to enter hibernation in the bases of the trees. Large numbers congregate in very small areas during this period. The larvae are more readily obtainable in September, as they feed close to the surface of the outer bark.

All three woodpecker species are effective predators of the Engelmann spruce beetle. The average number of insects per stomach of the Rocky Mountain hairy was 27.68; in the downy it was 26.89, and in the three-toed 21.39. The males of all species destroyed more beetles than the females, averaging 23.04 adults per stomach for males and 16.40 for females.

Of the insects found in the stomach contents of the woodpeckers, 65 percent were *Dendroctonus engelmanni*, 13 percent were other Scolytidae, 12 percent were Formicidae, and 6 percent were Cerambycidae.

Red-shafted flickers are plentiful in areas infested with the Engelmann spruce beetle, but their value as a predator of this insect is questionable. Fourteen of these birds were collected, but there was no sign that any of them had fed on Scolytidae; the food content of their stomachs consisted only of ants. Williamson's sapsucker and the red-naped sapsucker are seen infrequently in the areas infested with the beetle, and are unimportant as predators.

A list of the insects contained in the woodpeckers' stomachs follows. All were adults unless otherwise specified. The determinations of the Scolytidae are as accurate as the circumstances permitted; many of them were in the last stages of digestion. Some determinations were made on the bases of the insect species known to be in the area.

Insects Eaten by Woodpeckers:	*Number*
HEMIPTERA	13
HOMOPTERA: Aphidae	82
COLEOPTERA:	
Carabidae	1
Cleridae—	
Adults	8
Larvae	9
Ostomidae—Larvae	15
Nitidulidae—*Epuraea* sp	1
Cerambycidae—	
Tetropium (larvae)	202
Undetermined larvae	39
Scolytidae—	
Scolytus piceae (Sw.)	10
Polygraphus rufipennis (Kby.)	33
Dendroctonus engelmanni Hopk.—	
Adults	2, 387
Larvae	499
Scierus annectens Lec	14
Trypodendron (*bivittatum* (Kby.)) sp	2
Pityophthorus sp	46
Ips borealis Sw.	213
Ips pilifrons Sw.—	
Adults	43
Larvae	59
Dryocoetes affaber (Mann.)	1
Dryocoetes sp	2
Undetermined—larvae	167
Undetermined coleopterous larvae	12
LEPIDOPTERA	17
DIPTERA: Undetermined—	
Adults	15
Larvae	1
HYMENOPTERA:	
Formicidae—	
Camponotus sp	277
Lasius sp	264
Undetermined parasites	2
ARACHNIDA: Spiders	8

Entomophagous Insects [5]

Several species of insect parasites and predators have been reared from collections made on caged trees infested with the Engelmann spruce beetle. Studies indicate that these insects are responsible for about 50 percent of the brood mortality.

Hymenopterous Parasites

Braconidae.—*Coeloides dendroctoni* Cush. is the most important parasite of the Engelmann spruce beetle. The larva is an external parasite of the spruce beetle larva. However, its effectiveness is limited by the bark thickness of trees containing its host. Parasitization is more extensive in thin-barked than in thick-barked trees, and also in trees on which the bark has been thinned by woodpeckers.

Pteromalidae.—*Cecidostiba burkei* Cwfd. is collected abundantly in areas infested with the beetle. Its oviposition habits are similar to those of *Coeloides dendroctoni.* As far as is known, it is parasitic only on the larvae of the beetle. It may also be parasitic on some of the insects associated with the spruce beetle. *Roptrocerus eccoptogastri* (Ratz.) is collected in the same approximate numbers as *C. burkei.* The oviposition habits of the two species are similar.

Dipterous Predators

Dolichopodidae.—*Medetera alrichii* Wheeler is second in importance only to *Coeloides dendroctoni* in its effect on the Engelmann spruce beetle. However, its value is lessened somewhat by its indiscriminate feeding habits. The larvae feed on all insects associated with the beetle, some of which may be important predators. The eggs of this fly are laid in the egg galleries of the beetle, and the larvae feed on all developing forms of insects with which they come in contact.

Rhagionidae.—*Erinna abdominalis Loew.* (*E. fasciata* (Walk.)) preys on the immature forms of the beetle. It lays its eggs in the egg galleries of the host by backing into parent emergence holes, with the head and wings protruding.

Stratiomyidae.—*Zabrachia polita* Coq. has oviposition habits similar to those of the rhagionids, except that the entire insect enters an emergence hole.

Lonchaeidae.—*Lonchaea coloradensis* Mall. and *Lonchaea* sp. near *corticis* Taylor have oviposition habits similar to those of *Zabrachia polita.*

Coleopterous Predators

Cleridae.—Adults of *Thanasimus nigriventris* Lec. prey upon the adults of the spruce beetle, and the larvae upon its immature forms.

[5] The following members of the Division of Insect Identification determined most of the species: Hymenoptera, C. F. W. Muesebeck, H. K. Townes, and A. B. Gahan; Coleoptera, W. S. Fisher, L. L. Buchanan, H. S. Barber, B. E. Rees, E. A. Chapin, R. E. Blackwelder, and A. G. Boving; for Scolytidae, W. H. Anderson; for Formicidae, M. R. Smith; for Diptera, Alan Stone, C. T. Green, C. W. Sabrosky, and M. T. James; for Hemiptera, R. I. Sailer; and for Arachnida, H. H. Swift and E. A. MacGregor.

Carabidae.—Two species belonging to this family, *Pristodactyla advena* Lec. and *scolopax* Csy., were taken from caged trees. Little is known of their habits or predaceous characteristics.

Rhizophagidae.—*Rhizophagus dimidiatus* (Mann.) is more abundantly associated with the Engelmann spruce beetle than any other coleopteron. While little is known of its habits, close relatives of this species are known to be predaceous at times. They are thought to feed upon fungal growth.

LOW TEMPERATURES

From time to time low temperatures have killed large numbers of bark beetles in the Rocky Mountains. Unusually low temperatures in the fall or early winter months, before the insects have developed a cold-hardiness, have been known to wipe out entire infestations of beetles.

To determine the cold-hardiness of the Engelmann spruce beetle, tests were conducted in a temperature cabinet in the laboratory. Slabs of logs infested with larvae were stored in the field until tests were made. Adults were stored in frass in petri dishes. They were then brought into the laboratory and subjected to temperatures ranging from +6° to −30° F. Infested slabs and petri dishes of adults were removed from the cabinet at 5° intervals as the temperature was depressed in the cabinet. Three tests were made, in January and April 1945 and in March 1946. The results, summarized in table 7, show that −15° will kill nearly all the adults, but that −30° is required to kill all the larvae. The temperatures recorded in the tables were subcortical in the larval tests; in the adult tests, they were recorded in petri dishes.

Temperatures were extremely low over the entire State of Colorado in January and February of 1951, killing approximately 75 percent of the overwintering larvae. This kill aided tremendously in bringing the Colorado infestation under control. Temperatures as low as −56° F. were recorded. However, hibernating adults protected by snow cover were not affected by these low temperatures.

ASSOCIATED INSECTS

Several species of Scolytidae are found in trees attacked by the Engelmann spruce beetle. Most of them infest trees only after the trees have been attacked by the Engelmann spruce beetle.

Ips pilifrons Sw. occurs mostly in the tops of trees killed by *Dendroctonus engelmanni* and *Ips borealis* Sw. in the tops and larger limbs. Broods of the two species of *Ips* are often found intermixed.

Scierus annectens Lec. seems to congregate around the entrance holes of *D. engelmanni*, its galleries running laterally for a short distance from this point, then turning in a general upward direction. The galleries occur in the phloem. This species is not known to be aggressive in nature.

Trypodendron sp. near *bivittatum* (Kby.) is widespread throughout the infestation of the Engelmann spruce beetle in Colorado. Shot

TABLE 7.—*Effect of low temperatures in laboratory tests on adults and larvae of the Engelmann spruce beetle*

Month of test and temperature (° F.)	Adults		Larvae	
	Number	Percent mortality	Number	Percent mortality
January 1945:				
5	100	22		
0	107	37		
−5	98	50		
−10	101	82		
−15	94	94	109	13
−20	100	98	103	14
−25	100	100	130	54
−30			153	100
Check group	149	0	109	6
April 1945:				
6	100	6		
1	103	14		
−5	100	20	100	0
−11	107	92	54	4
−15	104	100	79	3
−20			118	41
−25			118	92
−30			36	97
−31			85	100
Check group	100	2		
March 1946:				
0	106	19		
−5	100	35		
−10	101	62		
−15	109	91		
−20	100	96		
Check group	100	13		

holes made by this ambrosia beetle are present in the basal log of most trees killed by the spruce beetle. The species is important because it quickly infests green logs that are cut and allowed to lie in the woods. Its galleries penetrate the sapwood and reduce the grade of the lumber cut from the logs.

Scolytus piceae (Sw.) occurs in dead and dying limbs of spruce attacked by the spruce beetle. It also occurs in the shaded-out limbs of living trees throughout the area.

Pityophthorus spp. Several species of this genera occur in the bole and limbs of infested trees.

Numerous other insects have been collected from caged trees infested with the Engelmann spruce beetle. Little is known of their habits, their characteristics, or their effect on spruce beetle populations. Some of them may be important in controlling the spruce beetle. However, their effect on populations of this beetle is not known. Some of the insects listed may have been associated only through accident.

Insects Reared From Caged Trees

ACARINA:
- Tetranychidae
  - *Bryobia praetiosa* Koch
- Erythraeidae
  - *Belaustium* sp.
- Bdellidae
  - *Cyta* sp.

ARANEIDA:
- Gnaphosidae
  - *Orodrassus coloradensis* Em.
  - *Haplodrassus signifer* (C. Koch)
- Amaurobiidae
  - *Amaurobius* sp.
- Dictynidae
  - *Dictyna* sp.
- Linyphiidae
  - *Lephthyphantes* sp.

PLECOPTERA:
- Nemouridae
  - *Nemoura flexura* Clsn.
  - *Nemoura* sp.

HEMIPTERA:
- Anthocoridae
  - *Anthocori melanocerus* Reuter
  - *Anthocori* sp.
  - *Lyctocoris stalli* (Reuter)
  - *Lyctocoris* sp.
- Miridae
  - *Deraeocoris* spp.
  - *Orthotylus candidatus* Van Duzee
  - *Orthotylus* sp.
  - *Stenodema virens* (L.)
  - *Lygus pabulinus* (L.)
- Aradidae
  - *Aradus* sp. (adults and nymphs)
- Lygaeidae
  - *Eremocoris ferus* (Say)
  - *Eremocoris* n. sp.
  - *Nysius minutus* Uhler
  - *Nysius grandis* Baker

COLEOPTERA:
- Carabidae
  - *Pristodactyla advena* (Lec.)
  - *Pristodactyla scolopax* Csy.
- Leiodidae
  - *Agathidium* sp.
- Clambidae
  - *Calyptomerus oblongulus* (Mann.)
- Orthoperidae
  - *Sacium montanum* Csy.
  - *Sacium* sp.
- Staphylinidae
  - *Mycetoporus* sp.
  - *Quedius* sp.
  - *Omalium* sp.
  - *Anthobium* sp.
  - *Micropeplus laticollis* Mäkl.
  - *Phyllodrepa* sp.
- Pselaphidae
  - Euplectini (gen. sp. ?)

COLEOPTERA—Continued
- Ptiliidae
  - *Acratrichis* sp.
- Histeridae
  - *Isolomalus debilis* (Lec.)
- Cantharidae
  - *Podabrus* sp.
- Cleridae
  - *Thanasimus undatulus* (Say) (adult)
  - *Thanasimus nigriventris* Lec. (adults and larvae)
  - *Enoclerus* sp. possibly *moestus* Klug (larvae)
- Salpingidae
  - *Lacconotus* sp.
- Pyrochroidae
  - New genus n. sp.
- Dermestidae
  - *Perimegatoma* sp.
- Nitidulidae
  - *Epuraea* sp.
  - *Epuraea linearis* Mäkl.
- Rhizophagidae
  - *Rhizophagus dimidiatus* (Mann.)
- Cucujidae
  - *Pediacus depressus* (Hbst.)
  - *Cucujus clavipes* F.
  - *Laemophloeus* sp.
  - *Dendrophagus cygnaei* Mann.
- Cryptophagidae
  - *Cryptophagus* spp.
  - *Atomaria crassula* Csy.
  - *Anchicera ephippiata* Zimm.
- Colydiidae
  - *Lasconotus intricatus* Kraus
- Lathridiidae
  - *Lathridius* sp. near *minutus* (L.)
  - *Corticaria planula* Fall.
  - *Corticaria* sp.
  - *Melanophthalma* sp.
- Tenebrionidae
  - *Corticeus parallelus* Melsh.
  - *Corticeus* sp.
- Melandryidae
  - *Stenotrachelus aeneus* (F.)
- Scraptiidae
  - *Scraptia* sp.
- Ptinidae
  - *Ptinus* sp.
- Anobiidae
  - *Microbregma emarginata* (Duft)
- Cisidae
  - *Cis* sp.
  - *Xestocis moznetti* Dury
- Cerambycidae
  - *Tetropium parvulum* Casey
  - *Anoplodera* sp.
  - *Phymatodes dimidiatus* (Kby.)
  - *Pogonocherus penicillatus* Lec.
- Chrysomelidae
  - *Syneta* sp.
  - *Monoxia* sp.

COLEOPTERA—Continued
- Curculionidae
  - *Pissodes fiskei* Hopk. or near
  - *Cossonus* (*pacificus* V. D. or *rufipenis* Buch.)
  - *Rhyncolus brunneus* Mann.
  - *Rhyncolus knowltoni* (Thatcher)
- Scolytidae
  - *Scolytus piceae* (Sw.)
  - *Crypturgus borealis* Sw.
  - *Carphoborus* sp.
  - *Phloeotribus puberulus* Lec.
  - *Scierus annectens* Lec.
  - *Scierus pubescens* Sw.
  - *Hylastes gracilis* Lec.
  - *Xylechinus montanus* Blkm.
  - *Trypodendron* sp. near *bivittatum* (Kby.)
  - *Trypodendron* sp. near *borealis* Sw.
  - *Cryphalus* sp.
  - *Pityophthorus* sp. near *nitidulis* (Mann.)
  - *Pityophthorus opimus* Blkm.
  - *Pityophthorus pseudotsugae* Sw.
  - *Pityophthorus occidentalis* Blkm.
  - *Pityophthorus* sp. near *demissus* Blkm.
  - *Pityophthorus* sp. group VI
  - *Pityophthorus* sp.
  - *Ips borealis* Sw.
  - *Ips pilifrons* Sw.
  - *Orthotomicus lasiocarpa* Sw.
  - *Dryocoetes sechelti* Sw.
  - *Dryocoetes* sp. near *sechelti* Sw.
  - *Dryocoetes* sp. prob. *affaber* (Mann.)
  - *Dryocoetes confusus* Sw.

DIPTERA:
- Stratiomyidae
  - *Zabrachia polita* Coq.
  - *Pachygaster* sp.
- Bibionidae
  - *Bibio* sp. near *pingreensis* James
  - *Bibio xanthopus* Wied.
  - *Bibio flukei* Hardy
  - *Bibio holtii* McAtee
  - *Bibio knowltoni* Hardy
  - *Bibio* spp.
  - *Philia* sp.
- Erinnidae (Rhagionidae)
  - *Erinna abdominalis* Loew. (*E. fasciata* (Walk.))
- Dolichopodidae
  - *Medetera aldrichii* Wheeler
- Empididae
  - *Platypalpus* sp.
- Phoridae
  - *Megaselia* spp.
  - *Phora* sp.
- Drosophilidae
  - *Chymomyza* sp. probably *aldrichii* or new
  - *Drosophila funebris* (F.)
  - *Drosophila* probably *affinis* Sturt.

DIPTERA—Continued
- Drosophilidae—Continued
  - *Scaptomyza* sp.
- Scatopsidae
  - *Arthria analis* (Kirby)
- Fungivoridae
  - *Zelmira* sp.
- Chloropidae
  - *Madiza* spp. probably new
  - *Chlorops* sp.
- Muscidae
  - *Limnophora* sp.
  - *Pegomya cresca* Huck.
  - *Pegomya* sp. (*lipsia* Wlk.)
- Larvaevoridae
  - *Goliathocera setigera* (Thoms.)
- Lonchaeidae
  - *Lonchaea* sp. near *coloradensis* Mall.
  - *Lonchaea coloradensis* Mall.
  - *Lonchaea* sp. near *corticis* Taylor

HYMENOPTERA:
- Tenthredinidae
  - *Pikonema dimmockii* (Cr.)
  - *Pikonema alaskensis* (Roh.)
- Braconidae
  - *Spathius* sp.
  - *Coeloides dendroctoni* Cush.
  - *Cosmophorus* sp.
- Ichneumonidae
  - *Stenomacrus* sp.
  - *Eriplanus* sp.
  - New genus n. sp.
  - *Atractodes* sp.
  - *Aoplus* n. sp.
  - *Phaeogenes* n. sp.
  - *Phaeogenes* sp.
  - *Phaeogenes epinotiae* Cush.
  - *Pimplopterus* sp.
  - *Ichneumon* sp.
  - *Phygadeuon* sp.
  - *Neoxorides borealis* (Cr.)
  - *Orthocentrus* sp.
  - *Alegina* sp.
  - *Aptesis* sp.
- Calliceratidae
  - *Calliceras* sp.
- Pteromalidae
  - *Roptrocerus eccoptogastri* (Ratz.)
  - *Asaphes californicus* Grit.
  - *Cecidostiba burkei* Cwfd.
  - *Amblymerus* sp.
- Encyrtidae
  - *Microterys montinus* Pack.
  - *Psyllaephagus* sp.
- Eurytomidae
  - *Eurytoma* sp.
- Diapriidae
  - *Aclista* spp.
  - *Belyta* sp.
- Pompilidae
  - *Priocnemis notha* (Cr.)
- Formicidae
  - *Lasius niger* var. near *sitkaensis* Perg.

HYMENOPTERA—Continued
Formicidae—Continued
Lasius sp.
Formica fusca var. *neorufibarbis* Emery
Formica sp.
Myrmica sp.
Camponotus herculeanus var. *whymperi* Forel

CONTROL MEASURES

Chemical Treatments

Various chemical treatments were tested for the control of Engelmann spruce beetles in logs and standing trees. Applications were made with compressed-air sprayers. Logs were sprayed on the upper surface and then turned until the bark was thoroughly wet. For treatment of standing trees a No. 6 solid-stream nozzle was attached to the sprayer.

Orthodichlorobenzene

In 1944 orthodichlorobenzene was tested against the Engelmann spruce beetle on the Grand Mesa National Forest.[6] On logs infested with mature broods it was used at 8 and 5 pounds, respectively, in sufficient fuel oil to make 5 gallons. Bark areas totaling 371 and 324 square inches, respectively, were later examined to note the effects. Beetle mortality was 99 percent with both concentrations.

Orthodichlorobenzene—8 pounds to 5 gallons of fuel oil—was also tested against adult beetles hibernating in the bases of standing trees. The solution was applied to the bases of several trees to a height of 2 feet, after all adjacent duff and detritus had been removed. Other trees were treated without disturbing the litter around the bases. Mortality in both groups of trees was almost 100 percent. In another test on five standing trees the mortality was 92 percent from 4 pounds and 94 percent from 8 pounds of orthodichlorobenzene in 5 gallons of solution.

Orthodichlorobenzene was used effectively on a large control project in western Colorado in 1950, 1951, and 1952. A spray containing 8 pounds of orthodichlorobenzene in sufficient fuel oil to make 5 gallons was applied to standing trees.

Ethylene Dibromide

Ethylene dibromide—¾ and 1½ pounds, respectively, per 5 gallons of fuel oil—was applied to standing trees in tests against all brood stages. Mortalities were 98 and 100 percent with the two concentrations and 14 percent in untreated trees. Ethylene dibromide was therefore superior to orthodichlorobenzene against broods of the beetles infesting standing trees.

Ethylene dibromide was also applied to logs and standing trees in various emulsions. No. 1 fuel oil and Stoddard solvent were used

[6] Unpublished report by G. R. Struble, Division of Forest Insect Investigations, Bureau of Entomology and Plant Quarantine. (On file in U. S. Forest Service.)

as solvents. In some of the tests the fuel oil was mixed with zone oil (a paraffin-base oil) to increase its viscosity. The emulsifier was a mixture of Triton X–100 (an alkylated aryl polyether alcohol) and Triton B–1956 (a phthalic glycerol alkyd resin). The results of these tests, shown in tables 8 and 9, indicate that 80 percent of water in the finished emulsion is the maximum amount that can be used to obtain satisfactory mortality. When more water was used, more ethylene dibromide was necessary to obtain comparable results. However, lesser amounts of water did not increase the effectiveness of the formulations sufficiently to justify their use. Both Stoddard solvent and No. 1 fuel oil proved to be satisfactory solvents. Both 2 and 3 pounds of ethylene dibromide per 5 gallons of emulsion gave satisfactory kill.

TABLE 8.—*Effectiveness against Engelmann spruce beetles of ethylene dibromide emulsions, applied to standing trees*

Emulsion			Live insects per square foot of bark at indicated height [1]					Relative survival at 5 feet
Solvent	Water	Ethylene dibromide per 5 gallons	Base	5 feet	10 feet	15 feet	18 feet	
	Percent	*Pounds*	*Number*	*Number*	*Number*	*Number*	*Number*	*Percent*
Fuel oil	60	0		121.7				86.2
		1		15.1				10.7
		2	0.5	4.0	45.2	38.6	58.0	2.8
		3	.5	3.9	2.6	63.0	0	2.8
Stoddard	60	0		82.9				58.7
		1		18.7				13.2
		2	0	6.4	21.0	7.7	25.7	4.5
		3	0	.6	1.2	23.3	26.0	.4
	80	0		50.5				35.8
		1		17.8				12.6
		2	0	11.1	27.3	26.3	36.3	7.9
		3	0	1.1	29.7	24.0	25.0	.8
		4	1.3	.9	2.7	26.0	24.0	.6
	90	3	0	7.2	27.2	46.8	69.3	5.1
		4	0	11.5	29.7	105.3	76.4	8.1
Untreated				141.1				100

[1] Treated trees, 20 samples at 5-foot level and 6 samples at other levels; untreated trees, 28 samples at 5-foot level.

The emulsion containing 3 pounds of ethylene dibromide was used by the U. S. Forest Service on the Engelmann spruce beetle control project in Colorado during August 1952. The results were equal to those obtained with the orthodichlorobenzene-fuel oil solution, which had been used to treat nearly 1 million trees during the preceding three seasons. The workmen found ethylene dibromide emulsion less disagreeable to handle. No comparison was made of the operation costs of the two materials.

TABLE 9.—*Effectiveness against Engelmann spruce beetles of ethylene dibromide emulsions plus additives, applied to logs.* (*Solvent fuel oil, 80 percent water; 6 replications, 4 samples per replication*)

Ethylene dibromide (pounds per 5 gallons)	Additive	Insects per square foot of bark	Mortality
	Pints	*Number*	*Percent*
2	None	86	97.7
	Zone oil 1	94	96.1
	2	87	97.9
3	None	111	99.3
	Zone oil 1	104	98.7
	2	62	96.0
Untreated		94	25.9

DDT and BHC

Logs and standing trees were treated with a 4-percent solution of DDT in fuel oil, and with fuel oil containing sufficient BHC to give 0.46 percent of the gamma isomer. Logs were also treated with fuel oil alone. The results of these tests, summarized in table 10, show that oil solutions of BHC were superior to those of DDT when applied to standing trees, but both were effective on infested logs.

DDT emulsions were tested on standing trees and logs infested with larvae and pupae of the beetle. The emulsifier used was Triton X–100. The following mortalities were obtained:

	Percent insect mortality	
Percent DDT:	*In trees*	*In logs*
2	21	33
4	35	62
Check	16	16

The heavy runoff of insecticide was probably responsible for the lower mortalities on standing trees. However, these DDT treatments were not satisfactory in either case.

It was suspected that the mortality obtained from the use of these emulsions was greater than the mortality counts revealed. This was confirmed by spraying several stumps infested with hibernating adults with a 4-percent DDT emulsion and caging green logs with them to absorb the emerging beetles (fig. 5). Although thousands of adult beetles were present in the stumps, only 22 egg galleries were found on the green logs. In contrast, a total of 632 galleries were counted in green logs caged with the same number of untreated infested stumps of the same size. The beetles probably received a lethal dose of DDT when they emerged through the bark treated with the emulsions.

To determine whether the Engelmann spruce beetle would attack trees sprayed with a 2-percent DDT emulsion, a group of 100 trees were treated to a height of 20 feet and another 100 were left unsprayed as checks. Examination over a 2-year period showed that

TABLE 10.—*Effectiveness of fuel-oil solutions of DDT and BHC against the Engelmann spruce beetle infesting logs and standing trees*

Treatment	Logs				Standing trees			
	Total beetles		Mortality		Total beetles		Mortality	
	Adults	Larvae	Adults	Larvae	Adults	Larvae	Adults	Larvae
DDT (4 percent):	*No.*	*No.*	*Pct.*	*Pct.*	*No.*	*No.*	*Pct.*	*Pct.*
DDT in oil	15	621	100	97	24	502	100	76
Oil alone	9	309	44	47	------	------	------	------
Untreated	0	128	------	2	0	256	0	2
BHC (0.46 percent gamma):								
BHC in oil	24	703	92	97	27	437	90	92
Oil alone	9	309	44	47	------	------	------	------
Untreated	0	128	------	2	0	256	0	2

16 of the treated trees were attacked but the brood was sparse, whereas 51 of the untreated trees were attacked and the broods were normal. Most of the attacks on the treated trees were above the height of the spray application.

In logs sprayed with BHC emulsion (0.46 percent gamma), emulsifier Triton X–100, the mortality was only 43 percent—too low to be considered satisfactory. This emulsion was also tested on stumps infested with hibernating adults. Green logs were caged separately with treated and untreated stumps to absorb the emerging beetles. Results indicated a high mortality of beetle adults in sprayed stumps, since only 47 egg galleries were found in the logs caged with them, as compared with 632 on logs caged with untreated stumps.

Solar Treatment of Infested Slabs

Many bark beetles infesting logs or milled slabs may be controlled by utilizing heat from the sun. To be effective, treatment must be made during the summer months. The logs are usually laid in a north-south direction to obtain a maximum exposure to the sun. They are turned at intervals so that their entire surfaces are exposed.

To test this method of control against the spruce beetle, slabs that had been taken from sawlogs at the mill were arranged in the following ways: (1) Indiscriminately, the long axis in a general north-south direction; (2) singly in one layer in a north-south direction, the bark surface up; (3) singly in one layer in a north-south direction, the bark surface down; and (4) in tiers with cross pieces between each to permit air circulation and drying of the slabs. The tests were established in September 1944 at an elevation of 9,500 feet. Examination was first made in October. At that time the second arrangement was the only one that had given satisfactory mortality in all slabs. Because of the possibility that temperatures in September might not have been conducive to good kill at that elevation, the slabs were placed in their original arrangements and examined again at the end of July 1945. The results of this examination were approximately the same as those of the previous October; at the time of the second examination emergence was taking place from the other three arrangements.

It was concluded from these tests that to destroy the brood in infested slabs at an elevation at which Engelmann spruce grows, it is necessary to arrange the slabs in a single layer, bark surface up, the long axis in a north-south direction.

Trap Logs

Trap logs are sometimes used as attractants for emerging adults of certain species of bark beetles. Their primary purpose is to attract flying beetles away from living trees. The brood developing in the trap logs is subsequently destroyed by logging, burning, or chemical treatment.

To determine the effectiveness of logs in attracting adults of the Engelmann spruce beetle, 200 trees ranging from 14 to 24 inches d. b. h. were felled and bucked on three plots during the summer of 1949. The logs were sampled for attack after the flight season of the beetle. The successful attacks per ½ square foot of area were then compared with those in the same size sample in newly attacked standing trees in the same plot. On standing trees the area sampled was between the heights of 1 and 6 feet, while on the trap logs it was between the basal log and the top of the felled tree. Results are summarized in table 11.

The average number of successful attacks on trap logs for all samples was 4.84 and for standing trees 4.03.

The average number of successful attacks per ½ square foot of bark was determined also at 10-foot intervals on trap logs (table 12). Results showed the attacks to be well distributed over the entire length of the tree with a tendency toward grouping at the midbole.

When the logs were separated into 5-inch diameter classes and the number of successful attacks recorded, a slight tendency was found for the number of attacks to increase with the diameter (table 13).

Samples were taken on all exposures of the trap logs to determine if the beetles had a special preference for the sides, top, or bottom (table 14).

TABLE 11.—*Number of successful attacks per ½ square foot sample of bark on trap logs and standing trees infested with Engelmann spruce beetles*

Item	Plot 1		Plot 2		Plot 3	
	Samples	Attacks	Samples	Attacks	Samples	Attacks
Standing trees	48	3. 69	75	4. 08	110	4. 14
Trap logs	574	4. 56	249	5. 33	124	5. 20

TABLE 12.—*Number of successful attacks by Engelmann spruce beetles in ½ square foot samples of bark taken at 10-foot intervals on trap logs*

Interval (feet)	Plot 1		Plot 2		Plot 3		Total	
	Samples	Attacks	Samples	Attacks	Samples	Attacks	Samples	Attacks
0–10	125	4. 11	46	4. 20	40	4. 87	211	4. 27
11–20	140	5. 51	50	7. 44	50	6. 37	240	6. 07
21–30	124	5. 27	48	5. 77	32	5. 72	204	5. 46
31–40	100	4. 25	33	6. 48	8	1. 37	141	4. 61
41–50	55	3. 52	34	5. 24	0	0	89	4. 18
51 and over	30	1. 93	40	2. 20	0	0	70	2. 09

TABLE 13.—*Number of successful attacks by Engelmann spruce beetles in ½ square foot samples of bark taken on logs of various diameter classes*

Diameter class (inches)	Plot 1		Plot 2		Plot 3		Total	
	Samples	Attacks	Samples	Attacks	Samples	Attacks	Samples	Attacks
10–15	21	4. 28	5	2. 40	19	5. 42	45	4. 56
16–20	178	4. 29	82	5. 37	86	5. 34	346	4. 80
21–25	211	4. 83	82	6. 10	18	5. 94	311	5. 23
26–30	151	5. 03	53	5. 67	0	0	204	5. 20

TABLE 14.—*Number of successful attacks by Engelmann spruce beetles in ½ square foot samples of bark taken on top, sides, and bottom of trap logs*

Location	Plot 1		Plot 2		Plot 3		Total	
	Samples	Attacks	Samples	Attacks	Samples	Attacks	Samples	Attacks
Top	211	2. 57	102	2. 91	45	1. 67	358	2. 55
Sides	218	4. 78	96	5. 65	47	6. 91	361	5. 29
Bottom	138	7. 45	50	9. 24	27	8. 85	215	8. 04

TABLE 15.—*Number of successful attacks by Engelmann spruce beetles in ½ square foot samples of bark taken on logs subject to sun, shade, and partial shade*

Light	Plot 1		Plot 2		Plot 3		Total	
	Samples	Attacks	Samples	Attacks	Samples	Attacks	Samples	Attacks
Sun	80	3. 35	62	4. 08	14	1. 90	156	3. 51
Shade	453	4. 96	191	5. 61	51	5. 47	695	5. 17
Partial shade	39	3. 23	0	0	47	6. 23	86	4. 87

As shown in table 14, the beetles exhibit a definite preference for the sides and bottom of the logs. The reason for the preference is not known; it may be an aversion to light and high temperature, which would be more intense on the top than on the sides and bottom.

Attack counts were also made on logs that were located in the sun, that were completely shaded, and that were partially shaded. Results showed that the beetles definitely prefer the shaded logs (table 15).

Comparisons were made of the total surface area of standing trees and trap logs of similar dimensions that were subject to attack. Several trees were felled in each trap-log plot and measurements of the attacked portions of the boles and logs were made. Standing trees were attacked to an average height of 28 feet and an average diameter of 12 inches, whereas trap logs were attacked to an average height of 58 feet and an average diameter of 5 inches.

SUMMARY

The Engelmann spruce beetle (*Dendroctonus engelmanni* Hopk.) is one of the most destructive insect pests of Engelmann spruce in the United States. Over a period of 10 years it has killed more than 4.3 billion board-feet of commercial sawtimber in western Colorado.

The chief host of this beetle is the Engelmann spruce (*Picea engelmannii* Parry). Nevertheless, this insect has killed lodgepole pine. It will attack blue spruce and white spruce. However, these species do not occur in extensive stands in this region and, as a result, the kill is usually limited to a small area.

The Engelmann spruce beetle may take 1 or 2 years to complete its life cycle. In the 1-year cycle the tree is attacked from the middle of June to the first part of July, and by early October the brood has developed into pupae and callow adults. During the winter months the pupae slowly transform into the adult stage. Sexual maturity is attained between the middle of June and the first part of July. Emergence and attack follow.

Beetles that require 2 years to complete their life cycle develop in trees that are attacked during the middle part of July. By mid-October the larvae are one-half to three-fourths grown, and it is in this stage of development that the first winter is passed. By the following June and July, the beetles have transformed into apparently mature adults. They commonly emerge during August and September. Instead of attacking, these beetles crawl or fall to the bases of the trees from which they have emerged. There they form small feeding galleries where they pass the second winter of their existence. Beetles that do not emerge at this time hibernate in the bole of the tree in which they develop. They emerge from hibernation during the latter part of June and in July and attack green trees in the surrounding area.

If the first winter is passed in the adult stage, the life cycle will be approximately 1 year in duration, but if it is passed in the larval stage, 2 years are necessary.

Hibernation seems to be a unique habit for this species of *Dendroctonus*. During August and September many adult beetles emerge and reenter the tree at its base to hibernate instead of attacking.

Woodpeckers are the most effective predators of the Engelmann spruce beetle. In certain areas practically the entire brood is destroyed by these birds. Entomophagus parasites and predators are responsible for about 50 percent of the mortality of the later stages. Low temperature at times destroys the brood of the beetle over extensive areas. During midwinter all larvae succumb to a subcortical temperature of −30° F. and all adults to −20°.

Chemical control is best accomplished with ethylene dibromide. It is used at 3 pounds in 5 gallons in an emulsion and at 1.5 pounds in 5 gallons in an oil solution. Orthodichlorobenzene, 8 pounds in fuel oil to give 5 gallons, is also effective.

Protection from attack of the beetle can be accomplished by treating uninfested trees with a 2-percent DDT emulsion.

Trap logs attract more beetles than do living trees.

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