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THE WHITE-PINE WEEVIL[1]

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CONTENTS

INTRODUCTION

Since about 1800 the white-pine weevil (*Pissodes strobi* Peck)[2] has attracted the attention of numerous investigators, stimulated no doubt by a popular demand for some direct method of control or some effective parasite. Those who have studied the problem of white-pine weevil control recently, however, realize that under forest conditions direct measures are impracticable from the standpoint of expense and for other reasons, and that the work of parasites, although of great value, can not be relied upon. It is becoming more and more evident that the white-pine weevil and many others of our forest pests must be recognized as an integral part of the forest environment just as are the different soil types or the various tree characteristics of those soils. If such pests are to be controlled, it is necessary that the conditions be determined under which they are most or least injurious and advantage taken of this knowledge in growing the forest crop. Usually it is not possible to avoid all

[1] This circular is more condensed and less technical than a previous publication on the same subject by the writer in Technical Publication 28 of the New York State College of Forestry at Syracuse University. Prosecution of the study was made possible through the cooperation of the New York State College of Forestry, certain timberland owners in Massachusetts, the Harvard Forest, the Connecticut and Vermont Agricultural Experiment Stations, the Northeastern Forest Experiment Station of the Forest Service, U. S. Department of Agriculture, and the entomological branch of the Dominion of Canada Department of Agriculture. Figs. 2, 8, 9, 10, and 14 were redrawn from Graphs I, II, VI, VII, and IV, respectively, in the publication mentioned above. The writer wishes to express his appreciation for criticisms and suggestions, during the course of the investigation and the preparation of the manuscripts, from F. C. Craighead and M. W. Blackman, Bureau of Entomology; and Director R. T. Fisher and Assistant Director A. C. Cline, of the Harvard Forest. Thanks are also due D. DeLeon, R. C. Hall, L. Rintel, and R. O. Hall for assistance in the field at various times during the progress of the work.

[2] Order Coleoptera, suborder Rhynchophora, family Curculionidae, subfamily Pissodini.

injury, but in the case of this and other native pests profitable yields can frequently be obtained.

How to grow white pine (*Pinus strobus* L.) successfully in a district where there is heavy weevil infestation has long been a problem. However, in certain localities, such as the Harvard Forest at Petersham, Mass., satisfactory methods have been developed for bringing young stands through to maturity in spite of the weevil. Although these silvicultural practices at the start were adopted primarily for reasons other than weevil control, they give promise of producing a crop that will go through the desired rotation without appreciable injury by the weevil and at the same time improve the forest environment and insure a stand of high-grade material more adjustable to future markets.

At present the white-pine weevil is the most serious insect pest affecting the white pine, and in some localities it is the most serious of all pests. This weevil is a native insect and has always been important throughout the range of the white pine.

The first known mention of the economic importance of the white-pine weevil was made by Peck (*17*)[3] in 1817, when he described the insect. At that time the manufacture of wooden ships was at its height, and one of the factors limiting the suitability of the pine tree for use as masts was the injury and consequent crook caused by white-pine weevil attack. Peck stated that if it were not for the parasites which preyed upon this insect "our forests would scarce produce a single mast." In regard to the distribution and abundance of this weevil, Peck stated that it was generally diffused over the entire country. Later this became especially true in sections where abandonment of farms was a common occurrence. About 1850 the farmers in the New England States began to abandon their farms, this movement reaching its peak in the period between the Civil War and 1880. Many of the fields which reverted to the forest types were seeded almost wholly by white pine. These old-field stands were in many cases poorly stocked, and the trees have been repeatedly infested by the weevil. Then there is the great acreage of white-pine plantations which has been set out in the last 30 years. All this has furnished plentiful food for the weevil, and recent observers agree that the insect has been more abundant and the percentage of infested pine greater in the last half-century than before.

Just as the boll weevil has been a blessing in disguise to southern agriculture in forcing diversified crops, however, so some benefit may be derived in the present case if the danger of white-pine weevil infestation encourages diversified forest crops.

RANGE OF THE WHITE-PINE WEEVIL

The range of the white-pine weevil is similar to that of the white pine itself, namely, from Newfoundland to Manitoba, south to Delaware, along the Alleghenies to Georgia, and westward to Illinois, Iowa, and Minnesota. The insect is not so important, however, in the more westerly or southerly regions as it is in the northeastern part of the United States and in southeastern Canada.

[3] Italic numbers in parentheses refer to Literature Cited, p. 29.

LIFE HISTORY AND HABITS

DESCRIPTION OF THE ADULT WEEVIL AND ITS IMMATURE STAGES

The white-pine weevil (fig. 1, A) is a small snout beetle, about one-fourth inch in length, and is light to dark brown, mottled with lighter scales over its wing covers. The pupa (fig. 1, B) is creamy white in general color, with the mandibles and eyes brown. As maturity is reached, the beak and legs turn brown and the general color of the adult is gradually assumed. The abdominal tip is armed with two spines. The pupa is about the same length as the adult. The larva (fig. 1, C), which does the damage, is a white, footless grub and when fully grown is slightly longer than the adult. The eggs are pearly white, somewhat translucent, slightly oblong, equally rounded at the ends, and a little less than a millimeter in length.

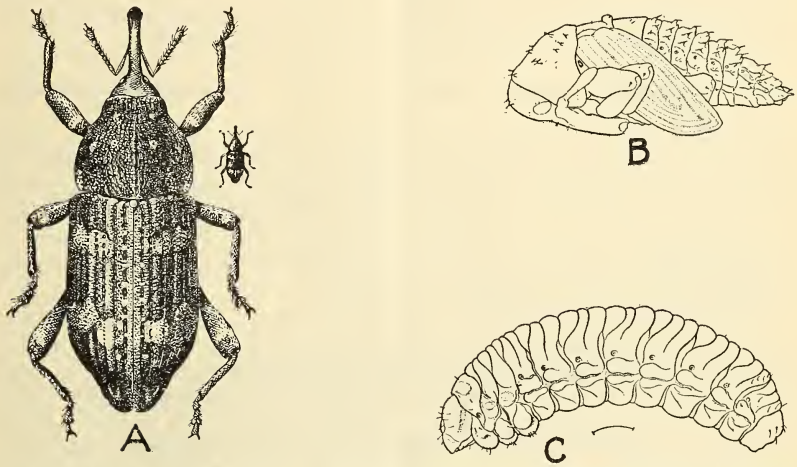

FIGURE 1.—Life-history stages of the white-pine weevil (*Pissodes strobi*); A, Adult (smaller figure is natural size; B, pupa (enlargement about the same as in C); C, larva (hair line shows natural length). (Hopkins)

HIBERNATION AND RESUMPTION OF ACTIVITY

The adult weevil hibernates usually in the lowest layer of the litter or duff, and occasionally in the upper layer of the soil beneath trees on which it fed during the previous fall. It may also winter in the same layers beneath stumps cut in the fall, attracted there by the odor of the escaping pitch, or in the masses of litter which collect in the forks of the large trees. Under extraordinarily favorable conditions adults from eggs laid late in the season may hibernate successfully in the leaders.

Activity is resumed about the time the buds on the pines begin to swell; so the time of this resumption depends entirely on the climatic and temperature ranges.

PERIOD OF EGG LAYING

Egg laying usually does not begin for several days after resumption of activity. The eggs are laid in the leading shoots of the previous season. Several female weevils may oviposit in one leader;

on the other hand, one female may oviposit in several leaders. Plummer and Pillsbury (*19, p. 30*) report that "the female may lay from 25 to 201 eggs in one season. The average in these observations was 129." The writer's averages were considerably below this figure and "it seems probable that an average of 50 eggs per female is low" (*11, p. 18*). The number of eggs laid in a single leader ranges from 20 to 350, the average being about 125 (*11*).

Weather conditions have a great bearing on the oviposition period. An early spring, and consequent early beginning of growth, will mean early beginning of oviposition, and a cold and late spring will mean late beginning of the period. If the beginning is late the cessation will be late, as the period of egg laying corresponds rather closely with that of accelerated height growth. (Fig. 2.) There will also be an overlapping of life stages due to this prolonged period of egg laying. However, the peak is reached within two weeks after accelerated height growth starts; then there is a gradual decrease, and after another month oviposition has practically ceased.

LARVAL FEEDING AND DEVELOPMENT, PUPATION, AND ADULT EMERGENCE

The eggs hatch in from 6 to 20 days, and immediately after hatching the larvae, which are voracious feeders, begin to feed down the stem on the phloem tissues, thereby depriving the shoots, wholly or in part, of the food necessary for elongation. As they grow larger they feed also on the outer portion of the wood. If there are a large number of larvae, the living tissue will be quickly eaten and the growth may be completely stopped.

The larvae follow down the stem side by side, often packed closely in a ring, and many of those at the rear starve to death. As a larva which is a little older than its companions attains full size, it drops behind, bores into the pith, and pupates. The remaining larvae continue down the stem side by side, and those that finally survive pupate in the pith or wood. If there is insufficient room for all to pupate in the pith, some will do so in the wood but as near the pith as possible. There is a striking difference in the character of the pupation chambers in the pith and in the wood. (Fig. 3.) Those in the pith have no "chip cocoon" or lining of frass; those in the wood have it, although only on the side toward the bark. The main part of the chamber is smooth, only the marks of the mandibles being visible.

Occasionally, when they come to a node, some of the larvae will bore into a lateral, feeding and pupating there. Larvae from late-laid eggs deposited in the growth of the previous season may rarely go up into the current season's growth. This occurs, however, when much of the growth has been completed, at the time the larvae hatch, or when the new growth has more fully matured and there will be sufficient food available to induce the larva to go up instead of down. In rare cases eggs may be laid in the growth of the present season and the larvae may kill it, but this only occurs late in the season when the shoots are nearly full grown.

From two and one-half to three months is required for development from the egg stage until the emergence of the adult from the leader. Practically all the new generation emerges in the late sum-

mer or early fall, but under favorable conditions larvae hatching from late-laid eggs may occasionally winter over as full-grown larvae or young adults (*11*).

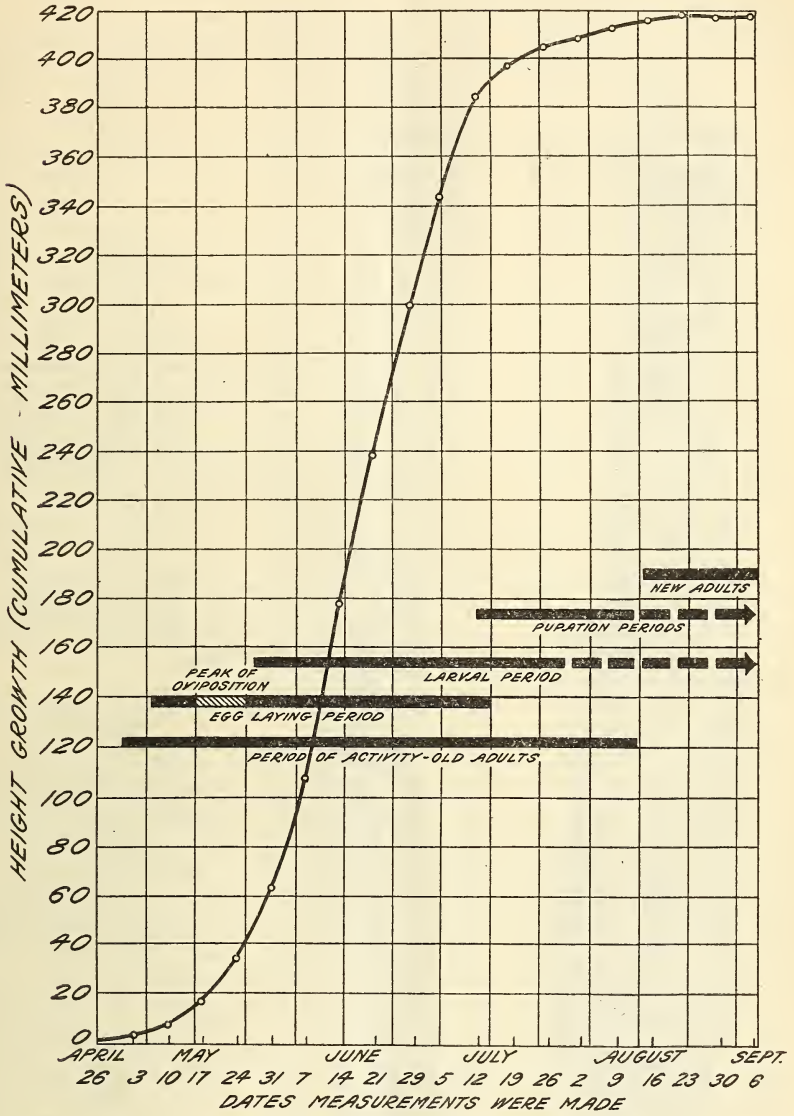

FIGURE 2.—Correlation between periods of development of the white-pine weevil and definite periods in the annual height-growth of the white pine

FLIGHT HABITS

The adult weevils may reach the leading shoot in one of three ways. In the early spring, before the temperature is high enough to enable them to fly easily, they crawl up the stem. As soon as

the temperature rises sufficiently to induce flight, they will fly directly to the tree itself, striking perhaps the leader but more often the branches, and then crawl up the stem until the leader is reached.

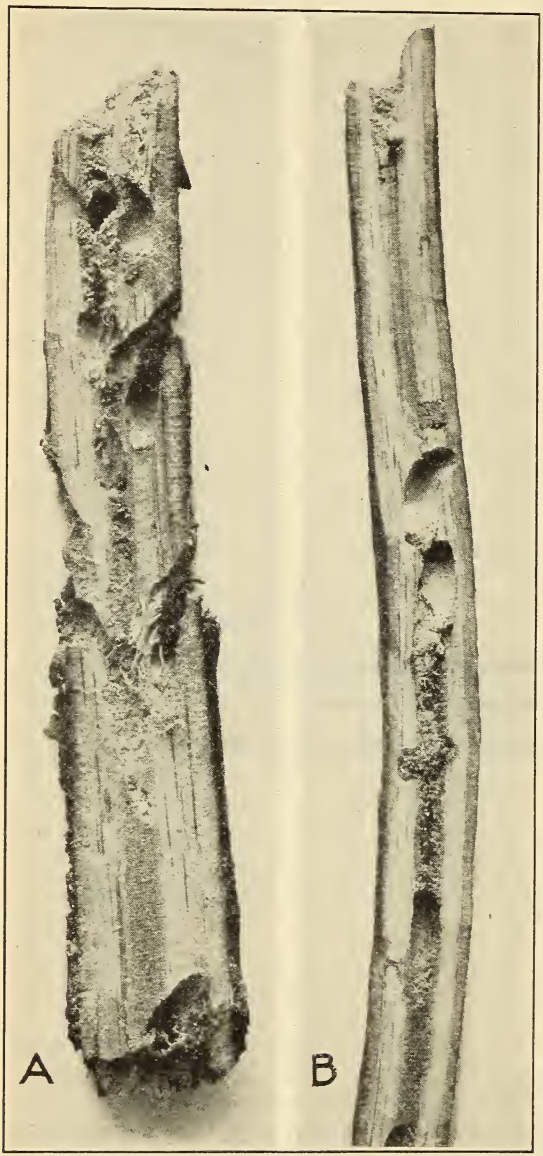

FIGURE 3.—Position and character of pupal chambers of the white-pine weevil: A, In wood; B, in pith

Weevils of both sexes have been observed in the spring, on warm days, flying directly to the leaders. An air temperature of at least 70° F. is ordinarily necessary before the weevils will fly, and the favorable temperature is between 75° and 80°. When the temperature is above 85°, especially if constant, the weevils seek shade. They are strong fliers and, when carried high in the air and wafted by the wind currents, they can cover a considerable distance. By this means migration to new areas is possible, particularly in the fall.

HABITS OF THE NEW GENERATION

Fall feeding has been observed only among adults of the new generation. They feed on any portion of the branches exposed to the sun, but preferably on the new growth of the upper laterals or leader. Feeding continues, even though snow may have fallen, until settled cold weather prevails, and then the weevils go into hibernation.

In experimental cages large numbers of pairs of weevils have been observed in copulation. Females were taken from hibernation and placed in cages where males had no possibility of entrance. Some of these females laid eggs, and the fact that some of these

eggs hatched shows that fertilization is possible in the fall (*11*). Graham (*8*) cites an example where fertilization apparently took place in the fall, but Plummer and Pillsbury (*19*) think that more likely the fertilized egg was laid by a female which hibernated a second winter. The author's observations, however, appear to corroborate those of Graham. There is little probability of parthenogenetic reproduction.

HOST TREES

The trees known to be attacked by the white-pine weevil are as follows:

SEVERELY ATTACKED

White pine (*Pinus strobus* L.).
Norway spruce (*Picea excelsa* Link.).[4]

COMMONLY ATTACKED

Pitch pine (*Pinus rigida* Mill.).
Jack pine (*Pinus banksiana* Lamb.).
Japanese red pine (*Pinus densiflora* S. and Z.).[4]
Western white pine (*Pinus monticola* D. Don.).[4]
Limber pine (*Pinus flexilis* James).[4]
Foxtail pine (*Pinus balfouriana* Murray).[4]
Red spruce (*Picea rubra* Link.).

OCCASIONALLY ATTACKED

Scotch pine (*Pinus sylvestris* L.).[4]
Western yellow pine (*Pinus ponderosa* Laws.).[4]
Mugho pine (*Pinus montana mughus* Willk.).[4]
Black spruce (*Picea mariana* B. S. and P.).

RARELY ATTACKED

Colorado spruce (*Picea pungens* Engelmann).[4]
White spruce (*Picea glauca* Voss).
Douglas fir (*Pseudotsuga taxifolia* (La Marck) Britton).[4]
Red or Norway pine (*Pinus resinosa* Sol.).
Himalayan pine (*Pinus excelsa* Wall.).[4]

The white pine is the favorite host and the injury is found in varying degrees in almost every locality where this species is common. The Norway spruce is also severely attacked and at times may be as severely injured as the white pine. All the native pines and spruces of the northern region are liable to attack, although the Canadian white spruce and the red or Norway pine are rarely affected. The western soft pines, when numerically more abundant, will probably be infested by weevils to a greater extent than at present. It must be borne in mind, however, that in localities, within the range of the weevil, where the insect is not abundant many of the species listed would only rarely be attacked. At times, where there is a mixed stand of conifers, the other species in the stand may be infested to a greater extent than the white pine. In such cases observed by the writer the other species have been taller, and this may have been the reason for the attack.

[4] Exotic species.

INDICATIONS OF INJURY AND CHARACTER OF THE DAMAGE

When seasonal activity is resumed in the spring, feeding punctures are often found in the apical buds as well as in the growth of the preceding year. This injury may be serious, as the inner portion of the bud is sometimes almost entirely consumed. After the eggs are laid, the first noticeable indication of infestation is the presence of splotches or tiny glistening droplets of pitch on the upper third of the leading shoot, which have come from the punctures. (Fig. 4.) For a time height growth continues normally in the infested leaders, but soon after the eggs have hatched and the larvae have begun to feed the leading shoot is girdled and assumes a wilted appearance, characteristic of this injury. There is considerable variation in the amount of growth in the leaders, depending on the time of attack and the number of eggs deposited. (Fig. 5.) Infested leaders are very conspicuous in a plantation or natural stand, especially in young, open stands in old fields or in young plantations if the infestation is severe. As a rule the new growth withers and the tip bends over and turns brown, but if the shoot is killed just after bud swelling begins there will be only a brown stub sticking up straight.

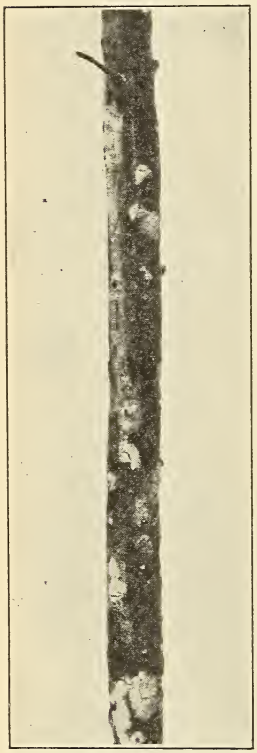

FIGURE 4.—Leading shoot of white pine, showing the masses of pitch which have exuded from the feeding and oviposition punctures of the white-pine weevil

A leader killed by weevils must be replaced by one or more laterals. The deformed trees that result from this injury are known as either "bayonet" or "staghorn" pines. (Fig. 6, A.) The first occurs when one lateral gains supremacy over the others and becomes the leading shoot. The second occurs when two or more laterals survive and form a crocheted tree. It is not uncommon to see several of each of these formations in a single tree, causing what is known as a "cabbage" pine. (Fig. 6, B.) These trees are sometimes attacked by weevils 50 or 60 times, and in such cases the trunk is practically worthless for lumber. Frequently in the 50 and 60 year old stands the cause of the dead stems in crocheted trees can be traced directly to infestation by the weevil. One and occasionally two or more laterals will eventually gain dominance, and the others will die. When these stubs, often several inches in diameter, break, a jagged wound is left which can not heal and which permits the entrance of wood rots. Frequently, the hearts of trees so injured are defective.

When the leading shoot is killed, there is always a loss of 2 years' height growth, as the eggs are deposited in the growth of the preceding year. However, quite often 3, and occasionally 4 or 5, years' growth may be killed. One case has come to the attention of the author where a Scotch pine sapling had the growth of 9 years killed.

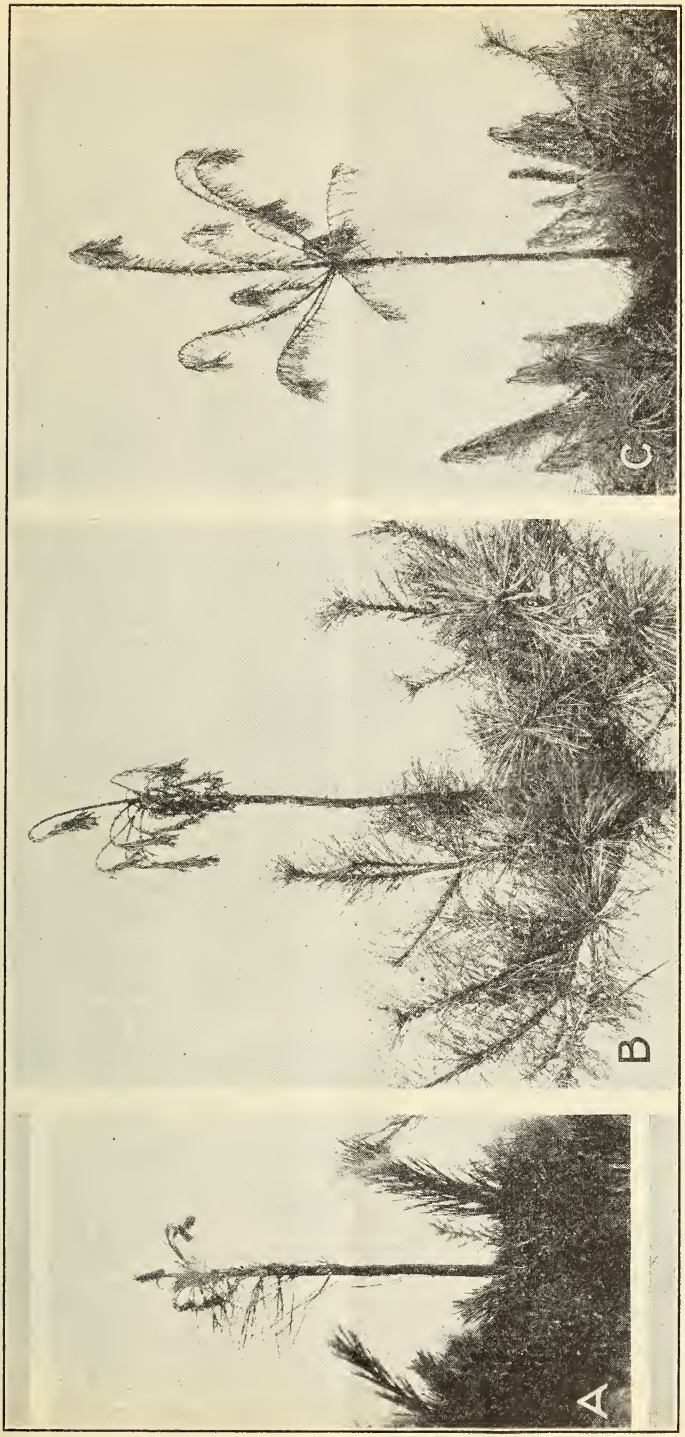

FIGURE 5.—Variations of growth in leaders infested by the white-pine weevil

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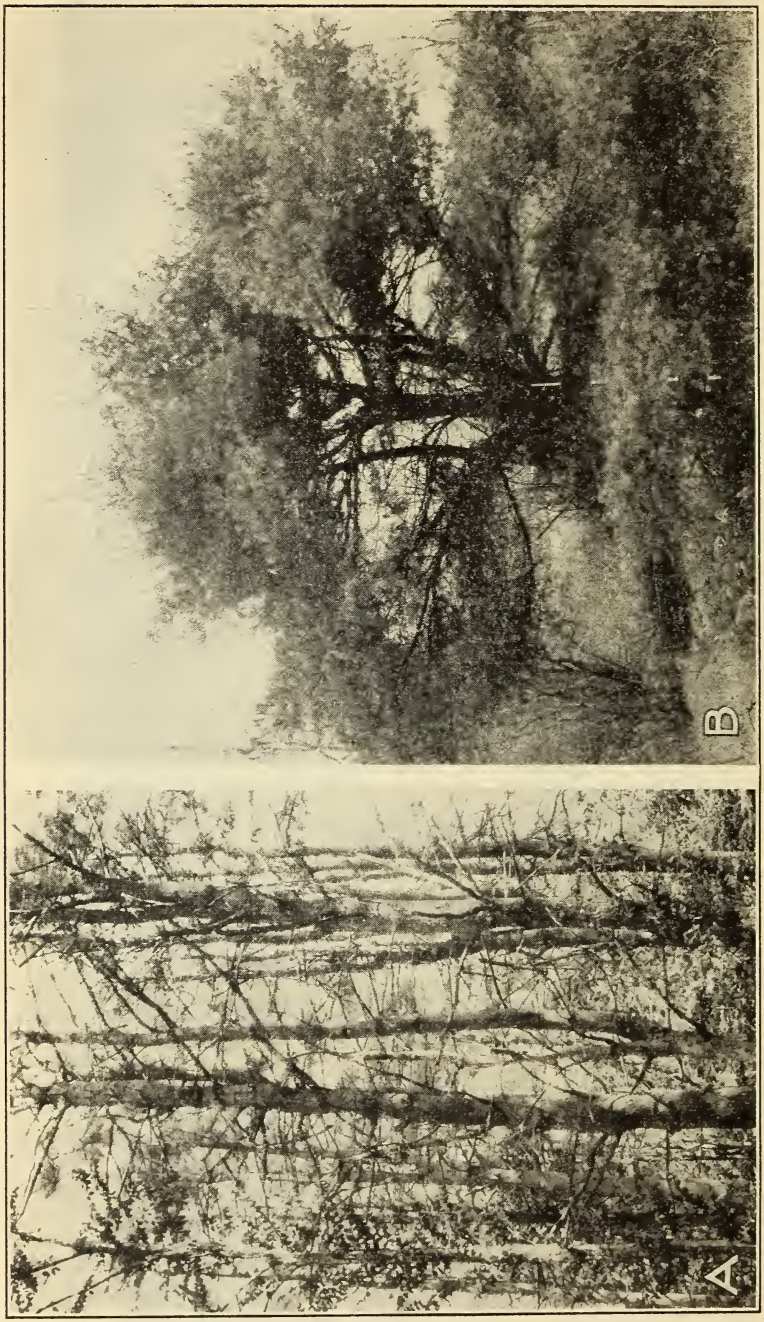

FIGURE 6.—A, "Staghorn" or "bayonet" pine; B, "cabbage" pine. (Courtesy of Harvard Forest)

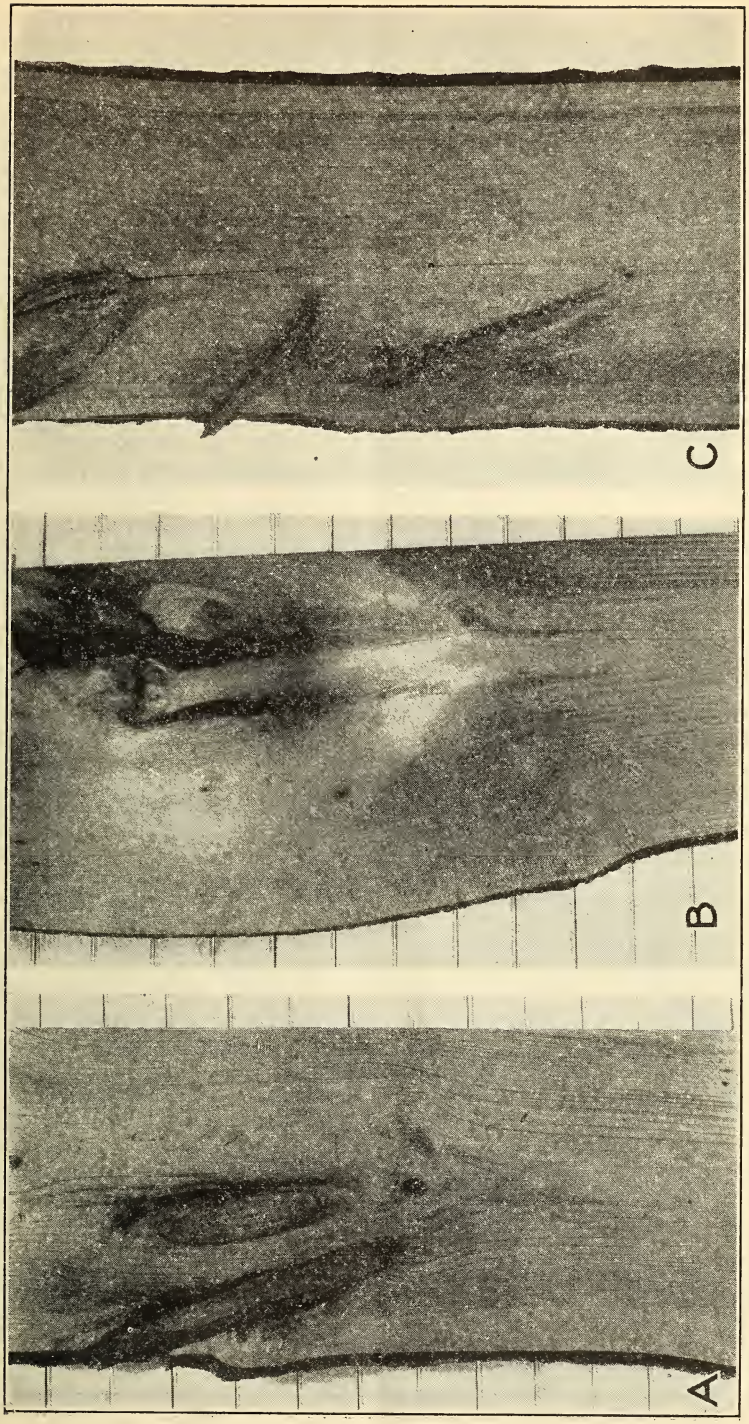

FIGURE 7.—Defects in lumber caused by white-pine weevil injury

The most noticeable result of the killing back of the leader is the crook or fork which almost inevitably results. This decreases the value of the tree materially, and as a rule the lumber sawed therefrom is usable only for box boards or other cheaper grades of boards. (Fig. 7.) The quality of the lumber in trees attacked by weevils once or several times may not be seriously impaired provided the trees have nearly straightened. In Figure 8, based on data collected from 60 infested trees and 60 noninfested trees, is shown the approximate loss in height growth of trees killed back 2 years, each time a tree is infested by the weevil.

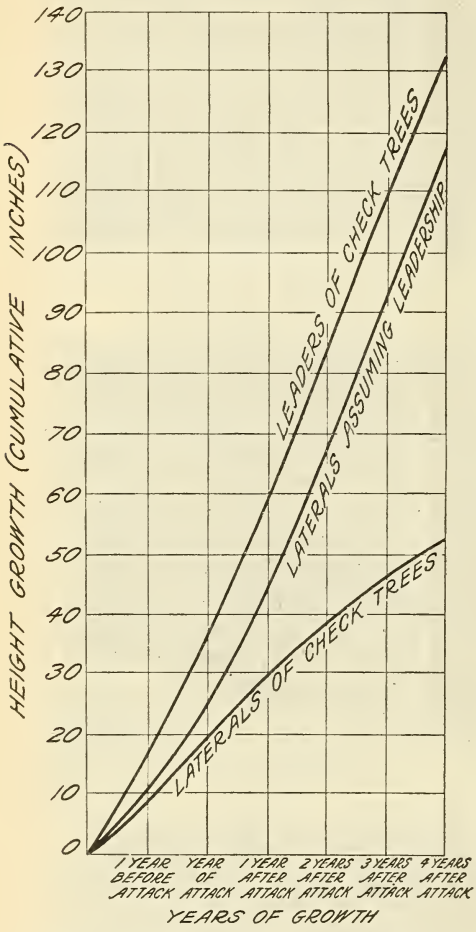

FIGURE 8.—Approximate loss in height growth of trees killed back 2 years by the white-pine weevil, each time a leader is killed. Based on data from 60 infested and 60 noninfested trees

Another type of injury which is rather difficult to express quantitatively is the loss in diameter growth. Such a loss in one tree alone is negligible, but if all affected trees over a wide area are considered the ultimate loss of wood will be large.

EFFECT OF SILVICAL AND HABITAT FACTORS ON AMOUNT OF INJURY

COMPOSITION OF THE STAND

The composition of the stand is of great importance in a locality where weevil infestation is common. Hopkins (*9*), Blackman (*1*), Blackman and Ellis (*2*, *p. 72*), and Fisher and Terry (*6*), as well as the present writer (*10*), commented on the small amount of injury in stands of mixed white pine and hardwood.

One hundred and fifty years ago there were practically no pure pine stands on the heavy soils. White pine formerly grew with hardwoods, and to a lesser extent with softwoods, either singly or in groups. In many natural second-growth stands, which are allowed to grow untouched by human hand, the tendency is toward a stemwise mixture.[5] Only a few pines remain per acre by the time such stands reach an age of 40 to 50 years, but they are usually of good form.

[5] See p. 26 for definition.

Both Peirson (*18*) and Graham (*8*), in widely separated parts of the range of the white pine, observed that the number of trees per acre in the pure stands had a direct bearing on the rate of infestation. With an increase in the number of trees per acre the percentage of infestation decreases. Figures 9 and 10, drawn from data collected from plantations on similar sites but having different spacings, clearly show this. However, it must be remembered that a fully stocked stand at 60 years should contain only 150 to 300 trees per acre, and when plantations are set out the cost rises proportionately with the decrease in spacing.

It was found in experimental cages that adult weevils feed more readily on shoots cut from pine growing in the open than on those cut from pine growing in mixture with hardwoods or in pure dense

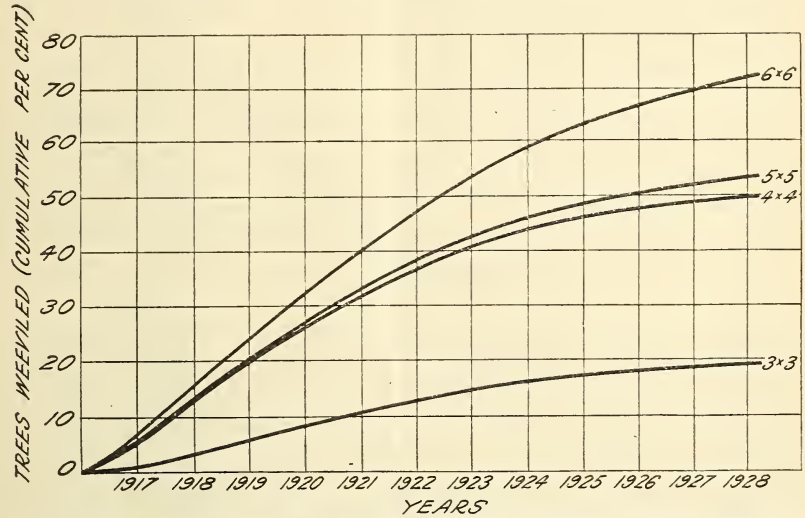

FIGURE 9.—Comparison of the cumulative increase in percentage of trees infested by the white-pine weevil in pure stands of different densities. Based on 125 trees from each plot

stands. Also the females almost invariably go to the most vigorous leaders to oviposit. Indeed, the shoots from the mixed and pure stands were not severely attacked until the others were riddled with punctures.

There is also evidence to show that the infested leaders in pure dense and mixed stands frequently recover and that very few weevils, if any, mature in those that are killed. This is undoubtedly due to the fact that fewer eggs are laid in these leaders, and the small numbers of larvae are almost certain to be smothered by the sap and resin.

AGE, HEIGHT, AND VIGOR OF TREES

Infestation by the weevil usually begins when the trees are 2 or 3 feet high and 5 or 6 years old, but often earlier. When trees 2 feet high are attacked, they are usually killed back to at least the lowest whorl of laterals, and thus a scrubby tree often results. Sometimes the tree is killed back under the ground, and in such cases death usually follows. Such an injury is similar to that caused by

Pissodes approximatus Hopk. and may easily be mistaken for it. Beginning with a height of 2 or 3 feet, the rate of infestation in a widely spaced old-field stand or a heavily infested plantation becomes progressively greater until at from 20 to 25 feet the peak is reached. From this point it gradually decreases until at a height of 60 feet it has practically ceased. Although the infestation in trees

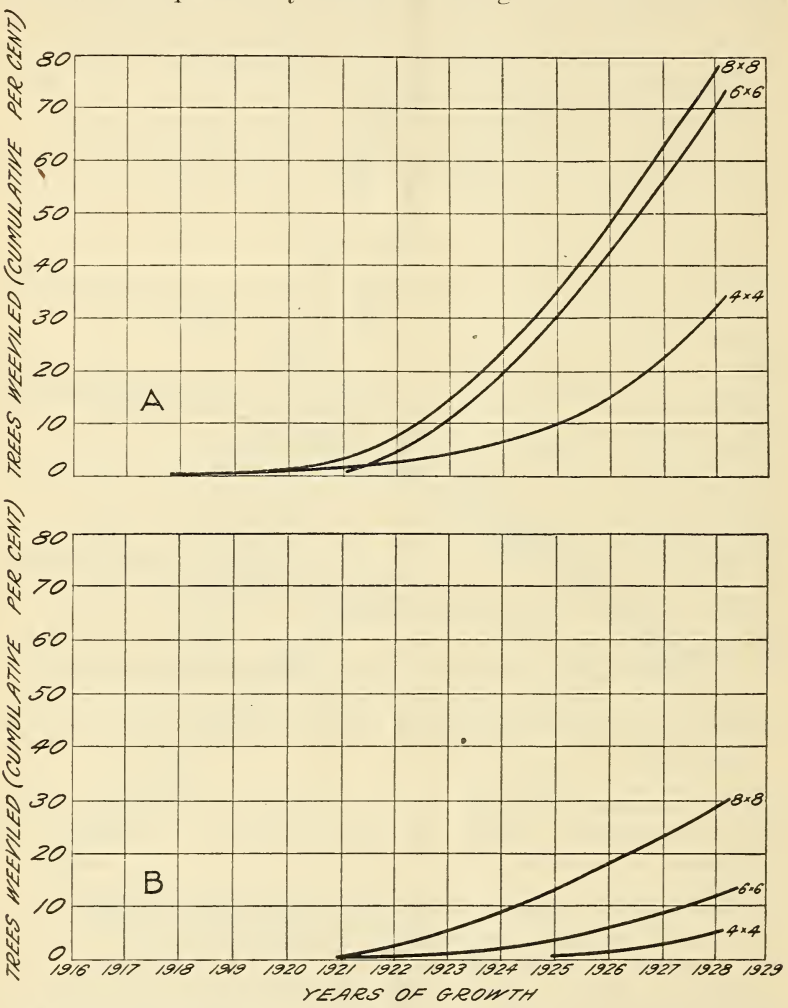

FIGURE 10.—Comparison of the percentages of trees infested by the white-pine weevil in stands of different densities: A, White pine in pure stands; B, white pine in stemwise mixed stands

above 30 feet in height is considered of little importance under the present silvicultural practice of growing white pine in short rotations, it will be of importance in longer rotations if clear lengths above this height are desired.

As previously stated, one factor limiting infestation by the weevil is the vigor of the tree. The most vigorous leaders are usually at-

tacked, but infested trees have been observed which were higher than the surrounding trees, although their leaders were less vigorous. The trees most often attacked are those in the upper canopy, or the dominant and codominant classes. This holds true in pure stands of varying densities, but the pine trees in certain mixed stands are normally not in these classes until they have reached a height of 30 feet or more. This partial suppression by the accompanying species is one reason why pines in these stands are relatively immune to weevil attack until the leaders are above the crown canopy of the other species.

SOIL CONDITIONS

The condition of the soil is an important factor determining the degree of infestation. It is generally understood that white pine will grow on any kind of soil, but the fact remains that it will not thrive equally well on all kinds of soil. Stands on light sandy soils or medium agricultural soils show the greatest infestation. A stand on a wet, cold soil has little infestation, but the growth conditions are also poor. Mixed white pine and hardwood stands are more prevalent on the better soils. On such soils, where the pine has a chance to develop and is not suppressed, the growth is generally good, and when the leaders are killed the recovery from the injury is much more rapid than in trees infested in pure stands.

EXPOSURE

The exposure also appears to have a direct bearing on the degree of infestation. As a rule stands on southern and eastern exposures, where the temperature would be higher earlier in the day than on the other exposures, are usually attacked with greater intensity than those on western or northern exposures. When a stand on a western or northern slope is badly infested, it can generally be explained by the fact that there is little pine near by on other slopes, or that the weevils have become established there and have not migrated to other stands. Of eastern and southern slopes, the steepest ones, which allow more light and sunshine for each leader, may show the greatest infestation, whereas on the protected northern and western exposures the steeper the slope the less is the severity of attack and most of what does occur is at the top of the slope.

CLIMATIC FACTORS

The temperature limits the time of weevil activity in each locality, but the other weather factors also have much to do with the degree of infestation (*12*). A wet, cold spring or an abnormal amount of precipitation during the oviposition period limits the infestation, because the weevil is a sun-loving insect and ovipostion generally takes place in the sun.

There is probably no other time during the life of the weevils that is so precarious as the hibernating period. The depletion in numbers must be enormous, especially when a wet autumn and an open winter, with great and sudden changes in temperature and rainfall and a subnormal amount of snow, are followed by a backward spring. This is what happened in New England in 1927–28. Over

a period of years the weevil infestation had been gradually increasing in the New England States, but in the spring of 1928 the infestation over the region as a whole did not increase, and in some areas it decreased very noticeably. During the winter of 1928–29 there were no great and sudden changes in temperature and precipitation such as characterized the preceding winter. Hibernation conditions were therefore more favorable. November and December were warm and dry, and after January 1 the ground was blanketed with snow until almost the beginning of spring. March was warm and wet. April had a little more than normal snowfall and more than normal precipitation. May and June were warm with more than average percentage of sunshine. Vegetation developed more quickly than in the preceding year, and in 1929 the weevil attack was exceptionally heavy. Data compiled from sample plot records show that the infestation was heavier than in any other year since the present studies were initiated.

The climatic differences in different portions of the range of the white pine also affect the degree of infestation. In Vermont, for example, the pine is found mostly in the rich valley bottoms, where conditions for development of the weevil and subsequent hibernation are rather unfavorable. This can be explained by a variety of factors, chief among which are (1) the late spring and early fall frosts followed by a rise in temperature often accompanied by rain, (2) the protection afforded by the slopes, and (3) the soil conditions, which are such that when infestation does occur the injury is not so serious as in other regions. The growth of the pine under these conditions is sufficiently vigorous to enable the injured tree to recover relatively early. On the other hand, stands on sandy soils in Vermont are infested to nearly as great an extent as are those in central New England.

Toward the more westerly and southerly portions of the range, where white pine is found only in scattering clumps, infestation is not severe. As the limits of the optimum range are neared, it has been found that the infestation decreases.

SCARCITY OF NATURAL FOOD SUPPLY AS A LIMITING FACTOR

In some localities in the general range of the weevil there is a marked scarcity of natural white pine. This means a lack of food for the weevils. They will not be present and when plantations are set out the trees are not damaged. This is the case in southern New Jersey, where plantations set out 10 to 15 years ago had not been damaged up to 1927. If the weevil should be introduced in these areas, it is a question whether there would be severe injury.

Quite often where there has been no pine on islands in lakes or reservoirs, natural seedlings come in or plantations are set out. Such a case is at the Cross River Reservoir of the New York City Water Supply Commission. A pine plantation set out there on an island, where there was no natural pine, escaped injury for 12 years. It is probable that the first weevils in that plantation were wafted across the water by a favorable wind, and in four years the infestation was well established.

CONTROL

In all efforts to prevent excessive loss from depredations of forest insects it must be remembered that as a rule it is useless to attempt the complete extermination of any species. In the case of the tree-killing bark beetles, such as the members of the genus Dendroctonus, it is now considered sufficient if 95 per cent of the beetles or larvae of a species in an infestation are destroyed. The remaining 5 per cent can not, theoretically, pursue an aggressive attack, but must occupy a defensive position against the enemies of the species until conditions favor its again becoming epidemic. Control of the white-pine weevil presents a different problem. The trees themselves are not often killed, but the leaders are. The result is a tree which may be crooked or forked, or both, depending on the number of times the leading shoots have been killed, and there is a consequent loss in timber value. In the case of the tree-killing bark beetles the progeny of many females are necessary in order that a tree may be girdled and killed, whereas one fertilized female weevil may lay enough eggs in one leader, and possibly in more than one, to cause death. But the number of weevil larvae necessary to kill a leader is small as compared with the many hundreds of bark-beetle larvae that must be present in order to kill a tree.

The problem of keeping the white-pine weevil in check and controlling the injury resulting from infestation must be considered from a number of angles. The most important of these are the cost and the completeness of the control measures. For convenience these measures and factors may be classed as natural control, prevention of attack, direct control of the insect, and silvicultural methods of control.

NATURAL CONTROL

The most important natural-control factor is the weather. This has already been discussed, and even though it can not be manipulated by man it is the cause of great depletion in the numbers both of the adult hibernating weevils and of the developing generation.

PARASITIC AND PREDATORY INSECTS

Parasitic and predatory insects are undoubtedly of value in control of the white-pine weevil. However, no practical means of utilizing these beneficial insects has yet been devised. In some areas they undeniably have been the most important means of lessening the amount of weevil emergence, but they must be regarded more in the light of a remedial or curative factor than of a preventive one. Twenty-nine species of parasites and predatory insects have been reared by the writer (*11*) from leaders collected in various parts of Pennsylvania, New York, Connecticut, Maine, and Massachusetts, and have been determined or have been reported by other investigators. At least four of these are secondary parasites, or parasites on parasites.

The most important insect enemies are the fly *Lonchaea corticis* Taylor (fig. 11) (formerly considered as *L. rufitarsis* Macq. or *L. laticornis* Mg.) and the minute wasplike parasites *Eurytoma pissodis* Gir., *Microbracon pini* Mues., *Doryctes* sp., and *Coeloides pissodis*

Ashm. The first three are external feeders, while the last two feed internally. Graham (*8*) reported a 50 per cent parasitism by *Eurytoma pissodis* in several pine clumps near Ithaca, N. Y. During the summer of 1927 several areas were found in the Canadian Provinces of New Brunswick and Nova Scotia where leaders were heavily parasitized, many of them 100 per cent. The most common species

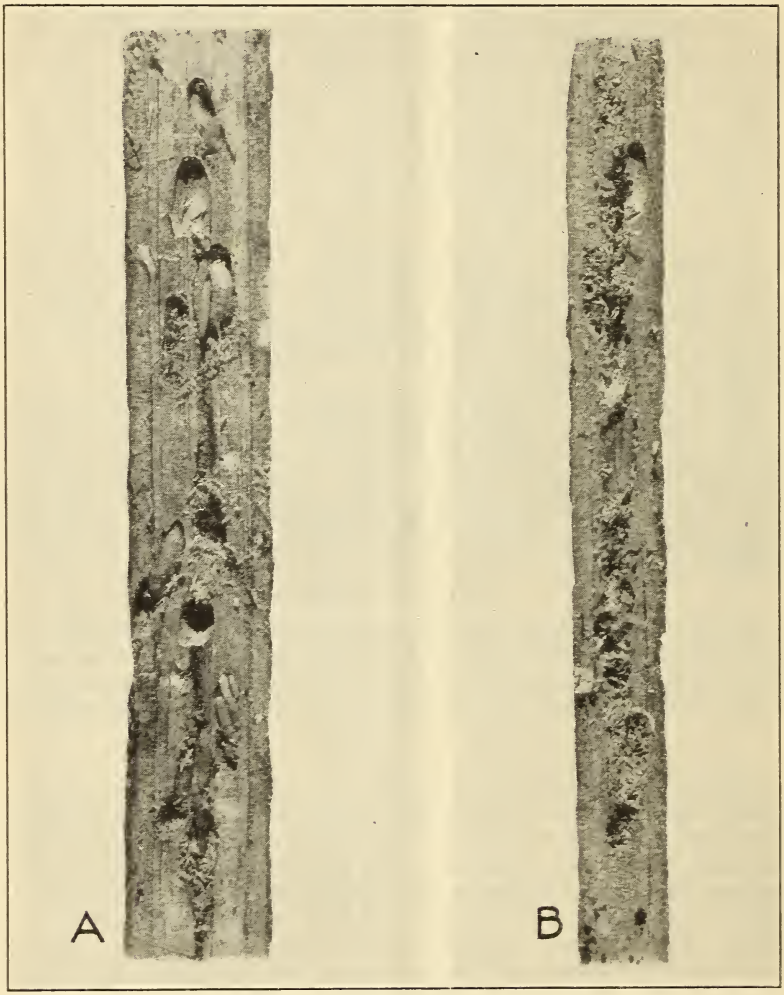

FIGURE 11.—Larvae of *Lonchaea corticis* in the larval tunnels and pupal chambers of the white-pine weevil

there appeared to be *Eurytoma pissodis* and *Lonchaea corticis*, which also seem to be the most common over the entire range of the weevil. However, in certain other areas in these Provinces there was little parasitism.

To get some idea of the probability of control by these beneficial insects, infested leaders were caged in suitable containers and placed

in the plantations. The mesh was large enough to allow the escape of the parasites but not of the weevils. No noticeable decrease in weevil attack was apparent for several seasons in any of the areas treated in this manner. In one plantation, where the trees were just becoming susceptible to attack, the infestation increased 600 per cent in one year. Where young pure stands are surrounded by an abundance of natural pine, it seems useless to hope for control, as these surrounding stands are the means of reinfestation year after year and, furthermore, there is no assurance that the parasites and predators will stay in that particular stand.

Graham (*8*) reported the rearing of a clerid beetle (*Elasmocerus*) *Monophylla terminata* Say, from a leader infested with weevils, and that larvae were found in the infested terminals, evidently feeding on the weevil larvae. A larva of a species of Enoclerus feeding on a weevil larva was taken in southern Pennsylvania in the autumn of 1928. Packard (*16*) also reported that the larvae of tenebrionid beetles are very commonly predacious on the white-pine weevil larvae. In New England the writer has taken adults of the clerid *Thanasimus dubius* Fab. as they were in the act of running up and down weevil-infested leaders.

BIRDS AND OTHER ANIMALS

The value of birds as an aid in preventing the increase of the white-pine weevil through destruction of the larvae was shown very strongly during the summers of 1926 and 1927. In every place visited the writer found that large numbers of leaders had had the bark stripped from the wood by birds, and the larvae contained therein had been eaten by them or had dropped to the ground to die or to be eaten by the various ground-feeding species of birds and rodents which are numerous in the stands. In practically all the leaders examined (several hundred) all the larvae which had been feeding at the time the bark was stripped had been destroyed. Many of the pupae, in addition, had been picked out of their chambers. The birds observed were the white-breasted nuthatch, downy woodpecker, chickadee, rose-breasted grosbeak, and certain unidentified warblers. McAtee (*13, p. 115*) reports that the Bureau of Biological Survey has records of the yellow-billed cuckoo, English sparrow, and bluebird feeding on this pest. Hopkins (*9*) reported the downy woodpecker in 1907, and Felt (*5, p. 30*) reported this same species in 1913. Forbush (*7, p. 254*) in 1913 also reported this species and the chickadee. Taylor (*20*) states that 17 or 18 per cent of the larvae in 3,009 infested shoots were destroyed by birds and that the birds were "about 29 per cent effective in attacked shoots."

Graham (*8*) reported the partial check of the weevil in one plantation in New York by allowing chickens to run among the trees, and suggested the possibility of destruction of the weevils by ground-feeding birds.

The various field mice, wood mice, and shrews are insect eaters, and the fact that runways can be found in the litter at the depth at which the weevils hibernate indicates that these species probably take their toll of the weevils during the hibernation period.

PREVENTION OF ATTACK BY THE WEEVIL

SPRAYS AND REPELLENTS

Experiments to determine the feasibility of stomach poisons and repellents as measures of control have been conducted by several investigators in various parts of the range of this insect. Good results have been obtained by the writer with dry lime-sulphur in the proportion of 10 ounces to 8 quarts of water with a spreader added, and with dry lead arsenate in the proportion of 2 ounces to 8 quarts of water, also with a spreader. Both were used as repellents. A good spreader or sticker is necessary so that the film of spray will adhere for the entire period of oviposition. Calcium caseinate was used as a spreader in these experiments, but it is believed that ordinary laundry soap in the proportion of 1 cubic inch to each gallon of spray material will be as suitable, and it is more easily obtained. For the two treatments mentioned above, the costs were $1.70 per acre for the lime-sulphur and $1.45 per acre for the lead arsenate. This cost is mostly for labor—about $1.25 per acre—as the materials are relatively inexpensive. The cost of labor is too high for widespread use of this measure in plantations or natural stands, but it would be an effective one for ornamental or shade trees.

BANDING MATERIALS

Banding the leaders with some material which will prevent the weevils from getting to them, except on the wing, was very effective for one season with the materials used and reduced the rate of weevil attack in severe infestations very noticeably. Sticky tree-banding material and raw wool have been used and in each case the infestation was reduced more than 50 per cent. Neither of these materials will last more than one season; the tree-banding material becomes hardened by the weather and the raw wool is blown off by the wind or removed by birds for nesting purposes. The main disadvantage, however, is the cost. Much time is required to apply the bands properly, and the tree-banding material is expensive and the raw wool scarcely less so. The cost in a young plantation will run into several dollars per acre per year. This method is practical for ornamental trees, but the raw wool in particular gives the leaders an unsightly appearance.

DIRECT CONTROL OF THE INSECT

PICKING THE WEEVILS BY HAND

Two instances have been reported where the weevils were picked from the leaders by hand. The cost was not considered, but it is estimated, on the basis of 50 cents per man-hour, to have been about $2.50 per acre. One of the operations had a distinct effect on the amount of infestation for two or three years, but by the end of that period the infestation was again rising high. This method is limited to trees within reach of the hand, and care must be taken to prevent the weevils from becoming aroused and dropping from the leader.

JARRING THE WEEVILS INTO A NET

The collection of the adults from the leaders during the short feeding period after they have come out of hibernation has often been advanced as a means of control. Several collections must be made in order to get all the weevils, as they do not emerge simultaneously. As the adults feed on the buds and take refuge there during unseasonable weather, these must also be examined. Jarring the leader on one side with a fairly heavy stick so as to knock the weevils off into the net on the opposite side is the best way to collect those on the leader itself, but those in the buds must be picked out, as they can not be dislodged by jarring. This method is practical with ornamentals and possibly in young plantations which are isolated, but the cost—at least $1.25 per acre per year—in an extensive plantation is prohibitive. Possibly a combination of bands of sticky tree-banding material and jarring would be suitable for isolated shade trees.

REMOVAL OF THE INFESTED LEADERS

The removal of the infested leaders after they have wilted and before the adults have emerged has been recommended for many years as a means of control. In areas where there is natural pine in the surrounding country, from which the treated areas could be reinfested, this is an impractical method for forest plantations or natural stands. Where there is a scarcity of pine in the neighborhood or where the plantations are of aesthetic value, removal of the leaders is practical only where they can be reached by hand. It will be necessary to go over the stand at least twice each season, the second time to remove those leaders that were missed the first time and those that have wilted since the first operation. The first operation should be conducted about the beginning of July and the second about one month later.

As the leaders are removed they must either be burned or be placed in tight receptacles. Burning is the one certain means of killing all the larvae and pupae, but if the leaders are placed in screened receptacles and left in the plantation the parasites will not be killed. These receptacles should remain in the plantation until the following spring, in order that some of the parasites which do not mature until that time may escape. Fourteen-mesh wire screening is recommended, as this allows the escape of all the primary parasites.

This method is not practical in forest plantations where there is liability of infestation from surrounding areas, as the cost of removal may exceed $1 per acre per year. When the trees are under 8 feet in height the cost should not be more than 25 cents per acre per year, if this method is to be an economic possibility. Above this height the cost will be greater, depending on the height of the trees, the extent to which the stand has closed, and the severity of infestation. The greater value of the stand, however, may warrant the expenditure.

Maughan (*14*) has shown that the removal of infested leaders in plantations in the Eli Whitney Forest, near New Haven, Conn.,

is economically possible in that locality. The total cost until the trees were 17 feet high (the equivalent of a log length of 16 feet) averaged about $5 per acre. This can be considered reasonable. But the plantations in question are not in a locality subject to severe infestations, and there is very little, if any, natural white pine near by. In 1930 the cost of removal of weeviled tips on all the plantations treated was 59 cents per acre. The lowest cost of 27 cents per acre was in a plantation of 102.3 acres, where the average height of the trees was 7 feet. The higher costs, ranging from 47 cents to $1.33 per acre, were in plantations totaling 183.7 acres, where the average height was over 8 feet. The average number of infested tips removed from the entire acreage was 46 per acre, the cost of removal of each one being about 1¼ cents if the average of 59 cents per acre is considered.

The writer removed 4,089 infested tips from a 3½-acre plantation in Petersham, Mass., over a period of three years, during which time the annual infestation in that area was severe. The cost of this treatment at even 1 cent per tip would have averaged over $5 per acre per year, which is prohibitive. The infestation was reduced 50 per cent at the end of the third season, but the cost of removing 1,000 tips the third year would average, at 1 cent per tip, nearly $3 per acre. By that time the average height was well over 8 feet and the project was given up because of the excessive cost of operation.

In 1927 the New York Conservation Department removed and burned the infested tips from 1,580 acres of plantations near Saratoga, at an average cost of 24 cents per acre (*15*). On 80 acres, where the height of the trees was in some cases 15 feet or more, the cost averaged $3.65 per acre, but it was believed that this figure could be reduced with more experience. In this area the number of infested tips per acre averaged about 210, which was nearly five times the average for 286 acres in the Eli Whitney Forest; hence the higher cost.

SILVICULTURAL METHODS OF CONTROL

Because of the probability, indicated in previous studies by Blackman (*1*), Pierson (*18*), and Graham (*8*), that control of the injury by silvicultural measures will, in the long run, prove to be the cheapest and most effective means of minimizing weevil damage, the chief stress in the investigation was placed on this phase of the subject. Study of the silvicultural methods practiced in such forests as that maintained by Harvard University at Petersham, Mass., has demonstrated that in a groupwise mixture [6] of white pine and hardwood the weevil damage is relatively small. Special attention was given to determining the prevalence of the weevil and the damage done by it in stands of different composition and on different sites. This information was obtained through the study of sample plots laid out in various parts of the States of Massachusetts, Connecticut, Vermont, New Hampshire, New York, Pennsylvania, and North Carolina, and in the Canadian Provinces of New Brunswick and Nova Scotia. The size of these plots varied, depending on the site and

[6] See p. 26 for definition.

forest conditions, but most of them were one-tenth or one fifth acre in area. Unless some particular condition was to be studied, stands were chosen in which the conditions were average. The information from these plots is in accord with that secured from previous studies in indicating clearly that under certain forest conditions the injury may be substantially decreased. Weevil damage is more prevalent in stands where the growing conditions are not of the best and there is not a reasonable minimum stocking. It can not be expected that a stand will be free from insect or other damage unless it is maintained at a reasonable standard of density and vigor.

DENSITY OF STOCKING

If growing conditions in the stand are optimum, density of stocking will tend to keep weevil injury at a minimum. (Fig. 12.) Both Peirson (*18*) and Graham (*8*) state that this minimum amount of damage can be expected at the end of a rotation if a fully stocked stand of from 1,200 to 1,500 trees per acre is maintained throughout the early years, and thereafter a fully stocked stand according to age-class requirements. This will hold where there is a light infestation, but where the average infestation every year is nearly 50 per cent, as is often the case in the "weevil country" in central Massachusetts even when the trees are 15 years old, it would appear that a greater number of trees is desirable. In the main, however, if this density is not maintained, the stand will be below the standard necessary to produce a good crop. Throughout the range where it can reproduce itself in pure stands on abandoned pastures, there are many thousands of acres of old-field white pine which are in good shape. In these stands the growing conditions and stocking are such that the trees are vigorous. Sparsely spaced stands, such as those which come in on medium soils in abandoned pastures, will generally be quite heavily infested. In a closely spaced stand of trees at 15 years of age only a small percentage will be in the dominant and codominant classes, and after the stand has reached a height of 30 feet it may be necessary to remove the suppressed trees in order to allow the remaining trees to develop more rapidly. The denser the stand the greater will be the tendency, owing to the competition, for the trees to produce relatively straight stems when infestation does occur.

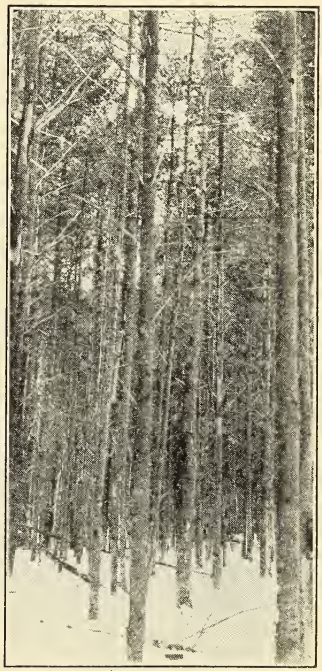

FIGURE 12.—Density of trees in pure stand resulting in minimum injury from white-pine weevil attack. (Courtesy of Harvard Forest)

Control of the weevil by dense planting is impractical from a monetary standpoint. The cost of planting in spacing closer than 6 by 6 feet is generally prohibitive; and at the present time, in most localities, a spacing which will give more than 1,500 trees per acre is

not considered in planning for a future forest unless it can be procured naturally. It appears, however, that on light sandy soils, where the weevil damage is not so severe as on the old-field medium soils, a densely stocked plantation for watershed protection or ornamental purposes would be practical.

A disadvantage with which the forest owner will have to contend, if a pure stand is produced, is the lack of natural pruning. In a pure stand the lower branches will often persist for at least two-thirds of a 60-year rotation, and the wider the spacing the larger will be the branches. Therefore, when the trees are removed there will be little clear lumber. While this disadvantage may not be so important as the high cost of original planting, it is a factor which must be considered if high-grade lumber is expected when the crop is harvested.

Under certain conditions artificial pruning of the best trees in a stand is a profitable undertaking. Cline and Fletcher (*3*) have shown that pruning badly infested dominant trees is not profitable but that a large profit can be expected if the pruning is confined to well-formed, small-limbed dominant trees. Subsequently Cline and MacAloney (*4*), investigating the possibility of reclaiming severely infested white-pine plantations, have concluded that such plantations can be improved in a marked degree and that the operation is economically feasible. Briefly, the treatment is one which involves seeking out the least-injured trees with due regard for crown class or vigor, and spacing and favoring them for development as final crop trees. This treatment completely upsets the usual course of development of a stand in that it takes away leadership from dominant trees, which are usually of little value because of the weevil injury, and turns it over to subordinate trees, which normally would be suppressed or killed before the crop reaches maturity. If, in addition, quality growth is made possible in the selected trees by pruning the lower portion of the boles, a crop of trees having valuable lumber in the butt logs will result. Since nearly one-half the entire volume of a tree grown in the ordinary rotation of 50 to 55 years is contained in the first 14 to 16 feet of bole, this procedure is amply justified. Study of plots laid out in the course of this investigation showed that approximately 275 trees in the codominant and intermediate crown classes were available, considering form and spacing in the stand, for the future crop, and according to good silvicultural practice this is more than enough.

PRODUCTION OF MIXED STANDS

There is abundant proof that the most advantageous way to protect white pine from the weevil is to grow it in mixture with some other species, such as the better hardwoods, that will be of value in the final crop. Investigators have suggested that the reason for this is the shading of the pines from the sun and the protective barrier against flight afforded by the accompanying trees. As stated previously, the weevils evidently prefer to feed on and oviposit in leaders of trees in pure, open stands. It has been definitely established (*11*) that where white pines grow in certain mixtures, such as with hardwoods, those which are infested show a high degree of mortality of the weevil in the larval stage and a low percentage of emergence of the adults. In mixed stands many leaders have been

observed in which eggs were laid and which have recovered completely.

The choice of the other species in the stand will be determined largely by the economic conditions in any given locality. For example, the better hardwoods, such as oak, ash, and sugar maple, might be used in southern New England, where in the future there should be a ready market for lumber of these species. Care must be taken, however, in regions where the gipsy moth is abundant, to avoid the use of hardwoods which may be subject to excessive defoliation by this insect. Ash, sugar maple, and yellow birch are some of the species that are not favored foods of the gipsy moth. In Maine and the Maritime Provinces there is more likelihood of a market for pulpwood from both broad-leaved and coniferous species, and consequently a mixture with such species would be desirable. Except where fuel wood is desired, it is doubtful if it would be advisable to allow the poorer hardwoods, such as gray birch and fire cherry, to grow.

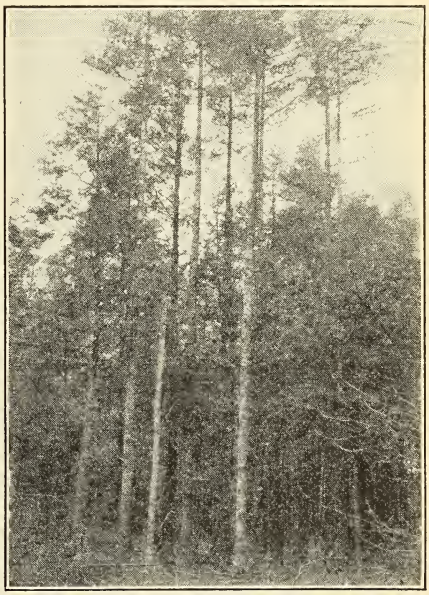

FIGURE 13.—Mixed white pine and hemlock, showing straight pines without white-pine weevil infestation. (Courtesy of Harvard Forest)

White pine growing naturally in mixture with other species is also common throughout the range. When growing with older and taller hemlock, it is usually of good form and high quality. (Fig. 13.) However, hemlock of the same age as white pine is smaller, does not offer good protection, does not command a good price, and therefore is unsuitable in many localities in a short rotation. In parts of Maine and the Maritime Provinces white pine grows naturally with the spruces and fir. In most of the stands studied the pines are dominant now and are of good form, but their number per acre is small. Infestation has occurred only occasionally. The annual growth of the spruces is usually less than that of the pines and unless they are older there would not be enough protection against the weevil to make such a mixture worth attempting. There is no danger of whipping in these stands, however, and a groupwise planting might be made in localities where these species are already present in large numbers. It appears that white pines growing with red pine, pitch pine, or larch, whether naturally or in plantations, are generally infested considerably unless the white pine is the understory. In Nova Scotia and New Hampshire there are a number of good stands in which the red pines are much older and the protection seems adequate. In all white pine-larch mixtures studied the pine was considerably damaged by the weevil. In one

locality in central New York a mixture of Scotch pine and white pine in alternate rows appears to have given good protection. The Scotch pine grows faster than the white pine in the earlier stages of its life, and its branches tend to spread laterally to a great degree, thus possibly giving a certain degree of protection after the white pine has been outstripped. Most of the white-pine trees which are in the uppermost part of the crown canopy have been infested, while those at least 2 feet below the Scotch pine have not been infested to any extent. Figure 14 shows this protection and, furthermore, shows that the infested white pines were always taller than the noninfested trees.

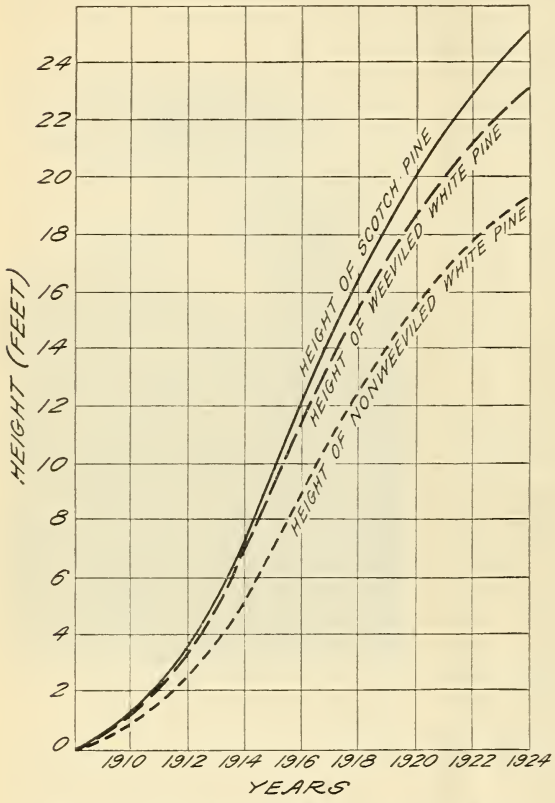

FIGURE 14.—Average annual heights of Scotch pine and of infested and noninfested white pine in even-aged mixture in alternate rows

There are two ways in which white pine is found naturally in mixture with other species, stemwise and groupwise. Both kinds of mixtures afford good protection against weevil attack. A stemwise mixture has the species mixed in singly over the area and the white pine is in danger of whipping if there are hardwoods present. A groupwise mixture has groups where pine is the dominant species surrounded by groups in which the other species are dominant. (Fig. 15.) This often occurs after logging or fires. The maximum protection is obtained in such a mixture where the pines are allowed to dominate the groups in which they are most numerous and vigorous. Adequate protection will be afforded by the species in the surrounding groups, and in addition there will be little danger of whipping. Groups of pine should not be larger than one-tenth acre and generally smaller. Larger groups tend to have the same status as a pure stand. Once weevils are established they may remain and do great damage. The old-field white pine stands usually have a dense understory of hardwoods, with spaces where the shade is dense. After a cutting operation, if the pines do not

seed in naturally, the spaces can be filled by planting and the necessary groupwise arrangement obtained. In open country the same groupwise arrangement can be had by planting in groups or blocks. If the accompanying species is coniferous, it should be one that is not liable to attack by the weevil, and it should be planted several years before the white pine; otherwise it may be overtopped if the white pine grows faster, and there will not be sufficient protection against the weevil. It is probable, however, that at the time of cutting many of the present pure-pine plantations will produce fairly good lumber if the trees are not repeatedly infested. In fire barrens, such as are found in Nova Scotia, where groups of hardwoods have come in, the open spaces can be filled in with white pine

FIGURE 15.—The groupwise system of growing white pine and hardwoods to protect the former from white-pine weevil attack. (Courtesy of Harvard Forest)

and the maximum protection can be expected. By judicious weeding, so that the pines will not be crowded out, the pine groups can be kept fairly well segregated, and the final stand will contain groups of pine of much better quality than can be grown in pure stands. Weeding will be necessary in the early years to prevent crowding and abrasion, and thinnings will have to be made systematically as the stand becomes older.

Aside from the protection offered, another advantage in growing pine in mixture with other species is that it cleans itself relatively early in life and the boles will be clean for some distance. There will not be so many white pines in a mature mixed stand, but those surviving will be clean-boled and straight. In a region heavily infested with weevils, it is probable that little of the pure pasture pine or that in widely spaced plantations will be straight and free enough of limbs to produce high-grade lumber.

SUMMARY

The white-pine weevil is the most serious insect pest attacking the white pine (*Pinus strobus* L.). The leading shoot is killed, resulting in loss in height and diameter, and often in poor form. The timber value is also materially affected; lumber sawed from infested trees usually shows large knots, and crooked boards are common.

The adult weevils hibernate mostly in the lowest layer of litter, just at the ground surface, under trees fed on during the fall, and occasionally at the bases of trees cut during the late summer or fall. The trees fed on may or may not have been infested that season. Under favorable conditions, young adults and full-grown larvae from eggs laid late in the season may hibernate in the leaders.

Activity is resumed in the spring about the time the buds begin to swell, and the period of egg laying corresponds rather closely with the period of accelerated height growth. This period depends on the growing season and the weather conditions. The new generation feeds on the tender inner bark of the tips of branches and leading shoots but does little damage compared with that done in the spring. Feeding ordinarily continues until settled cold weather prevails and then the weevils go into hibernation. There is but one generation a year. Fertilization of the female may take place in the fall.

The adult weevils in both spring and fall are relatively strong fliers. They can fly for considerable distances when wafted by the wind and can thus reinfest an area in a short time. The air temperature necessary to cause the weevils to take flight appears to be between 70° and 80° F. Both sexes will fly directly to the leading shoot, but the majority probably strike the trees lower down and crawl up the stem to the leader. In the early spring, before warm weather prevails, many of the weevils reach the leading shoot by crawling up from the ground.

The intensity of infestation depends primarily on the quantity of food available, the weather factors (chiefly temperature), the soil conditions, and the exposure. Adults feed and oviposit more readily on trees in pure widely spaced stands than on trees in pure dense stands or those in mixed stands of pine and other species, such as hemlocks or hardwoods. Stands on sandy loam soils generally show the most severe injury, although stands on light sandy soils may have as many trees infested per acre. Plantations or stands on sunny exposures are more likely to be infested than those on exposures protected from the morning sun.

Direct control measures are generally too expensive for common practice. In isolated stands, where the infestation is low and the danger of reinfestation is slight, or in stands which are being preserved for their aesthetic value, such control measures may be used advantageously. Infestation in stands which are subject to attack from surrounding areas year after year can sometimes be checked, but not controlled, by the removal of the infested leaders, by the collection of the adults during the spring feeding period, by spraying, or by banding the leaders. The cost of these treatments, often a dollar or more per acre per year, is prohibitive over wide areas.

The breeding and liberation of parasitic and predatory insects in infested areas is an uncertain measure of control. The cost neces-

sary for breeding and liberating a number sufficient to have an appreciable effect would be too great to make such a project economically practical over a wide area at the present time.

Insectivorous birds are valuable control agencies, and they should be protected and encouraged in pine woodlands.

In pure stands, both natural and artificial, the greater the number of trees per acre the smaller will be the percentage of weevil infestation. A dense stand is economically practical only when it can be produced naturally at a density high enough to offset any weevil infestation which may occur. Where conditions of the soil and the stocking are favorable for vigorous growth, good stands of merchantable old-field white pine are common.

The most advantageous and cheapest way to protect white pine from the weevil and to control the injury is to grow it in mixture, preferably with species that will be of value in the final crop. The choice of the other species will be determined by the economic conditions in any given locality. Weedings in the early stages, if the mixture is with hardwoods, and thinnings as the stand becomes older will be necessary so that the pines will not be crowded out. There will be fewer white pines in a mature mixed stand than in a pure stand of normal stocking, but those surviving will be clean-boled and straight, and the monetary value of the whole crop will be greater.

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