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Pine Root Collar Weevil— Its Ecology and Management

Cover picture- A red pine (*Pinus resinosa* Ait.) girdled and killed by pine root collar weevil larvae.
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Pine Root Collar Weevil- Its Ecology and Management

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Contents

Introduction

The pine root collar weevil, *Hylobius radicis* Buchanan, became a serious forest pest in North America after the planting of hard pines was increased in the 1930's. Felt (1926) gave the first precise account of its damage when he recognized that the injury to Scots pine, *Pinus sylvestris* L., at Ballston Spa, N.Y., differed from that caused by the pales weevil, *H. pales* Herbst. He thought it still might be the pales weevil, but in a new role. Further studies of the insect's morphology as well as numerous details in the life history, however, prompted Buchanan (1934) to assign it a new name: *H. radicis.*

Since the 1930's the weevil has appeared in many parts of eastern North America where pine has been planted. In spite of attempts at control over the years, it has ruined many stands. The pine root collar weevil continues to infest young stands, substantially affecting the thousands of acres of pine planted yearly for forest products, Christmas trees, and other uses. In fact, its impact is increasing, primarily because many plantings are being established in high-risk areas and on less-than-desirable site-situations conducive to weevil outbreaks and rapid tree decline.

In recent years, research has provided much new information about the behavior, habits, and ecology of the pine root collar weevil; management guidelines are now available that are generally compatible with contemporary forest management practices. We have assembled and synthesized this information here. For the convenience of the forest entomologist and forest manager, this bulletin is divided into two major parts. The first part presents the biology and ecology of the weevil and various proven and proposed control strategies. The second part presents survey techniques and guidelines for managing the weevil in forest, ornamental, and windbreak plantings.

Insect Description

Taxonomy.-*Hylobius radicis* Buchanan, described fully by Buchanan (1934), is in the order Coleoptera, family Curculioniadae, tribe Hylobiini. The approved common name in North America (Entomol. Soc. Am.) is the pine root collar weevil, but it has been referred to in the literature as Scots pine weevil, pine crown weevil, and pine root weevil. Its French name, used in Quebec, is *charancon du collet du pin.* Figure 1 shows its four live stages-egg, larva, pupa, and adult.

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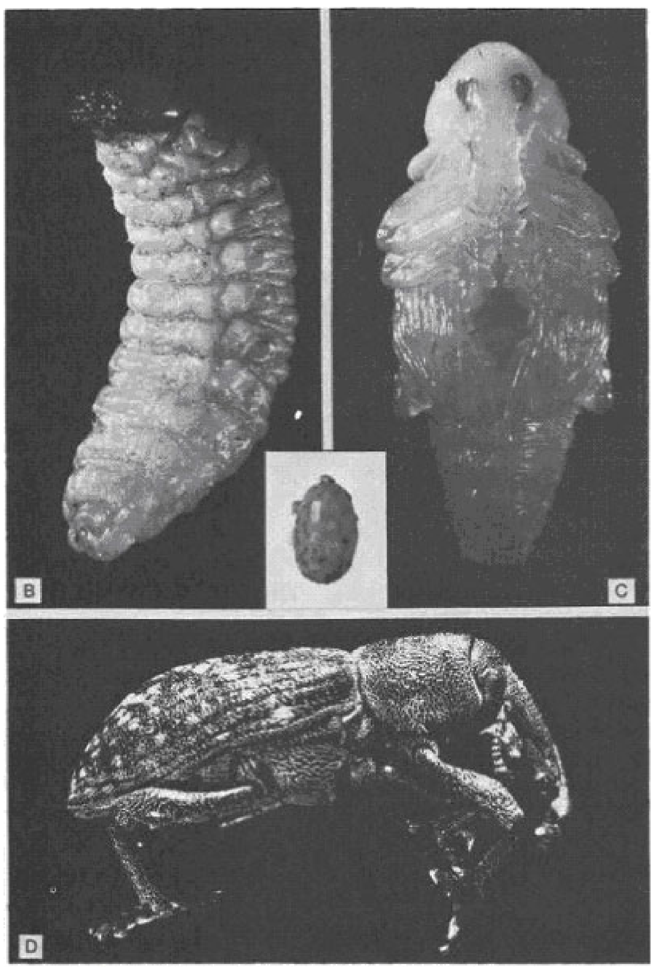

Figure 1.-Life stages of the pine root collar weevil: A. egg, B. larva, C. pupa, and D. adult.

Adult curculionids of the tribe Hylobiini have large, dark bodies frequently speckled with whitish or yellowish scales. The apex of each tibia bears large corbels, separating them from Pissodiini weevils such as the white pine weevil (*Pissodes strobi* Peck).

Germar (1817) first described the genus *Hylobius* and Schoenherr (1826), later characterized the genus, and designated a type species. *H. pales* was the first North American represeptative (Pierson 1921). Seven species of *Hylobius* are currently recognized in North America (Warner 1966).

The adult weevils in the genus *Hylobius* are characterized by beaks that are stout, cylindrical, and curved slightly down-ward. The antennae are stout, with the scapes barely reaching the eyes. The antennal grooves are directed to the lower part of the eyes. Each of the first two segments of the funicle is longer than segments three to six, which are moniliform; the seventh segment is larger, broader, and a part of the club. The eyes are large, coarsely granulated, transverse, and separated by a distance equal to the eye diameter. The femurae are club-shaped and feebly sinuate. The tibiae are slender and slightly sinuate on the inner side. The corbels are narrow and the uncus strong and pointed. Ventral segments two and five are wider than either three or four. Keys to the species of *Hylobius* have been designed by Warner 1966, Finnegan 1961, and Goyer and Hertel 1970.

Egg.-At oviposition the ovoid egg of *H. radicis* is glossy and pearly white; it becomes yellow during development (fig. 1). The mean length is 1.98 mm (± 0.08 mm S.D.) and the mean width is 1.10 mm (± 0.6 mm S.D.).

Larva.-The full-grown larva is falciform and white (fig. 1) with an amber-brown head capsule and pronotal shield. The length of the full-grown larva is 14 to 17 mm and the width of the head capsule varies from about 2.4 to 2.7 mm (Watson 1955).

The head, which is free, is widest at the middle. A narrow epicranial suture extends below the midpoint and bifurcates into slightly bisinuate epicranial arms, which end dorsolaterally at the antennae. The setal map of the head is as follows: five dorsal epicranial pairs, two lateral epicranial pairs and five frontal pairs (fig. 2A). The clypeus and labrum bear two setae each on the dorsum (fig. 2D).

The mandibles (fig. 2C, E) are thick, conical structures, with four teeth along the inner edge. The apical tooth is narrow and elongate, the second is shorter and more flattened. An arcuate crest posterior to this has a short third tooth, and at its base a minute fourth one.

The maxillae (fig. 2B) are larger and lightly pigmented. The stipes are broader at the apex than at the base and are sinuate on the outer margin. The maxillary palpus has two segments: the basal one is cylindrical and bears a short spine and two sensory setae near the distal margin; the apical one is bluntly conical and bears minute sensory setae at the apex. The labium is composed of a large postmentum and a smaller prementum. The labial palpus has two segments-the basal is larger and swollen, and the apical is short, conical, and truncate.

Each segment of the thorax (fig. 2F) has two dorsal lobes. The posterior lobe of the prothorax has a medially-divided shield.

The first seven segments of the abdomen are similar (fig. 2G, J). Each has three dorsal lobes, the first of which bears two short setae on each side. The second lobe is naked, and the third bears a transverse row of six shortened setae on each side. Above and posterior to the spiracle is a single, short seta. Ventral to the spiracle is a lobe with two setae, the upper one only half the length of the lower. The eighth and ninth segments (fig. 2H, J) have single dorsal lobes that are long and flat. The dorsal setae are reduced to two.

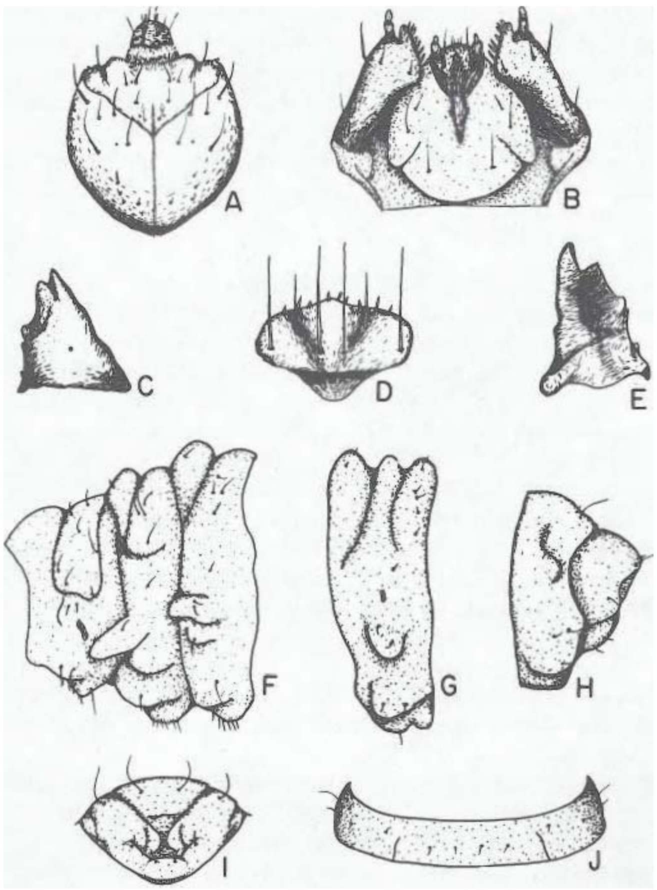

Figure 2.-Larval Morphology: A. head capsule (dorsal); B. head capsule (ventral); C. mandible (dorsal); D, labrum; E. mandible (ventral); F. thoracic segments; G. third abdominal segment; H. eighth and ninth abdominal segments; I. ninth abdominal segment (end view); J. third abdominal segment (ventral).

Pupa.-The exarate pupa of *H. radicis* is the same size and general shape as the adult weevil (fig. 1). It is white during development, but turns light reddish brown as transformation to callow adult occurs. Sexes are distinguished in the pupae by the folds and ridges of the last sternites (fig. 3A, B) (Millers 1965).

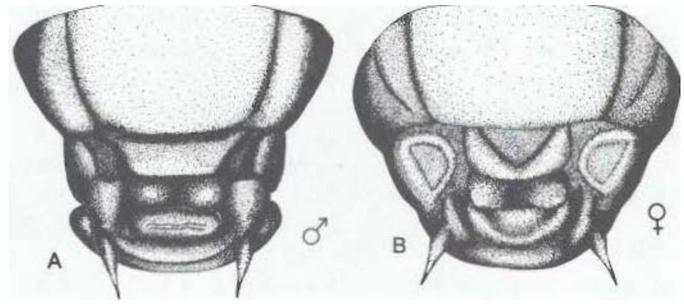

Figure 3.-Terminal abdominal sternites of pupae: A. male; B. female.

Adult.-The adult pine root collar weevil, according to Buchanan (1934), is characterized as follows. The weevil is rather large and robust, varying between 9.6 mm and 12.5 mm long, with most specimens between 10 mm and 11 mm. The body color varies from dark brown in young adults to black in older specimens (fig. 1). Small, whitish scales are scattered sparesely over the body, and larger ones form irregularly scattered, dense patches on the elytra. The rostrum is feebly arcuate, and as long, or a little longer than the prothorax. Dense punctures cover the surface of the elytra and generally, there is no smooth median line. The head is densely, finely punctate. The punctures behind the interocular fovea, though often larger than adjacent ones, are at most only slightly coalescent. Vestiture is fine, not condensed in a spot or line of coarser scales on the front. Strigose sculpturing on the pronotum is less developed than in the pales weevil. Hind tibial uncus of the male is rather narrow and generally

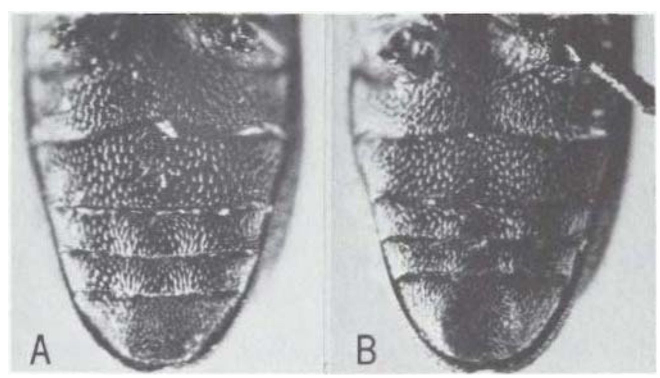

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Figure 4.-Abdominal sternites of adults; A. female; B. male.

with its sides converging toward the apex, which is subacute as a rule. This description would fit the majority of specimens. However, a small percentage intergrade with and are difficult to separate from the pales weevil.

Sexes differ by morphology of the last five visible abdominal sternites (nos. III-VII). In the female all these sternites are convex or somewhat flattened at the midline (fig. 4A). In contrast, those of the male are concave or depressed, forming a sulcus along the midline (fig. 4B). This saucerlike depression is most prominent on the last segment, and it alone sufficiently distinguishes the male from the female (Wilson *et al.* 1966).

Distribution

The pine root collar weevil is native to eastern North America (fig. 5). In the United States it is present from the Atlantic seaboard south into Virginia, westward through northern Kentucky, and northwestward through Minnesota. In Canada it is found from Newfoundland westward through the southern parts of all the intervening provinces to Manitoba. The distribution generally coincides with the range of its native hosts.

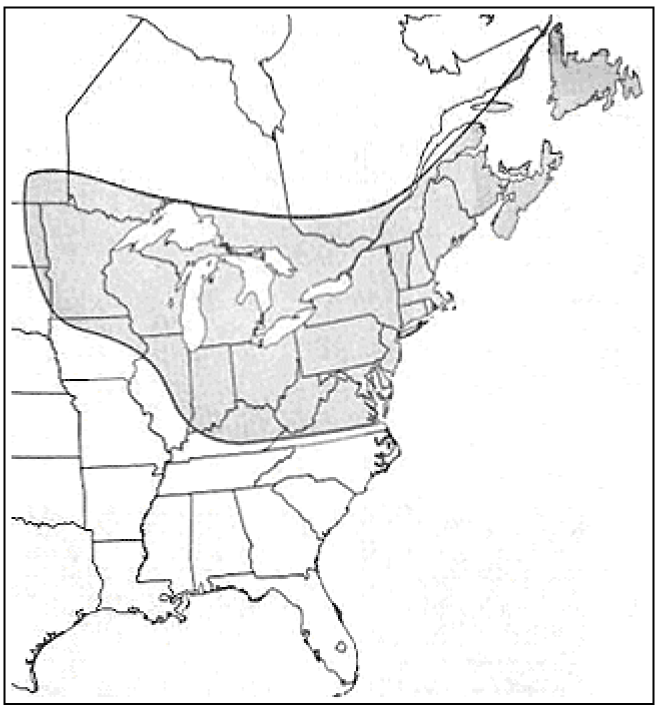

Figure 5.-Distribution of the pine root collar weevil in North America.

The northernmost locality known for this insect is in Newfoundland (Reeks *et al.* 1949), and the southernmost is in Kentucky (USDA 1964). The western limit of its known range occurs in pine stands in western Minnesota, and in an isolated mixed planting of Scots and lodgepole pines in the Sandilands Forest Reserve in Southeastern Manitoba (Prentice 1955). This latter infestation is of particular interest because the nearest known infestation is in central Minnesota several hundred miles to the southeast. Warren (1956a) speculated that the Sandilands infestation must have originated from endemic populations in natural stands of jack pine that comprise most of the forest cover in the Reserve. The occurrence of the weevil on lodgepole pine in Manitoba suggests a more western distribution than previously known.

Hosts

Several species of native and exotic pines are attacked by the pine root collar weevil, but order of preference is unclear (Finnegan 1962, Schaffner and McIntyre 1944, Schmiege 1958b). Adult weevils, for instance, selectively feed on shoots of eastern white, Scots, jack, and red pines, generally in that order when planted together or nearby. Frequency of attack at the root collar, however, is rare on eastern white, common on red and jack pine, and especially abundant on Scots pine in similar situations. Other pines are less commonly planted with these primary host trees, so ranking of their susceptibility is difficult at this time.

A brief description of weevil attack might be useful for better understanding host vulnerability. The female weevil, after choosing the tree, oviposits on or near the root collar. The larva, boring into the bark and cambium of the root collar and roots, destroys the growth and transport tissues. If sufficient amounts of tissue are killed, the tree dies or weakens and breaks over. Trees repeatedly attacked by new larvae each year succumb first. Small trees (5-10 cm, 2-4 in. in diameter at the ground line) need only two to five larvae for mortality or breakover-larger trees require more. The number of larvae needed to kill a tree also depends on the ability of the tree to withstand attack, its vigor, and its ability to recover from injury.

Below is some information on the known weevil hosts and on host tolerance or vulnerability to attack.

Scots pine, *Pinus sylvestris* L., is a European import that has long been associated with the weevil. Felt (1926) originally noticed this insect in a small Scots pine plantation near Ballston Spa, N.Y., where about 40 percent of the trees were dead. In the 1930's many infestations were reported, usually accompanied by severe damage. S.A. Graham, in an account of damaged pines in the Lake States, concluded that Scots pine was required for the survival of the weevil.[1] Trenk (1959) claimed that the weevil populations built up on Scots pine before infesting other pines. This is not necessarily true, however, because outbreaks have occurred without its presence. But Scots pine is certainly the least tolerant to attack

[1] Graham, S.A. Forest Entomologist. Memorandum concerning the insect situation on Upper Michigan forests, 1933 Sept. 10. On file at North Central Station, USDA Forest Service, East Lansing, Mich.

and succumbs the quickest. Repeatedly infested trees between 5 and 10 cm (2-4 in) in diameter at the base die about 3 to 4 years after infestation. Most other tree species of the same size can withstand 5 to 6 or more years of repeated attacks before mortality ensues. The preponderance of damage reports on Scots pine is undoubtedly related to its intensive management for Christmas tree culture.

S.A. Graham reported that Jack pine, *P. banksiana* Lamb., was not suitable for breeding of the weevil in an early report.[1] Trenk (1959) claimed that the insect built up in the exotic species before attacking jack pine. Our observationns and those of others, however, indicate that jack pine is one of the more commonly attacked hosts, and it is most likely the major natural reservoir for the insect. Jack pine withstands considerable feeding injury before it succumbs. Wind breakage commonly occurs with this species prior to tree death, especially if the trees are older than 20 years and have been attacked for many years.

Red pine, *P. resinosa* Aiton, closely follows jack pine in susceptibility to damage, although it was once thought to be highly resistant to attack. Finnegan (1962), in Onatrio, observed that this pine was attacked only when it was near other infested pines and that the attack generally occurred at an older age. Similary, in Manitoba, Prentice and Hildahl (1957) reported that red pines were damaged when planted among lodgepole and Scots pines. Observations over several years in the Lake States and other areas suggest that the weevil will readily attack red pine in pure plantations or windbreaks, but attacks are often earlier, spread faster, and result in greater mortality (Schmiege 1958a, Wallace 1954), when red pine is mixed with or adjacent to more susceptible species. Like jack pine, this species can withstand considerable feeding injury before dying, but trees are commonly windthrown when weakened.

Austrian pine, *P. nigra* var. *austriaca* A. & C., is planted as an ornamental and for Christmas trees from the Northeast to the Lake States (Felt 1938, 1940). Chambers (1955) rated it as one of the primary hosts of the weevil in Wisconsin. In mixed Scots-Austrian plantings we noticed that attacks on Austrian pine are relatively less severe. For example, in one 2-m (6.5-ft) tall Christmas tree planting with alternating rows of Austrian and Scots pine, these hosts had 1 percent and 20 percent mortality, respectively, in the fourth year after infestation began.

Corsican pine, *P. nigra* var. *calabrica* (Loud.) Schneider, appears to be a highly susceptible variety (Schaffner and McIntyre 1944). It is planted as an ornamental but, since it is not abundant, damage reports are uncommon. During the New England hurricane of 1938, fewer Corsican pines were wind-thrown than Scots and Austrian pines (Schaffner 1939).

Ponderosa pine, *P. ponderosa* Laws., is a western species planted occasionally in the east as on ornamental or in plantations. One mixed planting of ponderosa pine and Scots pine we examined suggested it is less susceptible to attack and mortality than Scots pine and perhaps about as susceptible as red or jack pine.

Pitch pine, *P. rigida* Mill., was among the first species noticed by Felt (1926) to be damaged by the weevil in New York. Schaffner and McIntyre (1944) considered it low in susceptibility. Millers (1965) noted that pitch pines planted in Wisconsin withstood considerable damage before mortality ensued.

Lodgepole pine, *P. contorta* Dougl., a western species related to jack pine (Tackle 1959), is planted occasionally within the range of the weevil, and it is present at the western edge of the weevil's range. Schmiege (1958a) reported damage to lodgepole pines in Minnesota and Millers (1965) found similar infestations in Wisconsin. In Manitoba, on the Sandilands Forest Reserve, lodgepole pines were severely damaged, with mortality about equaling that of Scots pine in the same plantations (Prentice and Hildahl 1955, 1956, 1957, 1958).

Mugo pine, *P. mugo* var. *mughus* Zenari, is planted mostly as an ornamental. Schaffner and McIntyre (1944) considered it more resistant to the weevil than other exotic pines, but Chambers (1955) ranked it highly susceptible to the weevil in Wisconsin.

Eastern white pine, *P. strobus* L., appears to be the most resistant of the host pines (Schaffner and McIntyre 1944, Schmiege 1958b). Damaged white pines are rarely found and then only when growing in the vicinity of heavily infested preferred host. We noted some dead white pines in two border rows of a planting adjacent to a severely infested Scots pine planting. We believe the larvae are normally not able to cope with the excessive pitch exuded by white pine, but in this instance population pressure most likely caused more than a normal attack level. The adults, however, seek out and readily feed on the bark of white pine shoots.

Life History and Habits

The life history of the pine root collar weevil presented here is a composite of our observations and others in states bordering the Atlantic seaboard, in southern Ontario, and in the Lake States; thus, it typifies development of the insect in an area roughly central to the north-south range (Finnegan 1962, Millers 1960, Schaffner and McIntyre 1944, Schmiege 1959, Wilson 1975). Seasonal development north and south of this central portion of its range could be curtailed or extended a few days or weeks depending on latitude and yearly weather patterns.

The time required for a single life cycle is about 2 years. That is, an individual requires about 2 years to develop from egg to

[1]Graham, S.A. Forest Entomologist. Memorandum concerning entomological observations on the Huron, Aug. 29-Sept. 16, 1933. On file at North Central Station, USDA Forest Service, East Lansing, Mich.

adult. But the adult may continue to live and reproduce for 2 more years, causing three generations to overlap.

Egg Stage.-Eggs are laid from early May to early September. At the latitude of central Michigan, eggs first appear in early to mid-May, increase in early June and peak in mid-June (Wilson 1975). Numbers decline thereafter, but often rise again to a small peak in late July, then steadily decline until the end in early September (fig. 6). The frequency of mating behaviour parallels the seasonal egg distribution even to a slight rise in sexual activity during the small peak in late July (fig. 6). In Ontario, egg laying also starts in early May but peaks in early July (Finnegan 1962).

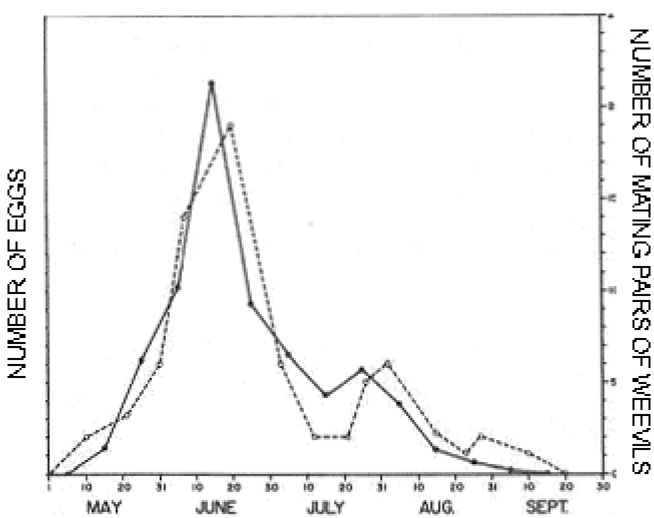

Figure 6.-Seasonal distribution of eggs (solid line) and copulatory behavior (dashed line) of adult weevils.

The number of eggs laid depends primarily on the age of the female weevils, with the younger ones generally laying more. In an insectary, the weevils averaged 18 eggs the first egg-laying season and 14 the second, with a maximum of 40 in one season (Finnegan 1962). In laboratory studies, they produced an average of 48 eggs/female, with a range of 40 to 64 in one season (Schaffner and McIntyre 1944). One female deposited 64 eggs during her first egg-laying season and 10 the next. Other laboratory rearings averaged 32 eggs per ovipositing female, but several females laid 60 or more and one laid 67 eggs (Millers 1965).

Eggs are laid in the root collar or in the soil within a few centimeters of the tree. A sample of 327 eggs collected from 100 different trees in Michigan (Wilson 1975) revealed 56 (17 percent) in the root collar tissues and 271 (83 percent) in the soil; no eggs were laid in the needle litter surrounding the tree. Eggs in the root collar tissues are usually deposited in small pockets in the inner bark (Finnegan 1962, Schaffner and McIntyre 1944). The female chews a cavity similar to a feeding wound but deeper and with a short chamber. An egg is then laid in this chamber and usually sealed in with a plug of tightly packed frass (fig. 7) (Millers 1965). The female weevil commonly deposits her eggs singly, but occasionally she may deposit two in the same cavity. She may infrequently lay an egg in the xylem, the surface bark, or the crevices between the bark and soil.

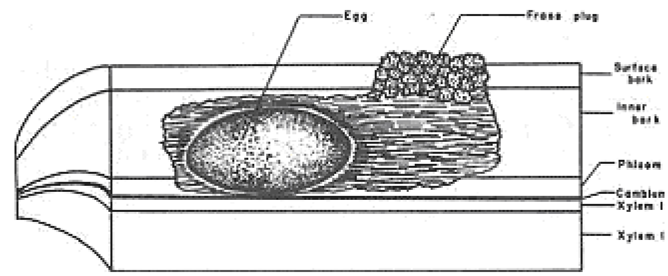

Figure 7.-Weevil egg in chamber in bark of root collar.

The majority of the eggs are laid at the ground line, but some can be found 16 cm (6.5 in) below the ground or 2.5 cm (1 in) above (table 1). Eggs tend to be laid deeper around trees that have considerable injury, probably because of the lack of good oviposition sites from heavy larval feeding, thus causing the insect to dig for undamaged sites. In dry weather, however, the female weevil may not dig at all because the pitch-drenched soil adjacent to the tree often cracks and separates around the root collar leaving an open crevice. Both sexes commonly inhabit these crevices on warm days.

Distribution of eggs in the soil is shown in table 2. Most eggs (88 percent) are nearest the tree-0 to 3 cm (0-1.2 in) from root collar and 0 to 3 cm (0-1.2 in) below soil line (Wilson

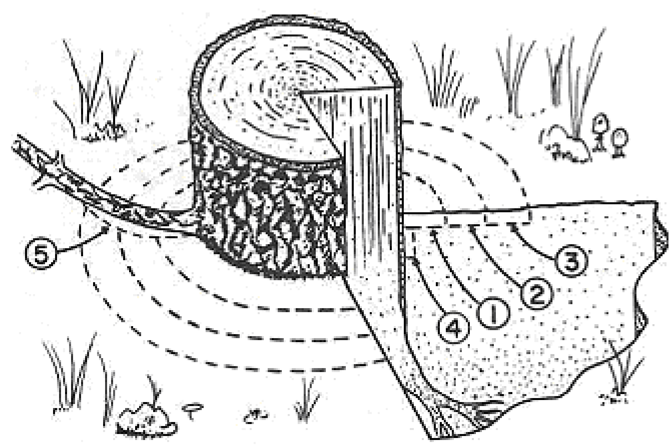

Figure 8.-Areas of weevil egg distribution in cm from root collar: 1. 0 to 3 cm; 2. 3 to 6 cm; 3. 6 to 9 cm; 4. 0 to 3 cm from root collar and 0 to 3 cm below ground line; 5. soil beneath branches that are touching the ground (see table 2).

1975); less than 5 percent are 3 to 6 cm (1.2-2.5 in) from the trunk and less than 1 percent are 6 to 9 cm (2.5-3.5 in) from the trunk. Schaffner and McIntyre (1944) reported that the female oviposits some of her eggs in the soil close to the tree, and Finnegan (1962) noted that eggs are often as far as 5 cm (2 in) from the tree. Eggs tend to be somewhat aggregated in the soil beneath branches that are touching the ground. About 93 percent of all the eggs, then, are in the zone that extends 3 cm (1.2 in) out from the root collar and 3 cm (1.2 in) down from the ground line. Of the remainder, about 2 percent occur under one or more branches and 5 percent are in other locations.

Table 1.-*Vertical distribution of pine root collar weevil eggs in the root collar and pitch soil surrounding infested trees*

	Distance from ground surface	Eggs	
	Cm	*Number*	*Percent*
Above ground	2	1	1.8
	1	1	1.8
Ground level	0	29	51.8
Below ground	1	10	17.8
	2	8	14.3
	4	2	3.6
	6	1	1.8
	8	3	5.3
	16	1	1.8
Total		56	100.0

Table 2.-*Distribution of pine root collar weevil eggs in the soil adjacent to the root collar (see fig. 8)*

Zone	Distance from root collar	Eggs	
	Cm	*Number*	*Percent*
1	0-3	103	38.0
2	3-6	12	4.4
3	6-9	1	0.4
4	(1)	136	50.2
5	(2)	19	7.0
Total		271	100.0

[1] Zone 4-0-3 cm (0-1.2 in) from root collar and 0-3 om (0-1.2 in) below soil line.

[2] Zone 5-soil beneath branches that are touching the ground.

Weevil eggs in pine plantations are aggregated or overdispersed, as are those of most insect populations (fig. 9), but the dispersion index is only 1.25 according to Taylor's Power Law (1.00 is random). This indicates a weak aggregation (Wilson 1975), and can be partially explained by behavior of the female weevils. In well-stocked pine plantations, each insect disperses mostly by walking from one tree to another almost every warm night (Wilson 1968b). Its movements regarding tree choice are nearly random, so that any tree has an almost equal opportunity of receiving a female each day. Once at a new tree a female may lay only a single egg or sometimes a pair each day. This means that few trees will receive many eggs and likewise few trees will receive zero eggs, a situation not encountered in highly over dispersed populations where many trees with zero eggs and many with high numbers of eggs would be expected.

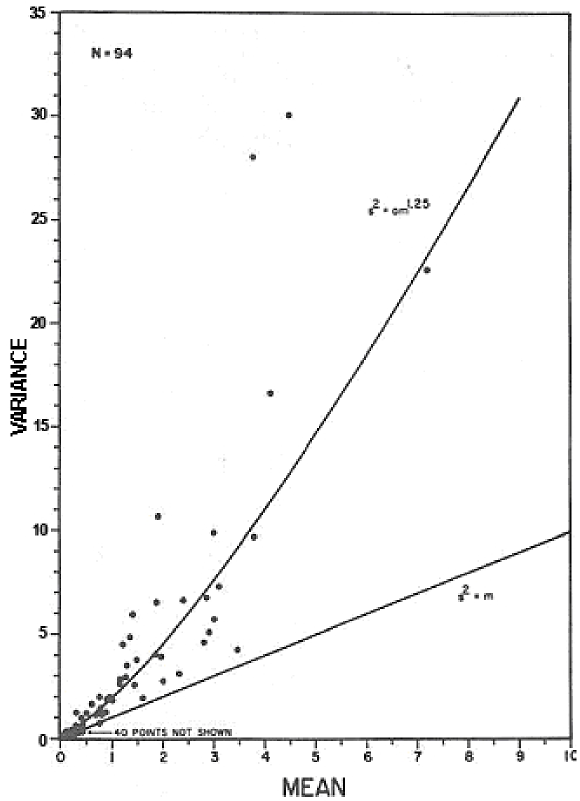

Figure 9.-Aggregated distribution of weevil eggs, based on the relation between intertree variance (S^2) and mean (m) number of weevil eggs per tree. Dispersion index $s^2 = am^{1.25}$ is based on Taylor's Power Laws. Equation $S^2 = m$ indicates a random relation.

Larvae from eggs reared in an insectary may eclose in 7 to 17 days depending on temperature (Finnegan 1962, Schaffner and McIntyre 1944) (table 3). When two cohorts of 70 eggs each were reared at 13 ° C and 28 ° C, the larvae eclosed in 23.3±0.8 days and 8.5±0.7 days, respectively (Millers 1965). Using Krogh's (1914) formula, one can show a developmental curve of eggs over a broad range of temperatures (fig. 10). At temperatures below 8.5 ° C, which is the theoretical threshold of minimum development, the weevil eggs do not develop (fig. 11). Using this threshold, 156 day-degrees are needed to reach larval eclosion. Northern areas where root collar area temperatures remain near 8.5 °C for much of the egg developmental period would not support many weevils; temperature is likely a major factor influencing the weevil's northern distribution. At about 18° C, a 1-degree increase in temperature brings about a 1-day decrease in the incubation period. At lower temperatures development is slower and at higher temperatures it is faster. Egg development is very sensitive to temperature changes under 12 ° C, but only slightly affected above 18 ° C (Millers 1965). Thus, a prolonged cooling of the root collar area (as occurs under heavy shade) should greatly influence egg development.

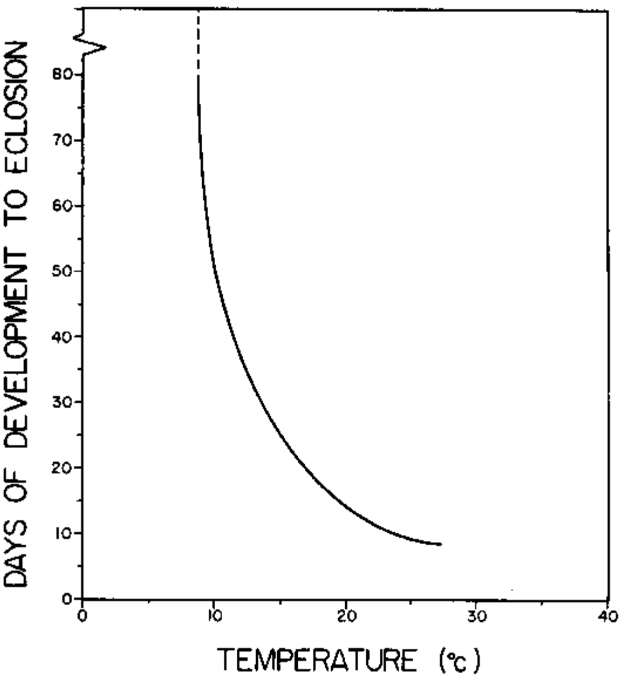

Figure 10.-Development of weevil eggs to eclosion relative to temperature

Table 3.-*Duration of immature stages of the pine root collar*

Stage	Duration in days Mean ± SD
Egg	14.5± 1.2
Larva I	8.6 ± 1.0
Larva II	8.3 ± 1.9
Larva I I I	9.5 ± 1.3
Larva IV	11.8 ±1.5
Larva V (prepupa)	27.5 ± 6.2
Larva V	17.0 ±4.0
Larva VI (prepupa)	31.0 ± 6.8
Larva VI	24.1 ± 4.4
Larva VII (prepupa)	28.2 ± 5.1
Pupa	19.8± 4.6

'Weevils were reared In an insectary in summer (after Finnegan P162.

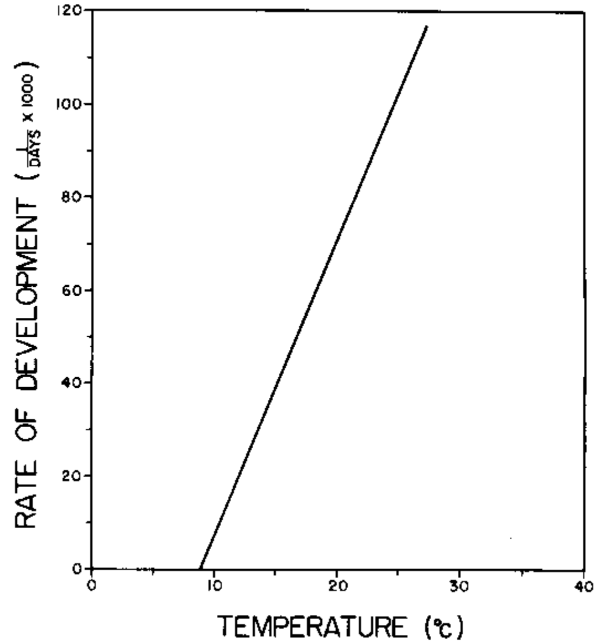

Figure 11.-Developmental rate over temperature for weevil eggs. (Thermal threshold of development is 8.5° C.)

Larval Stages.-Larvae eclose in the field about 2 weeks after the eggs are laid, and soon begin to feed and burrow in the host tissues-mostly in the inner bark of the root collar where they score the surface of the wood slightly. Most of the larval galleries occur on the trunk just below the soil surface, but some may extend 25 cm (10 in) below ground. Some extend along the larger roots and along buried lower branches (Millers 1965). Soil tunnels, which are extensions of the galleries in the tree, extend tube-like into the pitch-soaked soil surrounding the damaged root collar. These are usually perpendicular to the tree and plugged with frass at the points farthest from the tree. They are thought to protect the larvae during molting periods, and some perhaps are useful for channeling excess pitch flowing from the wounds. Tunnels that are completely free of pitch often contain cast larval head capsules (Millers 1965).

During development, the larvae pass through five to seven instars. Of 84 larvae reared from the egg stage to pupation, Finnegan (1962) found 7 females had 5 instars, 23 males and 22 females each had 6, and 23 males and 9 females each had 7. This indicates that the majority of females have six instars and that about half the males have six instars and half have seven. Head capsule width measurements of males and females overlap somewhat, but the mean values for the females are consistently greater than those for the males (table 4).

Table 4.-*Head capsule width measurements of 84 larvae of the pine root collar weevil*[1]

Instar	Head capsule width in *mm*			
	Female		Male	
	Number	*Mean* ± SE	*Number*	*Mean* ± SE
	38	0.790 ± 0.006	46	0.761 ± 0.005
I I	38	1.014 ± .007	46	0.954 ± .004
III	38	1.334 ± .011	46	1.238 ± .007
IV	38	1.647 ± .012	46	1.584 ± .010
V	38	1.961 ± .009	46	1.913 ± .012
VI	31	2.284 ± .012	46	2.227 ± .014
VII	9	2.610 ± .043	23	2.442 ± .028

[1] Data after Finnegan 1962.

At the approach of cold weather in autumn, the larvae stop feeding. They overwinter as third-to-last instar larvae in either the galleries in the bark or tunnels in the soil. Feeding commences the next spring after the soil warms sufficiently and continues until each larva becomes fully developed.

Shortly before pupation, the full grown larva enlarges a portion of one of the tunnels in the soil near the root collar, usually just below the soil surface. This becomes the pupal cell and insures easy escape later by the adult. Occasionally a cell may be constructed up to 25 cm (10 in) below the soil, in which case the emerging adult escapes to the surface through cracks and crevices nearby. Resin leached into the soil binds the soil particles of the cell walls into a hard shell-like structure (Finnegan 1962). Once settled in the cell, the insect lies quiescent for 20 to 40 days as a prepupa.

Larval populations are more abundant in open-grown plantations and less so in comparable dense plantations or those that have closed canopies (Schmiege 1958a, Millers 1965, Maki 1969). This may occur in part because the soils are considerably cooler under closed plantations (Della-Bianca and Dils 1960). Millers (1965) examined soil temperatures under open-canopy, border, and closed-canopy trees in 15-year-old, weevil-infested red pine plantation in Wisconsin over a 3-month period. He found that soil temperatures under open-grown trees averaged 2.5 ° C higher throughout the summer than under closed-canopy portions of the stand (fig. 12). Temperatures averaged 1.5 ° C higher under border trees than under closed-canopy trees. Also, insect development progressed faster on well-drained, sandy soils than on heavier soils-conditions recognized as producing warm and cool sites, respectively (Millers 1965).

Pupal Stage.-Pupation normally takes place between late June and mid-August. Most pupae develop in cells in the soil but occasionally a few are found in enlarged galleries in the bark of the root collar. They seem to survive and develop best when the atmosphere in their tunnels is near moisture saturation, but submersion in water for more than 1 hour is usually lethal. Heavy, persistent rainfall, which occurred during July

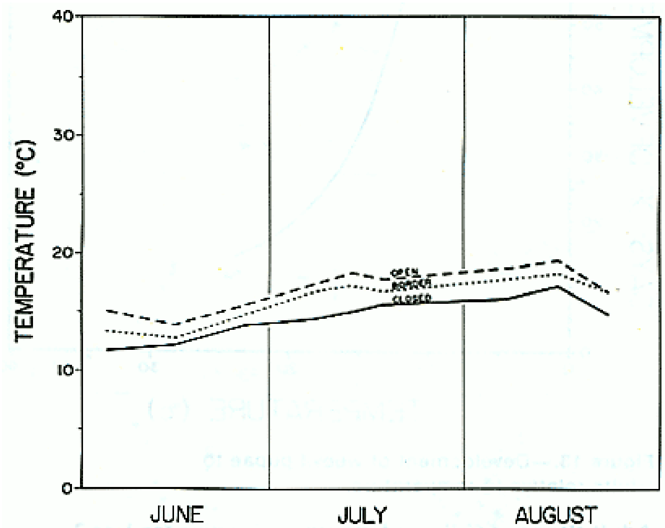

Figure 12.-Seasonal soil temperatures in a 15-year-old red pine plantation under different tree densities (i.e. open-canopy, border trees, closed-canopy) in central Wisconsin. Measurements were taken 15 cm (6 in) from trunk and 13 cm (5 in) below the surface.

1956 in Angus, Ontario, drowned 15 percent of the weevil pupal population (Finnegan 1962).

Pupae reared in an insectary in Canada developed to maturity in about 20 days (Finnegan 1962) (table 3), but the period is usually 30 to 40 days under natural conditions. Cool temperatures retard pupal development (fig. 13); the calculated threshold for minimum development of the pupa is approximately 8.5° C. While this threshold is the same as for the eggs, it is probably less critical to survival, because most pupation occurs in summer when soil and air temperatures are highest. At 8.5 ° C, 220 day-degrees are needed to reach adult eclosion. At 19 ° C, a 1-degree increase in temperature brings about a 1-day decrease in the incubation period.

Temperatures below 12 ° C greatly curtail pupal development time, while those above 20° C influence it only slightly (Millers 1965).

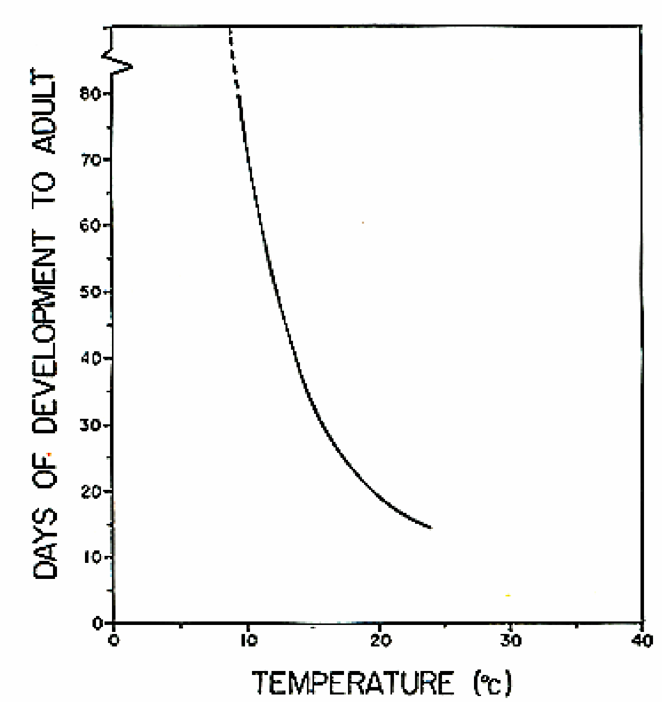

Figure 13.-Development of weevil pupae to adults relative to temperature.

Adult Stage.-Callow adults remain inactive for 1 or 2 weeks in their pupal cells before emergence between late July and early September. Males and females emerge at the same time by burrowing from their cells to the surface. The sex ratios of pupae and emerging adults are approximately equal.

Adults begin feeding on bark of pine branches soon after emergence and feed until the weather becomes unfavorable in late September or October. Then they crawl beneath the litter, into bark crevices, or enter the upper layers of the mineral soil near the base of the tree and hibernate. They re-emerge and resume feeding in late April or early May; copulation and oviposition soon follow. Adults overwinter a second time. Mating and oviposition occur again the following spring and continue into at least early summer. The lifespan of the adults may thus extend over parts of 3 calendar years, but the entire life span seldom exceeds 24 months.

From late April to October, adult weevils of both sexes exhibit daily cyclic behavior, so that their location and activities during the day differ considerably from those during the night. During daylight, the adults are nearly always near the base of the host tree. Ordinarily, 90 percent are within 15 cm (6 in) of the root collar, and more than 35 percent of these are adjacent to the tree. Rarely do adults venture beyond 45 cm (18 in) from the tree (fig. 14) during daytime. Normally, adults are on the soil surface beneath the pine needle litter. However, on hot or cold days they hide close to the root collar in small crevices or shallow burrows in the soil under the litter. They also hide in these places during prolonged dry periods, but after a rain they move into the moist litter above the soil and remain there until soil moisture diminishes.

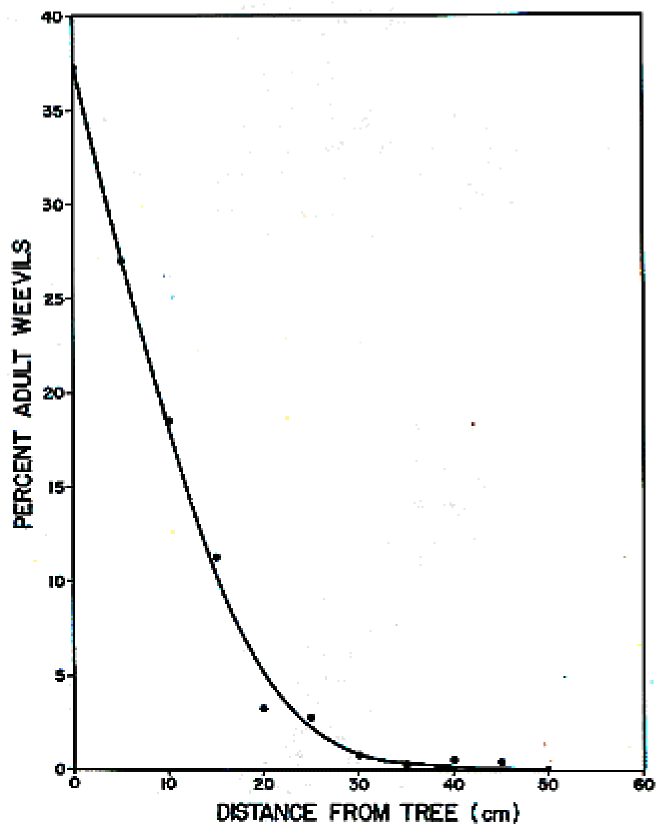

Figure 14.-Distribution of adult weevils during daytime relative to distance from the base of the host tree.

The weevils spend most of the day resting, feeding, or mating in the vicinity of the root collar. They feed on the inner bark of the trunk or on the bark of the sides and undersides of the lowest branches. They prefer small branches partly covered by soil. They venture onto the tree's crown during daylight only rarely and then only in early spring or on dark, overcast days (Schmiege 1958a).

Sexual activity occurs on or near the trunk throughout the day. Most mate on the bark or in soil crevices alongside the root collar, but occasionally pairing may take place 10 to 15 cm out from the trunk. Adults may mate several times in one season. Mating activity begins in late April or early May, peaks in mid-June, peaks again (but to a lesser extent) in early August, and then ends in late September. Oviposition parallels copulatory behavior (see fig. 6).

Adults climb the trees at dusk, when light intensity in the open drops to about 2 fc; low light is the stimulus that starts the nocturnal portion of the cycle (Wilson 1968b). Time of ascendance varies with the date, the evening sky condition, and temperature. On warm nights the weevils spend part of the time on the crown, returning to the root collar area when the light intensity increases at dawn. While on the trees the adults feed on the buds and tender bark of small shoots and branches (Wilson 1968a). On cool evenings the weevils may ascend the trees for awhile, but return to the litter if the temperature drops below 4 ° C. If it rains or if the temperature quickly drops to 4° C at twilight, the adults remain close to the root collar throughout the night.

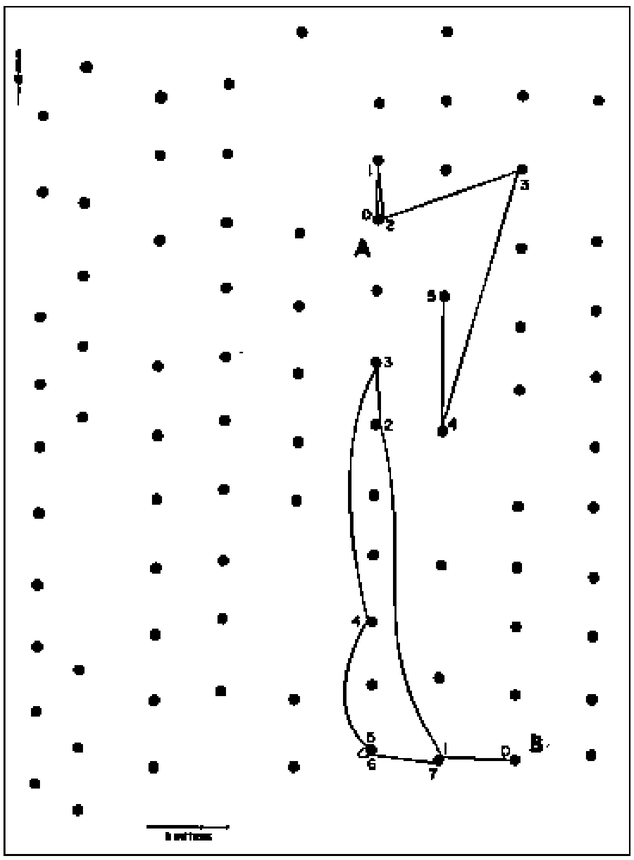

Figure 15.-Travel sequence, capture points, and pathways of two weevil adults in a red pine plantation. Insects first captured at location 0. Black discs represent trees. (Time between captures varies from 1 to 7 days.)

Besides moving onto the trees at night, many adults also travel several meters between trees (fig. 15) (Maki 1969, Millers 1965, Wilson 1968a). Most travel is accomplished by crawling; flight has been rarely seen and then only over very short distances and close to the ground. Occasionally, adults have been induced to fly to a blacklight on warm nights (Maki 1969, Wilson 1968b). Crawling adults may travel for minutes or hours at a slow pace (fig. 16). When blocked by an object they stop, reorient themselves, and then continue walking in a new direction.

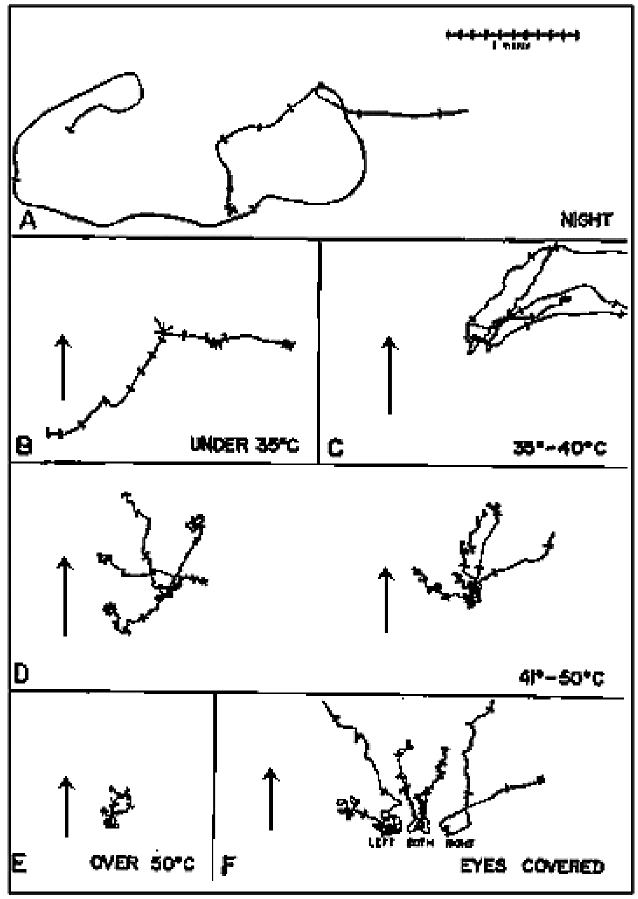

Figure 16.-Movement patterns of adult weevils at night (A); during the day under different temperature regimes (B-E); and with eyes covered with opaque paint (F). Arrows point away from the sun; short cross-marks on the movement patterns indicate 10-minute intervals for A and 1-minute intervals for B-F.

Adults exposed between trees or on trees at sunrise, when temperature and light intensity are low, react to sunlight only and cease movement. As light intensity increases and surpasses a threshold, they seek shelter for the day (fig. 16B).

Those on the trees drop off and crawl to the litter. Those on the ground between trees orient themselves visually and move toward a tree or other large object, continuing in that direction if unobstructed until they reach shelter. In search of shelter they move slowly but noticeably faster than at night. In a pine stand or plantation these reactions to light and temperature have the advantage of bringing the sexes together at the sheltered tree base (Wilson 1968b).

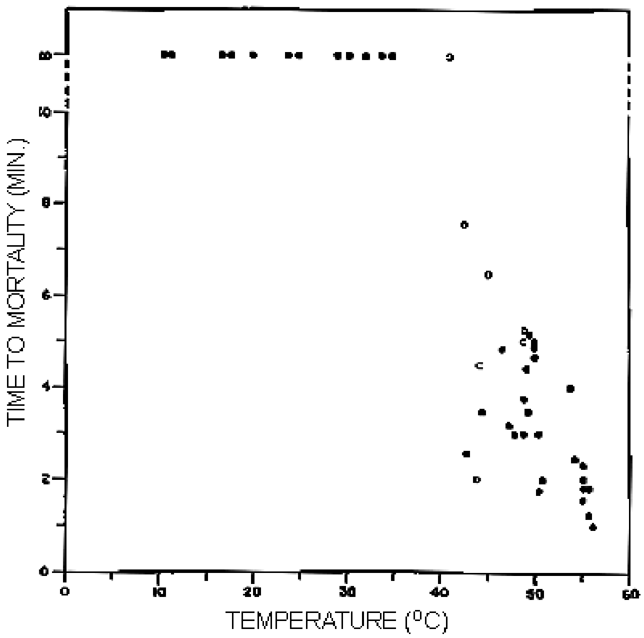

Figure 17.-Relation of mean ground surface temperature in a pine plantation to the length of time adult weevils take to die while walking. Infinity symbol on vertical axis indicates the Insect walked to a tree or other object and survived. White discs represent adults exposed to partly cloudy conditions black discs are adults in full sun; split discs are very small adults in full sun.

On warm, sunlit days, the adults normally would not be in the open, as temperatures there are often sufficiently high to kill them. As soil surface temperatures rise to 35° to 40° C, weevils caught in the open seek shelter by moving rapidly toward some object in as straight a line as the terrain permits. They can travel at 45 cm/min (18 in/min) with bursts of 75 cm/min (30 in/min) on relatively flat terrain, slowing down only when reaching shade (fig. 16C). Their movements are generally away from but not necessarily 180° opposite the sun, because they orient on the closest large object away from the sun. The weevils whose pathways are depicted in figure 16C moved toward a nearby group of red pines (not shown) located off to the right of the illustration.

Adults exposed to soil surface temperatures of more than 40 ° C must find shelter in less than 8 minutes or die (fig. 17). Lethal or near-lethal temperatures make weevils orient quickly and travel away from the sun. Some climb grasses, forbs, and sticks to get relief from the heated soil. Occasionally one will extend its wings in feigned flight but flight doesn't occur. If shelter is not found they soon circle, show erratic, disoriented movements, and then die (fig. 16D, E).

Weevils use their eyes to locate shelter, perhaps orienting by the sun. If one eye is covered the insect generally moves in the direction of the covered eye (fig. 16F). Sight is not essential for sun orientation, however, as adults with both eyes covered move away from the sun (fig. 16F).

Host Damage

Injury Description.-Both adult weevils and the larvae injure pines, but the adults seldom cause appreciable injury unless the trees are small. The adults create small wounds by feeding on the bark of small shoots and branches and on buds (fig. 18). If small shoots are girdled they flag (Hodson and Christensen 1942), and injured buds may yield distorted shoots (Schmiege 1958a). The wounds may also become infection courts for pathogens.

F-488103

Figure 18.-Wound on bark of pine twig from adult weevil feeding.

The larvae cause the principal injury by feeding below ground in the bark and cambial tissues of the root collar, root crown, and roots. The larvae bore into the inner bark between the phloem and the corky outer bark, and as they grow larger they injure the newly formed xylem as well. Heavy injury kills the tree (see cover).

The first external sign of larval feeding is the pitch-soaked soil adjacent to the tree base. Injured trees secrete copious quantities of resin into the soil, producing a 5 to 8 cm (2-3 in) zone of pitch-soaked soil next to the root collar (fig. 19). The outer bark of the root collar and roots often separates from the wood by as much as 2.5 cm (1 in), and the opening fills with semi-solid resin mixed with frass (Finnegan 1962). In a heavily or repeatedly infested tree, the stem in the injured area sometimes becomes greatly reduced. As long as a small portion of intact cambium remains bridging the injured area, the tree may remain alive for years, although it is subject to windthrow (fig. 20). As callous tissue overgrows the injury, the root collar becomes fluted (fig. 21). Large roots are rarely girdled completely and small roots are seldom fed upon (Schmiege 1958a).

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Figure 19.-Root collar injury from weevil larvae.

Complete girdling is more common on small trees, while partial girdling, which causes growth loss and/or windthrow, occurs more commonly in larger trees (Millers 1965). The foliage of severely injured trees first turns yellow, then red (see cover) and finally drops off as the trees progressively decline in vigor.

Trees may first manifest their weakened condition by producing shoots that are shorter than normal (fig. 22). Red pine, especially, may show some shoot reduction one, and some-times, two growing seasons prior to mortality (Schmiege 1958a). This is less obvious on jack, Scots, and Austrian pines, which show only a slight reduction 1 year prior to dy-ing (fig. 22).

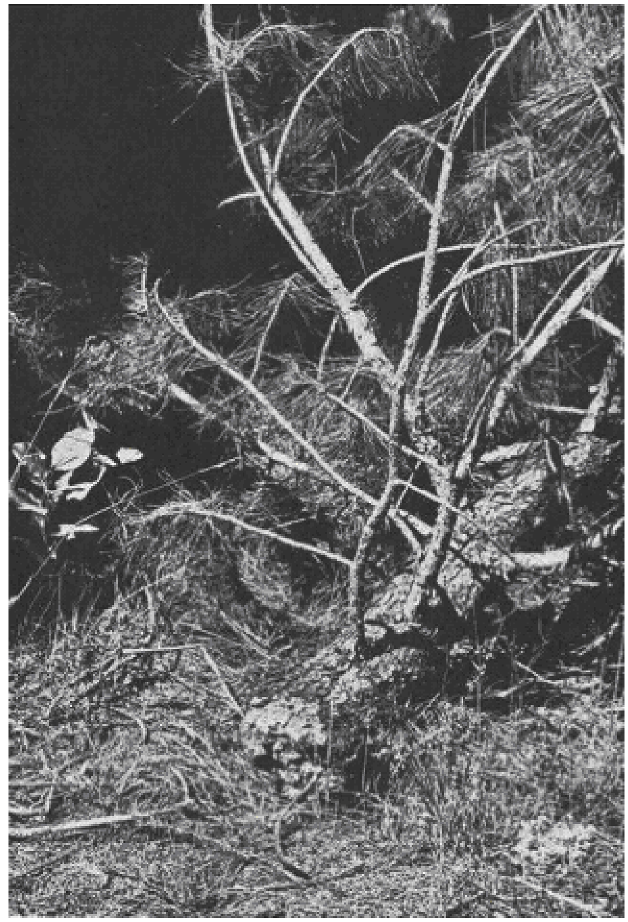

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Figure 20.-Windthrown pine weakened from weevil larval injury.

Shoot growth reduction due to girdling also depends on the size of the tree (Benjamin and Kearby 1965). Among even-aged trees ranging primarily from 1.2 to 3.0 m (4--10 ft) tall, the taller ones 2.5 to 3.0 m (8-10 ft) show the greatest leader length reduction due to root collar girdling. Leader growth in intermediate trees 1.9 to 2.9 m (6-8 ft) is affected by girdling, but to a lesser degree, while leader length in shorter trees 1.2 to 1.8 m (4-6 ft) is about the same under all degrees of girdling (fig. 23). It is noteworthy that trees which are 80 percent girdled or more have about the same leader length.

Decay fungi associated with weevil outbreaks may accelerate the decline or even cause the death of weevil-infested trees. The copious pitch flow tends initially to retard entrance of decay fungi (Schaffner and McIntyre 1944), but later the fungi may invade the host as it weakens. Smerlis (1957) studied *Hylobius* weevils attacking balsam fir *(Abies balsamea* (L.) Mill.) and found advanced decay associated directly with the degree of *Hylobius* injury. Most of the 33 different fungi he isolated from the wounds were wood-staining species, and one was a wood-destroying species *Haematostereum sanguinolentum* (Alb. & Schw. ex Fr.) Pouz. In general, *H. radicis* causes such rapid mortality, in young pines at least, that advanced decay is impossible prior to tree death. Fungal invasion and subsequent tree death are more likely in older trees that survive weevil onslaught but remain weakened for long periods.

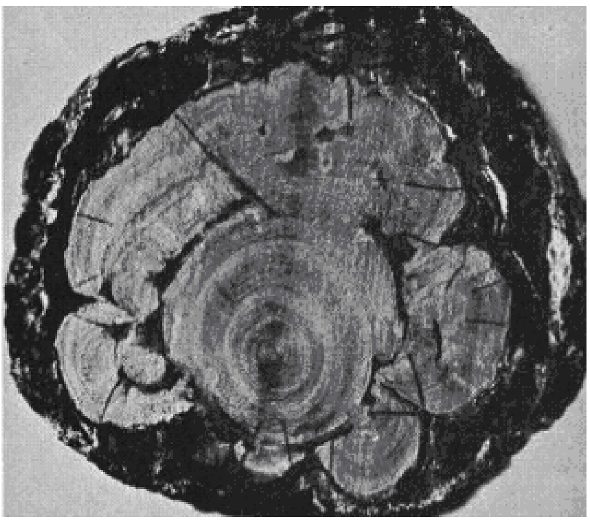

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Figure 21.-Cross-section of pine stem showing root collar injured from weevil larval feeding,

Weevil-weakened and weevil-killed trees also play host to secondary insects, especially the northern pine weevil, *Pissodes approximatus* Hopkins (Felt and Bromley 1941, Schaffner and McIntyre 1944), and bark beetles (Kennedy 1969, Sippell *et al.* 1955). Kennedy (1969) noted that high moisture stress and *H. radicis* attacks together lowered the resistance of red pine sufficiently to contribute to a pine engraver beetle *(Ips pini* (Say)) outbreak in Michigan in 1966.

Stand Damage.-Infestations are more severe in pine plantations and windbreaks than in natural stands, particularly if planted on unsuitable sites. Natural stands are the normal reservoir for this insect, but damage there is seldom heavy unless the trees are growing near infested plantations or windbreaks.

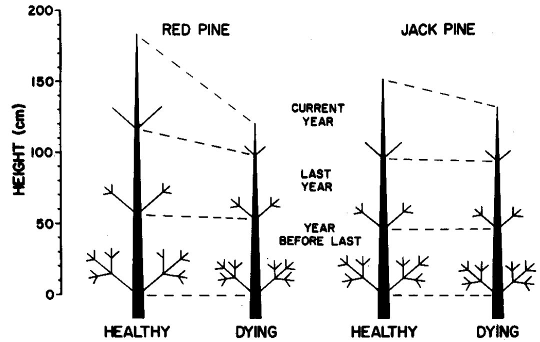

Figure 22.-Mean height growth of apparently healthy and dying pine saplings for three consecutive years in heavily injured red and jack pine plantations. Scots and Austrian pines show patterns similiar to that of jack pine.

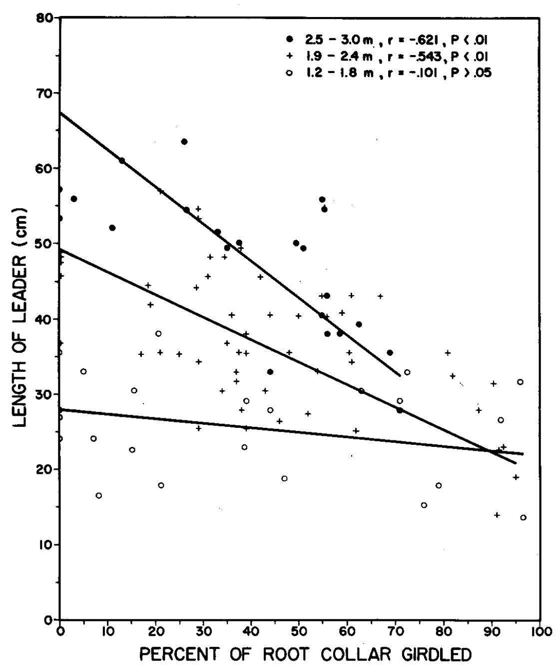

Figure 23.-Leader length of red pine relative to degree of root collar girdling for three height classes in an even-aged stand.

Weevil damage has long been considered most serious on sandy, well-drained soils (Schaffner and McIntyre 1944, Schmiege 1958a). Heavy attack and mortality, however, have occurred in stands bordering swamps, on loamy soils, and on clay soils, so texture and drainage alone are not necessarily related to degree of weevil damage.

Pine saplings less than 2.5 cm (1 in) in diameter at the ground line are rarely attacked-probably because the bark is too thin. All other sizes may be attacked and killed, however. Well-stocked plantations (800-1,200 trees/acre, 324-486 trees/hectare) at closing, however, incur far less injury than those with open-grown trees. In red pine plantations, damage generally increases until the trees are 12 to 13 years old and then declines (fig. 24).

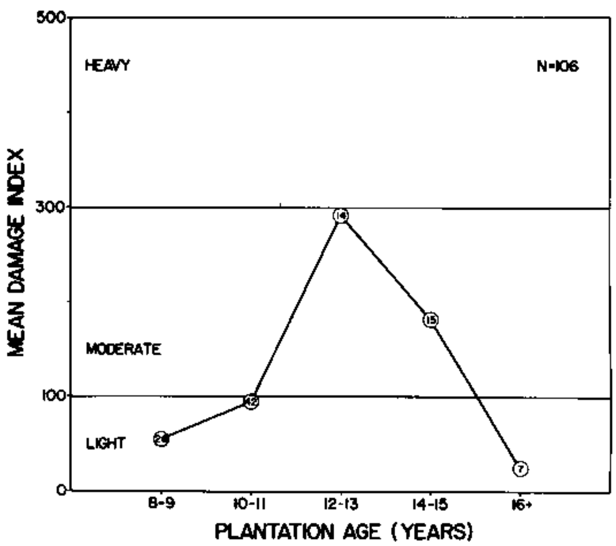

Figure 24.-Weevil damage relative to age of 106 red pine plantations.

Degree of weevil damage is inversely related to the distance to the nearest infested plantation, brood tree, or natural stand (fig. 25). In general, stands less than 1/8 mile (0.2 km) away are more often heavily injured; those between 1/8 and 1/2 mile (0.2-0.8 km) away tend to be more moderately injured; and those more than 1/2 mile (0.8 km) are usually lightly injured. Stand age makes little difference in this relation (Kennedy and Wilson 1971).

Planted pines are generally more severely injured than naturally growing pines of similar size and with similar insect population levels (Brown and Young 1955, Millers 1965). The major reason for this appears to be the large root collar available to the larvae in the planted pines. Typically, pines are planted so their roots are well below the surface, providing a root collar cylinder 12 to 15 cm (5-6 in) in depth

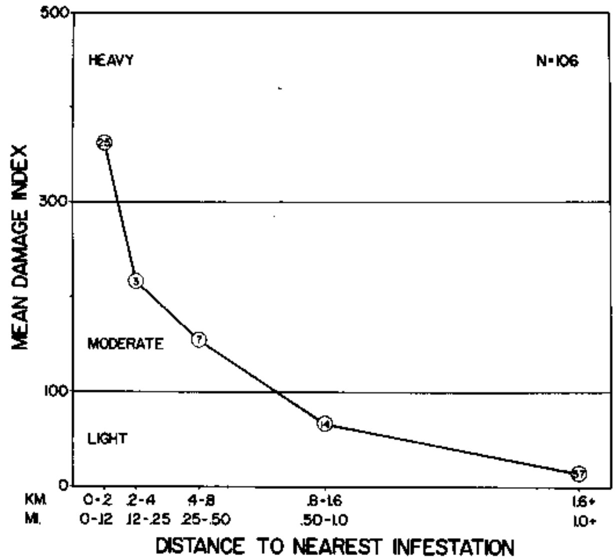

Figure 25.-Weevil damage relative to distance from nearest infestation for 106 red pine plantations.

under the soil. This permits the larvae to concentrate their feeding in the collar area and thus more readily girdle the tree, or at least weaken it so that it becomes subject to wind-throw. In contrast, the root collar of naturally growing pines seldom extends deeper than 5 or 6 cm (2-3 in) below ground. This short collar forces the larvae to spread out more and to feed on roots and in the root crotches, where more surface area is available.

Even-aged, well-stocked plantations show damage and mortality to be nearly randomly dispersed, except for occasional clusters of injured trees-locations where infestation centers may have commenced. Damage and mortality are more localized in even-aged stands after the canopy has closed, because it appears mostly on stand borders, the periphery of openings, and in poorly stocked areas. These are areas where weevil populations are highest.

Brood-tree outbreaks show clear epicentric infestation patterns. An infestation in an 8-year-old Scots pine plantation that contained a 20-year-old mixed red and eastern white pine windbreak clearly demonstrated this. The windbreak pines were lightly infested with the weevil prior to plantation establishment, and sustained a population that infested the more susceptible Scots pine about 3 years after planting. The first heavy injury and mortality of Scots pine occurred in the adjacent rows near the windbreak, but thereafter injury spread progressively outward (Millers 1965). Within 7 years after initial attack, tree mortality had spread beyond 40 rows on either side of the windbreak, with damage greatest on the more protected east side (fig. 26). Single, large brood trees cause similar epicentric injury, but with more circular infestation patterns.

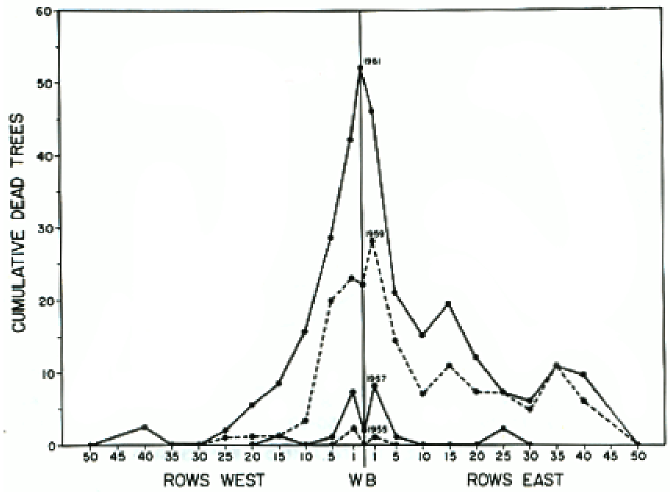

Figure 26.-Distribution of weevil-killed Scots pine trees over a 7-year period from a weevil-infested windbreak (WB).

Stands that have dense canopies following crown closure have considerably fewer insects and less damage than those that are open-grown. For example, in a 20-year-old Wisconsin red pine plantation that had variable stocking levels from differential survival, areas were selected with densities of approximately 1,000, 500, and 250 trees per acre. Larval populations and damage in these areas were inversely related to stocking level (Millers 1965). Larvae varied from 0.44 per 2.5 cm (1 in) of tree circumference in low-density areas to 0.01 per 2.5 cm (1 in) in high-density areas (table 5). Another Wisconsin red pine plantation that was 14 years old contained 0.40 larvae per 2.5 cm (1 in) of tree circumference in the open portion of the stand and only 0.09 larvae in the closed portion, where survival approached the original stocking level of 1,200 trees/acre. Old weevil damage was similar for both areas of the stand, suggesting little difference in larval populations prior to crown closure (Millers 1965).
Border trees and those on the periphery of small openings in dense stands have significantly more larvae and damage than interior trees (table 6) (Millers 1965). Differences in larval densities are probably attributable to adult behavior, since fewer adults frequent dense portions of stands and subsequently deposit fewer eggs there. Trees examined in a Michigan plantation produced 0.06 adult weevils/tree in a closed portion of the stand and 0.31 weevils/ tree in an open portion-a five-fold highly significant difference (Maki 1969). Similarly, egg samples from 60 trees yielded a mean of 0.23 eggs/tree in the closed portion and 0.60 in the open portion, Temperature is lower and humidity higher in closed stands-conditions less favorable to the weevils.

Table 5.-*Influence of stand density on larval populations of pine root collar weevil in a Wisconsin red pine plantation*

Stand density	Trees examined	Larval population[1]
Trees/acre	Number	*Mean ± S. D.*
250	16	0.443 ± 0.080
500	16	.288 ± .067
1,000	16	.010 ± .002

[1]Larvae per 2.5 cm (1 In) of roof collar circumference.

Table 6.-*Influence of tree location on larval populations of pine root collar weevil in a Wisconsin red pine plantation*

Tree location	Trees examined	Larval population[1]
	Number	Mean ± S. D.
Edge-row trees	23	0.180 ± 0.097
Opening, peripheral trees	35	.120 ± .115
Closed-in trees	49	.060 ± .076

[1]Larvae per 2.5 em (1 in) of root collar circumference.

Host Resistance.-Varietal differences in resistance to pine root collar weevil attack are known only for Scots pine-a European import with highly variable genotypes and phenotypes (Wright and Wilson 1972). Resistance to mortality from the weevil was first noted in a Scots pine provenance test plantation in Michigan that contained over 100 seedlots of 18 varieties covering the entire range of Scots pine (Ruby and Wright 1976). Eleven years after planting, 37 percent of the trees had been killed by the weevil.

Some mortality from the weevil occurs among all Scots pine varieties, but certain varieties are more resistant to attack than others. Generally, resistant trees have dark-green, short needles, are moderately fast growing, and are native to southern Europe and Turkey (table 7). The most susceptible varieties are those from middle latitudes of Europe; these vary in growth rate, needle length, and foliage color in winter.

There is no relation between height growth rate and resistance-northern and southern varieties growing at the same rate differed considerably in mortality. Foliage color during winter is the variable with the clearest north-south trend. Resistant varieties are greenest during the winter (table 7), but color differences are slight between June and August when weevil oviposition occurs.

The volatile monoterpenes from Scots pine were examined in detail by Tobolski and Hanover (1971). Their data hint at chemical resistance correlations, but none withstand close scrutiny. For example, high concentrations of α-pinene are typical of all the resistant varieties and of susceptible "East Anglia" trees. High levels of β-pinene are typical of all resistant varieties except var. *iberica*. Low concentrations of 3-carene and terpinolene characterize all the resistant varieties

Table *7.-Origin, growth rate, foliage characteristics, and susceptibility to pine root collar weevil injury of 18 varieties of Scots pine*

Variety of Scots pine	Country of origin[1]	Trees killed	Tree height	Winter foliage color[2]
		Percent	*Feet (Meters)*	
lapponica	FIN, SWE	14	4.7 (1.4)	2
altaica	SIB	30	7.3 (2.2)	4
septentrionalis	FIN, NOR, SWE	38	7.7 (2.3)	5
rigensis	LAT, SWE	45	9.2 (2.8)	6
uralensis	URA	40	8.6 (2.6)	3
polonica	POL	67	10.0 (3.0)	7
borussica	GER	69	10.3 (3.1)	8
hercynica	CZE, GER	43	11.8 (3.6)	9
haguenensis	BEL, FRA, GER	65	11.6 (3.5)	13
"E. Anglia"	ENG	55	10.5 (3.2)	14
pannonica	HUN	45	11.3 (3.4)	10
"N. Italy"	ITA	11	9.3 (2.8)	11
illyrica	YUG	10	11.5 (3.5)	12
scotica	SCO	18	9.2 (2.8)	15
iberica	SPA	17	7.6 (2.3)	19
aquitana	FRA	12	9.0 (2.7)	18
rhodopaea	GRE	19	9.6 (2.9)	16
armena	RUS, TUR	12	9.1 (2.8)	17

[1]BELgium, CZEchoslovakla, **ENGland,** FINland, FRAnce, GERmany, GREece, HUNgary, ITAly, LATvia, NORway, POLand, RUSsia, SCOtland, SIBeria, SPAIn, SWEden, TURkey, URAI Mtns., YUGoslavia.

[2]Ranked 1 = yellowest to 19 = greenest.

except var. *illyrica* and var. *scotica.* None of the various traits so far measured is correlated closely enough with weevil-caused mortality to provide convincing evidence of the probable mode of resistance.

Species Mixtures.-Mixed plantings, consisting of different pine species, different-aged pines, or both, have been tested in the past for resistance to the pine root collar weevil. These plantings, however, generally were more susceptible to weevil attack and injury than monocultures (Wilson 1977). This occurs because the weevils attack the most susceptible host species first, then, as insect numbers build up, the weevils attack the less susceptible trees in greater numbers than usual. The same thing occurs for mixed-age groups; the worst combination from the standpoint of attack consists of stands of mixed pine species and mixed ages. Such plantings have been common in Michigan for example, where most have 10-row blocks of jack pine alternating with 10- to 20-row blocks of red pine, all at 6 by 6 foot (1.8 by 1.8 m) spacing. The jack pine was planted first; the red pine usually 5 years later. Spaces resulting from poor survival of red pine were then replanted to red pine as late as 5 year later. Thus, these stands have a two-species and a three-age structure. Some red pine of both ages have died in all infested plantings. In each case, the jack pine had originally become infested from some outside brood source. In turn, the older red pine became infested, and both red and jack pine then provided brood material for the young replanted red pines. Most of the young red pines and 20 percent of the older ones died. In contrast, tree mortality in comparable pure stands of even-aged red pine seldom exceeds 10 percent.

Control Strategies

Numerous researchers have attempted various strategies to control populations of the pine root collar weevil. Techniques that have been proposed or tested are presented here. Some have proven useless, while others are outmoded and are of historical value only. Certain cultural, chemical, and integrated approaches, however, show promise for present and future weevil management programs.

Silvicultural Control.-Maxwell and MacLeod (1937) were the first to try a cultural control treatment against the pine root collar weevil. They removed much of the soil from around the bases of deeply planted Scots pines. This reduced the insect population because it virtually eliminated the weevil habitat and desicated the root collar area, making conditions unfavorable for both the adults and larvae. Warren (1956b) suggested that the related species *Hylobius pinicola* (Couper) and *H. warreni* Wood (Wood 1957) might be controlled by removing the humus from the vicinity of the root collar and basal portions of the major roots. He proposed that the humus layer protected these insects, providing the high humidity they require. In contrast, he felt controlling the pine root collar weevil by this method seemed unlikely because the insect sometimes occurs even in the absence of a well-developed humus layer.

Behavioral studies of the pine root collar weevil (Wilson 1968a) showed that the adult weevils were photo- and thermophobic, indicating that any treatment that permitted extra light and heat at the tree base would partially disrupt their activities, and thus reduce their populations. Wilson (1965) pruned the lower branches (fig. 27A, B) from red pine trees up to 60 cm (2 ft) up the stem and got more than a two-fold decrease in larval population after one season. He reduced the insect population further by removing the litter and scraping the topsoil from around the tree base (Wilson 1967). In the latter treatment, the litter was pulled back about 30 cm (1 ft) and the topsoil was scraped 5 cm (2 in) deep around the tree (fig. 27C, D). Neither treatment eliminated the population entirely (fig. 28), because a few adults found refuge in crevices adjacent to the trees and were able to lay eggs there. Some adults found and hid in these crevices at night and oviposited the following day.

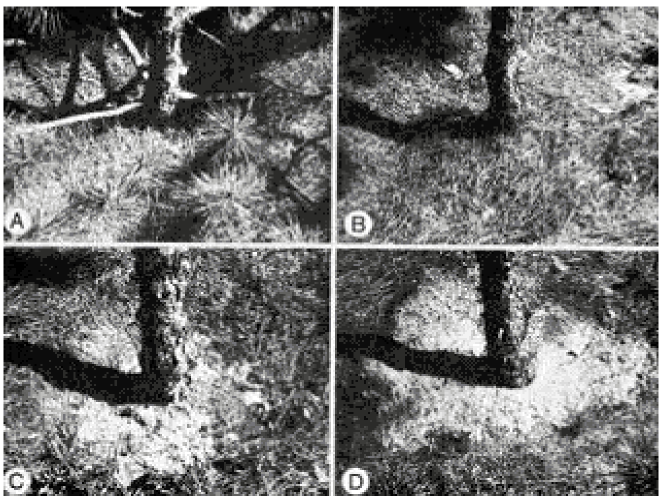

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Figure 27.-Stages in cultural control of the pine root collar weevil: A. untreated tree; B. pruned tree with litter intact; C. pruned tree with litter removed; D. pruned tree with surface soil scraped back.

Basal pruning and soil scraping usually controls the weevil satisfactorily, at least in red pine plantations. Pruning alone disrupts the weevil's habitat, but not always enough to prevent tree mortality. This is especially true in stands with high weevil populations or in stands where many trees are near the mortality threshold. Plantings with some trees near the mortality threshold require only an average of two or three full-grown larvae per tree to cause mortality. Soil scraping is better than just litter removal because the adult habitat is nearly eliminated. It usually keeps the mean population below two larvae per tree and thus below the mortality threshold (Wilson 1967) (fig. 28). The treatment usually suppresses the weevil for 4 to 5 years (Wilson 1973). This allows the tree time to recover from the injury, so that a population higher than two to three larvae per tree is needed to bring about mortality.

Wilson and Rudolph (1970a, 1970b) tested several tools for pruning trees and concluded hand clippers were best on trees under 1.8 m (6 ft) tall, and Meylan saws were most efficient and least tiring on larger trees. The cost of treatment varied by tree size, height of pruning, and difficulty of removing the soil. Sod-bound trees required more effort than those surrounded by needle litter; clearing the root collar area sometimes required hoes or other implements. Christmas trees cannot be pruned as high as larger forest plantation trees-usually 30 to 45 cm (1-1.5 ft) is maximum. This makes it more difficult to control the weevil, because the lower branches tend to sag and partially shade the root collar.

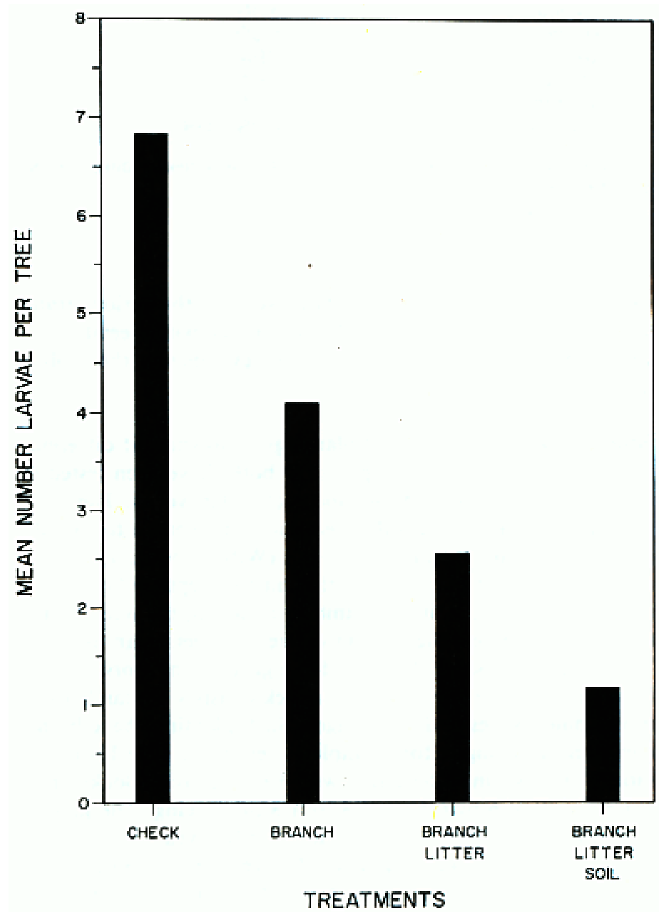

Figure 28.-Mean number of pine root collar weevil larvae per tree following cultural treatments. Check equals no treatment; branch trees pruned only; branchllitter equals pruning and litter removal; and branch/litter/soil equals pruning plus litter and soil scraped back

Table 8.-Larval reduction of the pine root collfar weevil after insecticide applications[1]

Insecticide[2]	Toxicant in formulation	Solution per tree	Larval reduction[3] First year	Second year	Third year	Fourth year
	Percent	*Pints*		*-Percent-*		
	Red Pine Treatments					
Dieldrin (20% e.c.)	0.40	0.7	94	100	100	96
	.20	.9	97	100	97	98
Lindane (25% e.c.)	.10	.8	91	100	96	98
	.05	.9	91	95	100	98
	Scots Pine Treatments					
Dieldrin (20% e.c.)	0.24	1.7	—[4]	96	97	—
	.16	1.0	—	100	99	—
	.16	0.9	—	83	91	—
	.08	1.9	—	96	96	—
Endrin (20% e.c.)	.16	1.2	—	73	82	—
BHC (6% w.p.)	.08	0.9	—	83	89	—

[1]Data from Finnegan and Stewart 1962.
[2]Applied as soil surface drench with power sprayer in June of first year. [3] Degree of control was assessed in fall of each year indicated.
[4] no data collected in first and fourth year.

Cost of low-pruning and soil scraping compares favorably with chemical control in most instances. Infested forest stands usually need treatment when the trees are 1.8 to 3.0 m (6-10 ft) tall; an acre (2.5 hectares) of 600 trees can be treated in about 10 person-hours if 1.8 m (6 ft) tall, and 11 person-hours if 3.0 m (10 ft) tali (Wilson and Rudolph 1970a). This is 2 minutes per tree, which, at $4.00 per hour would result in a cost of $0.07 to $0.08 per tree. Treatment of Christmas trees, which have denser foliage but are not pruned as high, costs about the same. An extra advantage of treating Christmas trees is that the pruning produces branch-free "handles" on the trees, which make harvesting easier.

Basal pruning and soil scraping also limits the European pine shoot moth, *Rhyacionia bouliana* (Schiff.), and Scleroderris canker, *Gremmeniella abietina* Grem., pests that are sympatric with the weevil (Wilson and Miller 1968). Opening up the base of the tree also lessens the dangers of injury from mice and rabbits (Bell and White 1966).

Chemical Control.-Attempts to chemically suppress the weevil were made even before the insect was formally described. The New York Conservation Department was the first to test numerous pesticides in 1932 and 1933. None was satisfactory, however, and some were considered too dangerous to use. Plumb (1936) later suggested using sodium cyanide, but it was not tried. Maxwell and MacLeod (1937) failed to control the weevil with lead arsenate, paradichlorobenzene, or carbon disulphide emulsion. Felt and Bromley (1942) also tested paradichlorobenzene and carbon disulphide as well as bortox and turpentine without accomplishing significant weevil reduction. But, lime sulphur and lime sulphur combined with lead arsenate seemed to repel the adult weevils somewhat. The best control resulted from a fumigant emulsion, dichlorethyl ether soap, which at that time was recommended for peach tree borer control, but it did not give fully satisfactory weevil control. Schaffner and McIntyre (1944) obtained 80 percent adult suppression from ethylene dichloride plus dichlorethyl ether, and ethylene dichloride plus dinitro-ocyclohexyl phenol. Though somewhat effective, the residual was too transitory; the cost of the extra applications that were needed would have been prohibitive.

Working in Wisconsin, Shenefelt (1950) also applied ethylene dichloride, propylene dichloride, DDT, chlordane, and BHC in June tests and got 61 to 99 percent larval reduction in the fall. BHC appeared to be the best chemical for control on Scots pine. However, he pruned the treated trees up to 1.2 m (4 ft) before the chemicals were applied, and pruning may have influenced the results of his tests (see silvicultural control strategies for effects of pruning.)

The best control results were obtained by Finnegan and Stewart (1962) in Ontario on infested Scots and red pine using several persistent pesticides as soil drenches. They tested dieldrin, lindane, BHC, and endrin, and except for the latter, larval reduction was highly significant and lasted at least 4 years (table 8). Their soil injection test results were less spectacular, and other soil drenches using chlordane, DDT, demeton and ethylene dichloride gave poor control.

They obtained best suppression with liquid dieldrin (20 percent e.c.) or lindane (25 percent e.c.). The use of dieldrin, however, is no longer certified by the U.S. Environmental Protection Agency. Adequate formulations of liquid lindane contained 0.5 pound of actual lindane in 100 gallons of water. The mixture was applied by hydraulic sprayer to penetrate the litter and upper soil with minimum runoff. The formulation was directed at the lower few centimeters of the trunk and the soil surrounding the tree out to at least 20 cm (8 in). About 0.47 liters (1 pint) of liquid was needed for each tree under 8 feet tall, and 0.60 to 0.95 liters (1.5-2 pints) for taller trees.

Though larval reduction occurred following treatment, neither dieldrin nor lindane killed the larvae protected under the soil. Rather, the freshly emerging adults and the adults under the litter contacted the chemicals and died.

Historically, one application of lindane generally has been satisfactory in both Scots pine Christmas tree plantations and red and jack pine plantations. Vulnerable Christmas tree plantations usually require treatment by the fifth and sixth year, or when 70 percent or more of the trees become infested. In well-stocked red and jack pine plantings, one application in the sixth to tenth years usually keeps the trees growing well until crown closure, the time when the insect population declines naturally. Ornamentals or single- and double-row wind-breaks, especially if Scots pine, sometimes need one or more additional applications at 5- to 6-year intervals.

The cost of chemical application depends on several factors. Finnegan and Stewart (1962) reported in their tests that two people sprayed about 1,200 trees (a fully stocked acre with 6 by 6 ft spacing or 2.5 hectares at 1.8 by 1.8 m spacing) in 5 hours on rough terrain with a 5-degree slope using a power 20-gallon tank applicator. Thus each tree required 30 seconds to treat. At $4.00/hour the labor cost would be $40.00/acre ($16.20/hectare). However, the costs of chemicals, equipment, down time for repairs, and the hauling time for the large quantities of water required must also be considered.

Concern for the environment has resulted in stricter regulations of persistent pesticides including dieldrin. Ethylene dichloride and propylene dichloride, which are safer and show moderate suppression effects (Shenefelt 1950, Shenefelt and Benjamin 1955), might be used in the future if properly registered. But, because they have a short residual, multiple applications or supplementary methods will be necessary and will increase the costs proportionately.

Other less costly chemical methods are possible, but these have yet to be tested. For instance, Maxwell and MacLeod (1937) suggested poison baits to control the adults. At night, the adults will come to and feed on freshly cut pieces of pine trunk, and perhaps if chemically treated discs of pine trunk were scattered throughout a plantation, they might draw in and kill some of the adults. Also, the tree crowns might be sprayed with a reasonably persistent (2 to 3 weeks) contact or stomach poison by mist blower or hydraulic sprayer. Adults ascending the trees at night would contact or feed on the poison-coated bark. Similarly, a nocturnal treatment of the crown with a contact poison applied on a warm night might kill the adults feeding in the trees.

Biological Control.-Biological control has some potential for reducing pine root collar weevil populations, but ways to increase or augment the natural enemies of the weevil are still largely unknown. The adult stage is not preyed upon heavily or susceptible to many diseases. Schmiege (1958b) observed the carabid beetle, *Pasimachus elongatus* Lec., feeding on the adults, although it probably destroyed only a small percentage of the population. Other predatory insects, spiders, and rodents certainly capture weevils that venture away from the root collar. We occasionally found adults in webs of *Latrodectus variolus* Walckenaer spun at the base of pine trees. Weevils dropping from the tree to the ground at sunrise fell victim to this spider. Small mites, *Rhizoglyphus* spp., and nematodes live on the adults, usually under the elytra, but how much they restrict the weevils' habits or whether they kill them is not known. Mites and nematodes could also restrict their flight and thus influence dispersal. Millers (1965) reared a few phorid flies, *Megaselia* spp., from the weevils. Although most phorids are scavengers, these appeared to be parasites.

We frequently found dead adults under the litter, and they were usually infected with fungi. Fungi may have killed some of these, although most probably they became infected after death. Pierson (1921) reported that *Beuvaria globulifera* (Speg.) killed the closely related pales weevil under certain conditions.

The cryptic eggs, larvae, and pupae are less exposed than adults, and apparently attacked even less by natural enemies. Ants, which forage incessantly near the root collar may feed upon some of the eggs laid in the soil or upon the young larvae (Wilson 1965).

Most mortality of the larvae is from the braconid *Bracon radicis* Shenefelt. After feeding on the larvae, it issues in late July or early August. Up to 16 parasites have been reared from a single parasitized larva (Shenefelt and Millers 1960). We noted that parasitized larvae were always in that portion of the root collar at or just beneath the ground line, suggesting that the parasite is capable of locating larvae only near the surface. Larvae undoubtedly are protected from most natural enemies once they have penetrated the bark and burrowed down the root collar. The overall small percentage (i.e., usually less than 2 percent) of larvae killed by this parasite indicates it probably does not significantly influence the population by itself. Finnegan (1962) also recorded a braconid, *Coeloides* spp., from the larvae. Pupae sometimes become infected by a bacterium (Wilson 1965).

Schmiege (1963) field-tested a neoplectanid nematode (DD-136) and found that the adult weevils were moderately susceptible to its attack. He was also able to infect the larvae with nematodes as deep as 15 to 20 cm (6-8 in) below ground. This nematode is difficult to store for long periods, but it can live in the soil for at least 6 months in the absence of a host and still be infective if the soil remains slightly moist. It also survives cold temperatures and probably will overwinter without loss of infectiveness (Schmiege 1963). This nematode appears to be compatible with several pesticides, and conventional high-pressure spray equipment does not injure it. Dutky (1956) reported that the ensheathed larvae were resistant to DDT, chlordane, endrin, lindane, methoxychlor, and toxaphene, and thus potential candidates for an integrated biological-chemical approach.

The nematode may not be compatible with low pruning (see silvicultural control), since the soil rapidly heats and dries under pruned trees. Temperatures over 32 ° C decrease larval nematode activity and drying causes rapid mortality.

Survey Methods

Several types of surveys can be conducted by forest landowners to detect, evaluate, or predict weevil populations or damage, and to rate the risk of potential damage. Should the risk of weevil injury be detected from such surveys, management guidelines can be applied to aid in host species selection, site preparation, planting, and maintenance of pine plantings.

Before executing a survey, you should be certain you can properly identify the pine root collar weevil. Several related weevils resemble the pine root collar weevil in the larval, pupal, and adult stages, but the damage they cause is usually distinct from that of the pine root collar weevil, whose presence is characterized by the following: The soil adjacent to a damaged root collar is blackened and pitchy. Larval tunnels and pupal cells may be present in the pitchy soil. The bark of the roots and portion of the root collar beneath the ground are blackened where pitch exudes. Outer bark, when scraped away, reveals larval tunnels in the inner bark. Heavily damaged trees may be dying, dead, or leaning.

The white, grub-like larvae are present in the tissue of the damaged area or in the pitchy soil nearby. Adults are black or brown snout beetles (see *Insect description* p. 2 for details) found under the litter or in crevices at the tree base.

If you are in doubt about an infestation, collect adult weevils and send them to an extension entomologist or insect taxonomist for identification.

Stand Hazard and Risk-Rating.-Young pine plantations or areas to be planted with pines can be risk-rated for their potential to sustain heavy weevil injury. Four elements should be considered in risk-rating: (1) stand location relative to area temperature, (2) stand proximity to a weevil brood source, (3) tree species susceptibility, and (4) tree diversity or mixture.

Although the weevil has a moderately broad range in North America, it is restricted locally in that its populations tend not to reach high levels in areas that have cool summers or cold winters (Kennedy and Wilson 1971). For example, red pine areas in the Lower Peninsula of Michigan tempered by the warmth of the Lake Michigan coastline contain the highest weevil populations, whereas areas to the east and north of this generally have lower populations. This has suggested three hazard zones-low, medium, and high-for northern lower Michigan (Wilson and Kennedy 1970) (fig. 29). Hazard zones have yet to be determined for other locations.

Trees planted among or in the vicinity of infested brood or overstory trees, or near an infested stand or windbreak, are likely to be severely damaged (Wilson 1977). The distance a new planting must be from such trees to reduce risk of a heavy outbreak ensuing depends on the insect's access to the new planting and its ability to disperse and search out such areas. The pine root collar weevil seems to be a reluctant flier, and thus the probability of heavy injury diminishes with the distance separating the planting and the brood source.

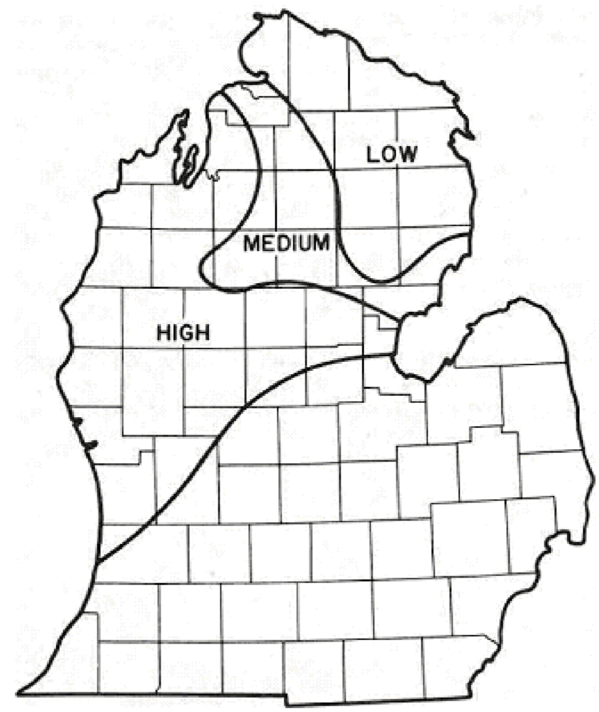

Figure 29.-Low, medium, and high weevil hazard zones for red pine in Michigan's Lower Peninsula. The weevil hazard in the unmarked zone is unknown.

Hazard zones are not applicable to Scots pine, the most susceptible weevil host. The weevil either builds up rapidly on Scots pine even in a low hazard zone, or is able to kill Scots pine at lower population levels. This may not be true for all varieties of Scots pine, since a few varieties show some weevil resistance; however, even the most resistant varieties appear to be more susceptible than other pine species (table 7). Resistance of varieties or cultivars of other pines is still unknown. Eastern white pine appears to be the most resistant pine host.

Risk of heavy attack increases as closely allied species of pines are planted together or nearby (for example, jack and red, Scots and jack), and as ages are mixed. Risk lessens with monocultures and with mixtures containing trees such as spruce or hardwoods.

Here is a way to risk-rate a pine plantation or an area proposed for planting:

1. If the stand is well stocked, and trees are over 5 m (15 ft) tall, closing in, and do not show current signs of heavy damage, the risk of heavy damage occurring to more than a few border trees is less than 5 percent.
2. If the stand is young or poorly stocked (or a proposed planting area), the probability of heavy damage increases as distance to a source of infestation diminishes. For a plantation or proposed site less than 1.6 km (1 mi) from an infestation source, it is necessary to determine the hazard zone before risk can be assessed. If nearby stands are heavily injured, it is automatically a high hazard zone. If nearby stands aren't heavily injured, hazard can be calculated by analyzing mean winter and summer temperatures (° F) taken from the nearest weather station (official long-term monthly means should be averaged for November through February to determine mean winter temperature, and for April through September to determine mean summer temperature):

Mean winter temp.	Mean summer temp.	Hazard zone
>27.5°F	>60.5°F	High
Intermediate	Intermediate	Medium
<24.5°F	<58.5°F	Low

3. If the hazard is low, heavy injury probably will not occur and the stand or proposed stand will be safe. If the hazard is medium or high, the probability of heavy injury will depend on the distances given in the tabulation below:

Distance to weevil infestation		Probability of heavy weevil damage — Hazard zones		
		Low	Medium	High
Kilometers	*Miles*		*Percent*	
0-0.2	0-1/8	5	15	>50
0.2-0.8	1/8-1/2	5	10	40
0.8-1.6	1/2-1	5	5	25
1.6+	1+	< 5	5	10

4. Risk will vary somewhat depending on tree susceptibility and planting mixture. The information above is relevant for red pine and probably suitable for most other pines except Scots and eastern white pines. Risk is generally higher for Scots pine and lower for eastern white pine. The latter is generally safe from any attack unless planted almost adjacent to an infested pine stand.

   Mixtures modify the risk also-Scots pine mixed with any other pine results in the highest risk for the other pines, and an age mixture exceeding 5 or more years provides a higher risk for the younger trees.

In summary, high-risk plantations occur (in Michigan at least) where summers and winters are relatively mild, where a brood source is nearby, and where the planting is a mixture of closely related pine species or different ages. Any association with Scots pine increases the risk.

Low-risk plantations occur where summers and winters are cooler, where the brood source is more than 1.6 km (1 mi) away, and where trees are planted in small monocultures, or in mixtures of distantly related conifers (e.g., pine/spruce) or hardwood trees or shrubs (see fig. 32 for guidelines).

Detection Survey.-The purpose of a detection survey is to learn whether the pine root collar weevil or its damage is present at any particular time or place. It can be used for simply locating the insect or its damage, or for mapping its range; it can be as casually or as systematically executed as the observer desires. It is usually a ground survey, but it can be made from the air when the infestation is sufficiently heavy to show gross symptoms, such as tree mortality or windthrow. Ground checks, however, are usually needed as well to verify the insect's presence, because rodents, diseases, and other agents can cause similar gross damage symptoms.

Here is a way to make a weevil detection survey:

1. First look for gross symptoms of weevil damage, such as recently dead (red foliage), dying (yellow foliage), or windthrown trees. These are present only in heavy infestations (see cover and fig. 20).
2. Examine the root collar of the injured or dead trees to ascertain the presence of girdling. (You may need to cut off a few lower branches to reach the base of the tree.)
3. Using a trowel or small shovel, dig around each tree and look for blackened, pitch-soaked soil adhering to the bark. This is a reasonably reliable sign of the weevil feeding injury.
4. Remove more soil from around the collar out to 15 cm (6 in) and search for the larvae or pupae in the outer bark tissues or pitchy soil. This is to verify the insect's presence (damage to the collar may not be recent).
5. Stop the survey when one or more trees are examined and insects are found and identified (a very light infestation may require sampling several trees before locating a weevil or its damage), or continue with an appraisal survey (as described below).

Immature Weevil Appraisal Survey.-The immature appraisal survey estimates the weevil population and amount of injury. It involves determining the percentage of trees having immature weevils present (i.e., larvae in the root collar, and pupae and callow adults in pupal cells underground). This survey estimates the number of insects per tree (fig. 30), and should be conducted only in stands with trees that average about 5 to 13 cm (2-5 in) in diameter at ground level or 1 to 5 m (3-15 ft) tall. Sampling should be done only between mid-June and mid-July, for several reasons.

The greatest numbers of insects are present at this time and many of the larvae are large and easy to detect. Also, pupae and callow adults are in cells in the soil at this time, and the new adults have not yet emerged.

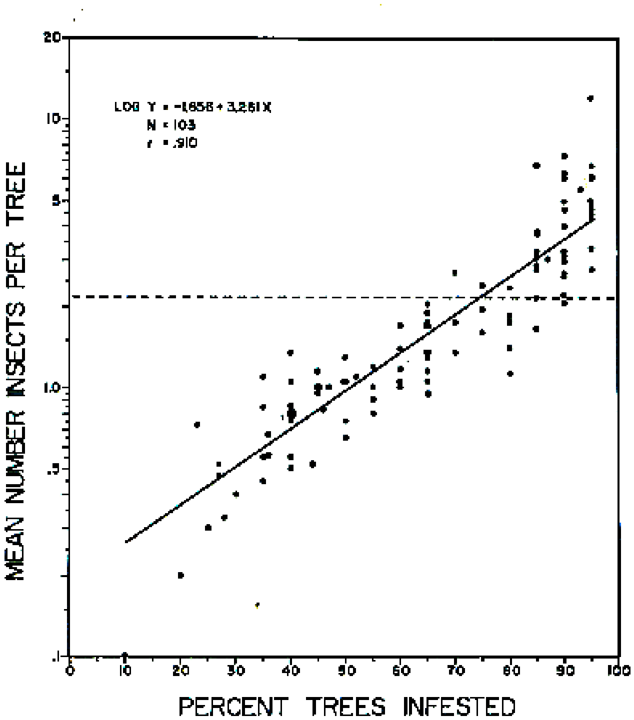

Figure 30-Relation between mean number of immature weevils (larvae, pupae, and callow adults) per tree and percentage of trees infested. The tree-mortality threshold usually occurs at about 2.2 insects per tree and a 75 percent infestation level (see dashed line).

The major problem with this survey occurs when larvae from other weevils and white grubs may be confused with those of the pine root collar weevil. A trained individual, however, can usually distinguish the pine root collar weevil from other insects.

Here is a way to make an immature appraisal survey:

1. Decide whether the entire stand or only a portion is to be sampled. Sample only a small portion if you suspect that portion to be especially susceptible.
2. Conduct the survey systematically and sample only live standing trees.
3. Sample trees according to the following chart:

Stand size		Sample trees	
Acres	*Hectares*	*Number per acre (0.4 ha)*	*Total*
1	0.4	20	20
3	1.2	7	21
5	2.0	4	20
10	4.0	3	30
> 20	> 8.0	2	40

4. Sample each tree by first cutting off one or more lower whorls or branches to get at the tree base.
5. Remove the needle litter out to about 30 cm (1 ft) and dig a small trench around the tree about 15 cm (6 in) away and 15 cm (6 in) down in the soil.
6. Remove the soil from the root collar in six to eight "pie" sections, crumble it and examine for larvae, pupae, or callow adults. (Callow adults are light brown or reddish-brown weevils still in pupal cells.) The soil should be pitchy and damage should be evident at the root collar. Record the tree as uninfested if there is no pitch, and move to the next tree.
7. If the tree is obviously damaged, keep searching for immatures. If none are found in the soil, then scrape away some of the bark where the injury occurs. Record the tree as infested when the first live specimen of the weevil is found and move to the next tree.
8. If no larvae, pupae, or callow adults are found after a thorough search, record the tree as uninfested and move to the next tree. (Note: damaged trees are not necessarily currently infested.)
9. When a sufficient number of trees have been sampled (20 or more depending upon size of stand), calculate the percentage of trees infested with immatures. If 75 percent or more of the trees have immatures, the population is sufficiently high to cause or continue causing tree mortality (see figure 29), and control may be warranted.

Adult Appraisal Survey.-This survey is easier to conduct than the immature appraisal; it requires only recording the percentage of trees having adult weevils present at the root collar. This survey estimates the number of weevils per tree (fig. 31), and proposes a level at which control might be considered. The survey should be made only in stands with trees that average 5 to 13 cm (2-5 in) in diameter at ground level or 1 to 5 m (about 3-15 ft) tall. Further, to obtain the most accurate results, it must be made between mid-May and the end of June. This is the time when the primary behavior is mating and egg laying (most weevils are close to the root collar during the day) and prior to emergence of the next generation of weevils.

The greatest chance of error in this survey occurs when there is a weevil complex involving two or more *Hylobius* species. The pales weevil, pine root tip weevil *(Hylobius rhizophagus* Millers) (Millers, *et al.* 1963) and others sometimes occur with the pine root collar weevil (Mosher and Wilson 1977). Adults of these species, which look very much alike, may be found together. If this is suspected, a survey of immatures should be made in addition to or instead of an adult survey. The larvae and pupae of these species also look alike, but are generally found in different locations. If the larvae are in the bark of the root collar of living or recently dead trees and the soil adjacent to the collar is pitchy, chances are they are pine root collar weevils.

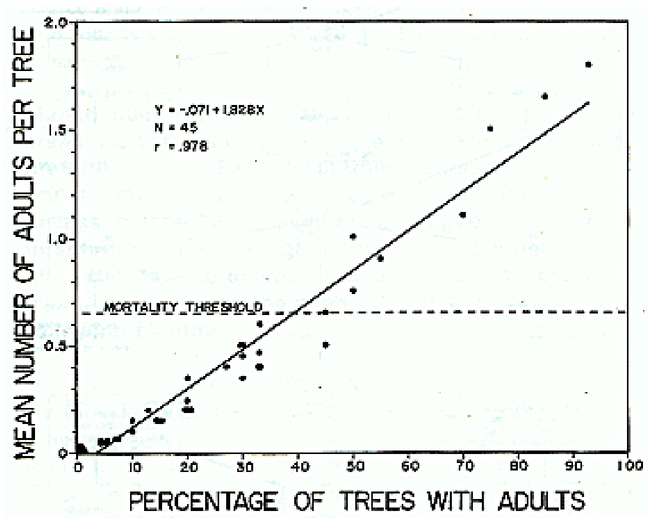

Figure 31.-Relation between mean number of adult weevils per tree and percentage of trees with adults. The tree mortality threshold usually occurs at about 0.65 adults per tree and a 40 percent infestation level (see dashed line).

Here is a way to make an adult appraisal survey:
1. Decide whether the entire stand or only a portion is to be sampled. Sample only a small portion if you suspect that portion to be especially susceptible.
2. Conduct the survey systematically and sample only live standing trees.
3. Sample trees according to the following chart:

Stand size		Sample trees	
Acres	*Hectare*	*Number per acre (0.4 ha)*	*Total*
1	0.4	20	20
3	1.2	7	21
5	2.0	4	20
10	4.0	3	30
>20	>8.0	2	40

4. Sample each tree by first cutting off one or more lower whorls or branches to get at the tree base.
5. Carefully lift the needle litter and examine the underside of it and the soil surface for adult weevils. Search around the root collar and out to 46 cm (18 in) from the tree. Carefully examine the bark and crevices around the tree base for the weevils.
6. When one live weevil is found, record the tree as infested and move to the next sample tree. Check carefully to see if the weevil is alive, because it will often feign death when handled. An easy way is to set it on your forefinger and press it gently with your thumb. A live weevil will grasp the finger with its legs. You may have to press two or three times to get this response.
7. If no weevils are found, continue the search. If necessary, dig the soil away from around the collar down to about 10 cm (4 in) and search for weevils against the bark. If weevils are still not found, record the tree as uninfested and move to the next tree.
8. When a sufficient number of trees has been sampled, calculate the percentage of trees with adults. If 40 percent or more of the trees have weevils (see fig. 3I), the population is sufficiently high to cause or continue causing tree mortality.

Damage Appraisal Survey.-This survey is done only when tree mortality and windthrow occur. An estimate of the percentage of dead trees (including those yellowing and wind-thrown) reasonably predicts the percentage of trees under attack in a rising or stable infestation.

Here is a way to make a damage appraisal survey:
1. Systematically traverse the stand by walking at some standard interval, such as every chain (66 ft, 20 m) tenth row, etc.
2. Record living and dead trees along rows or in clusters at these intervals, and then calculate the percentage of trees dead. Periodically, verify that the weevil is causing the damage and not some other agent (see *Detection Survey).*
3. If 3 to 5 percent of the trees are recently dead, then about 95 percent of the trees probably are infested. The weevil population is sufficiently high to cause subsequent mortality unless trees are densely planted and crown closure is occurring.

Stand Damage Index.-A damage index can be calculated for young pine plantations by measuring the larval injury on a sample of 20 to 30 trees (Kennedy and Wilson 1971). This involves cutting down some trees and thus is used mostly for research purposes, but it can be used in practical field application when a more precise estimate of damage is needed. Only trees 1 to 3 m (3-15 ft) tall should be used.

Here is a way to make a stand damage index:
1. Systematically sample 20 to 30 trees through the planta-

tion or portion of the plantation to be surveyed.
2. Dig around the root collar to root depth and search for larval injury.
3. If no injury is found, simply record the tree as uninfested and move to the next sample tree.
4. If injury is found, saw down the tree and chop out the stump.
5. Continue sampling trees until all have been recorded as either uninfested or as infested and dug up.
6. Saw each stump in cross section across the area that appears to have the worst external damage.
7. On one face of the cross section, calculate the degree of damage "d" by the formula:

$$d = \frac{G_{o_1} + G_{o_2} + \ldots + G_{on} + G_{i_1} + G_{i_2} + G_{in}}{C_{o_1} + C_{o_2} + \ldots + C_{on} + C_{i_1} + C_{i_2} + C_{in}}$$

   where G_o, G_i are measurements of girdled outer and inner bark (in or cm) for each root collar; C_o, C_i are circumferences (in or cm) for the outer and inner bark, respectively, for the same root collars; and "n" represents the sample size.
8. Then calculate the damage index (D.I.) for the stand by multiplying the total damage "d" by the proportion of trees infested. Thus, D.I. equals dpk, where "d" is the total damage, "p" is the proportion of trees infested, and "k" is a constant (1,000) to remove decimals. The D.I. ranges from 0 to 1,000, and provides an estimate of absolute damage.

Three general classes of damage-light, moderate, and heavy-can be partitioned from calculated damage indexes. The light damage class (indices 1 to 100) contains pines with less than 40 percent of the root collars scarred by larval feeding and no abnormal growth or off-color symptoms. The moderate damage class (indices 101 to 300) contains pines with 30 to 85 percent of the root collars scarred by larval feeding, and 10 percent or more with shortened terminal growth. At most, a very few off-color or dead trees may also occur and then only at the upper limit of this class. The heavy damage class (301 to 1,000) contains pines with 80 to 100 per-cent of the root collars scarred by larval feeding and from a few to many trees leaning, off-color, or dead.

By reversing this procedure-that is, by determining the percentage of trees damaged and examining growth loss and mortality in a stand-the general damage class can also be determined.

Management Guidelines

Pine root collar weevil management should be an integral portion of forest management, in order to prevent or control a weevil problem and thus maintain a productive forest. Preventive and control strategies developed for the weevil are compatible with current pine management practices, and can be used as needed in planning pine plantations or in managing existing plantations.

Management begins with an evaluation of the site before planting. You should first know whether there is a hazard of weevil infestation, and the degree of risk involved. For ease of decision making, management guidelines are proposed here, and a decision-making flow chart is provided (fig. 32) which gives the sequence of alternatives and consequences.

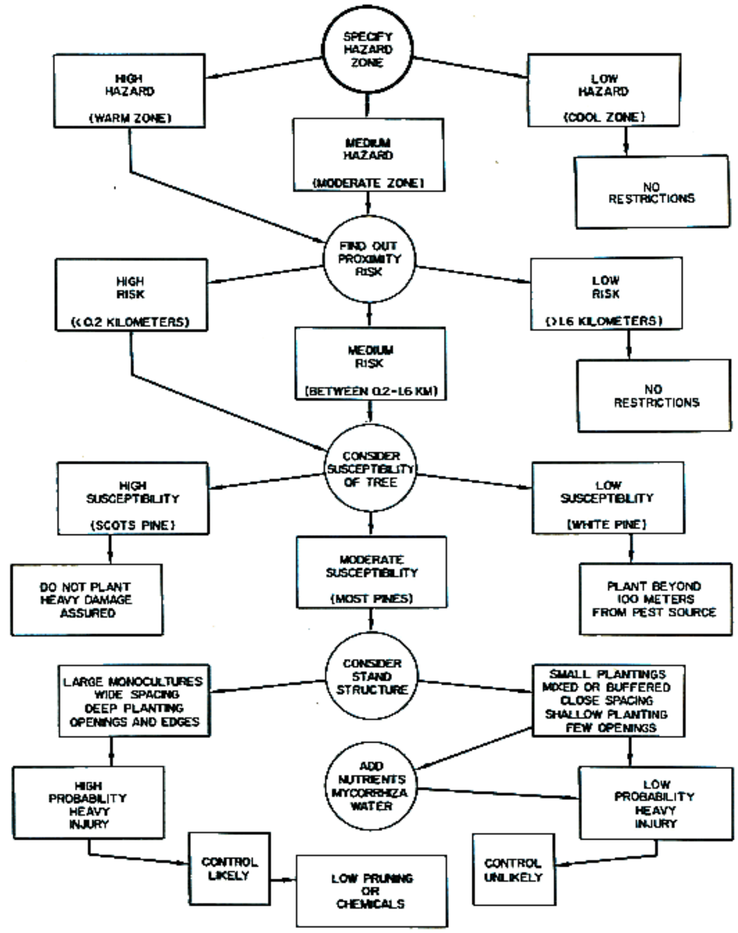

Figure 32.-Decision-making guidelines and probable consequences of pine root collar weevil management. (See *Management Guidelines* section for details.)

Site Evaluation and Pine Species Section.-Pine root collar weevil management begins with an estimation of weevil hazard. Certain areas are low hazard because conditions are unfavorable for the insect. Climate is important; the weevils survive best where summers and winters are relatively mild. General hazard zones (i.e., low, medium, high) have been assigned only for portions of the Lower Penninsula of Michigan and for red pine (see fig, 29), but they may eventually be established for the entire range of the weevil and other hosts.

Management Guideline No. 1: Assuming the site is favorable for good pine growth, evaluate the site for

low, medium or high weevil hazard. If a hazard zone is unknown for the area, determine hazard by noting whether stands nearby are heavily infested or not-if trees are dying from weevil, the hazard is high.

The next question to be asked is, what is the risk from the weevil? An area may be low, medium or high risk, even within a high-hazard zone, because risk of infestation and heavy injury depends on proximity of the site to the nearest infestation source. An area proposed for planting that is adjacent to an infestation source or has one or more infested brood trees on the site is high risk and almost certain to sustain heavy injury. Risk drops rapidly when the infestation source is more than 1.6 km (1 mi) distant. Generally, infestation sources exist when jack, red, pitch or Scots pines occur in natural standards, windbreaks, or Christmas tree plantings.

Management Guidelines No. 2: For medium- or high-risk areas, plant trees only if the site is 0.8 km (0.5 mi) and preferably over 1.6 km (1 mi) from the nearest infestation source. Use a stand hazard and risk-rating survey if necessary (see *Survey* section). Disregarding a nearby infestation source in high- or medium-risk areas will ultimately lead to one or more, usually costly, control treatments between the sixth and fifteenth years following planting.

What about host susceptibility; All two- and three-needle native and exotic pines that will grow within the weevil's range are susceptible to some injury. Most pine species appear about equally susceptible, except white pines and Scots pine. Eastern white pine and other five-needle pines are highly resistant, and are injured only when planted adjacent to or mixed with susceptible species. Planted only a few hundred meters away from a brood source, white pine retains high resistance to injury.

Scots pine, which is the most susceptible host, usually succumbs rapidly after initial attack. There are, however, a few varieties from France, Turkey, and Yugoslavia that are some-what less susceptible, or at least more tolerant to injury.

Management Guideline No. 3: Consider alternative pine species and when possible select the most resistant species when planting in all but low-hazard areas. When the infestation source is unusually close, white pines are the only safe species. Other pines, except Scots pine, are satisfactory and can be planted when the risk is low and the distance to the nearest infestation source is over 1.6 km (1 mi). Avoid planting Scots pine unless the area is outside the range of the weevil or the planting is for Christmas trees; then choose the best varieties for color, weevil resistance, and other suitable traits (varieties *aquitana, armena,* and *illyrica* are best).

Site Preparation and Planting.-What about infestation source? Brood trees that harbor the pine root collar weevil on or adjacent to the site assure a certain infestation to a new planting. The young pines will be infested within 3 or 4 years after planting or when they are about 2.5 cm (1 in) in diameter at the ground line. Brood trees on the site may be residual trees left from logging, volunteer trees, seed trees, windbreak trees, wolf trees, or any other type of tree that is infested and potentially dangerous to the stand.

Management Guidelines No. 4: Check potential brood trees for weevils on or adjacent to the proposed planting site and treat chemically or remove before planting. Use the detection survey (see *Survey* section) for locating the insect or damage.

How do planting procedures affect the weevil? When trees are planted at high density, crown closure occurs early and weevil populations drop before tree mortality occurs. Normally, on a good site, 2.4 m by 2.4 m (8 by 8 ft) spacing is maximum distance for red pine and 1.8 m by 1.8 m (6 by 6 ft) spacing is maximum distance for jack and other pines. (Closer spacing is better on poor sites where initial growth will be slow-such as very dry, sandy, or heavily sodded areas. Firebreaks or openings left for wildlife within the stand provide border trees that are attractive to the weevil.

Spaces left from early tree mortality or planting failures delay crown closure. If replacement of missing trees is made within 1 to 2 years, using the same or older planting stock, the crown will close sufficiently to hinder weevil populations.

Severity of weevil damage tends to increase as planting depth increases. Normally, when trees are planted in furrows, the root crown is 20 to 25 cm (8-10 in) below ground-a condition that favors the weevil. In high-hazard areas, damage can be reduced by planting trees only 10 to 13 cm (4-5 in) deep.

Management Guideline No. 5: Establish a new pine plantation at 6 by 6 ft (1.8 by 1.8 m) spacing with minimum firebreaks and openings, maintain field stocking by replanting within 2 years, and plant as shallow as possible.

What about tree species diversity? Large monoculture plantings tend to encourage weevil outbreaks. Mixtures of pines by age or species, however, are no better, and often worse, because damage is encouraged on the younger or less susceptible species. Small blocks of pines separated by non-host trees are less inviting to attack. Row mixtures of pine and non-host trees such as spruce, larch, or broadleaf trees or shrubs also discourage heavy weevil infestation.

Management Guidelines No. 6: Plant small, solid blocks (1-2 acres, 2.5-5.0 hectares) of trees of one species

separated by buffers of non-host species of trees or shrubs. If large blocks are planted, mix pine with spruce, larch, or other compatible non-host trees or shrubs.

Plantation Maintenance.-How can stands be maintained that are unattractive to the weevil? Vigorous, healthy pines resist attack, and, on a good site, the pines tend to outgrow weevil injury. On marginal soils, however, the addition of water, nutrients, and mycorrhizae, and the reduction of bracken fern, sweet-fern and dense sod, will increase vigor. The addition of water and nutrients can be costly in forest plantations or may not be feasible, but sewage disposal effluent and sludge is becoming more readily available-at no cost in some locations.

The rate of sewage application will depend on the type of applicator and available nutrients.

Trees weakened, dying, or dead not only foster weevil buildup but also attract secondary insects such as bark beetles; these are especially injurious in dry years when trees become stressed.

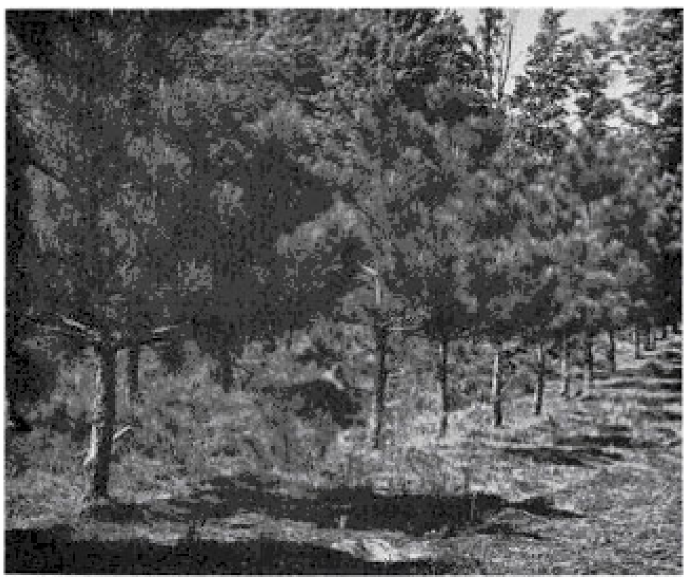

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Figure 33.-Young red pine plantation treated by low pruning and soil scraping to control the pine root collar weevil.

Management Guideline No. 7: Maintain tree vigor by planting on good sites or by supplying mycorrhizae, water, and nutrients when feasible. Practice sanitation by removing dead and dying trees.

Prevention of a problem is more desirable and usually less costly than its cure. Young plantings that are monitored occasionally, especially when the risk is high, should show problems before they develop too far. Pines between 1 and 5 m (3-15 ft) tall are most susceptible.

Management Guideline No. 8: Survey plantings regularly (2 to 3 year intervals) during susceptible stage of growth to detect and evaluate the weevil and its injury (see *Survey* section for specific surveys).

If control becomes essential, what are some of the options? Low pruning and soil scraping usually controls the weevil, and although it costs about the same as chemical treatments, it is not harmful to the environment. It is both a preventive and control tool and applicable to all young pine forest plantings (fig. 33).

The technique simply requires pruning off the lower branches 60 to 90 cm (2-3 ft) above ground and scraping back litter and 5 cm (2 in) of topsoil out to 15 cm (6 in) from the tree (see also fig. 27). Pruning can be done with a Meylan saw, hand saw, and hand clippers; soil scraping can be done by hand, with a tool such as a hoe, or with the foot. The technique is reasonably rapid and needs to be done only once.

Chemical control using pesticides registered for weevil suppression is an option and available when all else fails. Specific registered chemicals should be applied using at least 113 liter (12 or) as a drench to the base of the tree, and following label directions for specific mixtures.

Management Guideline No. 9: To prevent or control the weevil, low prune and remove the litter and soil (5 cm, 2 in deep) out to 15 cm (6 in) around each tree. Apply pesticides only as last resort when all else fails.

Windbreaks and Ornamental Plantings.-Pines (except the white pines) that are planted for windbreaks or for aesthetic purposes are more vulnerable to attack and injury than those in pulp or timber plantations, because they are more open-grown and remain attractive to the insect longer.

Christmas tree plantings, especially if they contain mostly Scots pines, are most vulnerable to attack. If in a high-hazard/high-risk area, they usually require at least one treatment for weevil control before harvest, even when the more resistant varieties are used. Low pruning (see *Plantation Maintenance),* which controls the weevil in most pine plantations, is less feasible in Christmas tree plantings, because removing the amount of foliage necessary for control is undesirable on Christmas trees. A very low pruning of 0.5 m (1.5 ft) or less is usually not enough to drive away all the weevils. Chemicals still offer the best control for Christmas trees, although an integrated approach, using a minimum chemical dosage and low pruning together, gives highly satisfactory control and at the same time provides trees with "handles" at the base, making harvesting and handling easier.

Management Guideline No. 10: Avoid planting Scots pine for windbreaks and aesthetic purposes where the risk of injury is high. In Scots pine Christmas tree plantings, use the most resistant varieties, such as *aquitana*, *armena*, and *illyrica*. Fortunately, these varieties grow well and are among the greenest, and are thus most suitable for the Christmas tree industry.

The entire weevil management scheme, including all steps in the decision-making process, is summarized in figure 32.

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Pesticide Precautionary Statement

Pesticides used improperly can be injurious to human, animals, and plants. Follow the directions and heed all precautions on the labels.

Store pesticides in original containers under lock and key-out of the reach of children and animals-and away from food and feed.

Apply pesticides so that they do not endanger humans, livestock, crops, beneficial insects, fish, and wildlife. Do not apply pesticides when there is danger of drift, when honey bees or other pollinating insects are visiting plants, or in ways that may contaminate water or leave illegal residues.

Avoid prolonged inhalation of pesticide sprays or dusts; wear protective clothing and equipment if specified on the container.

If your hands become contaminated with a pesticide, do not eat or drink until you have washed. In case a pesticide is swallowed or gets in the eyes, follow the first-aid treatment given on the label, and get prompt medical attention. If a pesticide is spilled on your skin or clothing, remove clothing immediately and wash skin thoroughly.

Do not clean spray equipment or dump excess spray material near ponds, streams, or wells. Because it is difficult to remove all traces of herbicides from equipment, do not use the same equipment for insecticides or fungicides that you use for herbicides.

Dispose of empty pesticide containers promptly. Have them buried at a sanitary land-fill dump, or crush and bury them in a level, isolated place.

NOTE: Some States have restrictions on the use of certain pesticides. Check your State and local regulations. Also, because registrations of pesticides are under constant review by the Federal Environmental Protection Agency, consult your county agricultural agent or State extension specialist to be sure the intended use is still registered.

Wilson, Louis F.; Millers, Imants.
Pine root collar weevil-its ecology and management. Tech. Bull. No. 1675.
Washington, DC: U.S. Department of Agriculture; 1982.
34p.

Presents the biology and ecology of the pine root collar weevil, and provides survey techniques and management strategies for its identification and control.

KEYWORDS: pine root collar weevil, *Hylobius radicis,* pest management, pine, prevention, risk-rating, sampling, survey.