AN ABSTRACT OF THE THESIS OF

John Howard McGhehey for the M. S. in Forest Management
(Name) (Degree) (Major)

Date thesis is presented December 16, 1966

Title THE BIOLOGIES OF TWO HEMLOCK BARKBEETLES IN WESTERN OREGON

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The objectives undertaken in this study were to investigate the biologies and potential economic importance of Pseudohylesinus tsugae Swaine and P. grandis Swaine in young coastal stands of western hemlock (Tsuga heterophylla (Rafn.) Sarg.).

The life and seasonal histories of P. tsugae and P. grandis and the association of these two scolytids with the hemlock bark maggot (Cheilosia alaskensis Hunter) are presented.

Both P. tsugae and P. grandis were found to have one generation a year with two broods. Both species had four larval instars. P. grandis overwintered either as a fourth instar larva or as a teneral adult. P. tsugae usually overwintered as a fourth instar larva.

Within thinned stands of western hemlock P. tsugae preferred fresh stumps for breeding material, whereas P. grandis preferred fresh slash.

The teneral adults of both P. tsugae and P. grandis fed in the inner-bark region of standing live host trees before initiating egg galleries in suitable breeding material.

Within the thinned stands these feeding sites provided entry to the cambial region of the tree for the hemlock bark maggot. Both the number of maggot infestations and Pseudohylesinus spp. feeding sites within a stand increased after the stand was thinned.

A potential method of control of both P. tsugae and P. grandis and the hemlock bark maggot was found.

THE BIOLOGIES OF TWO HEMLOCK BARKBEETLES IN WESTERN OREGON

by

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A THESIS

submitted to

OREGON STATE UNIVERSITY

in partial fulfillment of
the requirements for the

MASTER OF SCIENCE

June 1967

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Date thesis is presented December 16, 1966

Typed by Donna Olson

ACKNOWLEDGEMENTS

The writer is indebted to the following people who provided assistance and guidance throughout the preparation of this thesis:

To Dr. W. P. Nagel, Assistant Professor of Entomology, Oregon State University, who assisted in outlining the study and offered suggestions and criticism during the conduct of the study and preparation of the thesis.

To Dr. W. K. Ferrell, Professor of Forest Management, Oregon State University and Dr. J. A. Rudinsky, Professor of Forest Entomology, Oregon State University, who reviewed the thesis and offered suggestions.

To Dr. J. R. Dilworth, Head of the Department of Forest Management, Oregon State University, for help in obtaining various assistantships.

To the Louis W. and Maud Hill Family Foundation for their financial assistance through the South Santiam Fellowship.

To the administration of the U.S. Forest Service, Siuslaw National Forest, Waldport Ranger District and the Forest Research Laboratory, Corvallis, Oregon, for permission to use the area on which the field experiments were conducted.

To Gordon Howse and Terry Fitzgerald, graduate assistants, Department of Entomology, Oregon State University, for their help in the field.

To my wife, Patty, for her encouragement and support during the conduct of the study and preparation of the thesis.

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THE BIOLOGIES OF TWO HEMLOCK BARKBEETLES IN WESTERN OREGON

INTRODUCTION

The genus *Pseudohylesinus* Swaine (Coleoptera: Scolytidae) has been recognized as a potential pest of western conifers since the turn of the century. However, little attention has been given to these bark beetles since their breeding material usually consists of logging slash or weakened or decadent trees of species of little commercial value. Recent trends in forest management have changed this situation. Not only are previous "weed" trees being utilized but also silvicultural practices are being intensified. For example, site preparation and intermediate cuttings are commonly employed practices today. Accordingly, forest managers are being forced to reconsider the role of *Pseudohylesinus* spp. as forest insect pests.

Western hemlock (*Tsuga heterophylla* (Rafn.) Sarg.) was virtually unused as a commercial timber resource until recently. Now it is one of the principal pulpwood species in the Pacific Northwest. As a result, preliminary experiments concerning such silvicultural treatments as precommercial thinnings have been initiated in coastal hemlock stands of Oregon by the personnel of the Forest Research Laboratory, Corvallis, Oregon. These experiments have been followed by infestations of *Pseudohylesinus tsugae* Sw. and

P. grandis Sw. Since these insects have not been serious pests in the past, little is known about their general biologies or potential destructiveness. Therefore, the objectives undertaken in this study were to investigate the biologies and potential economic importance of these two scolytids in young coastal stands of western hemlock.

LITERATURE REVIEW

Following a brief review of the genus *Pseudohylesinus*, this section will be devoted to a review of the known biologies of *P. tsugae*, *P. grandis*, the hemlock bark maggot (*Cheilosia alaskensis* Hunter (Diptera: Syrphidae)) and the silvics of western hemlock. Also, precommercial thinnings will be briefly discussed.

Pseudohylesinus Swaine

The genus *Pseudohylesinus* was erected by Swaine in 1917. It included three North American species originally described as *Hylurgus sericeus* Mannerheim, *Hylastes granulatus* LeConte and *Hylesinus nebulosus* LeConte, and five new species described for the first time (Swaine,1917). In 1942, Blackman revised the genus and described several new species. Presently, there are 17 described species (Schedl,1951; Blackman,1942). Bright (1966) has completed revising the genus but the results have not been published. Blackman (1942) stated that the nearest North American relatives of *Pseudohylesinus* are *Hylurgops* LeConte, *Hylastes* Erickson and *Leperisinus* Reitter, but these genera are readily separated by morphological characters as well as by many biological characters such as host preference. No examples of the true *Hylesinus* Fabricius are known to occur in North America (Blackman, 1942).

Pseudohylesinus is typical of the family Scolytidae. It consists of subcortical feeders which exhibit distinct adaptations to certain hosts or to particular parts of the host. Known hosts include western hemlock; Douglas-fir, Pseudotsuga menziesii (Mirb.) Franco; bigcone Douglas-Fir, P. macrocarpa (Vasey) Mayr.; lodgepole pine, Pinus contorta Dougl.; Monterey pine, P. radiata D. Don.; Sitka spruce, Picea sitchensis (Bong.) Carr.; and all Abies Mill. indigenous to the Pacific Northwest (Blackman, 1942). When Swaine (1917) erected the genus, he listed four species that were known to attack western hemlock. Blackman (1942) in his revision of Pseudohylesinus described two new species attacking the same host. However, the taxonomic validity of these two new species was questioned by Chamberlin (1958).

Little biological data has been collected for the species of Pseudohylesinus. The most recent and complete studies include those by Chamberlin (1958), Thomas and Wright (1961), and Walters and McMullen (1956). Bushing (1965) listed three hymenopterous parasites of Pseudohylesinus: Coeloides brunneri Viereck (Hymenoptera: Braconidae) on P. granulatus (LeConte); Opius n. sp. (Hymenoptera: Braconidae) on P. nebulosus (LeConte); and Eubadizon strigitergum (Cushman) (Hymenoptera: Braconidae) on Pseudohylesinus sp.; no other predators or parasites have been listed. Both Burke (1905) and Chamberlin (1960) reported about a relationship between Pseudohylesinus spp. and Cheilosia spp. in western hemlock, Abies spp. and Sitka spruce.

Pseudohylesinus tsugae Swaine

P. tsugae was first observed by Burke (1905). He called it the hemlock bark beetle and believed it to be a new species of Hylesinus but no description was given. This species was first described by Swaine (1917) and later redescribed by Blackman (1942). Both descriptions are long and complicated. Chamberlin (1958) described P. tsugae as follows:

> A reddish-brown, stout species, moderately clothed with short, stout hairs, has tufted hairs on the sides and narrow scales on the declivity. It is very close to nobilis but the striae are distinctly narrower than the interspaces; the elytral scales are very noticeably elongate. Differs from granulatus by being much stouter in form, with a less dense and less strongly roughed pronotum as well as by the tufted vestiture laterally. Length 3.5 to 3.5 mm. If our determinations are correct, this is the only species showing a definite medium carina from base to front of the pronotum.
>
> Type locality: Stanley Park, Vancouver, British Columbia.
>
> Distribution: British Columbia to California. Specimens have been collected from Glacier and Naselle, Washington; Astoria and Otis, Oregon.
>
> Host: Western hemlock (Tsugae heterophylla) and rarely in Abies amabilis.
>
> Notes: Swaine reports that this species infests

> dead and dying trees, and slash, and at times attacks and kills living trees. Specimens were collected from recently cut hemlock at Astoria, Oregon and in the Mount Rainier area of Washington.
>
> The transverse egg galleries are found under the bark.

The life and seasonal history of *P. tsugae* has never been studied. However, Blackman (1942) and Burke (1905), among others, have made note of some of its habits.

Blackman (1942) reported that adults of the hemlock bark-beetle often penetrate the bark of healthy trees in the fall where they overwinter and feed on the phloem. Burke (1905) had observed the same phenomenon earlier while investigating the biology of the hemlock bark maggot. He described the feeding sites as being short galleries that just score the sapwood.

Pseudohylesinus grandis Swaine

P. grandis has been described by Swaine (1917), Blackman (1942) and Chamberlin (1958). The description given by Chamberlin is the least complicated and the most complete:

> A stout, more oval species (length 3.5 mm.); densely clothed with brown and gray scales; pronotum distinctly narrower than the elytra, sides slightly arcuate, front margin rounded; disk roughly, not coarsely punctured; punctures shallow and irregular. Elytra strongly rounded at the base; striae narrow, faintly impressed on the disk, more strongly at the sides; interspaces wide, faintly convex, more strongly so on the declivity.

Type locality: British Columbia.

Distribution: British Columbia to California, east to Idaho and Colorado.

Hosts: Abies grandis, A. amabilis, A. lasiocarpa, A. magnifica, Pseudotsuga menziesii, and Tsuga heterophylla.

The biology of P. grandis has been studied by Chamberlin (1939) and Thomas and Wright (1961). Additional data have been reported by Blackman (1942), Daterman, Rudinsky,and Nagel (1965), and Dyer and Nijholt (1965).

Chamberlin (1918) followed the life and seasonal history of P. grandis attacking Douglas-fir in the Willamette Valley. He found two generations a year, each with a single brood. Thomas and Wright (1961) reported that in northwestern Washington in silver fir (Abies amabilis (Dougl.) Forbes) there is one generation every two years with two broods. Daterman, Rudinsky, and Nagel (1965) also concluded that there is one generation per two years after following the flight patterns of P. grandis on Mary's Peak, near Corvallis, Oregon. However, they were not able to account for the increase in relative abundance of P. grandis that occurred in 1964 following the 1962 Columbus Day windstorm in Oregon that predisposed great amounts of windthrown timber to beetle attack in 1963. Dyer and Nijholt (1965) indicated that on Vancouver Island in British Columbia, P. grandis has one generation per year.

Chamberlin (1939) and Thomas and Wright (1961) reported that the adult beetles construct transverse galleries varying from 12.7 to 127.0 millimeters in length that score the sapwood. Shea, Johnson, and McKee (1962) found P. grandis attacking all along the bole of its host but preferring the tops. This agreed with that reported by Thomas and Wright (1961). Chamberlin (1939) reported that females deposit about 75 eggs, which require ten to 15 days to hatch. He also found that the larval stage lasted less than six weeks. Thomas and Wright (1961) determined that the larval stage lasted 12 to 14 months. It has been reported several times that this insect overwinters in standing, live trees as a teneral adult where it feeds to some extent on the phloem (Chamberlin, 1958; Thomas and Wright, 1961).

Chamberlin (1939) stated that P. grandis is occasionally quite injurious to both grand fir and Douglas-fir. Thomas and Wright (1961) reported that in northwestern Washington, during the period of 1947 to 1955, P. grandis and P. granulatus killed over 528 million board feet of silver fir. Orr, Pettinger, and Dolph (1966) reported that these same two species were found in epidemic numbers in 1963 in over 54,840 acres in Washington. The area of infestation dropped considerably in 1964, but was found to be trending upward again in 1965.

Thomas and Wright (1961) felt that P. grandis was usually held in check by natural factors and the only practical control was maintenance of vigorous stands and salvage logging. Chamberlin (1939) stated that parasites are sometimes abundant where the beetles are working under thin bark and predacious mites have been observed in the mines. These predators and parasites have never been identified.

Hemlock Bark Maggot (*Cheilosia alaskensis* Hunter)

Chamberlin (1960) described the adult hemlock bark maggot as a small black fly about ten millimeters in length with a wing spread of about 18 millimeters densely covered by black hairs. He described the larvae as being a whitish maggot belonging to the rat-tail group--the body terminates in a whip-like tail about as long as the body proper. The length of a full-grown larvae is 15 to 20 millimeters.

Burke (1905) and Keen (1952) reported that the adult lays its eggs in the spring on oleoresin exudating from abandoned feeding sites of *P. tsugae.* Burke (1905) found that these entry courts were utilized in preference to any other wound. The larvae feed up to five years on the growing tissues of the cambium, enlarging the wound but not the entrance to it (Burke,1905; Chamberlin, 1960). Chamberlin (1960) stated that the resultant wound, which may be up to one inch in diameter, heals over a few years after pupation and adult emergence. The wound fills with resin and appears as a dark brown or black resinous scar above which layers of wood are distorted. The injury is often called black check (Burke, 1905).

Chamberlin (1960) reported the distribution of the hemlock bark maggot to be from Alaska south to southern Oregon along the Pacific Coast. In addition, Burke (1905) found it inland in the northern Willamette Valley. No control has been recommended for this insect except that Chamberlin (1960) reported that trees growing above elevations of 1800 feet are not attacked by the maggot.

Western Hemlock (*Tsuga heterophylla* (Rafn.) Sarg.)

Western hemlock is a thin-barked very tolerant conifer which requires an abundance of moisture. Harlow and Harrar (1958) reported that the best growth is attained in regions where the annual precipitation is at least 70 inches. Western hemlock is found along the Pacific Coast from Kenai Peninsula in Alaska to northwestern California and inland along the Rocky Mountains in British Columbia, Idaho and Montana; and the Cascade Mountains in Washington and Oregon (Fowells, 1965). The coastal stands are occasionally pure and dense while inland western hemlock is subordinate in association with other species (Fowells, 1965).

As late at 1930, there was no market for western hemlock

(Ross, 1966). Now it is one of the four major timber-contributing species and the principal pulpwood species in the Pacific Northwest (Harlow and Harrar, 1958; Randall, 1961). Presently, in the Siuslaw National Forest of Oregon, the amount of western hemlock included in the annual cut varies from five to 15 million board feet (Fessel, 1966).

Malmberg (1966) found that western hemlock, 30 years of age or less, responds well to thinnings. Kangur (1966) has substantiated this with his preliminary work with precommercial thinning in coastal stands. Fowells (1965) reported that hemlock responds well to release even after long periods of suppression. The U.S. Forest Service has administrated several thinning sales in western hemlock stands in the Siuslaw National Forest and more sales are being planned for the future (Fessel, 1966).

Fowells (1965) stated that the principal enemies of young growth hemlock are wind, snow, disease, and defoliating insects. Chamberlin (1960) and Keen (1952) reported that the hemlock bark maggot has been very injurious to western hemlock growing in western Washington and Oregon, causing a defect in the wood known as black check. This defect often makes the timber worthless for finishing, but does not impair the wood for pulping or structural purposes (VanVliet, 1966).

Precommercial Thinning

The idea of early or precommercial thinning is not new. As pointed out by Berg (1963) and Malmberg (1966) among others, thinning in young forest stands has been a management practice since the early 1900's in European countries. However, it has been only in the last two decades that such thinnings have been seriously considered in North America. Several federal, state, and private agencies have experimented with precommercial thinnings. The results showed that early thinning is one way to increase volume and quality yield from coniferous stands. Flora (1966) feels the U.S. Forest Service in the Pacific Northwest spends more money annually on precommercial thinning than any other aspect of stand improvement. Furthermore, he pointed out that the annual number of acres precommercially thinned by the U.S. Forest Service in Region 6 has increased five-fold since 1956 to a high of almost 29,000 acres in 1965. Since the trend in the United States is toward maximum yield forest management, precommercial thinning may eventually become a standardized practice once the economical and biological problems involved are solved.

An extensive review of the literature revealed that insect problems have not been observed following precommercial thinnings. However, the possibility that precommercial thinning could create insect problems should be recognized. Accumulation of thinning slash over large areas could provide ideal breeding material for such scolytids as members of the genera *Pseudohylesinus*, *Scolytus*, and *Ips*. Since these bark beetles have been reported to injure or kill standing, live trees when conditions warrant population buildup, the residual trees in a precommercially thinned stand could be jeopardized.

MATERIALS AND METHODS

Research to determine the biologies and potential economic importance of *Pseudohylesinus tsugae* and *P. grandis* was initiated in June 1965 and continued through October 1966. All field studies were conducted about ten miles southeast of Waldport, Oregon. The same area had been utilized by the Forest Research Laboratory, Corvallis, Oregon, since 1961, to study the response of western hemlock to precommercial thinnings, and these study plots were adapted for use in the present investigations.

Study Area

The study area was located on a west slope, approximately 880 feet elevation, in Township 13 South, Range 11 West, Section 9, of the Waldport Ranger District, Siuslaw National Forest. The area has a site index of 150 and is densely stocked with 28-year-old western hemlock but with scattered trees of Douglas-fir; Sitka spruce; and red alder, *Alnus rubra* Bong. (Figure 1). When an understory is present, it usually includes red huckleberry, *Vaccinium parvifolium* Smith; salmonberry, *Rubus spectabilis* Pursh.; and salal, *Gaultheria shallon* Pursh. Also, two nearby 40-acre tracts of hemlock that had been clearcut during the summer of 1965 and spring of 1966, respectively, were used as supplementary study areas.

Figure 1. A young-growth stand of western hemlock in the Waldport Ranger District, Siuslaw National Forest, Oregon.

Plot Treatment

Plot treatments were chosen to provide a gradation of conditions so that insect response to precommercial thinning could be followed. A total of six rectangular plots 0.1 acre in size were used. Two of the plots were originally established in 1961 and adapted for use in the spring of 1965. The remaining four plots were established in the fall of 1965. The following describes the various plot treatments:

Plot UTC. Control, unthinned; established in August 1961 (Figure 2).

Plot TWS-1. Thinned in February 1961, December 1962, October 1964; slash not removed.

Plot TWOS. Thinned in December 1965; slash removed in December 1965.

Plot UTWS. Unthinned; with slash dragged in from plot TWOS, December 1965.

Plot TWS-2. Thinned in December 1965; slash not removed (Figure 3).

Plot ChT. Chemically thinned with cacodylic acid in January 1966.

All thinnings were mechanical with an 8- by 8-foot spacing utilized on plots TWOS, TWS-2, and ChT. Plot TWS-1 was thinned to a 4- by 4-foot spacing in 1961, a 6- by 6-foot spacing in 1962, and an 8- by 8-foot spacing in 1964. The chemical treatment was applied with

Figure 2. Plot UTC; an unthinned stand of 28-year-old western hemlock in the Waldport Ranger District, Siuslaw National Forest, Oregon.

Figure 3. Plot TWS-2; a stand of 28-year-old western hemlock thinned to an 8- by 8-foot spacing, Waldport Ranger District, Siuslaw National Forest, Oregon.

a Hypo-hatchet (Newton, 1966b)(Figure 4). Table I summarizes the mensurational aspects of all six plots.

On each tree to be treated with cacodylic acid, one cut was made near the base for each inch of basal diameter. The result was a dosage rate of approximately 1 cubic centimeter per inch of diameter. Since cacodylic acid tends to crystallize at low temperature, the solution was diluted with water to 90 percent of its original concentration.

Insect response to chemically killed trees was treated separately. The plot was established primarily to help screen cacodylic acid as an herbicide; although it was felt that either or both *P. tsugae* and *P. grandis* might show a definite response to the chemically killed trees. Previously, both Newton (1966a) and Smith (1966) had observed that conifers treated with this herbicide were usually not attacked by bark beetles, and if they were, the progeny of the beetles in the chemically killed trees suffered high mortality.

Identification of *Pseudohylesinus tsugae* and *P. grandis*

Adult specimens of *Pseudohylesinus* were collected during the spring and summer of 1965 from slash and live trees within the main study area and from surrounding windthrown old-growth hemlock. One hundred and fourteen specimens were sent to D. E. Bright[1]

[1] Entomology Research Institute, Central Experimental Farm, Ottawa, Ontario.

Figure 4. Hypo-hatchet used to chemically thin a stand of 28-year-old western hemlock, Waldport Ranger District, Siuslaw National Forest, Oregon.

Table I. Mensurational aspects of the six 0.1 acre plots utilized to study the biologies of *Pseudohylesinus tsugae* Sw. and *P. grandis* Sw. infesting precommercially thinned stands of western hemlock, Waldport Ranger District, Siuslaw National Forest, Oregon.

Plot	Date	Before Thinning		After Thinning			
		Number of Trees	Av. DBH* (inches)	Number of Trees		Av. DBH (inches)	
				Residual	Cut	Residual	Cut
UTC	Aug. 1966	294	4.1	---	---	---	---
TWS-1	Feb. 1961	583	2.3	258	325	3.4	1.4
	Dec. 1962	258	3.4	123	135	4.6	2.3
	Oct. 1964	123	4.6	69	54	5.8	3.1
TWOS	Dec. 1965	399	3.0	70	---	4.7	---
UTWS	Dec. 1965	311	3.3	---	329	---	2.6
TWS-2	Dec. 1965	217	4.1	66	151	5.4	3.5
ChT	Jan. 1966	298	3.4	64	234	3.7	2.7

*Average Diameter at Breast Height--4.5 feet above the ground for identification. They were identified as P. tsugae (57 specimens) and P. grandis (57 specimens).

The first problem encountered was acquiring the ability to distinguish the adults of P. grandis from those of P. tsugae. The specimens were separated by using the following morphological characters provided by Bright (1965):

1. P. grandis often has a row of setae in the second declivital interspace while P. tsugae has never been seen with this character.
2. P. tsugae has hairlike pronotal setae while P. grandis has flat scales.
3. The female P. tsugae is unique in having elytral scales that are narrow and sharply pointed.
4. P. tsugae can usually be separated by the pronotal shape, its generally larger size and its reddish color.

Life Histories

The life histories of P. tsugae and P. grandis were studied by selecting several locations within each plot to follow beetle development. In plots TWS-1, UTWS, and TWS-2, one 8- by 2- by 2-foot rack supporting 15 bolts of slash was erected at the center of each plot (Figure 6). Each bolt of slash was approximately 3.0 feet in length and 3.0 inches in diameter at mid-length. The bark surface area of each set of 15 slash bolts was approximately 35 square feet. The racks with slash bolts were assembled on June 8, 1965, and January 15, 1966, on plots TWS-1 and UTWS, and TWS-2 respectively. The bolts of slash were observed weekly and all attacks occurring the preceding week were marked with colored map tacks. This procedure was continued until no new attacks were observed for a period of two consecutive weeks. A similar marking procedure was followed beginning on June 8, 1965, in plot TWS-1, and on January 15, 1966, in plots TWOS and TWS-2, with 30 stumps, ten from each plot. Also, one tree was felled weekly on plot TWS-1 from June 6 to August 20, 1965, and the resulting attacks were marked in the same manner as those occurring in the slash bolts and stumps. Throughout the study, additional attacks were marked periodically in the scattered slash and stumps in plots TWS-1, TWOS, UTWS, and TWS-2. A total of over 3,000 attacks were marked.

The marked attacks were periodically analyzed to determine the species attacking, length and width of parent galleries, number of eggs laid, and development of the progeny. In cases where the parents were no longer present, it was necessary to wait until callow adults appeared before judgment could be made as to which species initiated the attacks.

The number of larval instars was determined for each species by measuring the head capsule width of individual larvae with a calibrated eyepiece in a dissecting microscope at a magnification of 3X. The larvae had been held in labeled vials containing 70 percent ethanol prior to being measured. A total of 149 *P. tsugae* and 158 *P. grandis* larvae were measured.

Infested material in plots TWS-1, TWOS, and TWS-2 was caged in the field at various times during the fall of 1965 and spring and summer of 1966 to determine the number of generations and broods per year for each species and to collect emerging parasites and predators. Fresh, non-infested slash was put in each cage whenever the adults in the infested slash or stumps began to re-emerge or the progeny in the infested slash began to emerge. One of the trees felled in plot TWS-1 during the summer of 1965 and four bolts of slash from the rack at the center of the plot were taken into the laboratory on September 14, 1965. Here, the two groups of slash were held at 70°F in separate cages in a greenhouse until emergence was completed. Records of insect re-emergence or emergence were kept for all the caged material. Cages used in the field measured 4- by 2- by 2-feet (Figure 5), while those used in the laboratory were 1.5- by 1.5- by 3.5-feet.

Attack Distribution

While following the life histories of *P. tsugae* and *P. grandis*, it was noted that each species appeared to have a unique attack

Figure 5. Type of field cage used in studying the biologies of Pseudohylesinus tsugae Sw. and P. grandis Sw. infesting precommercially thinned stands of western hemlock.

distribution. To determine this distribution, six trees were felled during May 1966 in plot TWS-2. Each tree was felled so that a 1.5-foot stump remained. During June, the stems of these trees were cut into three-foot sections and the number of attacks were recorded by species for each section. Similar data werecollected for each stump. Results were expressed as the average number of attacks per square of bark surface by tree height for each species. The average dbh[2] and height of the six trees were 3.56 inches and 30.5 feet respectively.

Supplementary information concerning the attack distribution of both species in mature hemlock trees was collected during the summer of 1966. Three windthrown hemlock trees, each approximately 2.5 feet dbh and 100 feet long were examined. They had been attacked during the spring and summer of 1965. The relative distribution of each species was noted by the presence of teneral adults and emergence holes.

Insect Response to Plot Treatment

A number of field studies were conducted to determine how density of attack and insect development as well as adult feeding and the behavior of the hemlock bark maggot were influenced by stand treatment.

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[2] diameter at breat height--4.5 feet from the ground.

Density of Attack and Insect Development

In plots UTWS and TWS-2, information concerning attack density and development of *P. grandis* in the thinning slash was collected during the first week of October 1966. Twenty-four square feet of bark were sampled in each plot by starting at the respective plot centers and pacing toward each plot corner. Every ten feet, two square feet of bark were removed from the slash and the number of attacks, live pupae, and emerged progeny were recorded. Additional information concerning attack density of *P. grandis* in the in the slash of plots UTWS and TWS-2 was provided by the slash bolts used to study its life history.

Information concerning the attack density and development of *P. tsugae* was collected in plots TWS-1, TWOS, and TWS-2 by examining ten stumps in each plot. The ten stumps closest to the plot center were selected and their diameter and height were measured. Approximately 11 square feet of bark were sampled in each plot. In plots TWOS and TWS-2 only the number of attacks were recorded for each stump. In plot TWS-1, both the number of attacks and emergence holes were recorded. Additional information concerning attack density of *P. tsugae* in the slash of plots UTWS and TWS-2 was provided by the slash bolts used to study its life history.

Hemlock Bark Maggot and *Pseudohylesinus* spp. Feeding Niches

Studies were conducted during the fall of 1965 and summer of 1966 concerning the feeding niches constructed by the adult *P. tsugae* and the association of the hemlock bark maggot, (*Cheilosia alaskensis*) with these niches, as reported by Burke (1905). In October 1965, 25 trees were randomly selected from each of the six study plots. During the same month, these trees were examined and the number of resin masses of the maggot per sample tree in each plot was recorded. By walking around the base of each tree, it was possible to observe all resin masses caused by the maggot in that tree. The same trees were examined again on August 23, 1966, and any change in number of resin masses present was noted.

During the summer of 1966, the teneral adult feeding habit of female *P. tsugae* and *P. grandis* was studied. In plot TWS-2 the 25 trees used for studying the hemlock bark maggot were also used to follow the occurrences of feeding niches. A total of 80 attacks were marked as they occurred over a period of one week. Fifty of these were used to determine the length of time spent in the feeding niche. Time periods of 1, 3, 5, 11, and 13 days were selected and ten niches representing each time period were examined. The remaining 30 attacks were used to test the sexual maturity of the attacking females. Fifteen of these attacks were examined the day they occurred. The adults were removed and taken to the laboratory where they were examined under a dissecting scope. The other 15 attacks were examined five days after they were initiated. Eight females were found and their sexual maturity was checked. A female was considered sexually mature if its oocytes were distinctly enlarged.

To determine if the distribution of feeding sites varied with plot treatment, one tree was felled on each of the six plots during the last week of August 1966. Each tree felled was approximately 3.25 inches dbh and 30 feet long. Simultaneously with each felling, the basal seven feet of three additional trees were examined and the number of feeding sites occurring in both 1965 and 1966 and the mid-diameter of the section were recorded. The felled trees were divided into three-foot sections and data similar to that recorded for the basal sections were noted for each section of the stem. The data collected from the 18 seven-foot basal sections were expressed as the mean number of feeding sites occurring per square foot of bark surface in both 1965 and 1966 in each plot. These results were subjected to analyses of variance. The results of the data collected from the three felled trees were expressed as the average number of feeding sites per square foot of bark surface by tree height and presented graphically. All trees examined or felled were selected from those trees used to study the bark maggot. The feeding niches of *P. tsugae* could not always be separated from those of *P. grandis*; therefore, the results were expressed as the number of *Pseudohylesinus* spp. feeding niches per square foot of bark surface.

Chemical Treatment

By the end of March 1966, 71 percent of the chemically treated trees in plot ChT had lost 50 percent or more of their needles. On April 2, three treated trees near the plot center that had lost all of their needles were chosen for studying insect development. Periodically, throughout the spring and summer of 1966, these three trees as well as the other treated trees within the plot were observed and the presence or absence of *P. tsugae* or *P. grandis* was observed. On September 14, 1966, the three selected trees were felled and one-foot sections were analyzed from the middle portions of the basal, middle and top one-third of each tree. For each section examined, the following information was recorded: number of attacks, length of parent galleries, number of eggs laid, and stage of development reached by living and dead larvae. A total of 4.57 square feet of bark was sampled from the three trees. The average dbh and height of the three trees were 2.58 inches and 30.5 feet respectively.

Meteorological Records

Measurements and records of temperature, evaporation rate, and light intensity were made periodically throughout the duration of the study. All measurements were designed to emphasize meteorological differences occurring between the various plot treatments. Temperature was measured continuously in plots UTC and TWS-1 from June to September 1965, and on plots UTWS and TWS-2 from February to August 1966. The temperature was recorded by a hygrothermograph. One instrument was located at the center of each of the above plots and was protected from sunlight in an open enclosure approximately four feet above the ground (Figure 6). Also, in plot TWS-1, one hygrothermograph was placed amidst the slash bolts at the center of the plot. Within plot TWS-1 the location of the hygrothermograph in the slash will be referred to as station 2 while that in the enclosure will be designated station 1.

Evaporation rate was measured with a modified Piche evaporimeter as described by Waring and Hermann (1966). Three evaporimeters were attached to the bottom of each hygrothermograph enclosure (Figure 6). Periodically, the evaporimeters were weighed with a balance and the water loss was recorded. In plot TWS-1, three evaporimeters were also suspended from the rack supporting the slash bolts (station 2). This was to allow the evaporation rate in

Figure 6. Hygrothermograph, evaporimeters,and slash bolts as placed in a thinned stand of 28-year-old western hemlock.

the slash to be measured. These three evaporimeters were set out at the same time as the others on plot TWS-1 and were handled in a similar manner.

Light intensity was measured periodically throughout the study on all plots. All measurements were taken between 11:00 a.m. and 1:00 p.m. Standard Time, at four feet above the ground or slash, with a Wesson light meter pointed at a true bearing of S45^{o}W. For each plot, readings were recorded both at the plot center and at a distance of 15 feet from the plot center in all four cardinal directions. Two sets of readings were taken for each plot at all stations by visiting the plots in their numerical sequence and repeating this procedure once. It required about 60 minutes to complete both sets of readings.

RESULTS AND DISCUSSION

A comparison of the climatic conditions found within the various plots will be presented first. These findings will be referred to periodically in the subsequent discussions of the life histories and habits of *Pseudohylesinus tsugae*, *P. grandis*, and *Cheilosia alaskensis*.

Meteorological Records

Figures 7, 8, and 9, and Tables II and III summarize the climatic conditions found within the various plots. In general, it appeared that the thinned stands had increased temperatures and light intensities but no change in evaporation rate in relation to unthinned stands when these variables were measured at four feet above the ground or slash. The climatic conditions in the slash were found to be quite different than that four feet above the slash. Figure 7 illustrates that the air temperature in the slash in plot TWS-1 was usually 2 or 3°F cooler than the temperature at four feet above the ground in the same plot. Very often it was at least 1°F cooler than the temperature realized in the unthinned control plot. In addition, the evaporation rate at station 2 in plot TWS-1 was about one-half that encountered at station 1 (Table II). Figures 8 and 9 and Table II indicate that the presence of slash in plot UTWS resulted in both reduced temperatures and evaporation rates in comparison to plot TWS-2.

Table II. Comparison of the mean evaporation rates measured at four feet above the ground or slash and in the slash in unthinned and thinned 0.1 acre plots of 28-year-old western hemlock during 1965 and 1966, Waldport Ranger District, Siuslaw National Forest, Oregon.

Time Period	Evaporimeters Number	Evaporimeters Location	Plot Treatment: Unthinned without Slash (Plot UTC)	Thinned with Slash (Plot TWS-1)	Unthinned with Slash (Plot UTWS)	Thinned with Slash (Plot TWS-2)
			Mean Evaporation Rate in Grams of Water Loss			
Aug. 7 to Sept. 14 1965	3	4 feet above the ground or slash	22.42±0.21*	25.63±1.01	---	---
	3	in slash	---	12.95±1.20	---	---
Mar. 23 to July 24, 1966	3	4 feet above the slash	---	---	71.05±0.21	143.67±1.55

*Standard Deviation

Table III. Comparison of the mean light intensities measured at four feet above the ground or slash in unthinned and thinned 0.1 acre plots of 28-year-old western hemlock, Waldport Ranger District, Siuslaw National Forest, Oregon.

		Plot Treatment					
Date (1966)	Number of Readings	Unthinned (Plot UTC)	Thinned Oct. 1964 (Plot TWS-1)	Thinned Dec. 1966 (Plot TWOS)	Unthinned (Plot UTWS)	Thinned Dec. 1966 (Plot TWS-2)	Thinned* Jan. 1966 (Plot ChT)
		Mean Light Intensity in Foot Candles					
April 5	10	11±5**	93±28	3040±1498	47±47	3032±2115	98±27
April 16	10	21±6	129±108	2375±2387	24±2	3150±3714	142±151
June 16	5	15	108	1800	20	2000	250
July 24	10	9±4	74±18	1745±2083	15±4	2107±1815	230±127

*Chemically thinned with cacodylic acid

**Standard deviation

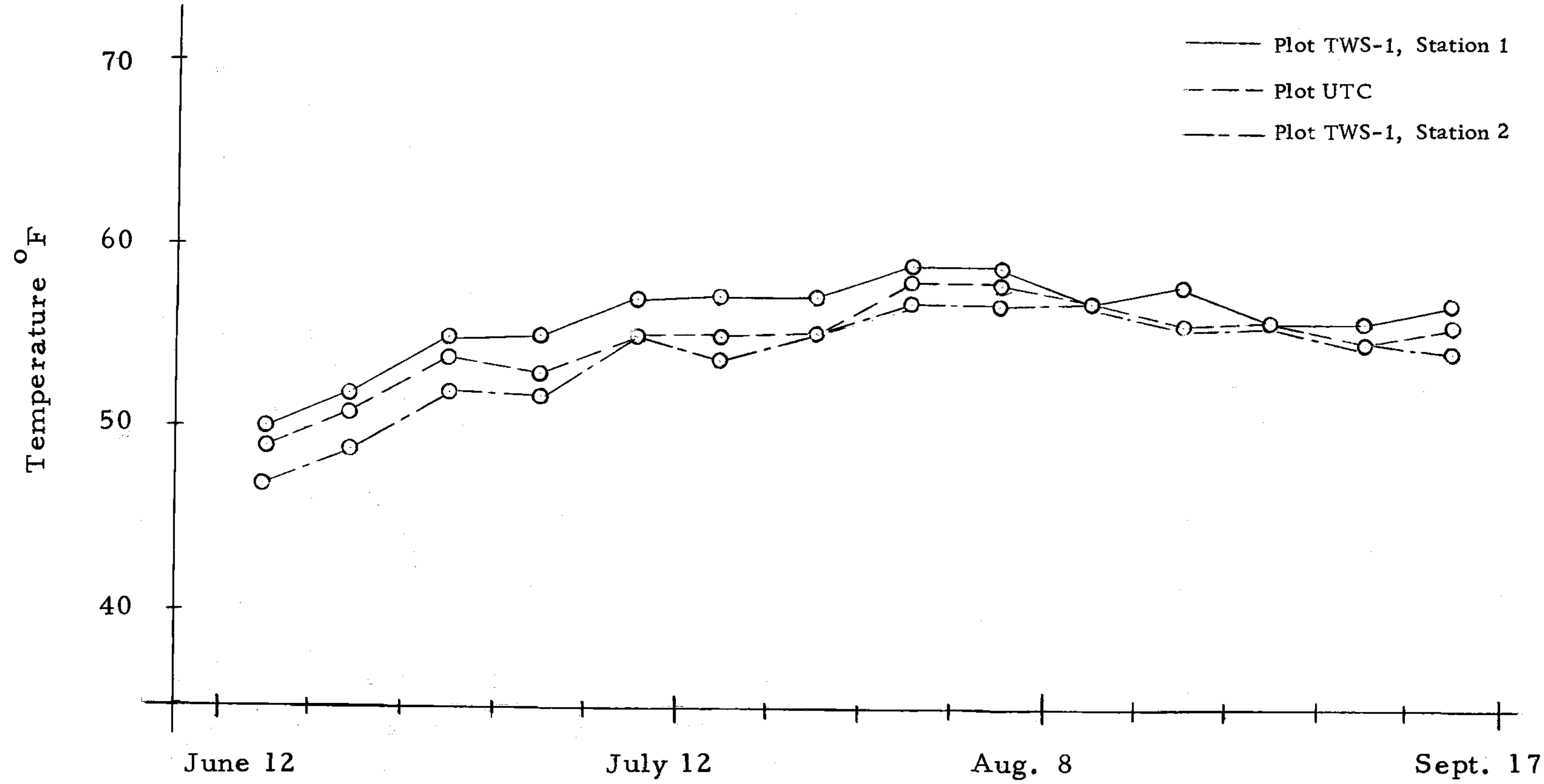

Figure 7. Comparison of the average weekly temperatures that occurred from June 12 to September 17, 1965 within a thinned western hemlock stand at four feet above the slash (plot TWS-1, station 1) and in the slash (plot TWS-1, station 2), and within an unthinned western hemlock stand (plot UTC) at four feet above the ground, Waldport Ranger District, Siuslaw National Forest, Oregon.

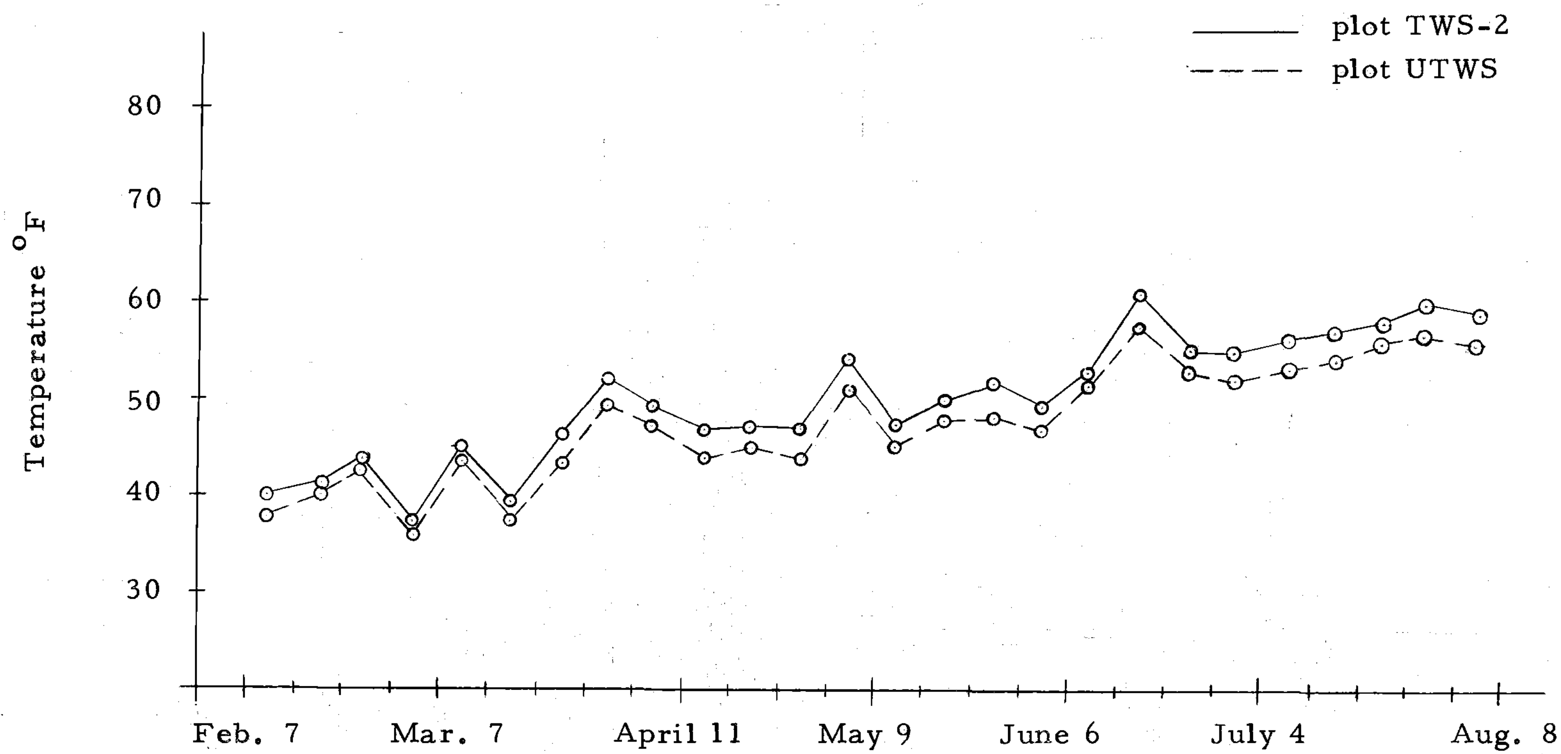

Figure 8. Comparison of the average weekly temperatures that occurred from February 7 to August 7, 1966 within unthinned (plot UTWS) and thinned (plot TWS-2) stands of western hemlock with slash present, Waldport Ranger District, Siuslaw National Forest, Oregon.

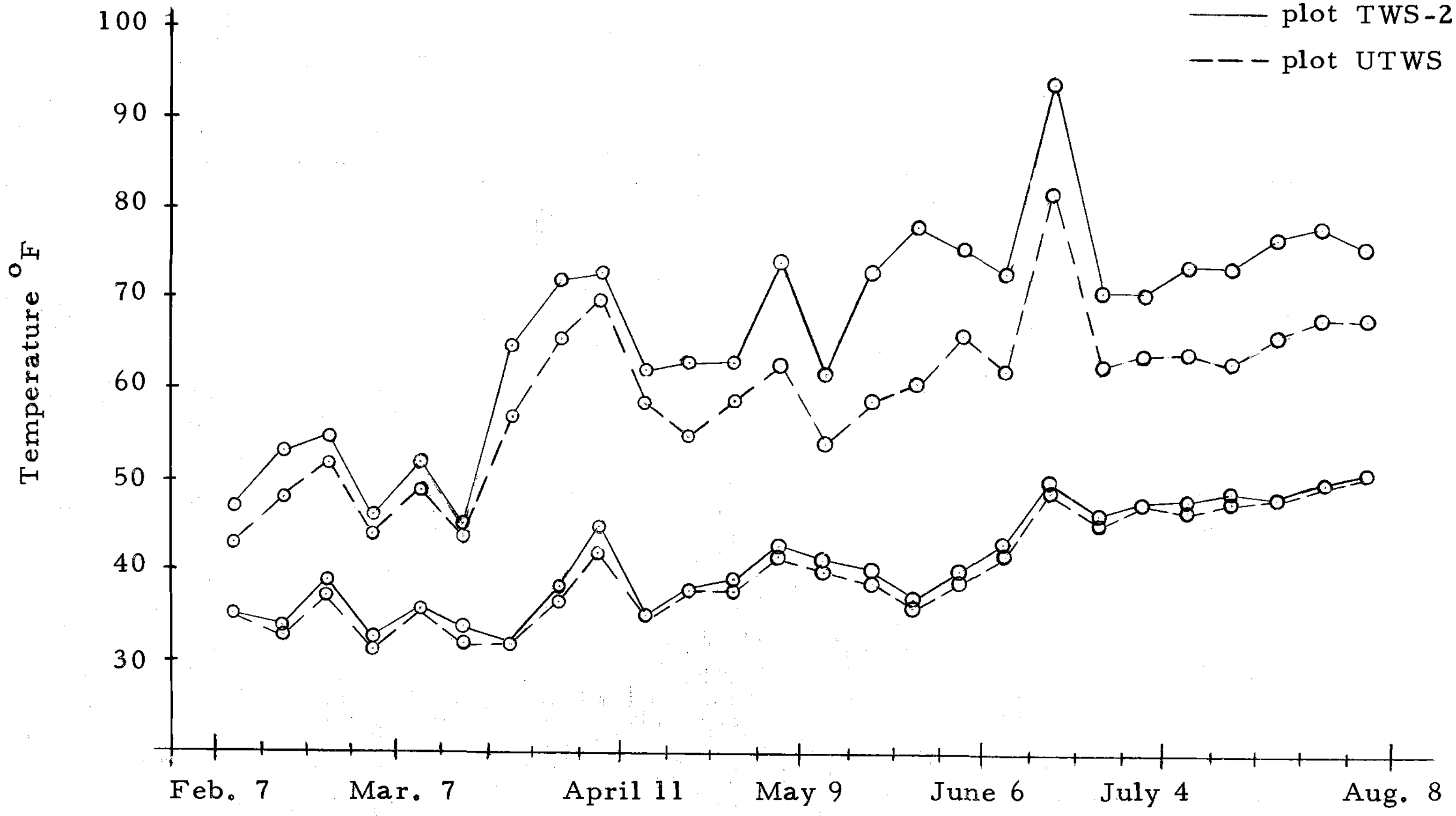

Figure 9. Comparison of the maximum-minimum weekly temperatures that occurred from February 7 to August 7, 1966 within unthinned (plot UTWS) and thinned (plot TWS-2) stands of western hemlock with slash present, Waldport Ranger District, Siuslaw National Forest, Oregon.

Life Histories and Habits

The life histories and habits of *P. tsugae* and *P. grandis* will be considered separately for clarity even though both species are similar in many respects.

Pseudohylesinus tsugae Sw.

Initial Attack. When the present investigations were initiated in June 1965, *P. tsugae* had already infested the slash and stumps resulting from a precommercial thinning of plot TWS-1 in October 1964. The last attacks observed in the slash bolts at the center of the plot and in the slash scattered throughout the plot were on June 8, 1965. No new attacks were noted after August 24 in the stumps. Examinations through November 1965 of 12 trees that had been felled at weekly intervals from June 6 to August 20, 1965, and of slash and stumps from summer logging operations, revealed that *P. tsugae* attacked fresh material until October 6, 1965.

On May 7, 1966, *P. tsugae* was first observed attacking the slash and stumps from the December 1965 thinning of plots TWOS, UTWS, and TWS-2. In plot TWS-2 during the week of May 2 through May 9, the temperature averaged 58°F (Figure 8), and the maxiumum temperature was 74°F (Figure 9). Both temperatures were the highest realized up to that period. The attacks ceased in the slash and slash bolts on May 29 in plot TWS-2, and on June 21 in plot UTWS, a difference of 23 days. This difference was probably due to the relative dryness of the available host material. The slash in plot TWS-2 was exposed to direct sunlight whereas the slash in plot UTWS was shaded. Consequently, by June, the inner bark regions of the slash in plot TWS-2 were much dryer than that in plot UTWS. The stumps in both plots TWOS and TWS-2 were attacked until the end of August. Again, the difference between the attack periods of the slash and stumps was probably related to the comparative dryness of the inner bark. The inner bark of the stumps remained very moist throughout the summer.

Number of Broods. The infested stumps (Figure 10) that had been marked with map tacks and caged in plots TWOS and TWS-2 during May 1966 revealed that *P. tsugae* has two broods per year. Approximately 30 days after their initial attack, the adults re-emerged and either re-infested the stumps or attacked the fresh slash that had been placed in the cages. After the second batch of eggs had been laid, the adults were found dead in the parent galleries or on the ground litter in the cages. It was not determined if the beetles copulated again prior to producing the second brood.

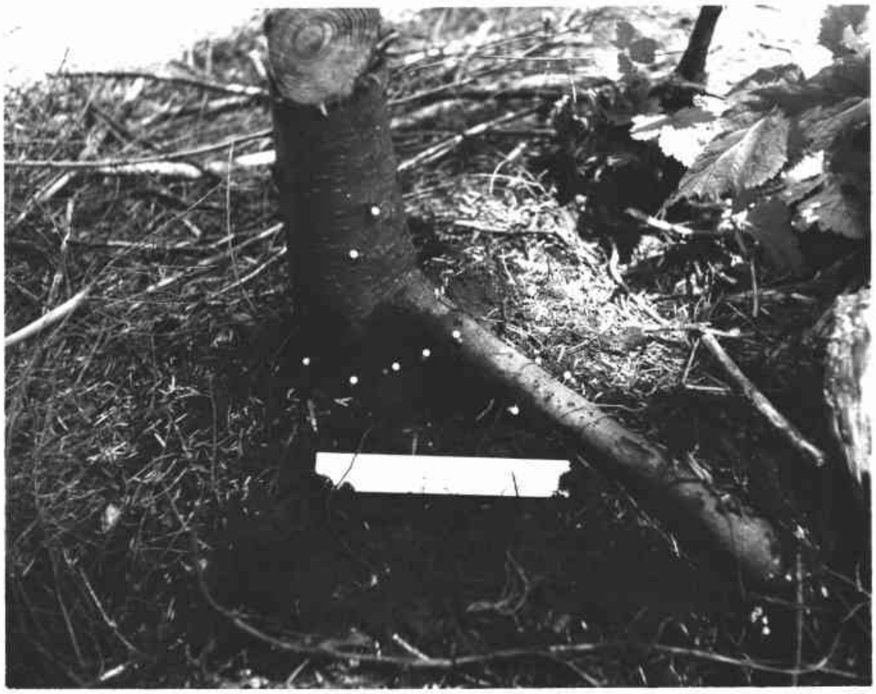

Figure 10. A western hemlock stump with map tacks marking _Pseudohylesinus tsugae_ Sw. attacks. (Six inch ruler in foreground)

Attack Density and Distribution. The attack density on the stumps was found to vary with plot treatment. The ten stumps sampled in plots TWS-1, TWOS, and TWS-2 in 1966 realized 2.61 ± 2.17[3], 4.85 ± 1.67, and 12.69 ± 4.18 attacks per square foot of bark surface area respectively. A "t" test showed that there was a highly significant difference between the mean attack density of the stumps sampled in plots TWOS and TWS-2 ($t = 5.51$ with 18 degrees of freedom). Three factors could aid in explaining this difference. First, in plot TWS-2 there was slash present from the thinning in December 1965 in addition to the stumps, while in plot TWOS all of the slash had been removed. Therefore, there could have been a greater host attraction present in plot TWS-2 than in plot TWOS. Secondly, *P. grandis* was found to attack the slash in plot TWS-2. Infrequently, both *P. grandis* and *P. tsugae* were found together in the same gallery. Therefore, besides being attracted to the greater concentration of host material in plot TWS-2, *P. tsugae* could have also been attracted by the presence of *P. grandis*. Finally, the stumps in plot TWS-2 were shaded by slash. This circumstance could have made the stumps in plot TWS-2 more acceptable as host material than those in plot TWOS.

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[3] The variances of all means are expressed as one standard deviation of the mean.

Attack density in the slash did not appear to be affected by plot treatment. The slash bolts at the centers of plots UTWS and TWS-2 realized an average of 1.78 ± 1.06 and 1.27 ± 0.58 attacks per square foot respectively. A "t" test showed there was no significant difference between these two means ($t = 1.47$ with 28 degrees of freedom). However, a highly significant difference was found when a "t" test was applied to the mean attack densities of the stumps and slash in plot TWS-2 ($t = 8.62$ with 23 degrees of freedom). This fact indicates that the stumps are preferred to slash as host material.

The attack distribution also indicated that the stumps were the preferred host material. Figure 11 shows the average attack distribution of P. tsugae on six trees felled during the month of May 1966. The stumps were the most heavily infested with the number of attacks gradually decreasing toward the crown of the tree until no attacks occurred in the upper portions.

Similar distributions were noted on the three mature hemlock trees examined. Attacks were found from the ground line to a point just below the occurrence of live branches. The minimum bark thickness associated with these attacks was 8.0 millimeters. On the trees felled during May in plot TWS-2, attacks were found occurring where the bark was only 1.2 millimeters in thickness. Therefore, the distribution is not entirely dependent on bark thickness. Other factors such as the distribution of moisture within the tree at

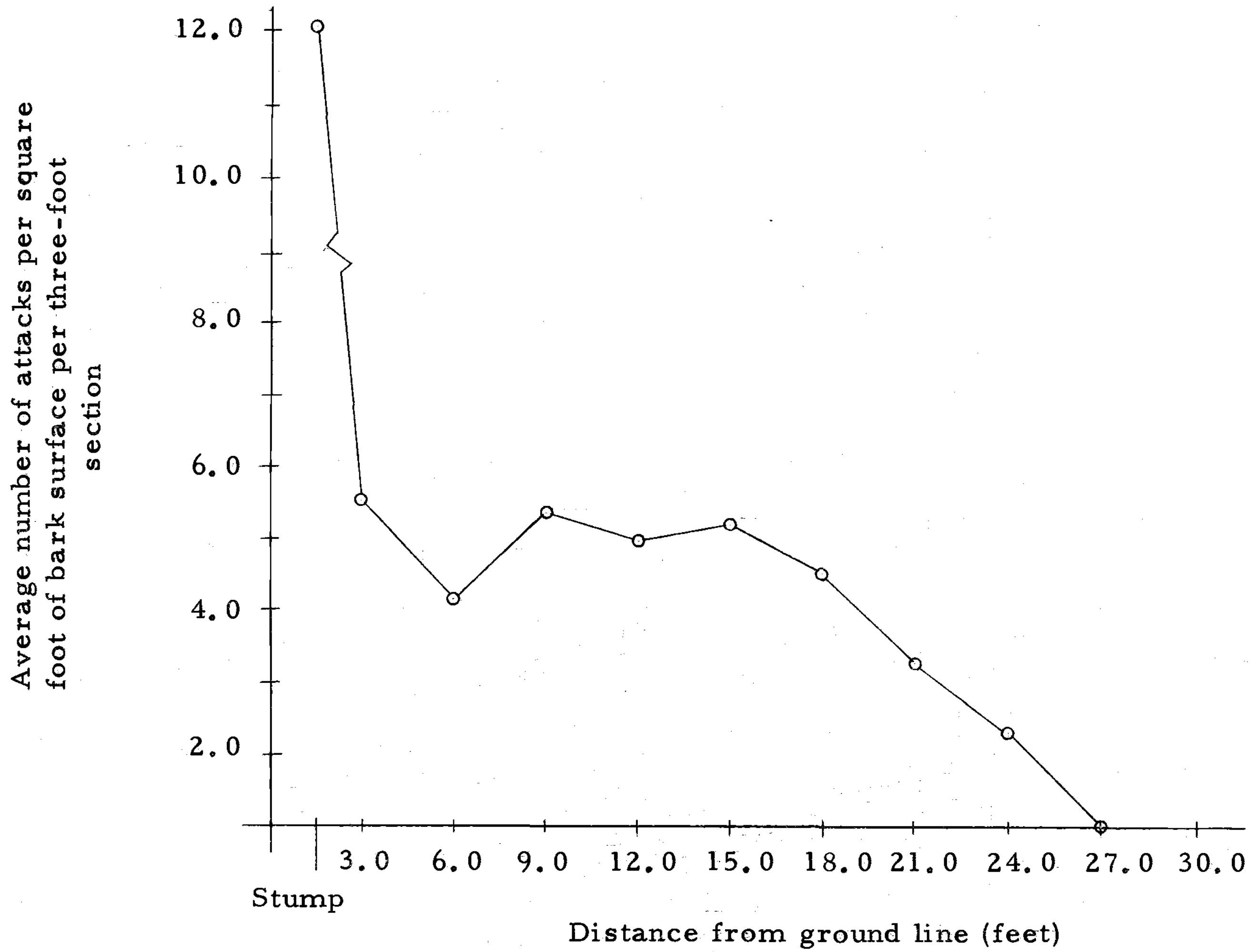

Figure 11. Average distribution of <u>Pseudohylesinus tsugae</u> Sw. attacks on six western hemlock trees felled during May, 1966.

the time of attack may also play an important role.

Parent Galleries. The females of *P. tsugae* initiated the egg galleries. Mating took place either on the bark surface near the entrance hole or in a nuptial chamber located just under the bark surface at the entrance to the gallery.

The insects worked in pairs to excavate a transverse egg gallery which was either monomerous or biramous (Figure 12). Of 191 galleries examined, 68 percent were of the monomerous type. The lengths of the same 191 galleries ranged from a minimum of 19 millimeters to a maximum of 76 millimeters and averaged 41.99 ± 14.03 millimeters. The widths of the galleries ranged from a minimum of 1.5 millimeters to a maximum of 2.0 millimeters and averaged 1.82 ± 0.19 millimeters. The parent galleries were found to score the sapwood to varying depths, depending upon bark thickness. The maximum depth observed was approximately 1.0 millimeters.

Egg Stage. Eggs were laid singly in niches cut opposite to one another in the egg gallery. The niches were usually constructed at 0.5 millimeter intervals. A total of 191 galleries yielded 5,873 eggs; an average of 30.75 ± 18.04 eggs per parent gallery. Of these 5,873 eggs, 77.83 percent hatched. The incubation period was approximately 30 days.

Figure 12. Two types of parent galleries constructed by Pseudohylesinus tsugae Sw. breeding in western hemlock: upper monomerous type; lower biramous type.

Larval, Pupal, and Adult Stages. A histogram of the frequency distribution of the head-capsule width measured for 149 larvae indicated that *P. tsugae* has four larval instars (Figure 13). Table IV presents a summary of head-capsule measurements for each instar.

Upon eclosion the larvae mined at right angles to the egg galleries, just scoring the sapwood. Under crowded conditions, they often turned 180 degrees and mined back toward their parent gallery during their last two instars. The longest larval mine observed was 262 millimeters. The larvae mining in stumps tended to mine down the roots, often pupating as far under ground as four inches.

Table IV. Head capsule width in millimeters of the instars of *Pseudohylesinus tsugae* Sw.

Instar	Number Measured	Width		
		Mean	S.D.*	Range
1	26	0.369	±0.028	0.302-0.436
2	24	0.530	±0.038	0.470-0.604
3	26	0.721	±0.077	0.630-0.805
4	73	0.970	±0.064	0.839-1.141

*Standard Deviation

Those larvae in the thinning slash and stumps in plot TWS-1 overwintered as fourth instars. However, examination of the trees felled in plot TWS-1 during the summer of 1965 showed that the

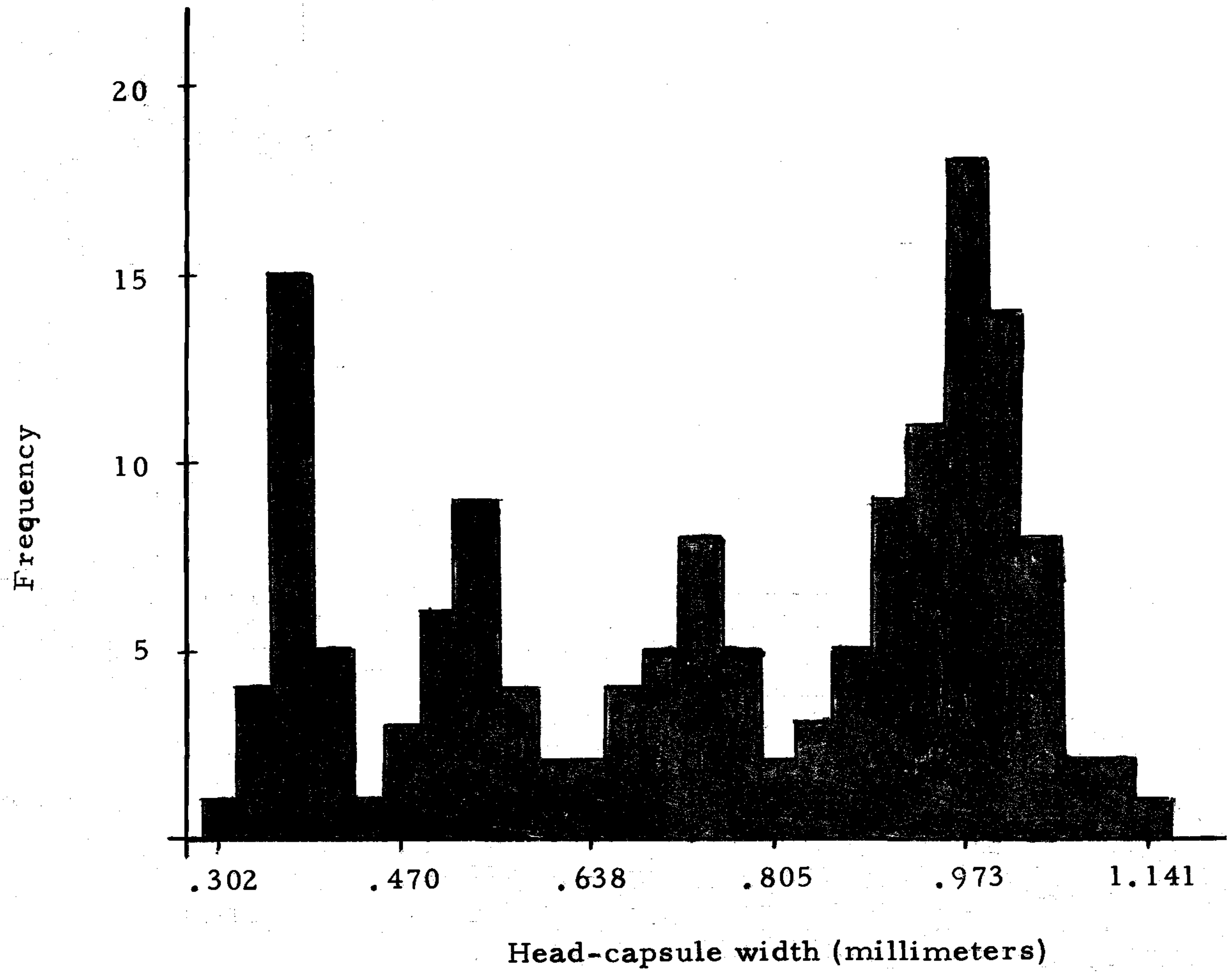

Figure 13. Histogram of frequency distribution of head-capsule widths of <u>Pseudohylesinus tsugae</u> Sw. in millimeters.

overwintering larval stage depended upon the time of the parent attack. In no instances were eggs or teneral adults found during the winter months in parent galleries.

During the last instar, larvae mining in the stumps and slash in plot TWS-1 bored into the sapwood to pupate. The larvae mining in the stumps and main boles of nearby mature hemlock trees usually pupated in the bark. This difference can probably be attributed to the bark thickness of the host material. The portions of the mature hemlocks sampled had an average bark thickness of 12 millimeters. The bark thickness of the stumps or slash in plot TWS-1 was never found to be greater than 4.0 millimeters.

The larval stage lasted approximately ten months, while together the pupal and teneral adult stages lasted about one month. Larvae from parent attacks occurring in the slash and stumps within plot TWS-1 had begun pupating by April 29, 1966. By May 7, callow adults were observed and on May 29 the first emergence holes were noted. By August 8, emergence was completed in both the slash and stumps.

Larvae from eggs laid in the trees felled during July 1965 had begun to pupate by June 14, 1966. Teneral adults were present by June 24 and had started to emerge by July 6. Emergence was completed by September 28.

Larvae in the material infested during the first week of August

Table V. Seasonal occurrence of life stages of <u>Pseudohylesinus tsugae</u> Sw. in the slash and stumps of a precommercially thinned stand of western hemlock, Waldport Ranger District, Siuslaw National Forest, Oregon.

Sampling Date	Stage of Development				
	Parent Adults	Eggs	Larvae	Pupae	Teneral Adults
June 8, 1965	X	X			
July 3, 1965	X	X	X		
July 27, 1965	X	X	X		
August 24, 1965	X	X	X		
October 1, 1965			X		
November 19, 1965			X		
February 12, 1966			X		
March 29, 1966			X		
April 12, 1966			X		
April 19, 1966			X		
April 29, 1966			X	X	
May 7, 1966			X	X	X
May 29, 1966			X	X	X
June 14, 1966				X	X
June 21, 1966				X	X
July 12, 1966				X	X
August 8, 1966					X

1965 and taken into the laboratory on September 14 failed to reach the pupal stage. By November 5 most of the larvae had died. Apparently, the inner bark region became too dry. *P. grandis* mining in the same material during the same time period was not affected.

Table V summarizes the seasonal occurrence of the life stages of *P. tsugae* in the slash and stumps within plot TWS-1.

Maturation Feeding. On June 1, 1965, and June 24, 1966, female *P. tsugae* were found attacking the residual trees in plots TWS-1 and TWS-2 respectively. These beetles constructed short galleries 5.0 to 8.0 millimeters in length which were abandoned within three to 11 days after they were initiated (Table VI). Males were not observed joining the females in these galleries. The 15 females examined the same day that they attacked the standing live trees appeared to be sexually immature. Their oocytes were not yet differentiated. However, the eight beetles examined after they had fed for a period of five days were found to have swollen, clearly defined oocytes. The beetles attacking the live trees were characteristically light colored in appearance (not fully sclerotized) and with abundant elytral scales. These characters also suggested that the beetles were not fully matured and had not attacked other material previous to their attacks on the residual trees.

Table VI. Length of time Pseudohylesinus tsugae Sw. teneral adult females remained in feeding galleries constructed in 28-year-old western hemlock, Waldport Ranger District, Siuslaw National Forest, Oregon, (based on 50 feeding galleries, 10 for each time period.)

Time Period Days	Number of Galleries Examined for Each Time Period	Number of Galleries With Beetles Present
1	10	10
3	10	8
5	10	5
11	10	1
13	10	0

Feeding niches were found on live trees in all six study plots Upon examination of several live trees in each plot, it was apparent that these attacks occurred annually. Niches could be found in these trees that had occurred at least one year prior to the beginning of the present study. Also, similar attacks were found on nearby mature hemlock trees.

A similar phenomenon to that of the attacks in the standing live tree was observed with the female P. tsugae emerging during July 1966 in plot TWS-1 in the cages provided with fresh slash. Soon after emergence, these females attacked the fresh slash made available to them. Short galleries were constructed, but these galleries were not always abandoned. In several instances, a male was found joining the female and an egg gallery was constructed. However, eggs were never laid in the original gallery constructed by the female. This gallery would usually appear as a sterile branch of the main gallery.

New feeding niches were observed throughout the summer and fall of both 1965 and 1966. The last ones observed in 1965 were on November 18 and in 1966 they were still being observed in October when the present study was terminated. Those niches occurring as late as November were also used as overwintering sites. Those females overwintering in the niches were frequently joined by at least one male. It is felt that these overwintering beetles were the first to attack available host material the spring of 1966. By May 7, 1966, all the feeding and overwintering sites constructed during the fall of 1965 seemed to be vacated. Also, on May 7 the first attacks by *P. tsugae* in the slash and stumps in plots TWOS, UTWS, and TWS-2 were noted. The insects in the slash in plot TWS-1 had not emerged by this time.

In conclusion, these results suggest that *P. tsugae* takes approximately 12 to 17 months to complete one generation, depending upon whether it overwinters in the larval or teneral adult stage.

Survival and Mortality. For the ten stumps sampled within plot TWS-1, 30 attacks had produced 130 teneral adults that emerged; an average of 4.33 progeny produced per parent attack. The majority of the mortality was observed to occur during the third and fourth larval instars.

Table VII lists all the predators and parasites of P. tsugae that were observed during the present study. In the slash and stumps, parasitism by Cecidostiba acuta[4] (Prov.) (Hymenoptera: Pteromalidae) seemed to be the greatest mortality factor. In mature timber, Medetera aldrichii[5] Wheeler (Diptera: Dolichopodidae) seemed to be the most abundant of the predators and parasites present.

Pseudohylesinus grandis Sw.

Initial Attack. As with P. tsugae, when the present investigations were initiated in June 1965, P. grandis had already infested the slash resulting from a precommercial thinning of plot TWS-1 in October 1964. The last attacks observed in the slash bolts at the center of the plot and in the slash scattered throughout the plot were on July 16, 1965. However, examinations through November 1965 of the 12 trees that had been felled at weekly intervals from June 6 to

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[4] Identified by B. D. Burks, U. S. Department of Agriculture, Agricultural Research Service, Entomology Research Division, Beltsville, Maryland 20705

[5] Identified by G. C. Steyskal, ibid.

Table VII. Insect parasites and predators of Pseudohylesinus tsugae Sw.

Parasites:

Celoides brunneri* Viereck (Hymenoptera: Braconidae)

Cecidostiba acuta (Provancher)(Hymenoptera: Pteromalidae)

Roptrocerus sp.** (Hymenoptera: Torymidae)

Spathius brunneri*** Viereck (Hymenoptera: Braconidae)

Bracon pini*** (Muesebeck) (Hymenoptera: Braconidae)

Predators:

Medetera aldrichii Wheeler (Diptera: Dolichopodidae)

Enoclerus sphegeus Fabricius (Coleoptera: Cleridae)

Thanasiumus undatulus Say (Coleoptera: Cleridae)

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*Identified by: R. B. Ryan, U. S. Forest Service, Pacific Northwest Forest and Range Experimental Station, Corvallis, Oregon 97330

**Identified by: B. D. Burks, U. S. Dept. of Agriculture, Agricultural Research Service, Entomology Research Division, Beltsville, Maryland 20705

***Identified by: P. M. Marsh, ibid.

August 20, 1965, and of slash from summer logging operations revealed that *P. grandis* would attack fresh material until September 15, 1965.

On March 29 and April 2, 1966, *P. grandis* was first observed attacking the slash bolts and slash in plots TWS-2 and UTWS respectively. In plot TWS-2, during the week of March 28 through April 4, the mean temperature was 52°F (Figure 8) and the maximum temperature was 72°F (Figure 9). Both temperatures were the highest realized up to that period. Attacks had ceased in both plots by June 21.

Number of Broods. The infested slash that had been marked and caged in plots UTWS and TWS-2 during April 1966 revealed that *P. grandis* usually has at least two broods per year. Within 28 days after the initial attack, adults were found re-emerging and reinfesting the old slash or attacking the fresh slash that had been placed in the cages. By removing the infested fresh slash and placing it in another cage with non-infested fresh slash, it was found that a small number of beetles were capable of laying three batches of eggs. The third brood was initiated approximately 30 days after the second. It was not determined whether the beetles copulated again after laying the first batch of eggs.

Attack Density and Distribution. The attack density was found to vary between, but not within, the plot treatments. Within plot UTWS an average of 3.40 ± 1.63 and 4.08 ± 2.21 attacks per square foot were found in the slash bolts at the center of the plot and the slash scattered throughout the plot respectively. An "F" test (F = 1.83 with 11 and 14 degrees of freedom) revealed that there was no significant difference between the variances and a "t" test (t = 0.92 with 25 degrees of freedom) showed that there was no significant difference between the means. Therefore, the means were weighted and the variances pooled, giving an average of 3.68 ± 1.91 attacks per square foot in the slash of plot UTWS. Within plot TWS-2 averages of 8.32 ± 3.16 and 8.62 ± 3.99 attacks per square foot occurred in the slash bolts and scattered slash respectively. Again, an "F" test (F = 1.59 with 11 and 14 degrees of freedom) and a "t" test (t = 0.002 with 25 degrees of freedom) showed no significant differences between the variances and means at these two locations. The weighted mean and pooled variance was calculated to be 8.44 ± 3.55 attacks per square foot of bark surface in the slash of plot TWS-2.

When a "t" test (t = 6.25 with 26 degrees of freedom) was applied to the mean attack densities of plots UTWS and TWS-2, a highly significant difference was found. The reasons for this could be numerous. However, it is suspected that the differences in light intensities realized between plots UTWS and TWS-2 was an important factor (Table II). Daterman, Rudinsky,and Nagel (1965) found that the flight behavior of P. grandis depended upon light intensity after threshold temperatures were reached. When the light intensity dropped below a certain level, flight stopped even though the temperature was still sufficient to support flight. Accordingly, dense, unthinned stands are possibly avoided by P. grandis because of insufficient light within these stands to allow the continuation of flight activity.

Figure 14 shows the average attack distribution of P. grandis on six trees felled during the month of May 1966 in plot TWS-2. The distribution is opposite to that of P. tsugae with the number of attacks increasing toward the live crown. Figure 15 shows the individual attack distribution of P. tsugae and P. grandis as percent of total attacks occurring per 3-foot section in the six trees. The total number of attacks was 1252 of which 37.2 percent were P. tsugae.

P. grandis was found to concentrate its attacks in the tops and larger limbs on the three mature hemlock trees examined, as was reported by Shea, Johnson,and McKee (1962) on silver fir. Attacks were seldom found on the bole where the bark was 8 millimeters or more in thickness. It is doubtful though that the bark thickness was the main factor influencing the attack distribution. Rather, the distribution was probably influenced by the moisture

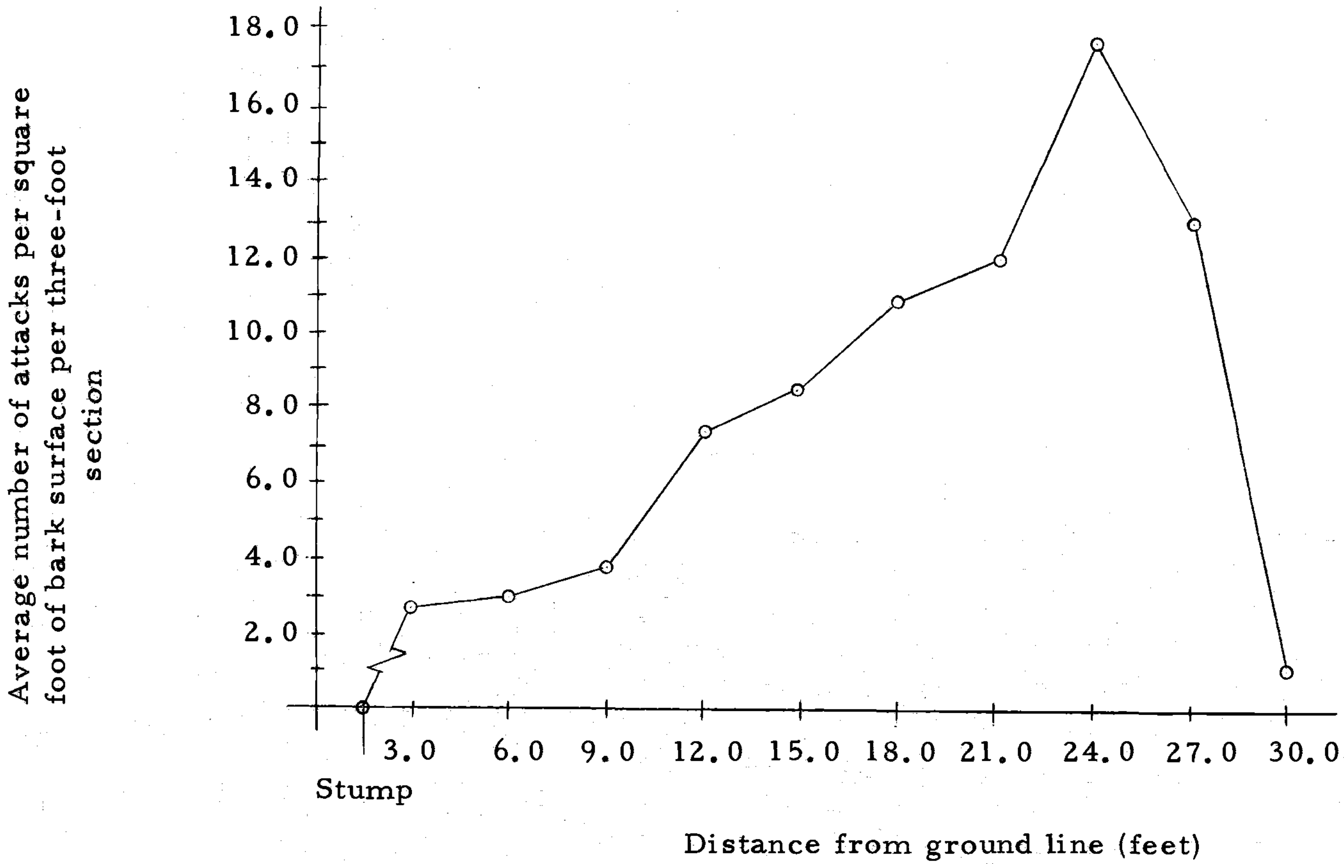

Figure 14. Average distribution of Pseudohylesinus grandis Sw. attacks on six western hemlock trees felled during May, 1966.

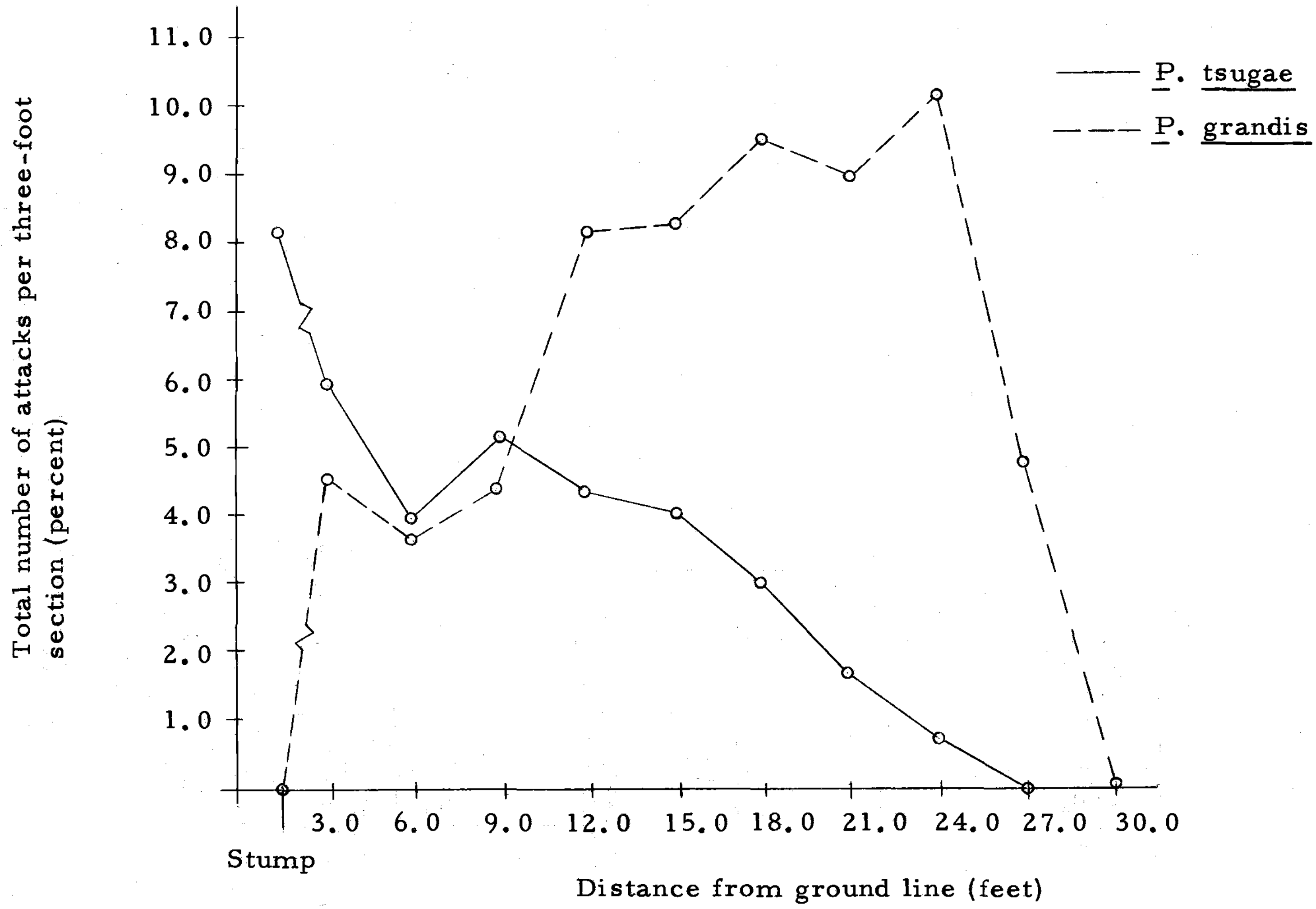

Figure 15. Individual attack distributions of Pseudohylesinus tsugae Sw. and P. grandis Sw. on six western hemlock trees felled during May, 1966.

content of the inner bark. For example, P. grandis was never found to attack stumps in plots TWOS or TWS-2, yet the bark thickness of the stumps was seldom greater than 4.0 millimeters. However, the inner bark regions of the stumps appeared more moist than that of the slash in either of the two plots. Also, Figure 14 shows that as with the mature trees examined, P. grandis concentrated its attacks in the crown portion of younger trees. Johnson (1964) reported that with western hemlock, the sapwood in the crown area of a felled, intact tree drys out much faster and to a greater degree than the sapwood in the basal portion of the tree.

During the present study, P. grandis was found to attack both Douglas-fir and Sitka spruce in addition to western hemlock. This is the first time that P. grandis has been reported breeding in Sitka spruce.

Parent Galleries. The females of P. grandis initiated the egg galleries. As with P. tsugae, mating was found to take place both on the bark surface near the entrance holes and in a nuptial chamber located just under the bark surface at the entrance to the gallery.

A transverse egg gallery which was either monomerous (Figure 16) or biramous (Figure 17) was constructed. Of 140 galleries examined, 67 percent were of the biramous type. The

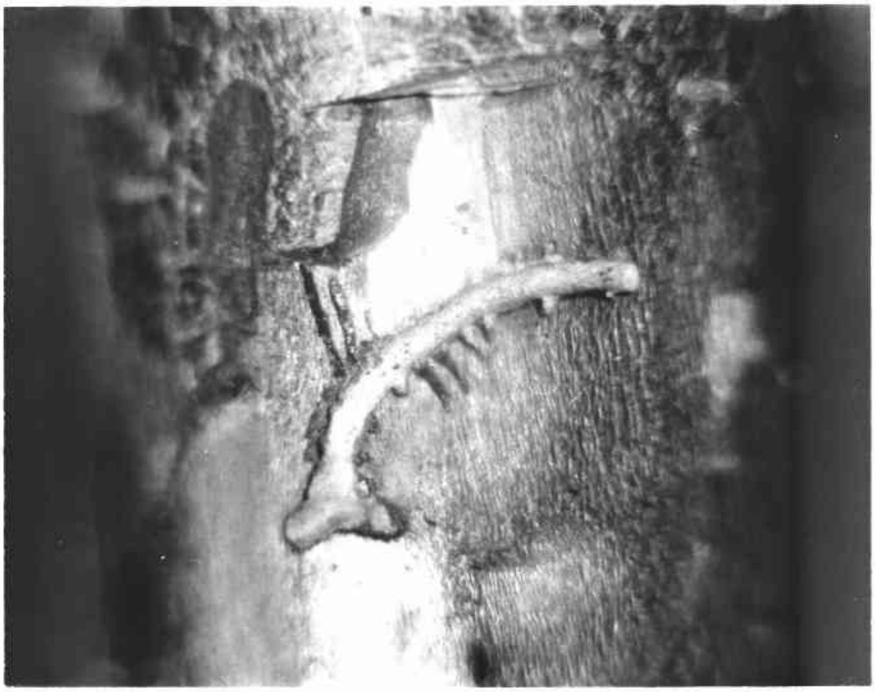

Figure 16. Simple or monomerous transverse egg gallery constructed by Pseudohylesinus grandis Sw. breeding in western hemlock.

Figure 17. Biramous transverse egg gallery constructed by Pseudohylesinus grandis Sw. breeding in western hemlock.

lengths of the same 140 galleries ranged from a minimum of 24 millimeters to a maximum of 67 millimeters and averaged 46.55 $\pm$ 15.19 millimeters. The widths of the galleries ranged from 1.50 to 2.00 millimeters and averaged 1.64 $\pm$ 0.190 millimeters. The parent galleries scored the sapwood to varying depths depending upon the bark thickness. The maximum depth observed was approximately 1.5 millimeters.

Egg Stage. Eggs were laid singly in niches that were cut opposite to one another in the egg gallery. The niches were usually constructed at intervals of 0.5 millimeters. A total of 140 galleries yielded 4,386 eggs; an average of 31.33 $\pm$ 13.54 eggs per gallery. Of these 4,386 eggs, 78.50 percent hatched. The incubation period was approximately 28 days.

Larval, Pupal, and Teneral Adult Stages. A histogram of the frequency distribution of the head-capsule width measured for 158 larvae indicates that *P. grandis* has four larval instars (Figure 18). The head-capsule measurements are summarized in Table VIII.

Upon eclosion, the larvae mined at right angles to the parent galleries, just scoring the sapwood. When crowded conditions prevailed, the larvae often reversed their direction and mined back toward their parent gallery during their last two instars. Few larval mines exceeded 120 millimeters in length. During the fourth instar,

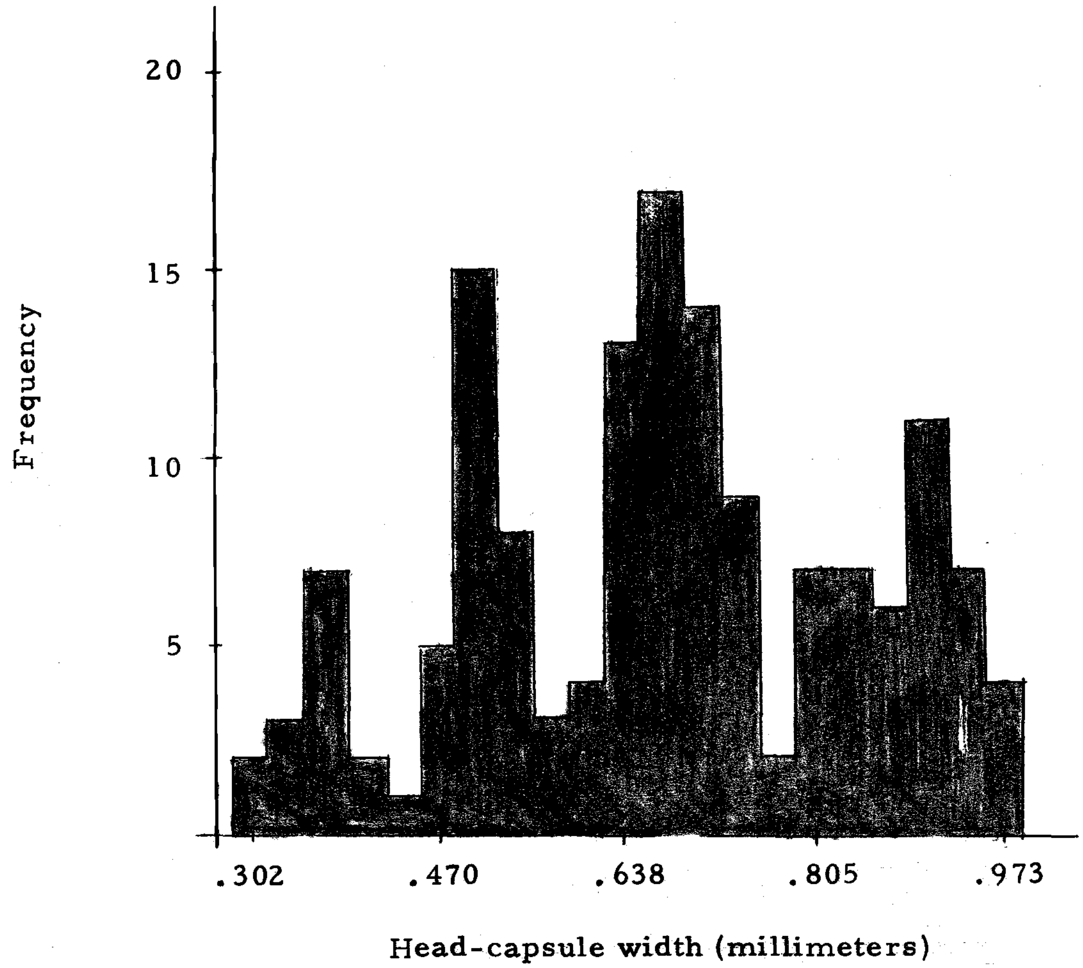

Figure 18. Histogram of frequency distribution of head-capsule widths of Pseudohylesinus grandis Sw. in millimeters.

larvae tended to bore into the sapwood where they would pupate.

Table VIII. Head-capsule width in millimeters of the instars of Pseudohylesinus grandis Sw.

Instar	Number Measured	Width	
		Mean S.D.*	Range
1	15	0.362 ± 0.027	0.302-0.436
2	32	0.513 ± 0.028	0.470-0.570
3	59	0.681 ± 0.042	0.604-0.772
4	52	0.887 ± 0.048	0.805-0.973

*Standard Deviation

The larval stage lasted from four to eight months, depending upon time of parent attack and the degree of exposure of the host material. Together the pupal and teneral adult stages lasted approximately one month.

Larvae from parents attacking on or before June 8, 1965, in the slash of plot TWS-1,had begun to pupate by August 20, 1965. By September 3, callow adults started to appear and shortly thereafter, on September 15, the first emergence holes were noted. By November 22, emergence was completed. During 1966 in plots UTWS and TWS-2, larvae from parents attacking between March 29 and April 9 were observed in the pupal stage on August 8. By August 23, emergence had commenced. Adults were still emerging when the present study was terminated in October.

In plot TWS-1 the majority of the larvae resulting from parents attacking after mid-June 1965 overwintered in the fourth instar and began pupating the following spring. For example, larvae from parents attacking from July 23 to August 31, 1965 in recently felled trees did not begin to pupate in the field until April 29, 1966. Emergence had started by May 14 and was completed by August 8. However, larvae in material infested during the same period but taken into the laboratory where it was held at 70°F from September 14 to December 5, 1966, had reached the pupal stage by October 22. Emergence started on November 5 and was completed by November 18. Therefore, the number of larvae overwintering, and consequently, the duration of the larval stage of development must be dependent upon late summer and fall temperatures as well as time of parent attack.

Tables IX and X summarize and compare the seasonal occurrence of the life stages of *P. grandis* as they occurred in the field and laboratory.

Maturation Feeding. The caging experiments conducted in plots TWS-1 and TWS-2 indicated that the beetles which overwintered as larvae and emerged in the spring were capable of initiating successful egg galleries soon after emergence, while beetles emerging

Table IX. Seasonal occurrence of life stages of Pseudohylesinus grandis Sw. in relation to the initial attack of March 29 to April 9, 1966, in the slash of a precommercially thinned stand of western hemlock, Waldport Ranger District, Siuslaw National Forest, Oregon.

Sampling Date	Stage of Development				
	Adult	Egg	Larval	Pupal	Teneral Adult
April 9, 1966	X	X			
April 12, 1966	X	X			
April 30, 1966	X	X	X		
May 15, 1966	X	X	X		
May 29, 1966			X		
June 21, 1966			X		
July 26, 1966			X		
August 8, 1966			X	X	
August 23, 1966			X	X	X
September 28, 1966			X	X	X
October 12, 1966					X

Table X. Comparison of the occurrence of life stages of <u>Pseudohylesinus grandis</u> Sw. breeding in western hemlock under field and laboratory conditions.

	Held in Field; Plot TWS-1 Initial Attack Period: July 23 to Aug. 31, 1965 Stage of Development					Held in Greenhouse at 70°F. Initial Attack Period: July 20 to Aug. 24, 1965 Stage of Development				
Sampling Date	Adult	Egg	Larval	Pupal	Teneral Adults	Adult	Egg	Larval	Pupal	Teneral Adults
Sept. 14	X	X	X			X	X	X		
Oct. 1			X					--		
Oct. 22			--					X	X	
Nov. 5			X					X	X	X
Nov. 18			--							X
Mar. 29			X							
Apr. 29			X	X						
May 14			X	X	X					
July 12			X	X	X					
Aug. 8					X					

in the late summer and fall overwintered as teneral adults before initiating egg galleries.

In both cases an adult feeding period apparently intervened between the emergence of the tenerals and their subsequent initiation of egg galleries. During the spring and summer of both 1965 and 1966, female callow adults were found to attack standing live trees in all study plots. Galleries approximately 8.0 millimeters in length were constructed and abandoned within one week after they were initiated. Males were not observed joining the females in these galleries. Of the two species initiating feeding sites during the summer months, P. tsugae was found to be the more abundant. Of 120 feeding sites examined, from June through August 1966, only 4.2 percent were constructed by P. grandis.

During the fall and winter months, feeding niches by P. grandis seemed more abundant than those by P. tsugae, although no measurements were made to determine if this observation was correct. Niches made by P. grandis during October and November in the standing live trees within plot TWS-1 were not immediately abandoned. Instead, the female overwintered in the niches and were frequently joined by at least one male. These niches were abandoned by April 1966. By this time the adults appeared fully sclerotized. The sexual maturity of the adults attacking the standing live trees was not checked. However, of ten female callow adults emerging in the cages during September 1966, all were found to have undifferentiated oocytes.

In summary, these results suggest that P. grandis took ten to 12 months to complete its life cycle when infesting the coastal stands of western hemlock in Oregon. Progeny from attacks initiated in the spring emerged as teneral adults during the late summer and early fall. These teneral adults overwintered in standing live trees and emerged the following spring as brood adults ready to start the new generation. Progeny from attacks occurring during the summer overwintered as larvae. The following spring and summer, pupation occurred and the teneral adults emerged. The immature females immediately attacked standing live trees where they fed for a short period and reached sexual maturity. The female then left the feeding site ready to initiate the next generation.

Survival and Mortality. Insect survival was found to differ among plot treatments. For the 24 square feet of bark sampled in plot UTWS, 98 parent attacks produced a total of 880 live pupae and brood adults, while in plot TWS-2, 207 attacks produced only a total of 287 live pupae and brood adults (Table XI). Therefore, even though rate of development was approximately the same in both plots, there was a higher mortality rate realized in plot TWS-2 than in plot UTWS. This difference could be attributed to several physical

Table XI. Summary of Pseudohylesinus grandis Sw. brood counts made on October 5, 1966, in the western hemlock thinning slash present in the unthinned plot UTWS and thinned plot TWS-2.

Plot	Square Feet of Bark Examined	Total Number of Attacks	Total Number of Pupae and Brood Adults	Average Number of Attacks Per Square Foot	Average Number of Progeny Per Square Foot
UTWS	24	98	880	4.08	36.67
TWS-2	24	207	287	8.62	11.96

factors since plot TWS-2 realized higher temperatures, light intensities and evaporation rates than plot UTWS. However, it is felt that parasitism by *Cecidostiba acuta* (Prov.) (Hymenoptera: Pteromalidae) accounted for the majority of the difference. Very few parasites or predators were noted in the slash in plot UTWS. This could have been a result of the fewer beetle attacks realized there, or the parasites and predators themselves could have shown a negative response to the climatic conditions within plot UTWS. Table XI shows that if such a high mortality rate was consistently realized in thinning slash as was in plot TWS-2, *P. grandis* would have little potential of becoming a serious economic pest in precommercially thinned stands of western hemlock.

Table XII lists all of the predators and parasites of *P. grandis* observed during the present study. Most of the mortality incurred by *P. grandis* was realized in the third and fourth larval instars.

Table XII. Insect parasites and predators of *Pseudohylesinus grandis* Sw.

Parasites:	
	Cecidostiba acuta (Prov.) (Hymenoptera: Pteromalidae)
	Roptrocerus sp. (Hymenoptera: Torymidae)
	Spathius brunneri Vier. (Hymenoptera: Braconidae)
	Bracon pini (Mues.) (Hymenoptera: Braconidae)
	Celoides brunneri Vier. (Hymenoptera: Braconidae)
Predators:	
	Medetera aldrichii Wheeler (Diptera: Dolichopodidae)

Cheilosia alaskensis Hunter

When the present studies were initiated in 1965, many of the residual trees in plot TWS-1 were already infested with the larvae of the hemlock bark maggot. Kangur (1966) reported that maggot infestations had been observed in the trees in plot TWS-1 since shortly after the plot was first thinned in 1961.

Oviposition Sites. As reported by Burke (1905), the adult hemlock bark maggot apparently lays its eggs singly on oleoresin exduating from abandoned feeding sites of *P. tsugae*. During the summer of 1966, maggots were found to inhabit feeding niches that *P. tsugae* had constructed and abandoned earlier the same summer.

Never more than one larvae was found occupying a single site. It is probable that the abandoned feeding sites of P. grandis were also utilized, but no substantiating evidence was found. In 1966, only the niches constructed since the previous fall were used as oviposition sites by the adult bark maggot. Apparently, this resulted from the fact that the oleoresin exudating from niches constructed prior to that time had hardened by the spring of 1966.

Abandoned feeding sites were the only places where larvae of the bark maggot could be found during the present study. This substantiates similar observations made by Burke (1905). Wounds resulting from the thinning operations conducted in the various study plots were numerous, but none showed signs of being infested. Larvae were never observed above the first live branches of the crown of a tree even though beetle feeding sites were available there.

Detection of Maggot Chambers. In the spring of both 1965 and 1966, a small, dull-orange colored, resinous mass exudating from the entrance to the feeding site was the first indication of the presence of a bark maggot. The orange-colored substance appeared to consist of waste material excreted by the larvae as it fed in the cambial region of the tree. These masses gradually increased in size, sometimes reaching more than 10 millimeters in diameter by the fall months (Figure 19). During the winter of 1965, the resinous mass on the trees in plot TWS-1 became hard and chalky white in

Figure 19. Resinous mass indicating the presence of a Cheilosia alaskensis Hunter maggot in western hemlock.

appearance. However, they regained their orange, resinous appearance the following spring, indicating that the maggots were not active during the winter months.

Injury. The resultant wounds made by the maggots were typically circular in shape (Figure 20). The largest observed measured 38 millimeters in diameter. The entrance to the wound was never enlarged (Burke, 1905; Chamberlin, 1960).

Life Cycle. The time allocated to complete the present study was insufficient to determine the life cycle of the hemlock bark maggot infesting young-growth hemlock. Burke (1905) and Chamberlin (1960), among others, have reported the hemlock bark maggot to take up to five years to complete one generation.

In 1966, recently eclosed maggots were observed from July 13 to August 23 in the residual trees in plots TWS-1, TWOS, TWS-2, and ChT. Also, previously occupied maggot chambers were found vacated in plot TWS-1 during the spring of 1966. Therefore, as reported by Burke (1905) the adults must emerge and lay their eggs during the spring.

Response to Plot Treatment. Table XIII compares the degree of hemlock bark maggot infestation during 1965 and 1966 in the 25 trees examined in each of the six study plots. In 1965, 52 percent

Figure 20. Typical wound made by a Cheilosia alaskenis Hunter maggot infesting western hemlock.

Table XIII. Trend and intensity of *Cheilosia alaskensis* Hunter infestations in 25 western hemlock trees examined from each study plot, 1965-1966, Waldport Ranger District, Siuslaw National Forest, Oregon.

Plot	Number of Trees Examined	Plot-Treatment, 1964	Percent of Trees With 1 or More Maggots Present (1965)				Plot Treatment, 1965	Percent of Trees With 1 or More Maggots Present (1966)				Percent Increase			
			1	2	3	Total		1	2	3	Total	1	2	3	Total
UTC	25	unthinned	0	0	0	0	unthinned	0	0	0	0	0	0	0	0
TWS-1	25	thinned	36	12	4	52	unthinned	36	16	20	72	0	4	16	20
TWOS	25	unthinned	0	0	0	0	thinned	20	8	4	32	20	8	4	32
UTWS	25	unthinned	0	0	0	0	unthinned	0	0	0	0	0	0	0	0
TWS-2	25	unthinned	0	0	0	0	thinned	16	0	4	20	16	0	4	20
ChT	25	unthinned	0	0	0	0	thinned*	8	0	0	8	8	0	0	8

*Chemically thinned with cacodylic acid

of the trees examined in plot TWS-1 were infested with one or more maggots. During the same year, none of the trees examined in the other five plots showed signs of being infested. In 1966, after the respective treatments had been applied to the plots, the trees in plots UTC and UTWS (the unthinned plots) still showed no signs of being infested with maggots. By the end of August 1966, 32, 20, and 8 percent of the trees examined in plots TWOS, TWS-2, and ChT (the thinned plots) showed signs of being infested with one or more bark maggots. Also, in 1966, an additional 20 percent of the trees examined in plot TWS-1 became infested with bark maggots. These results show that following the precommercial thinning of western hemlock, an increase in the occurrence of hemlock bark maggot infestations can be expected within the thinned stands.

Examination of the unthinned stands adjacent to the main study area showed that maggot infestations were frequently present whenever a natural opening occurred within the stands. Also, resin masses similar to those observed within the thinned study plots were found throughout the general vicinity on the boles of both young- and old-growth hemlock trees that were growing along roads and timber cutting boundaries. These observations, in addition to the results presented in Table XIII, indicate that only those trees growing in exposed locations are usually infested by bark maggots.

Potential Economic Importance. Further studies are needed to determine the potential economic importance of the hemlock bark maggot. It is likely that the severity of the damage caused by bark maggots within a particular stand would depend upon the frequency and intensity to which the stand was thinned.

In evaluating the hemlock bark maggot, as a forest pest, the future utilization of western hemlock as a natural resource should be considered. If hemlock is to be used strictly as a pulpwood species, the damage by the maggot would appear to be of no importance (Van Vliet, 1966; Brown, Panshin, and Forsaith, 1949). However, if wood products suitable for finishing are to be produced, the damage could be of the utmost importance (Chamberlin, 1960).

Distribution of Feeding Sites

As indicated previously, *Pseudohylesinus tsugae* and *P. grandis* were treated as one in studying the distribution of their feeding sites. However, of 120 feeding sites examined during the summer of 1966, 95.8 percent had been constructed by *P. tsugae*. As a result, the data collected during the summer of 1966 pertains primarily to the feeding sites constructed by *P. tsugae*.

Difference Between Plots

The results of the analyses of variance for the mean densities of feeding sites occurring in the 18 seven-foot basal sections are presented in Tables XIV and XVI. These results show that in both 1965 and 1966 highly significant differences occurred between the plots. A new multiple range test was applied to each set of means to find where the differences occurred, (Tables XV and XVII).

In plot TWS-1 in 1965, and in plot TWS-2 in 1966, the mean number of feeding sites per square foot of bark surface was found to be significantly different from all other plots within the .01 level of probability. No significant differences occurred between the other plots in either year (Tables XV and XVII). These results show that the occurrence of feeding sites increased within a stand following thinning as long as the slash was not removed. Considering that plot TWS-1 was thinned in 1964 and that plot TWS-2 was thinned in 1965, the ranking of the means in Tables XV and XVII indicate that an increased number of feeding sites was realized for only one year following thinning. In plot TWS-1 the mean number of feeding sites occurring during 1965 and 1966 was 4.160 and 0.043 per square foot of bark surface respectively. In plot TWS-2, the mean number of feeding sites per square foot of bark surface was 1.353 in 1965 and 2.187 in 1966.

Distribution of Feeding Sites Within Trees

Figure 21 summarizes the differences that occurred in the

Table XIV. Analysis of variance of the mean number of *Pseudohylesinus* spp. Sw. feeding sites per square foot of bark surface within the six study plots during 1965.

Source of Variance	Degrees of Freedom	Sum of Squares	Mean Square	F
Among plots	5	23.7097	4.7419	16.0906**
Within plots	12	3.5365	0.2947	
Total	17	27.2462		

**Significant within the .01 level of probability

Table XV. Results of the new multiple range test when applied to the mean number of *Pseudohylesinus* spp. Sw. feeding sites per square foot of bark surface that occurred within each of the six study plots during 1965.

	Plot					
	TWS-1	UTWS	TWS-2	TWOS	UTC	ChT
Mean	4.160**	1.403	1.353	1.107	0.903	0.873

**Significant within the .01 level of probability

Table XVI. Analysis of variance of the mean number of *Pseudohylesinus* spp. Sw. feeding sites per square foot of bark surface that occurred within the six study plots during the summer of 1966.

Source of Variance	Degrees of Freedom	Sum of Squares	Mean Square	F
Among plots	5	10.3795	2.0759	12.0482**
Within plots	12	2.0672	0.1723	
Total	17	12.4467		

**Significant within the .01 level of probability

Table XVII. Results of the new multiple range test when applied to the mean number of *Pseudohylesinus* spp. feeding sites per square foot of bark surface that occurred within each of the study plots during the summer of 1966.

	Plot					
	TWS-2	TWOS	UTWS	ChT	UTC	TWS-1
Mean	2.187**	0.890	0.303	0.130	0.110	0.043

**Significant within the .01 level of probability

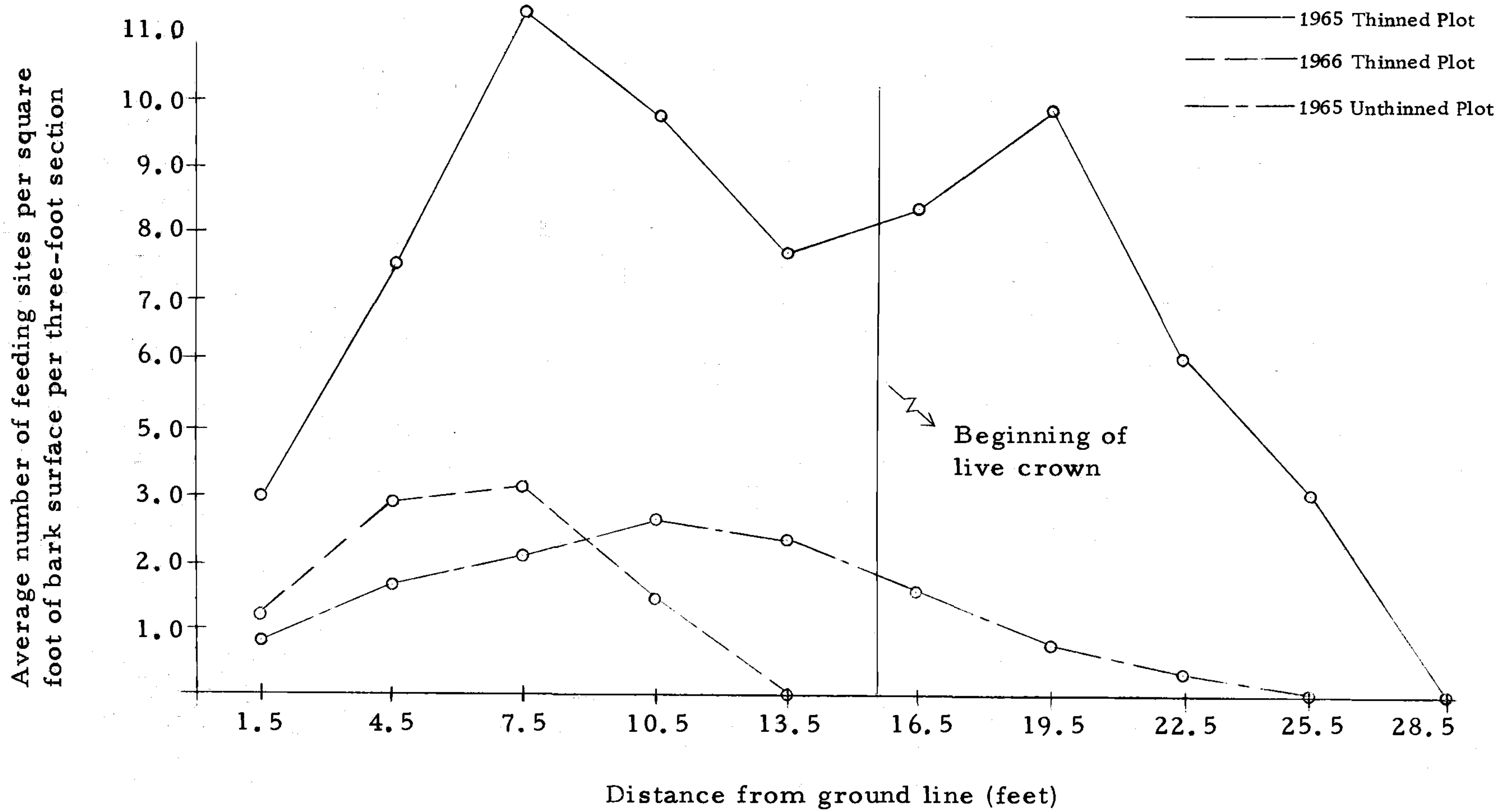

Figure 21. Comparison of the average number of Pseudohylesinus spp. Sw. feeding niches per square foot of bark surface per three-foot section that occurred in western hemlock trees in five unthinned plots (UTC, TWOS, UTWS, TWS-2, and ChT) during 1965 against those that occurred in the thinned plot TWS-1 during 1965, and in the thinned plot TWS-2 during the summer of 1966.

distribution of feeding sites within trees between the six study plots. The bottom curve represents the average distribution that occurred in the five trees, one each from plots UTC, TWOS, UTWS, TWS-2, and ChT during 1965 before the respective plot treatments were applied. The top curve represents the distribution of the feeding sites that were initiated during 1965 in the tree analyzed from plot TWS-1. The middle curve represents the distribution of the feeding sites that occurred during the summer of 1966 in the tree analyzed from plot TWS-2. If the three curves are compared, it can be seen that the upper curve has two definite peaks while the lower two have only one. Since the residual trees in plot TWS-2 had not been exposed in their thinned state to the fall emergence of P. grandis, and 95.8 percent of the feeding sites examined during the summer were constructed by P. grandis, it is felt that the second peak occurring in the upper curve largely represents the feeding sites of P. grandis. If this were true, the middle curve indicates that the hemlock bark maggot is primarily associated with the feeding sites of P. tsugae since bark maggots were never found above the first live branches of the lower crown. Also, it could be concluded that very few of the feeding sites occurring in the trees of the unthinned plots were constructed by P. grandis because the lower curve shows no second peak.

Chemical Treatment

The data collected for *Pseudohylesinus tsugae* and *P. grandis* infesting the chemically-treated trees in plot ChT are expressed as *Pseudohylesinus* spp. unless otherwise noted. This resulted from the fact that very few adult beetles were present when the selected trees were analyzed in September 1966.

Response to Chemically Treated Trees

Period of Infestation. Parent adults of *P. grandis* and *P. tsugae* were found to attack the chemically treated tree within plot ChT throughout the spring, summer, and fall of 1966. For example, *P. grandis* was found present from April 9 to September 14 and *P. tsugae* from May 29 to the time the study was terminated in October. Of 300 attacks examined between May 29 and September 14, 70 percent had been initiated by *P. tsugae* and the remaining 30 percent by *P. grandis*.

Only those trees losing more than 50 percent of the foliage were susceptible to attack by parent beetles. Then successful egg galleries were completed only in those trees which had lost essentially all of their foliage.

Attack Density. A total of 83 attacks were counted within the 4.57 square feet of bark sampled from the three trees felled on

September 14; an average of 18.16 attacks per square foot. Table XVIII compares the attack density of Pseudohylesinus spp. in the available breeding material in plots TWS-2 and ChT. It can be seen that the density of attacks in the chemically treated trees was higher than that in either the stumps or slash within plot TWS-2.

Table XVIII. Comparison of mean number of Pseudohylesinus spp. attacks per square foot of bark surface in western hemlock slash resulting from a chemical thinning with cacodylic acid and a mechanical thinning.

Plot	Square Feet of Bark Examined	Source	Number of Pseudohylesinus spp. Attacks per Square Foot
TWS-2	11.00	10 stumps	12.69
TWS-2	35.32	15 slash bolts	9.59*
ChT	4.57	3 treated trees	18.16

*1.27 P. tsugae plus 8.32 P. grandis

Beetle Development

Parent Galleries. The length of 40 galleries that were measured averaged 31.80 $\pm$ 17.31 millimeters and ranged from a minimum of 8 millimeters to a maximum of 89 millimeters. In the slash and stumps within the other study plots, P. tsugae had an average gallery length of 41.99 millimeters and P. grandis, an average of 46.55 millimeters. It appears that either one or both of the two species constructed shorter parent galleries in the treated trees than were constructed in the non-treated slash or stumps.

Survival. The same forty galleries used to determine the mean gallery length produced 770 eggs of which 37.66 percent hatched. In the adjacent plots egg survival for either *P. grandis* or *P. tsugae* was not less than 77.83 percent, a difference of 40 percent.

The brood production in the trees killed with cacodylic acid appeared to be very low. This is typified by the results of the one-foot bark samples taken from the basal, middle, and top one-third of three trees (Table XIX). Even if all the larvae present at the time of sampling survived to become parent adults, the brood potential was not sufficient to maintain the infestation at its present level; particularly if it is assumed that two parent adults are required to produce one parent gallery.

Table XX illustrates that survival of *Pseudohylesinus* spp. was not affected by tree height. Low survival rates were experienced throughout the entire tree. The high percent survival indicated for the top one-third of tree 2 is misleading. All the live larvae present had hatched just prior to when the sample was taken.

As pointed out by Table XX, larvae mining in chemically treated trees had not yet reached the fourth or ultimate instar of development by September 14. In contrast, *P. grandis* had been emerging from the slash in plot TWS-2 since August 23. Also, by

Table XIX. Summary of Pseudohylesinus spp. Sw. brood counts made in three 28-year-old western hemlock trees that had been killed with cacodylic acid, Waldport Ranger District, Siuslaw National Forest, Oregon.

Square Feet of Bark Attacked	Total Number				Number of Attacks Per Square Foot	Number of Immature Bark Beetles Per Square Foot
	Attacks	Larvae	Pupae	Teneral Adults		
4.57	83	92	0	0	18.2	20.1

Table XX. Survival of Pseudohylesinus spp. Sw. in three 28-year-old western hemlock trees that had been killed with cacodylic acid, Waldport Ranger District, Siuslaw National Forest, Oregon (based on complete galleries within one-foot bark samples taken from the basal, middle, and top one-third of each tree on September 14, 1966).

Position	Tree Number	Number of Galleries	Number of Eggs		Life Stages: First Instar Larvae		Life Stages: Second Instar Larvae		Life Stages: Third Instar Larvae		Percent Survival
			Laid	Dead	Live	Dead	Live	Dead	Live	Dead	
Basal 1/3	1	4	58	22	1	16	0	13	2	4	5.2
	2	6	172	91	0	55	0	18	3	5	1.7
	3	7	61	49	0	6	2	0	2	2	6.6
Middle 1/3	1	2	21	15	0	4	1	1	0	0	4.8
	2	5	122	63	0	19	0	38	2	0	1.6
	3	1	10	8	0	0	0	2	0	0	0.0
Top 1/3	1	2	40	16	0	9	2	10	0	3	5.0
	2	1	16	5	11	0	0	0	0	0	68.8
	3	2	12	10	0	2	0	0	0	0	0.0
	Total	30	512	279	12	111	5	82	9	14	5.1

September 14, most of the *P. tsugae* larvae mining in the stumps of plot TWS-2 had reached the fourth larval instar.

The chemical treatment appeared to have no adverse effect on the development of the predators and parasites of *P. tsugae* and *P. grandis*. For example, third instar *Medetera aldrichii* Wheeler (Diptera: Dolichopodidae) were found in the *Pseudohylesinus* spp. larval mines and adult *Cecidostiba acuta* (Prov.) (Hymenoptera: Pteromalidae) were found emerging from the beetle-infested trees. The parasitic population within the chemically killed trees appeared to be much lower than that in the slash of plot TWS-2. Predators seemed just as abundant in plot ChT as in plot TWS-2.

In summary it appears that neither *Psdudohylesinus tsugae* nor *P. grandis* were able to build-up their populations in the trees treated with cacodylic acid even though these trees were accepted as suitable breeding material by the parent adults. Smith (1966) noted similar results with *Ips pini* (Say) (Coleoptera: Scolytidae) breeding in *Pinus banksiana* Lamb. that had been treated with cacodylic acid. The mortality rates appear to be a direct effect of the chemical itself but this has yet to be proved.

SUMMARY AND CONCLUSIONS

A study was conducted in the coastal region of Oregon on the bark beetles *Pseudohylesinus tsugae* and *P. grandis* infesting pre-commercially thinned stands of western hemlock. The objectives undertaken were to investigate the biologies and potential economic importance of these two scolytids.

Both *P. tsugae* and *P. grandis* were found to have one generation per year with two broods. In the early spring, *P. grandis* adults that had overwintered in standing live host trees began to attack suitable breeding material, where they constructed egg galleries and laid their first brood. Approximately 28 days after the first batch of eggs were laid, the adults re-emerged and initiated a second brood. The larvae had four instars. Those larvae from parents attacking during the spring, emerged during the late summer or fall of the same year as teneral adults. The teneral adults then overwintered under the bark of standing live host trees where they fed on the phloem and the female beetles reached sexual maturity. The beetles evacuated their overwintering sites the following spring and initiated the second generation. Those larvae from parents attacking during the summer months overwintered in the fourth instar and emerged the following spring or summer as teneral adults. The sexually immature females immediately attacked standing live trees where they fed for a short period and reached sexual maturity. The females left the feeding site ready to initiate the next generation.

P. tsugae adults began to attack suitable breeding material in the late spring. Approximately 30 days after the first brood was initiated, the adults re-emerged and laid a second batch of eggs. The larvae passed through four instars, usually overwintering in the last instar and pupating the following spring or summer. The female teneral adults attacked standing live trees immediately after their emergence where they fed for five to 11 days and reached sexual maturity. The females left the feeding sites ready to start the new generation.

Within the thinned young-growth stands of western hemlock P. tsugae preferred fresh stumps as breeding material although fresh slash was also accepted. However, P. grandis would breed only in fresh slash. In the old-growth hemlock trees examined, P. tsugae concentrated its attacks in the stumps and lower portions of the trees, whereas P. grandis was usually found to attack only in the tops and larger branches of these trees. Both species constructed similar types of egg galleries.

The potential economic importance of P. tsugae and P. grandis needs further clarification. In the thinning slash and stumps within the thinned stands P. grandis was held in check by natural factors, whereas P. tsugae seemed capable of increasing its population. Neither species was found to kill live trees.

The feeding habit of the teneral adult stage of these two scolytids could pose a serious problem in thinned stands of western hemlock. As reported by Burke (1905) the feeding sites of P. tsugae (and possibly those of P. grandis) provided entry to the cambial region of the tree for the hemlock bark maggot (Cheilosia alaskensis). The maggot caused the formation of small resinous scarred areas in the cambium region of the infested trees (Burke, 1905). It has been reported that these scars eventually become embedded in the wood and cause the lumber or other products cut from heavily infested trees to be severely degraded (Chamberlin, 1960).

When the study was initiated in 1965, many of the residual trees in the plot that had been thinned three times since 1961 were already infested with the hemlock bark maggot. By the winter of 1965, of 25 trees sampled within this plot, 52 percent showed signs of being infested with one or more maggots. By the summer of 1966, an additional 20 percent of the 25 trees showed signs of being infested. The residual trees in three plots that had not been thinned until the winter of 1965 showed similar increases in hemlock bark maggot infestations during the summer of 1966. No maggot infestations were found in the unthinned plots even though Pseudohylesinus spp. feeding sites were available there. The response of the maggot to thinned stands may be due to the increased exposure of the residual trees following thinning. Therefore, it is likely that the severity of the damage caused by bark maggots within a particular stand would depend upon the frequency and intensity to which the stand was thinned.

Feeding sites of P. tsugae and P. grandis occurred in standing live trees in both thinned and unthinned plots. The occurrence of feeding sites increased within a stand following its thinning, as long as the slash was not removed. However, there was evidence that the teneral adults also responded to factors other than the presence of slash. For example, in the unthinned plot that had slash dragged into it, very few feeding sites occurred in the standing trees. Hence, meteorological variables such as light intensity and temperature may also influence the response of teneral adults to thinned stands. There was also evidence that significant increases in the occurrence of feeding sites may occur for only one year following a thinning. For example, in both 1965 and 1966, the number of feeding sites in the most recently thinned plots was found to be significantly higher than that in the other plots.

A potential method of control of both P. tsugae and P. grandis and the hemlock bark maggot was found. Within a plot that had been chemically thinned with cacodylic acid, neither P. tsugae nor P. grandis were able to build up their populations in the treated trees, even though these trees were accepted as suitable breeding material by the parent adults. Also, the increase in hemlock bark maggot infestations and Pseudohylesinus spp. feeding sites in the residual trees within the chemically thinned plot was lower than that in the other thinned plots.

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