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THE WHITE GRUB IN UPPER MICHIGAN AND NORTHERN WISCONSIN 1-2 YEAR OLD RED PINE PLANTATIONS: POPULATION-DAMAGE CORRELATION, HIGH-GRUB-HAZARD AREA IDENTIFICATION, AND CHEMICAL APPLICATION TECHNIQUES.

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# THE WHITE GRUB IN UPPER MICHIGAN AND NORTHERN WISCONSIN 1-2 YEAR OLD RED PINE PLANTATIONS

## Population-Damage Correlation, High-Grub-Hazard Area Identification, and Chemical Application Techniques

By

Richard Francis Fowler

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ABSTRACT

# THE WHITE GRUB IN UPPER MICHIGAN AND NORTHERN WISCONSIN 1-2 YEAR OLD RED PINE PLANTATIONS

## Population-Damage Correlation, High-Grub-Hazard Area Identification, and Chemical Application Techniques

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The white grub (Coleoptera, Scarabaeidae), a soil-inhabiting insect, is a serious pest in some young pine plantations because of its root feeding habits.

Grub population and damage surveys were conducted in young red pine (*Pinus resinosa* Ait.) plantations on the Hiawatha National Forest in Upper Michigan and the Chequamegon and Nicolet National Forests in northern Wisconsin in 1967 and 1968. The plantation size varied from 11 acres to 400 acres, and a 40 acre section was randomly selected for sampling in the larger plantations. Sixteen or 30 systematically located one-cubic-foot soil samples were taken in each plantation. Ten or 20 seedlings at each sample location were examined for root damage.

The mean white grub population for the three forests was 0.77 grubs per cubic foot of soil with a range of 0 to 2.38. Six genera of grubs were found: *Phyllophaga*, *Serica*, *Diplotaxis*, *Dichelonyx*, *Aphodius*, and *Geotrupes*. *Phyllophaga* grubs were the most numerous, with a mean of 0.43 grubs per

cubic foot of soil and a range of 0 to 1.75.

Grub feeding damage was recorded both as percentage of trees damaged and amount of roots removed. Root scores from 1 (no damage) to 5 (complete removal of fibrous roots) were ocularly determined. A damage index was computed for each plantation by multiplying the number of trees having each root score by the assigned score numbers (1 to 5), adding their products, and dividing this sum by the total number of trees examined. These damage indexes ranged from 1.04 to 3.88 (minimum 1.00; maximum 5.00); 1 per cent to 86 per cent of the trees were damaged. A strong relationship ($r^2$=.89) exists for predicting damage index from percentage of trees damaged.

Regression curves were prepared for predicting damage index and percentage of trees damaged from Phyllophaga populations per cubic foot of soil. The coefficients of determination ($r^2$'s) are .66 and .65, respectively.

The highest grub populations, especially Phyllophaga, and highest damage indexes and percentages of trees damaged were on the Hiawatha National Forest in Michigan.

A Phyllophaga feeding index was computed for each plantation by grouping the larvae according to head capsule size, multiplying the number of larvae in each group by the group factor (1, 2, 4, or 8), and adding their products. The indexes were 8 to 12 on the Chequamegon National Forest, 0 to 218 on the Hiawatha National Forest, and 0 to 16 on the Nicolet National Forest.

The regression curves for predicting damage index and percentage of trees damaged from *Phyllophaga* feeding index have $r^2$'s of .78 and .70, respectively.

The attempt to identify high-grub-hazard areas on the bases of soil types, soil pH, root mass in the one-cubic-foot soil samples, and vegetation (both trees and shrubs as well as low-growing vegetation) was unsuccessful. The highest grub (all genera) and *Phyllophaga* populations occurred in the sand and loamy sand soils. However, a wide range of populations occurred in most of the sandier soil types examined. Coefficients of determination were only 5 per cent for soil pH and 1 per cent for root mass. No correlations at the 10 per cent level were found between *Phyllophaga spp*. and species of vegetation, or damage index and species of vegetation.

Techniques for applying aldrin insecticide were tested. These tests consisted of: 1) liquid aldrin applied at the time of planting using a planting-machine-mounted application device, 2) liquid aldrin applied immediately after planting to the planted seedlings using a backpack pump and wand, 3) granular aldrin applied at the time of planting by a planting-machine-mounted dispenser, and 4) no-treatment check plots. All applications were made to the soil in the vicinity of the seedling roots either at the time the planting furrow was open (treatments 1 and 3) or by inserting the wand into the soil after planting (treatment 2). A randomized complete block design was used. An F test and a Duncan range test showed that at the 5 per cent level significantly fewer trees were grub-damaged in the chemically treated plots than in the check plots, and that no differences were found among the various chemical treatments. In addition, the check trees grew significantly less (5 per cent level) in height during the first two growing seasons after planting than did the treated trees.

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Finally I acknowledge my wife Ellen's encouragement and invaluable assistance from field data collection through statistical calculations to manuscript preparation.

R.F.F.

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# INTRODUCTION

White grubs (Coleoptera, Scarabaeidae), which are the larvae of May beetles and related genera, are destructive pests in some young pine plantations in the Lake States. The larval stages live in the soil and feed on roots of trees and other vegetation. They feed on pine seedlings by removing smaller roots and girdling the larger ones, which results in weakening and reduced growth or mortality of the seedlings.

Hammond (1948a) claimed that white grubs of the genus _Phyllophaga_ are native to America, and he postulated that white grubs have been present since farming began. He recorded that the first report of damage by white grubs in Canada was in Quebec in 1853. Hubbard and Schwarz (1878) failed to find any _Phyllophaga_ at nine insect-collection points in Michigan's Upper Peninsula. Their collections were made during the logging era before futile farming attempts. Morofsky (1933) reported four species of _Phyllophaga_ collected in Upper Michigan from 1927 to 1932. Five additional species were recorded by Graham (1956), who collected from 1934 to 1937. In addition, Graham reported two species collected in northern Wisconsin.

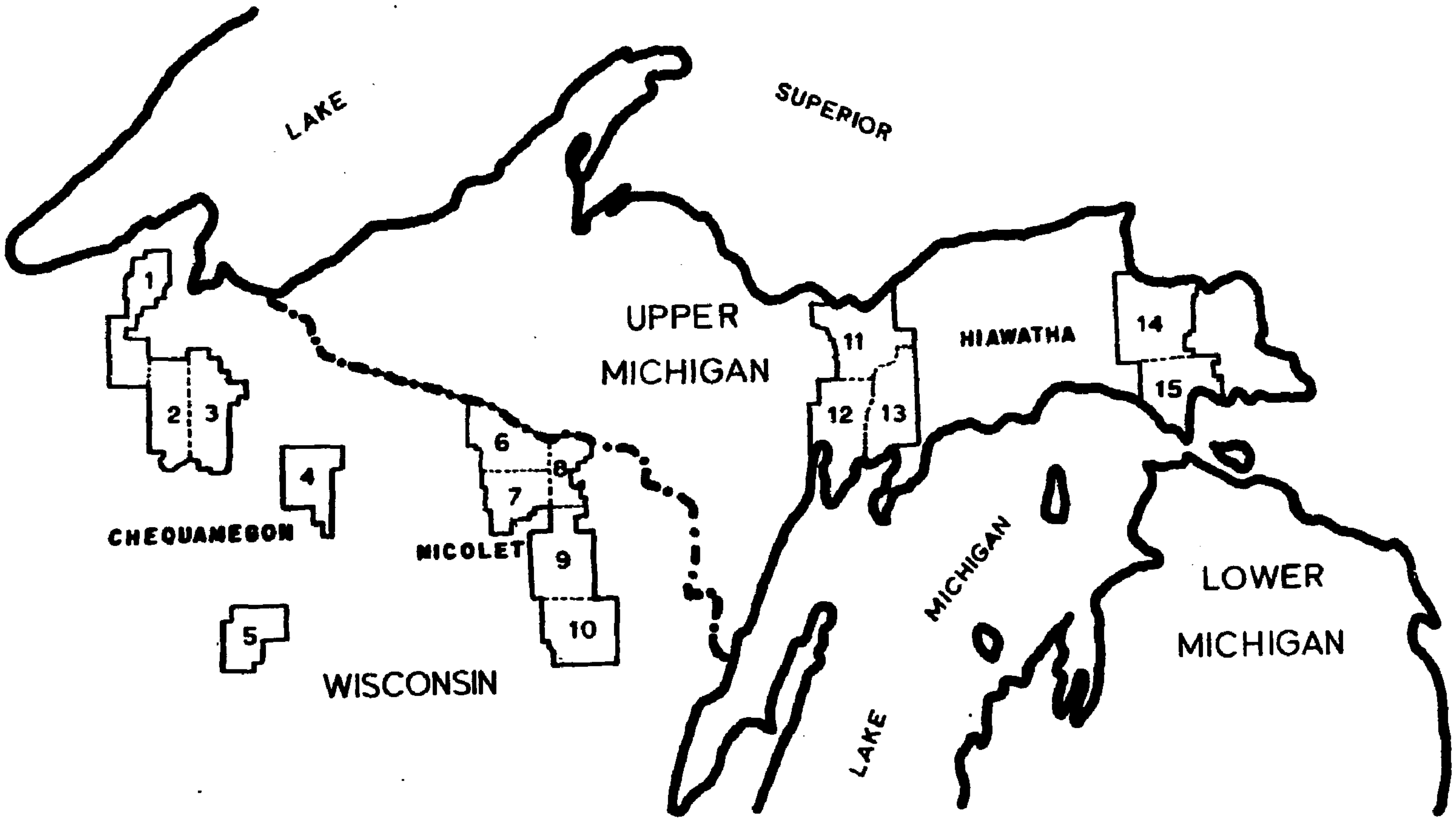
The first mention of white grub damage in Lake States pine plantations was by Kittredge in 1929. He stated that "undoubtedly" white grubs caused some mortality in plantations.

He noted "heavy losses" in eastern Upper Michigan, "considerable damage" on the Minnesota (Chippewa) National Forest, and lesser damage elsewhere in the Lake States.

Graham (1956) also reported that the most severe damage occurred on the Marquette National Forest (now a part of the Hiawatha National Forest). The Huron National Forest in Lower Michigan ranked second in severity of grub damage. The forests in western Upper Michigan, Wisconsin, and Minnesota had locally severely damaged plantations, and the Manistee National Forest in Lower Michigan suffered the least amount of damage. Conversely, Rudolf (1950) reported white grubs not a serious problem in Lower Michigan.

Losses as high as 90 per cent of the pine seedlings in plantations on the Marquette (Hiawatha) National Forest were reported by Craighead (1950). He also reported that losses of 5 per cent to 20 per cent of the trees were common throughout the eastern part of the United States prior to 1950.

Grub populations and damage surveys in this study were conducted in 1967 and 1968, on federal forest lands of the Hiawatha National Forest in Upper Michigan and the Chequamegon and Nicolet National Forests in northern Wisconsin (Figure 1). Specifically, work was done on the Washburn (District 1 of Figure 1), Hayward (2), and Glidden (3) Ranger Districts located on the Chequamegon National Forest; Eagle River (6), Florence (8), Laona (9), and Lakewood (10) Ranger Districts on the Nicolet National Forest; and Munising (11), Rapid River (12), Manistique (13), Sault Ste. Marie (14), and St. Ignace (15) Ranger Districts on the Hiawatha National Forest.




NATIONAL FOREST RANGER DISTRICTS

**CHEQUAMEGON**

1. Washburn
2. Hayward
3. Glidden
4. Park Falls
5. Medford

**NICOLET**

6. Eagle River
7. Three Lakes
8. Florence
9. Laona
10. Lakewood

**HIAWATHA**

11. Munising
12. Rapid River
13. Manistique
14. Sault Ste Marie
15. St. Ignace

Figure 1.--Locations of Surveyed National Forests in Northern Wisconsin and Upper Michigan, Divided into Ranger Districts.

The four objectives of this study were: (1) to compare white grub feeding damage with population levels in young red pine (*Pinus resinosa* Ait.) plantations; (2) to develop a method of identifying high-grub-hazard areas during pre-planting inspections of planting sites; (3) to evaluate the effectiveness of the currently used chemical control application technique; and (4) to test two new chemical control techniques.

## Taxonomy and Morphology

Authors such as Johnston and Eaton (1939), Hammond (1954), and Shenefelt *et al*. (1961) considered white grubs to be members of the genus *Phyllophaga*, while Anderson (1960) and Ives and Warren (1965) included both *Phyllophaga* and *Serica* in the group. Rudolf (1950), Shenefelt and Simkover (1950), Graham (1952), and Speers and Schmiege (1961) referred to both *Phyllophaga* and related genera as white grubs. Stone and Schwardt (1943) and Shenefelt *et al*. (1954) did not define the group in their papers. Craighead (1950) included five injurious genera in his list, but pointed out that *Phyllophaga* are the most important because of their destructive feeding habits, dense populations, wide distribution, and large number of species.

In this text, Ritcher's (1966) definition of white grubs is used, which includes all larvae of the family Scarabaeidae. The most distinguishing characteristic of this family is the stout, curled or C-shaped body. White grubs have three pairs of well-developed legs, and large, downward-projecting mandibles.

The body is white, orange, yellow, or bluish, and the head is reddish-brown or yellowish (Figure 2,A).

A B

Figure 2.--Typical Members of Family Scarabaeidae: A, Larvae; B, Adults.

Adults of the family Scarabaeidae vary considerably in size and form, but are usually stout-bodied beetles (Figure 2,B) which are awkward at flying and crawling. While often brown or black, some are green, blue, or yellow with a metallic luster. The antennae are lamellate, i.e. the last three or more segments are flat and platelike structures that can be opened and closed. The front legs are often dilated with the outer edge toothed or scalloped and suitable for digging.

During his studies in Lake States plantations Graham (1956) observed the following genera of root-feeding white grubs: Phyllophaga, Diplotaxis, Dichelonyx, Serica, Macrodactylus, Cotalpa, and Anomala. Shenefelt and Simkover (1950) found many of these white grub genera in Wisconsin forest tree nurseries, as well as the following genera: Aphonus, Ligyrus, and Strigoderma. Not all white grubs found in forest plantations and nurseries are necessarily living root feeders, as exemplified by the finding of the genera Aphodius and Geotrupes during this study. (A field key developed by the author to the more common Lake States white grubs is in Appendix A.)

## Life History

Life cycles have not been determined for the various genera of white grubs in Upper Michigan and northern Wisconsin. Craighead (1950) reported a one year life cycle for Anomala, Macrodactylus, Strigoderma, and Ligyrus; and a two-to-three year cycle for Serica, Dichelonyx, Diplotaxis, and Cotalpa. The Phyllophaga life cycle in the Lake States is at least three or four years (Luginbill and Painter 1953; Speers and Schmiege 1961) or up to five years (Craighead 1950; Graham 1956). The life cycle of the genus Aphonus is unknown.

The adults generally emerge from the soil in June or July and egg-laying begins within a few days. The larvae hatch and feed until cold weather. After hibernation, feeding resumes in the spring. Larvae of genera with a two year cycle pupate the second summer, and the resulting adults remain in the soil until the following summer. Larvae of genera with longer life cycles feed for several summers until fully developed. Pupation occurs during the summer and the adults emerge in the fall, but remain in the soil until the following June or July.

## CORRELATION BETWEEN ROOT DAMAGE AND GRUB POPULATION

White grubs cause seedling mortality in young red pine plantations by feeding on the roots. The amount of root damage and size of responsible grub populations occurring in young red pine plantations on federal lands in Upper Michigan and northern Wisconsin are unknown.

The literature varies greatly as to the size of grub population that is damaging. Shenefelt *et al.* (1954) in Wisconsin recommended that control should be used whenever grub populations are one or more grubs per two square feet of soil surface (i.e. at least 0.5 grubs per square foot). Rudolf (1950) recommended that planting in the Lake States be postponed in areas where two or more grubs per cubic foot are found. Stone and Schwardt (1943) in New York recommended not to plant where populations exceed 40 per square yard of soil surface (4.4 per square foot), but suggested that smaller numbers may cause injury. Sixty percent loss was reported by Watts and Hatcher (1954) in North Carolina areas where the population averaged slightly less than one grub per square foot of soil surface. Speers and Schmiege (1961) suggested that chemical control should be used where the grub population is two per square foot of soil surface.

Ives and Warren (1965) in Manitoba pointed out that not enough was known about damage caused by different grub population levels, but they tentatively adopted Shenefelt _et al's_ (1954) recommendation that control measures be performed when the population exceeds 0.5 grubs per square foot of soil surface.

Graham (1956) reported results of an experiment showing that not all white grubs are root feeders nor do all _Phyllophaga_ species cause serious damage. King (1939) mentioned that the natural tendency when dealing with insects that cannot be observed, such as soil insects, is to assume that the population level is completely correlated with damage symptoms.

## Objective

This part of the study sought to compare root damage caused by white grub feeding with white grub population. To accomplish this, damage surveys and grub population surveys were made.

## Methods and Materials

Seventeen red pine plantations, planted the spring of 1967, were randomly selected for the summer 1967 grub population surveys on the Chequamegon, Hiawatha, and Nicolet National Forests (Table 1,A). The number of plantations selected on the Chequamegon and Nicolet National Forests was 16, which was approximately proportional to the number of plantations per district. On the Hiawatha National Forest, population surveys were conducted in six more plantations (Tables 1,A and D).

Table 1.--Locations of Plantations Used for Population and Damage Surveys and for Chemical Treatments.

| National Forest and Ranger District | Code and/or Name | Legal Description |
|---|---|---|
| A. White Grub Population and Damage Survey Plantations--Planted Spring 1967. | | |
| CHEQUAMEGON N.F. | | |
| Washburn R.D. | W I | T49N,R7W,Sec.14 |
| | W II | T48N,R6W,Sec.26 |
| | W III | T49N,R7W,Sec.11 |
| | W IV | T47N,R7W,Sec.10 |
| Glidden R.D. | G I | T41N,R4W,Sec.19 |
| | G II | T42N,R3W,Sec.35 |
| Hayward R.D. | HA I | T40N,R5W,Sec. 5 |
| | HA II | T42N,R6W,Sec.33 |
| HIAWATHA N.F. | | |
| Rapid River R.D. | ST | T40N,R22W,Sec.25 |
| NICOLET N.F. | | |
| Eagle River R.D. | E I | T41N,R11E,Sec.35 |
| | E II | T41N,R11E,Sec.36 |
| | E III | T41N,R11E,Sec.34 |
| Florence R.D. | F I | T39N,R15E,Sec.31 |
| | F II | T40N,R16E,Sec.15 |
| Lakewood R.D. | L I | T33N,R17E,Sec. 8 |
| | L II | T33N,R16E,Sec.10 |
| Laona R.D. | X I | T34N,R16E,Sec. 9 |
| B. White Grub Population and Damage Survey Plantations--Planted Spring 1968. | | |
| CHEQUAMEGON N.F. | | |
| Hayward R.D. | HA III | T42N,R5W,Sec.27 |
| | HA IV | T43N,R5W,Sec. 7 |
| HIAWATHA N.F. | | |
| Rapid River R.D. | SL-Sleepy Sentinel | T40N,R21W,Sec.19 |
| Manistique R.D. | FD-Fishdam River | T41N,R18W,Sec.16 |
| | TL-Thunder Lk. Rd. | T43N,R17W,Sec.32 |
| | ML-Muleshoe Lake | T43N,R17W,Sec.15 |
| | CR-Corner Lake | T43N,R18W,Sec. 5 |

Table 1 (cont'd.)

| National Forest and Ranger District | Code and/or Name | Legal Description |
|---|---|---|
| HIAWATHA N.F. (cont'd.) | | |
| Munising R.D. | LP-Lonesome Pine | T45N,R20W,Sec.21NW |
| | FP-Flattop Pine | T45N,R20W,Sec.21SE |
| NICOLET N.F. | | |
| Lakewood R.D. | L III | T33N,R17E,Sec.22 |
| | L IV | T32N,R16E,Sec.26 |
| | L V | T31N,R15E,Sec.18 |
| C. Other Plantations Surveyed for White Grub Populations in 1968--Planted Prior to 1967. | | |
| HIAWATHA N.F. | | |
| Manistique R.D. | CL-Camp 41 Lake | T44N,R17W,Sec.28 |
| Sault Ste. Marie R.D. | T-FR 3144 | T45N,R6W,Sec.13 |
| | SS-Soo Spur | T44N,R4W,Sec.20 |
| St. Ignace R.D. | ST-FR 3124 | T42N,R5W,Sec. 9 |
| D. Aldrin Application Plantings--Planted Spring 1967. | | |
| HIAWATHA N.F. | | |
| Sault Ste. Marie R.D. | R-Raco CCC Camp | T46N,R4W,Sec.24SE¼ |
| | H-Highbanks Lake | T46N,R5W,Sec.13SW¼ |
| | S-Townhall (Strongs) | T46N,R6W,Sec.36NE¼ |
| Munising R.D. | MU-Townline Lake | T45N,R18W,Sec.34E½ |
| Manistique R.D. | MA-Bird Area | T44N,R18W,Sec.29NE¼ |

The summer 1968 grub population surveys were conducted in twelve randomly selected spring 1968 plantations (Table 1,B) and four plantations planted spring 1966 or earlier (Table 1,C). Since the grub problem is more acute on the Hiawatha National Forest, more plantations were selected there in 1968.

On the Hiawatha National Forest, five plantings were used in the evaluation of aldrin insecticide application techniques (Table 1,D). White grub population data from these plantations and damage data from the untreated plots are used in this section of the report. These areas are referred to in the text as "aldrin application plantings".

The sampled plantations varied in size from 11 acres to 400 acres. In each plantation, regardless of size, except the aldrin application plantings, four transects were run across each plantation, with four plots sampled per line for a total of 16 plots. In large plantations an area of about 40 acres was randomly selected and sampled. In each aldrin application planting a line was run across each of the five blocks, with six plots taken per line, or 30 per planting.

Each plot, or sample, consisted of one cubic foot of soil measuring twelve inches square on the soil surface and twelve inches deep, taken midway between the planting rows. The average spacing of trees varied among sampled plantations, with six to ten feet between rows and six to eight feet between trees in the rows.

A metal frame was driven into the ground to define the sample and prevent the sides of the hole from falling in. The sifting screen, a wooden frame with a 1/4" hardware cloth bottom, was used to remove insects from the soil sample.

Grub feeding damage surveys were conducted in the same plantations as the grub population surveys. At each of the 16 plots, 20 trees were examined, for a total of 320 trees. In the aldrin application plantings, all untreated trees (450 per planting) were examined.

A numerical rating system, modified from Johnston and Eaton (1939), was used to ocularly score the amount of grub feeding on red pine seedling roots. The root scores were defined as follows. (See Figure 3. The "U" is an unplanted 3-0 seedling.)

Score 1 - no sign of grub feeding.

Score 2 - 1 per cent to 33 per cent of fibrous roots removed as a result of grub feeding.

Score 3 - 34 per cent to 66 per cent of fibrous roots removed as a result of grub feeding.

Score 4 - 67 per cent to 99 per cent of fibrous roots removed as a result of grub feeding. Also included are trees completely stripped of fibrous roots, but which have started growing new root tips.

Score 5 - all fibrous roots removed as a result of grub feeding. Includes trees with tap roots cut off just below ground surface.

In the spring 1967 plantations only dead trees were dug and root-scored. Damage surveys were conducted in those areas during fall 1967, spring 1968, and fall 1968, with some exceptions. Inadequate time limited damage surveys on the Chequamegon and Nicolet National Forests to areas with a

1 2 3 U 4 5

Figure 3.--White Grub Feeding Damage Scores.

mean of 0.50 or more grubs per cubic foot of soil--the tentative figure set as a damaging population. In addition, certain areas could not be surveyed as they were underplantings with no ground preparation to aid the surveyor in locating the trees. Surveys were conducted only in the spring of 1968 in the spring 1967 plantings on the Washburn Ranger District of the Chequamegon National Forest as difficulties were encountered in relocating plots. Observations made in the Washburn plantations indicated that re-survey was unnecessary because less than 1 per cent additional mortality had occurred.

In the spring 1968 plantations the same survey method of selecting 20 trees per plot was used. This time all 20 trees were dug, regardless of above-ground condition, and the root feeding damage scored. The scores from these samples were computed into a damage index used to correlate feeding damage with grub populations.

The damage indexes were computed using the root scores and numbers of trees examined. Mathematically the formula is:

$$\text{Damage Index} = \frac{\text{sum of products of no. trees with each root score X score no.}}{\text{no. of trees examined}}$$

or:

$$DI = \frac{\sum xy}{n}$$

where x = no. trees with each root score

y = root score no.

n = total no. trees scored

**Example:**

| No. Trees | Score No. | Product |
|---|---|---|
| x | y | xy |
| 3 | 1 | 3 |
| 2 | 2 | 4 |
| 0 | 3 | 0 |
| 3 | 4 | 12 |
| 2 | 5 | 10 |
| 10 | | 29 |

$$\frac{29}{10} = \underline{\underline{2.90\ DI}}$$

Minimum DI = 1.00
Maximum DI = 5.00

Surveys in the aldrin application plantings were conducted in fall 1967, spring 1968, and fall 1968. The fall 1968 survey included the excavation of 50 trees, regardless of above-ground condition, in the no-aldrin treatment, and computation of a damage index.

The damage indexes computed from the fall 1968 damage survey data, and the white grub population data from the summer 1968 population surveys, were used in the population-damage correlations. The population data were combined in four ways: (1) mean number of grubs of all species per cubic foot, (2) mean number of <u>Phyllophaga</u> and <u>Serica</u> per cubic foot, (3) mean number of <u>Serica</u> per cubic foot, and (4) mean number of <u>Phyllophaga</u> per cubic foot. The above groupings were made for the combined data for the three national forests (Chequamegon, Hiawatha, and Nicolet), and for the Hiawatha alone.

The <u>Phyllophaga</u> and <u>Serica</u> larvae were measured in order to obtain a size-numbers index called a Feeding Index. The width of the head capsule of each larva was measured using a micrometer disc inserted into the eyepiece of a dissecting microscope.

The larvae were segregated by genus and then separated into size groupings. Since the amount of food ingested increases approximately geometrically as larvae grow larger, numbers in geometric progression were assigned to each size group. Number 1 was assigned to the group with the smallest head size, 2 to the next larger, 4 to the next, and 8 to the largest size larvae. The size group number was then multiplied by the number of larvae in the group and the group totals added to obtain the feeding index for the plantation.

## Grub Population and Damage Survey Results

The white grubs collected during the 1967 population survey were identified to genera by the author. David J. Hall (graduate student Michigan State University) identified the 1968 collection. Both used Ritcher's (1966) key. Six genera were found: Phyllophaga, Serica, Diplotaxis, Dichelonyx, Aphodius, and Geotrupes. The species involved were not determined because of the difficulty in keying these genera. Further, as Böving (1937) pointed out, adults are needed to check authenticity of the identifications. Rearing members of this group to adults for positive identification may take one or more years, due to the length of the life cycle of some of the species involved. This is impractical for purposes of this evaluation.

According to Graham (1956), members of the genus Phyllophaga are the most destructive to roots of conifer seedlings in the Lake States, although not all species are equally damaging. Graham reports the results of tests in which 78 per cent, 48 per cent, and 3 per cent of the red pine seedlings were killed by three separate species. In each test three larvae were placed in each container with a seedling and grass. The members of this genus have a three-to-five year life cycle in this region. The larvae grow large and are voracious feeders for as long as three consecutive years.

The members of the genus Serica are smaller than the above and have a two-to-three year life cycle in Michigan (Craighead 1950). In the same tests reported by Graham (1956), four and eight Serica larvae per test tree and grass were used; 13 per cent and 18 per cent of the seedlings were killed. The smaller amount of damage reported in these tests and/or the smaller size and fewer numbers of this genus found in plantations led Craighead (1950), Graham (1956), and Ives and Warren (1965) to believe the genus unimportant in forest plantations.

Graham (1956) also reported tests using four and eight Diplotaxis larvae per test. Here 15 per cent and 14 per cent of the test seedlings were killed. Craighead (1950) and Graham (1956) also doubt that this genus is important in plantations. The larvae are small; the insects have a two-to-three year life cycle.

Dichelonyx larvae, four and eight per test, killed only 2 per cent and 0 per cent of the seedlings in tests reported by Graham. These also are small larvae; the insects have a two-to-three year life cycle.

Most Aphodius and all Geotrupes species are dung feeders, although some of the former feed on living roots.

The white grub populations were found to be quite variable in size and generic composition on all three forests surveyed. A summary of the grub population survey is presented in Table 2. For detailed information see Appendix Table B 4.

The highest grub populations (all species) and Phyllophaga spp. occur on the Hiawatha National Forest although

Table 2.--Summary of White Grub Genera from Population Surveys, by National Forests and Ranger Districts.

| | Mean Grubs per Cubic Foot of Soil | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Forest & District | Phyllophaga | Serica | Diplotaxis | Dichelonyx | Aphodius | Geotrupes | Other | All Grubs |
| CHEQUAMEGON N.F. | | | | | | | | |
| Washburn R.D. | 0.11 | 0.95 | 0.00 | 0.11 | 0.00 | 0.02 | 0.06 | 1.25 |
| Glidden R.D. | 0.03 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.03 |
| Hayward R.D. | 0.08 | 0.21 | 0.00 | 0.05 | 0.02 | 0.00 | 0.00 | 0.36 |
| HIAWATHA N.F. | | | | | | | | |
| Rapid River R.D. | 0.00 | 0.03 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.03 |
| Manistique R.D. | 0.50 | 0.20 | 0.02 | 0.01 | 0.00 | 0.01 | 0.01 | 0.75 |
| Munising R.D. | 1.25 | 0.20 | 0.03 | 0.00 | 0.00 | 0.00 | 0.01 | 1.49 |
| Sault Ste. Marie R.D. | 0.57 | 0.24 | 0.03 | 0.02 | 0.13 | 0.00 | 0.04 | 1.03 |
| St. Ignace R.D. | 0.56 | 0.69 | 0.00 | 0.00 | 0.00 | 0.06 | 0.00 | 1.31 |
| NICOLET N.F. | | | | | | | | |
| Eagle River R.D. | 0.02 | 0.27 | 0.00 | 0.02 | 0.00 | 0.00 | 0.08 | 0.40 |
| Florence R.D. | 0.16 | 0.03 | 0.00 | 0.03 | 0.00 | 0.00 | 0.00 | 0.22 |
| Lakewood R.D. | 0.24 | 0.03 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.28 |
| Laona R.D. | 0.00 | 0.06 | 0.00 | 0.06 | 0.00 | 0.00 | 0.00 | 0.13 |
| GRAND MEAN | 0.43 | 0.24 | 0.02 | 0.02 | 0.03 | <0.01 | 0.01 | 0.77 |

considerable variation in size of these populations was found among plantations. The *Serica* spp. populations are variable also, but not as numerically high as the *Phyllophaga*.

According to Graham's (1956) tests, some members of the genus *Phyllophaga* are very destructive, killing 78 per cent of the test trees. The high population levels found in several of the plantations surveyed add to its importance.

*Serica*, although found in large numbers in some plantations during these surveys, killed only about 15 per cent of Graham's (1956) test trees.

Although the grub populations are high in some areas of the Chequamegon National Forest, very few *Phyllophaga* larvae were found. *Serica* make up the majority of the population.

The numbers of all grubs, *Phyllophaga*, and *Serica* were generally low in the areas surveyed on the Nicolet National Forest, although a high grub population was found in the L II plantation.

Members of the genus Diplotaxis were found only on the Hiawatha National Forest. Although they killed 15 per cent of the seedlings in Graham's (1956) tests (about the same damage as Serica), they are considered by Craighead (1950) and this author as unimportant because of the low population levels found. The genus Dichelonyx is unimportant, although found on all three forests, because of low population levels and Graham's (1956) reported 2 per cent of the test trees killed.

Although one large population of Aphodius was found on the Hiawatha National Forest, the genus is disregarded because most of the species of Aphodius do not feed on living roots. Members of the genus Geotrupes were found in low numbers on the Chequamegon and Hiawatha National Forests. These too are not root feeders.

The results of the 1967 and 1968 grub feeding damage surveys and data from the check treatments of the aldrin application plantings are presented in Table 3. More complete information is available in Appendix Tables B 1, B 2, and B 3.

The damage index is a measure of the degree of root damage. The highest percentage of trees damaged, however,and the highest indexes do not always represent the same plantation. (This occurred in the fall 1968 survey on the Lakewood Ranger District--see Table 3 and Appendix Table D 2.)

Table 3.--Summary of White Grub Root Damage Surveys by National Forests and Ranger Districts.

| Forest & District | Year Planted | Season Surveyed | Tree Condition | % Trees Damaged Low[a] | % Trees Damaged High[a] | Damage Index Low[a] | Damage Index High[a] |
|---|---|---|---|---|---|---|---|
| | | | GENERAL SURVEY | | | | |
| CHEQUAMEGON N.F. | | | | | | | |
| Washburn R.D. | S'67 | S'68 | Dead | 2 | 3 | - | - |
| Hayward R.D. | S'68 | F'68 | Living & Dead | 17 | 20 | 1.35 | 1.47 |
| HIAWATHA N.F. | | | | | | | |
| Rapid River R.D. | S'67 | F'67,S'68,F'68 | Dead | 1 | 1[b] | - | - |
| | S'68 | F'68 | Living & Dead | 1 | 1[b] | 1.04 | 1.04 |
| Manistique R.D. | S'68 | F'68 | Living & Dead | 29 | 84 | 1.83 | 3.88 |
| Munising R.D. | S'68 | F'68 | Living & Dead | 42 | 72 | 2.11 | 3.28 |
| NICOLET N.F. | | | | | | | |
| Lakewood R.D. | S'67 | F'67,S'68,F'68 | Dead | 18 | 18[b] | - | - |
| | S'68 | F'68 | Living & Dead | 13 | 37 | 1.08 | 1.34 |
| | | TREATMENT 4 (CHECK) ALDRIN APPLICATION PLANTINGS | | | | | |
| HIAWATHA N.F. | | | | | | | |
| Sault Ste. Marie R.D. | S'67 | F'68 | Living & Dead | 58 | 58 | 2.20 | 2.42 |
| Manistique R.D. | S'67 | F'68 | Living & Dead | 86 | 86[b] | 3.02 | 3.02 |
| Munising R.D. | S'67 | F'68 | Living & Dead | 74 | 74[b] | 3.10 | 3.10 |

[a]Extremes of the range of values in these classifications.
[b]Only one plantation sampled.

On the Chequamegon National Forest the mortality in the 1967 plantations and damage indexes in the 1968 plantations surveyed were quite low, i.e. indexes less than 1.50. (The minimum and maximum damage indexes are 1.00 and 5.00, respectively.)

Damage indexes on the Hiawatha National Forest are quite variable, ranging from near 1.00 to almost 4.00. In one plantation 84 per cent of the sample trees were damaged, with scores from 2 to 5.

Grub damage was generally low on the Nicolet National Forest, with indexes of less than 1.50. However, 17 per cent of the trees in the one plantation (L II) were dead with root damage.

The Phyllophaga larvae range in head capsule size from 1.28 mm to 6.72 mm. Measurements were made on 146 larvae from 15 plantations. The larval size groups and numbers of larvae per group are as follows:

1.28 mm to 1.28 mm - 1 larva
1.92 mm to 2.24 mm - 27 larvae
2.28 mm to 4.32 mm - 49 larvae
4.64 mm to 6.72 mm - 69 larvae

The Phyllophaga feeding indexes range from 0 to 218. By Forests, the ranges are 8 to 12 on the Chequamegon National Forest, 0 to 16 on the Nicolet National Forest, and 0 to 218 on the Hiawatha National Forest.

The Serica larvae range in head capsule size from 1.04 mm to 3.84 mm. Measurements were made on 56 larvae from 15 plantations. The larval size groups and numbers of larvae per group are as follows:

1.04 mm to 1.12 mm - 3 larvae
1.52 mm to 1.76 mm - 10 larvae
2.08 mm to 3.84 mm - 43 larvae

The Serica feeding indexes range from 0 to 50. By Forests, the ranges are 12 to 13 on the Chequamegon National Forest, 0 on the Nicolet National Forest, and 0 to 50 on the Hiawatha National Forest.

Since Serica as well as Phyllophaga feed on the red pine seedlings, a combined feeding index was prepared. The head capsule widths of Serica larvae generally occur in sizes between widths of the Phyllophaga larvae, although some overlapping does occur. To overcome this, half of the Serica larvae in each group were assigned to the group number of the next smaller *Phyllophaga* group and half to the number of the next larger group. The data was then combined into a *Phyllophaga* and *Serica* feeding index.

Both the *Phyllophaga* feeding index and the *Phyllophaga* and *Serica* feeding index were plotted as independent variables, with damage index and percentage of trees damaged as dependent variables. Inspection of graphs of the combined *Phyllophaga* and *Serica* feeding index showed the author that the curves for predicting damage index and percentage of trees damaged would not be a considerable improvement over those using *Phyllophaga* feeding index alone; the combination was therefore omitted from further consideration.

## Analyses and Discussion

Root damage is related to white grub population level. *Phyllophaga* account for most of the damage, which varies depending upon location; *Serica* contribute less damage. Simple linear regression lines (linear model $Y = a+bX$) were computed for predicting damage index from the mean white grub populations per cubic foot of soil (Figure 4), damage index from the mean *Phyllophaga* and *Serica* populations per cubic foot of soil (Figure 5), damage index from the mean *Phyllophaga* populations per cubic foot of soil (Figure 6), and percentage of trees damaged from the mean *Phyllophaga* populations per cubic foot of soil (Figure 8). Inspection of Figures 6 and 8 indicates that the data might be curvilinearly related. The nonlinear model $Y = a+b(1-e^{cX})$ was used to compute the curves

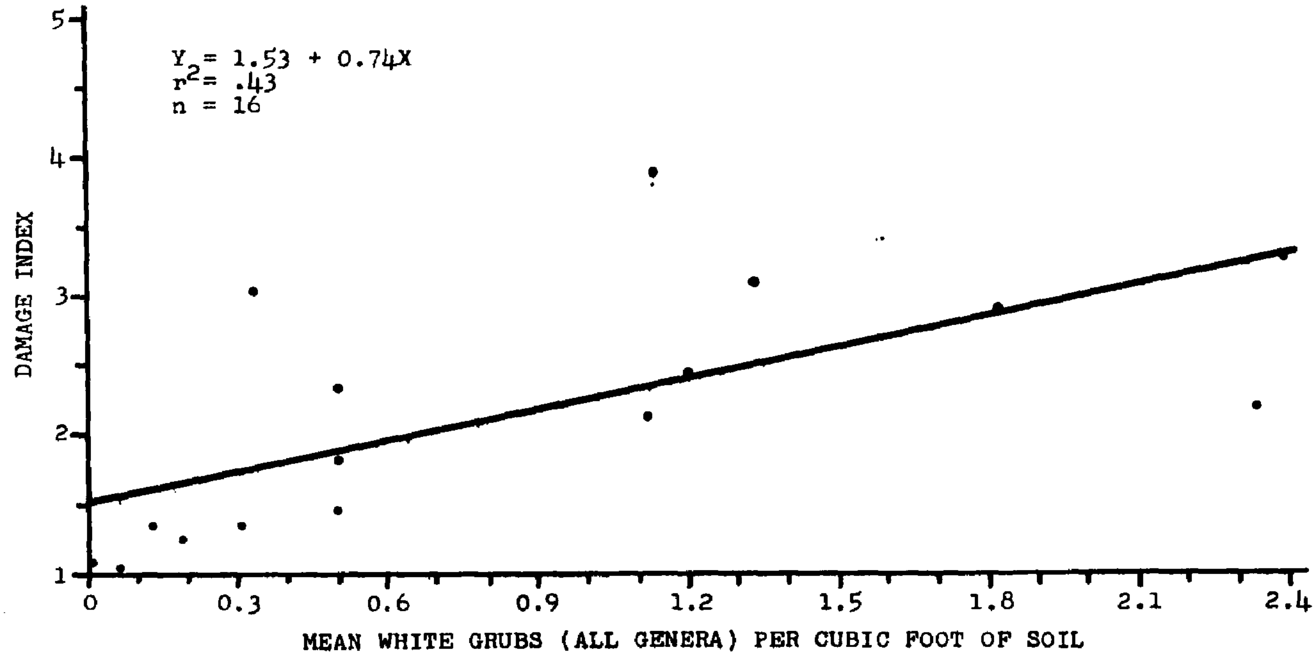



Figure 4.--Linear Relationship between the Mean White Grub Populations (All Genera) per Cubic Foot of Soil and Damage Index.

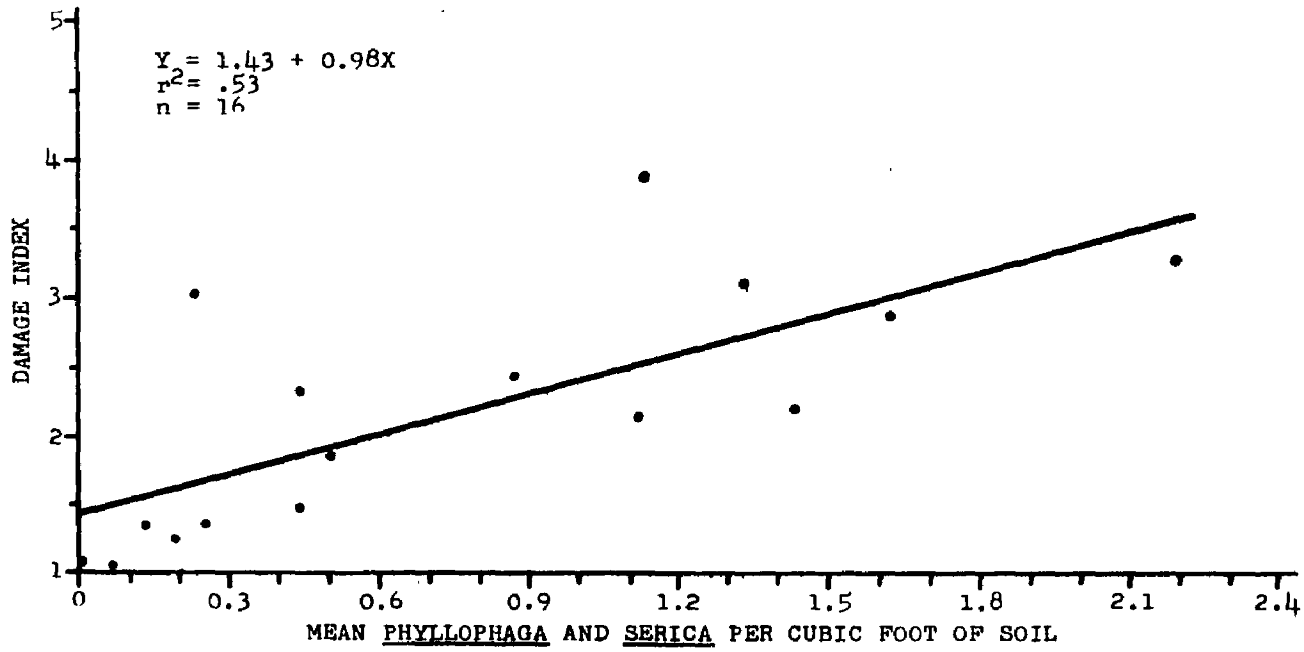



Figure 5.--Linear Relationship between the Mean *Phyllophaga* and *Serica* Populations per Cubic Foot of Soil and Damage Index.

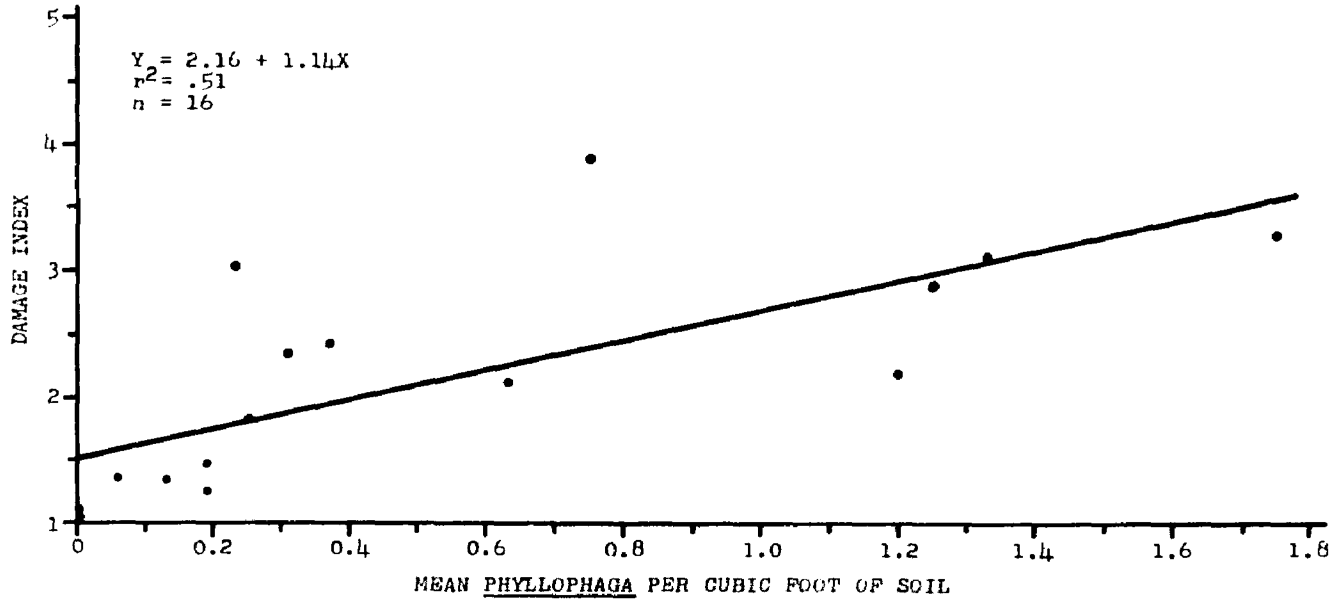



Figure 6.--Linear Relationship between the Mean *Phyllophaga* Populations per Cubic Foot of Soil and Damage Index.

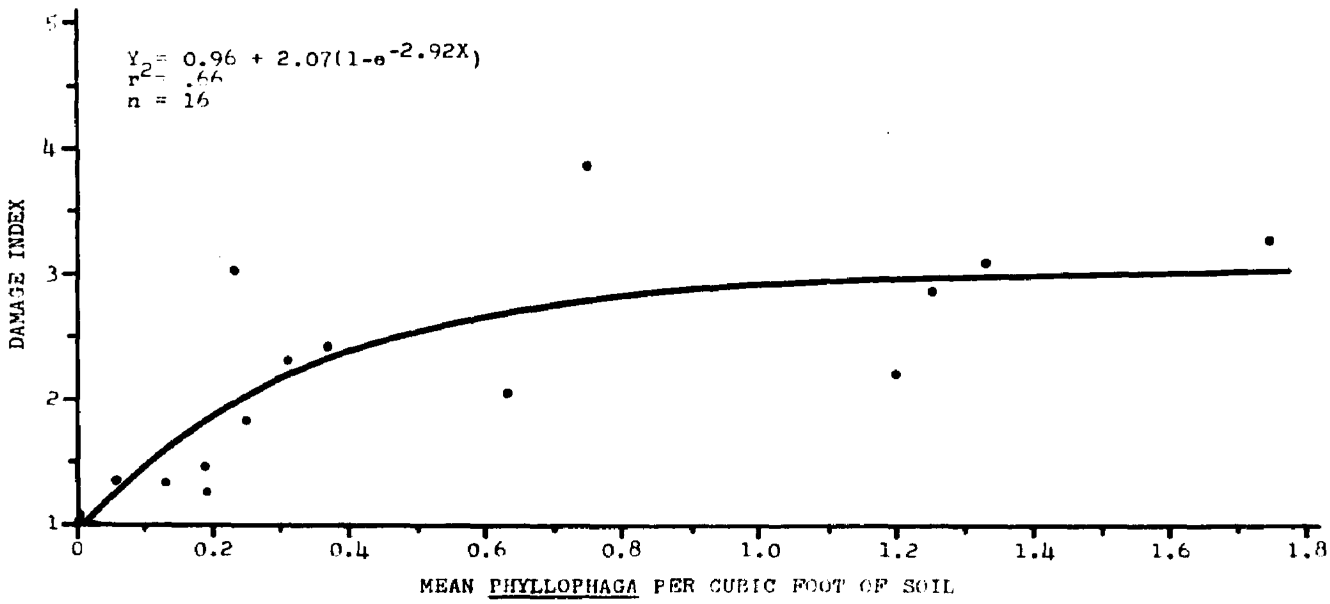



Figure 7.--Curvilinear Relationship between the Mean *Phyllophaga* Populations per Cubic Foot of Soil and Damage Index.

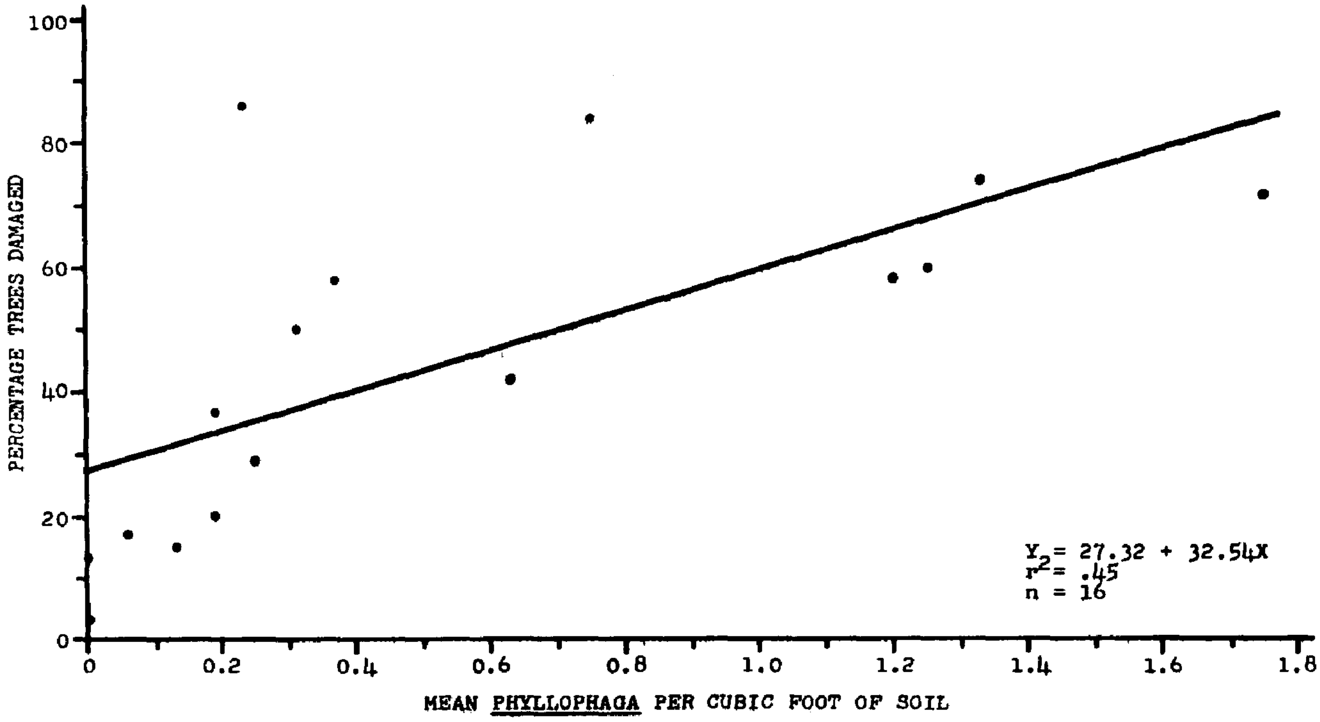



Figure 8.--Linear Relationship between the Mean *Phyllophaga* Populations per Cubic Foot of Soil and Percentage of Trees Damaged.

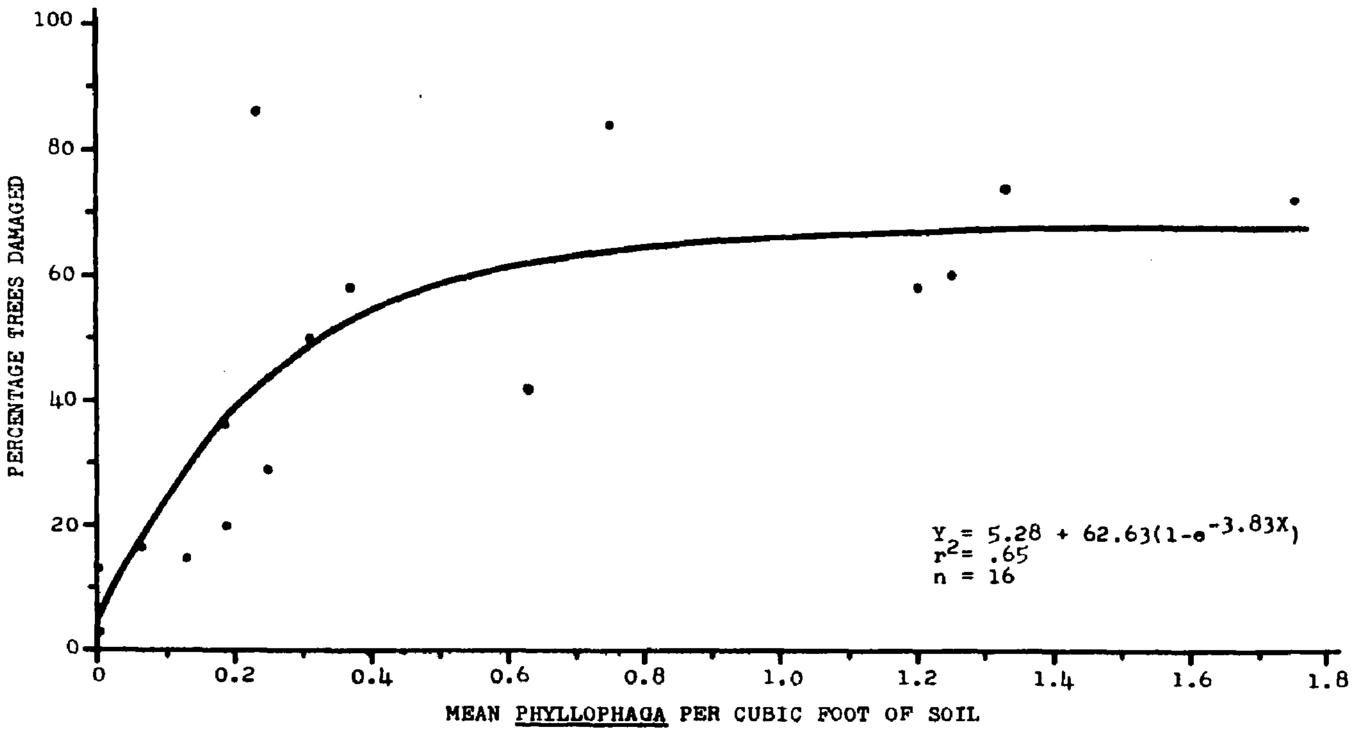



Figure 9.--Curvilinear Relationship between the Mean *Phyllophaga* Populations per Cubic Foot of Soil and Percentage of Trees Damaged.

for predicting damage index from the mean *Phyllophaga* populations per cubic foot of soil (Figure 7), and percentage of trees damaged from the mean *Phyllophaga* populations per cubic foot of soil (Figure 9).

A coefficient of determination ($r^2$) was computed for each line.[1] The $r^2$'s are .51 and .66, respectively, for predicting damage index from the mean *Phyllophaga* populations per cubic foot of soil for the linear and nonlinear models. The $r^2$'s for predicting percentage of trees damaged from the mean *Phyllophaga* populations per cubic foot of soil are .45 and .65, respectively. The $r^2$'s indicate that the nonlinear model provides a better fit than the linear model.

Examination of the individual points plotted in Figures 7 and 9 reveals considerable variation among plantations having the same grub population. Large standard errors are associated with prediction-equations. The standard error for predicting damage index from the mean *Phyllophaga* populations per cubic foot of soil is 0.55 and for predicting percentage of trees damaged is 17.

The relationship between damage index and the mean *Phyllophaga* populations per cubic foot of soil is shown in Figure 7. The regression line meets the Y axis very close to a damage index of 1, as would be expected--that is, no damage occurs when no *Phyllophaga* population is present. The curve initially increases rapidly, tending to increase more

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[1]Freese (1967) defines coefficient of determination as "the proportion of the variation in Y that is associated with the regression".

slowly as the mean *Phyllophaga* populations increase in size. The curve becomes relatively fixed at a damage index of 3 and a mean *Phyllophaga* population of about 1.3 per cubic foot of soil. The curve changes little beyond this point. The curve is expected to become asymptotic at a damage index of 5 (the highest possible root score). Unidentified factors, perhaps competition, among others, are preventing this occurrence.

Figure 9 shows the relationship between percentage of trees damaged and the mean *Phyllophaga* populations per cubic foot of soil. The curve intersects the Y axis at about 5 per cent. Actually, without the presence of *Phyllophaga* no damage is expected. The weakness in both curves most likely lies in the measurement of the mean *Phyllophaga* populations values, as the number and size of the soil samples taken to estimate the insect populations are small. The insect populations are based on one-cubic-foot soil samples, whereas the group of examined trees associated with each soil sample occupies several hundred square feet of planting area. The curve initially increases sharply, becoming less steep as the mean *Phyllophaga* populations increase. Again, at approximately 1.3 *Phyllophaga* per cubic foot of soil, the curve is relatively fixed and changes little thereafter. At this point about 63 per cent of the trees are damaged. The expected asymptote at the 100 per cent of trees damaged figure is not reached.

The coefficients of determination ($r^2$'s) for the linear regressions for predicting damage index from the mean white grub populations per cubic foot of soil, from the mean *Serica* populations per cubic foot of soil, and from the mean *Phyllophaga* and *Serica* populations per cubic foot of soil are .43, .18, and .53, respectively. The data from the Hiawatha National Forest alone yielded $r^2$'s of .20, .03, and .32, respectively, and the $r^2$ for predicting damage index from *Phyllophaga*-only populations per cubic foot of soil is .35. Because of the low $r^2$ values for all-grubs populations and for *Serica*-only populations, and because combining the *Phyllophaga* and *Serica* populations data changed the $r^2$ only two or three points, the *Phyllophaga*-only populations data was used throughout the remainder of this study.

Several authors have indicated that a white grub population of 0.5 grubs per cubic foot of soil is a damaging population (see Page 7). Examination of Figures 7 and 9 indicates that with a population of 0.5 *Phyllophaga* per cubic foot of soil, a damage index of about 2.50 could be expected and about 59 per cent of the trees would be damaged. The large standard errors associated with these curves indicate that the damage could be considerably higher or lower than the curves indicate. The curves also indicate that even with a population as low as 0.1 *Phyllophaga* per cubic foot of soil, the damage index would be near 1.5 and almost 25 per cent of the trees would be damaged.

The relationship between root damage and *Phyllophaga* population is better expressed when size of larvae as well as numbers is considered. Again, the nonlinear model $Y = a+b(1-e^{cX})$ was used. Figures 10 and 11 show the curves for predicting damage index from Phyllophaga feeding index, and percentage of trees damaged from Phyllophaga feeding index, respectively. The coefficient of determination ($r^2$) for predicting damage index from Phyllophaga feeding index is .78. This is an improvement over the $r^2$ of .66 obtained when only the mean-Phyllophaga-populations-per-cubic-foot-of-soil figure was used. The $r^2$ for predicting percentage of trees damaged from Phyllophaga feeding index increased to .70 from an $r^2$ of .65 using the mean-Phyllophaga-populations-per-cubic-foot-of-soil figure.

Considerable variation occurs among plantations having similar Phyllophaga feeding indexes as shown by the individual points plotted in Figures 10 and 11. The standard errors for predicting damage index from Phyllophaga feeding index and percentage of trees damaged from Phyllophaga feeding index are 0.46 and 16, respectively. The standard errors for predicting damage index and for predicting percentage of trees damaged from the mean Phyllophaga populations per cubic foot of soil, as discussed earlier, were 0.55 and 17, respectively.

Examination of Figure 10 reveals that the curve is similar in shape to Figure 7. The curve meets the Y axis very close to a damage index of 1, and initially increases rapidly, tending to increase more slowly as the Phyllophaga feeding index increases in size. The curve becomes relatively fixed at a damage index of 3.10 and a Phyllophaga feeding

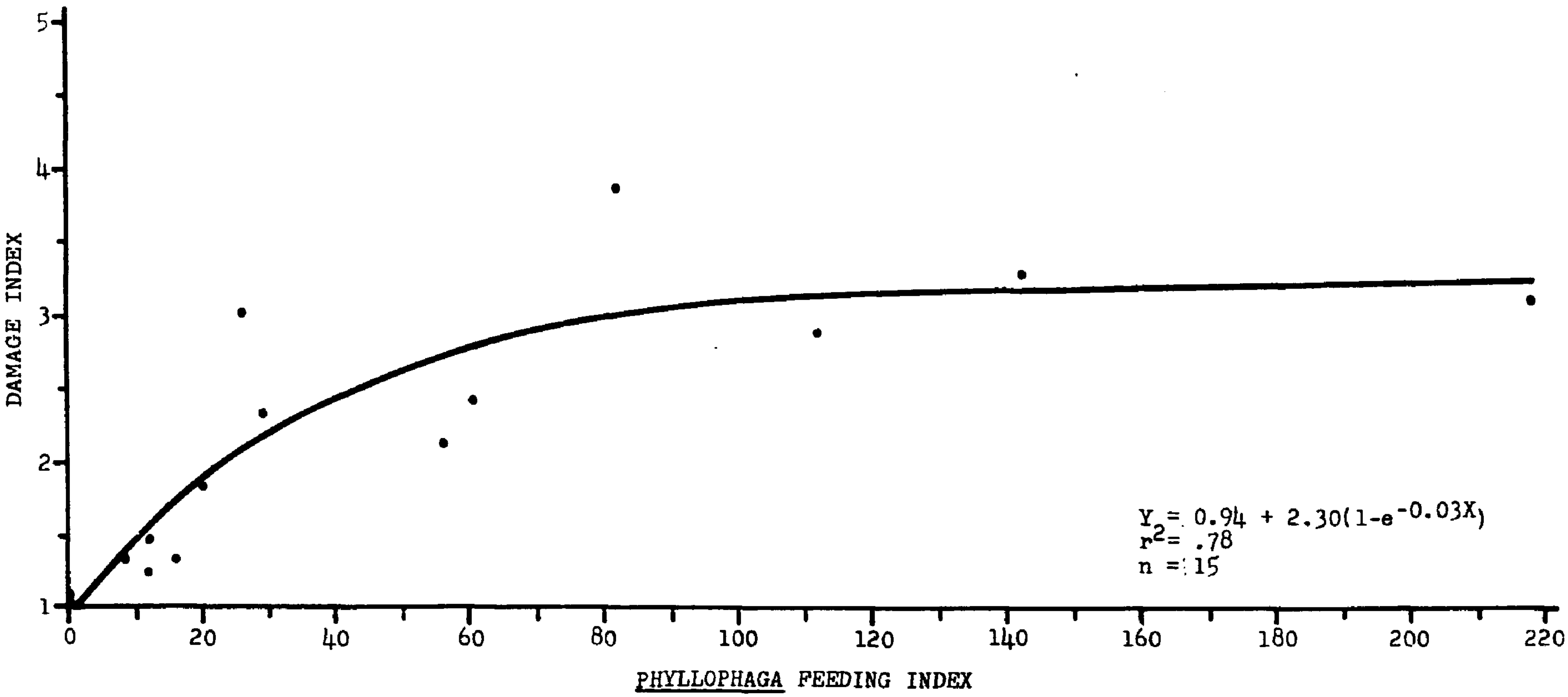


Figure 10.--Curvilinear Relationship between *Phyllophaga* Feeding Index and Damage Index.

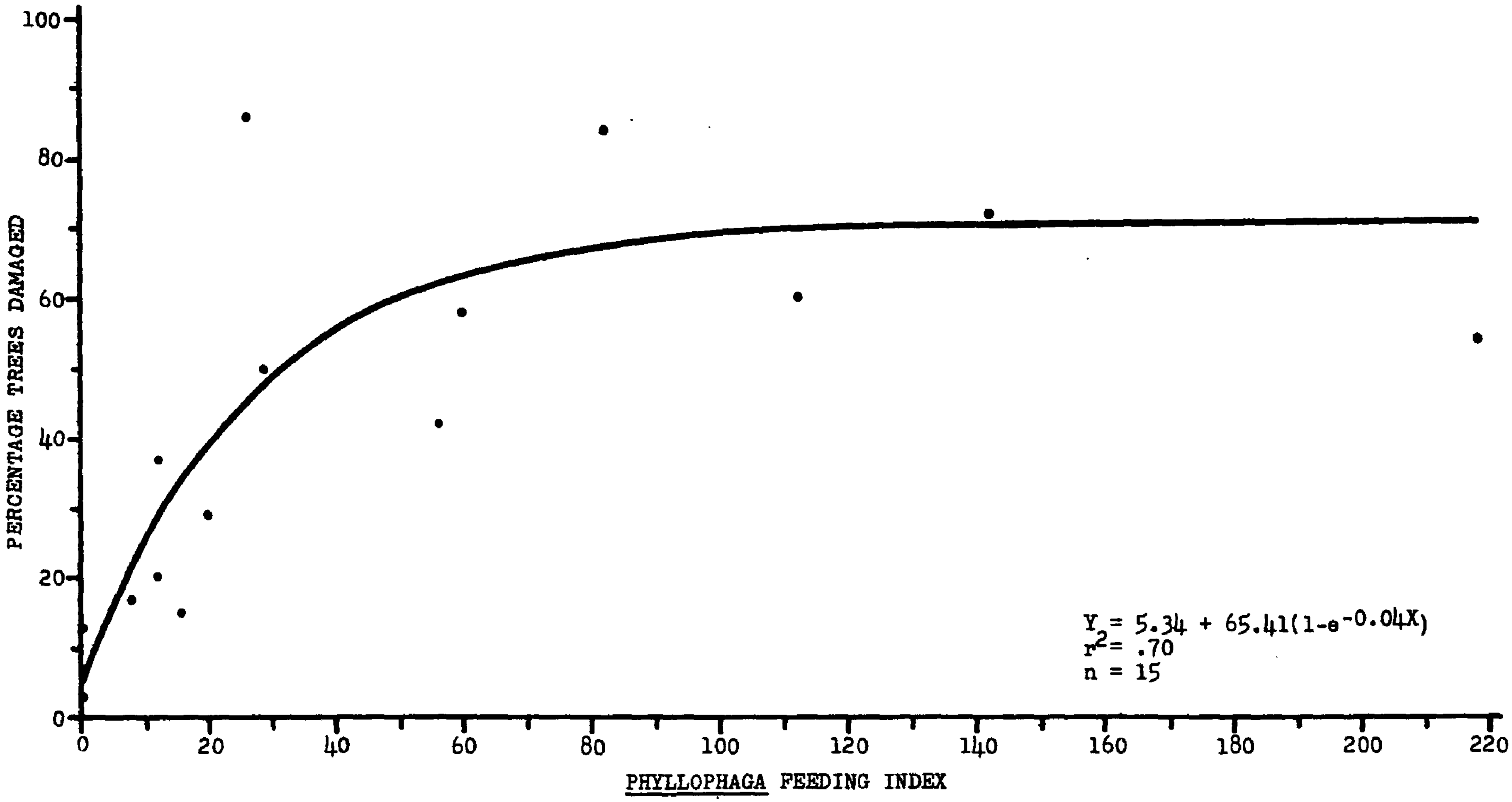


Figure 11.--Curvilinear Relationship between *Phyllophaga* Feeding Index and Percentage of Trees Damaged.

index of approximately 110. The expected asymptote at a damage index of 5 is not reached.

The curve in Figure 11 is very similar to the curve in Figure 9. The curve meets the Y axis at 5 per cent of the trees damaged and increases rapidly. The curve increases more slowly as the Phyllophaga feeding index increases, becoming relatively fixed at a feeding index of 110 and about 65 per cent of the trees damaged. The expected asymptote at the 100 per cent of trees damaged figure is not reached.

The relationship between damage index and percentage of trees damaged was examined. A simple linear regression line (linear model Y = a+bX) was computed for predicting damage index from percentage of trees damaged (Figure 12). The relationship is very strong with a coefficient of determination ($r^2$) of .89. The standard error is 0.22. The line

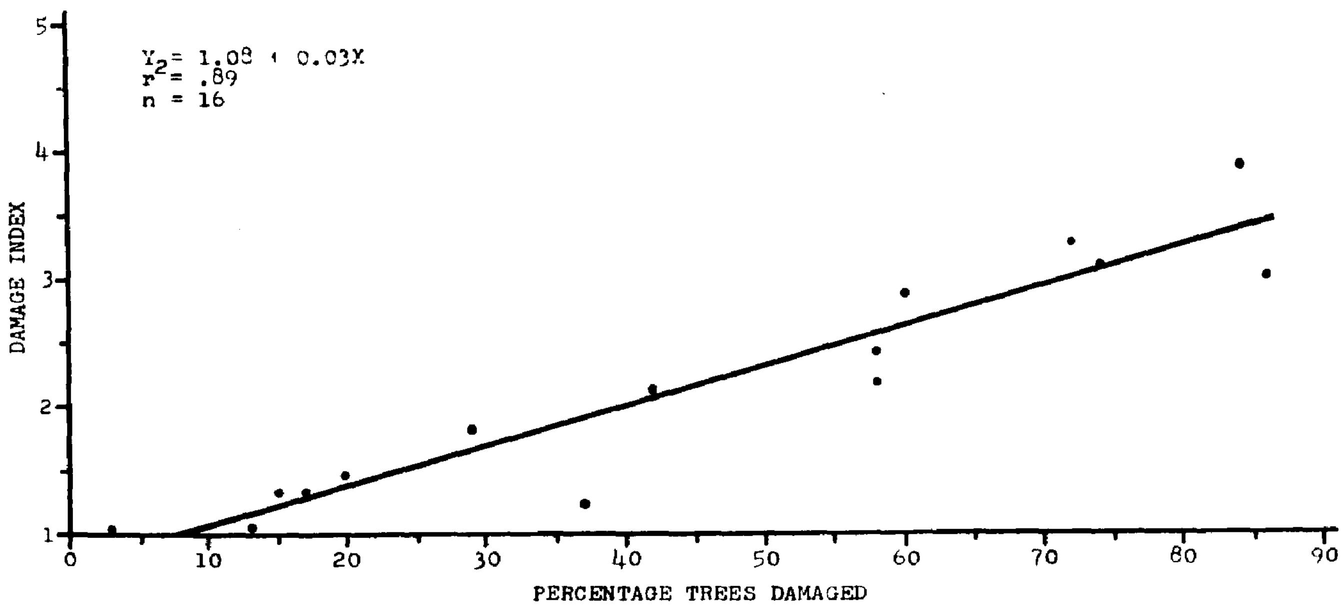


Figure 12.--Linear Relationship between Damage Index and Percentage of Trees Damaged.

appears to give a good estimate of the damage index when more than 10 per cent of the trees are damaged.

The regression curves for predicting damage index and percentage of trees damaged from either the mean *Phyllophaga* populations per cubic foot of soil or *Phyllophaga* feeding index are useful during pre-planting examinations of proposed planting sites. From these curves a reasonable estimate can be made of damage that could be expected if the area is planted. Decisions regarding control could be based on these estimations.

The relationship between damage index and percentage of trees damaged (Figure 12) is useful in damage surveys. Tallying trees only as damaged or undamaged will save considerable time by eliminating the need to make an ocular estimate of percentage of roots missing from each seedling to arrive at a root score. However, the trees must still be excavated to determine grub feeding damage to the roots.

It is not known how much of the root system must be lost to kill a tree. Loss of height growth occurs in unprotected trees and presumably this loss results from damage to the root system. (See Effectiveness of Chemical Control Application Techniques section of this paper.) It is not safe to say that trees with root scores of 5 are dead. A number of trees were found that would have fit into Class 5 except that a new root tip was growing. These trees were classed as 4's. Whether this new growth would be enough to sustain the tree was not determined. Availability of soil moisture for the next several growing seasons is probably the most important factor in survival. The time during the season when the roots are removed may also be a factor.

A number of trees in a plantation die from causes other than white grubs, as becomes evident when the Root Score 1 data is examined. It would be presumptious to say that all trees with root scores of 5 would have lived had it not been for grub feeding. Theoretically a proportionate number would have died from "other" causes.

All suspected causes of mortality other than white grubs were recorded in this study, also. Planting depth above or below the root collar was tallied, but according to Mullin (1964), this is not a cause of mortality until extremes are reached.

Two unidentified stem conditions were noted. The first is a swelling on the lower stem at the root collar. The other condition can best be described as a blue pencil-like line drawn on the stem immediately under the bark. Less than 2 per cent of the dead trees, and none of the sampled living trees, had these conditions. The future importance of these conditions is unknown. No pathogens have been successfully cultured to date.

A large number of the seedlings, both living and dead, were seriously J-rooted, i.e. bent to an angle greater than 30 degrees. This condition was noted particularly on the 2-1 stock, where samples from the bales before planting revealed that 64 per cent to 81 per cent were seriously J-rooted. Since many of the living, as well as dead, trees were J-rooted, this fact was not considered important under the climatic conditions that prevailed in the area through fall 1967. What effect this would have in a dry year is not known.

This J-rooted condition apparently favors white grub feeding. The roots of such trees are generally clumped together and lie horizontally in the planting trench. Grubs feed in a horizontal plane, and it appears that when a grub comes to such a tree it seldom fails to cut all the roots. Trees with their roots properly fanned along the trench often have some roots remaining.

Examination of the root score data for dead trees and for trees dug living and dead reveals that considerably more of the living and dead trees have partially damaged roots, i.e. scores 2, 3, and 4. For example, in the Townhall aldrin application planting (Appendix Table B 3) 38 per cent, 31 per cent, 17 per cent, and 14 per cent of the trees dug, regardless of condition (fall 1968 survey) had root scores of 2, 3, 4, and 5, respectively. By contrast, the dead trees found in the same survey had 5 per cent, 12 per cent, 5 per cent, and 78 per cent of the trees with root scores 2-5, respectively.

Apparently, partially fed-on trees do not die under the climatic conditions that have prevailed in 1967 and 1968. However, feeding may continue on the same trees the following year, resulting in mortality with higher root scores. This explanation is possible since the grubs overwinter in the soil below the root level and return to feed the following spring. If they descend and return vertically, they would be at the same tree in the spring. Also, the literature indicates that first instar larvae feed first on dead organic matter, switching to live roots later (Speers and Schmiege 1961), or on both dead organic matter and living roots (Johnston and Eaton 1939), thus feeding on dead or perhaps weakened trees in early larval life. Another possibility is that grubs may be attracted to injured seedlings. It has not yet been established whether grubs are attracted to seedlings at all, or find them by chance.

## IDENTIFICATION OF HIGH-GRUB-HAZARD AREAS

The ability to predict, during pre-planting site inspections, the probable tree losses caused by white grubs is extremely important now that presently recommended chemical control materials are not acceptable in some states. The literature suggests three variables which may be related to grub population buildups. These are soil types, soil pH, and vegetation in and near plantations. In addition, there may be relationships between the quantity of roots in the proposed planting sites and the numbers of Phyllophaga present, and between the quantity of roots and amount of grub damage to the pine trees.

Many authors refer to the fact that white grubs are found in greatest numbers in lighter, sandier soils (Criddle 1918; Hammond 1948a; Gambrell and Strickland 1952; Graham 1956; and others). Ritcher and Fluke (1935) said that different species preferred different soil types.

Gambrell and Strickland (1952) included a silt loam in the lighter soils. Hammond (1948a) reported severe crop damage and highest grub populations on sandy loams, moderate damage on clay loams, and light spotty damage on heavy clays. Most of the reports did not distinguish genera or species of white grubs. Kühnelt (1963) cited several authors who have found that correlations are weak between soil fauna and major soil groups.

Indications are that soil acidity and white grub populations are related. Hammond (1948b), working in Ontario, found highest Phyllophaga spp. populations in soils with pH between 5.25 and 6.20. His study plots ranged from pH 4.50 to 8.25. Since the neutral (pH 7.0) and alkaline soils had grass species considered most preferred by adult beetles for egg laying sites, he concluded that soil pH might be an important factor in adult selection of oviposition sites.

Studies in Ohio by Polivka (1960) also indicated that Phyllophaga grubs are most abundant in soils with a pH about 6.0. He found few grubs in soils with pH below 5.0.

Ritcher and Fluke (1935) thought there was a correlation between adult food plants and Phyllophaga grub damage. Graham (1956) saw some indication that a correlation exists between high grub damage and a combination of preferred woody food plants and herbaceous species found in forest openings.

Many authors discuss adult food preferences, and the relationships between adult or larval food plants and grub infestations. Sweetman (1927) reviewed much of the work published prior to 1926.

Later reports, such as Sweetman (1931), Chamberlin et al. (1943), Hammond (1948a), and Graham (1956), contained lengthy lists of adult host foods. Some listed the food plants preferred by each Phyllophaga species and some gave first and second choices. Review of these lists indicates that although preferences for food plants may exist, most species are polyphagous.

## Objective

The objective of this part of the study was to develop a method of identifying high-grub-hazard areas during preplanting inspection of planting sites.

## Methods and Materials

Soil types.--Soil scientists E. Neumann, S. Radtke, and G. Wigger, assigned to the national forests involved in this study, determined the soil types using standard field procedures. Briefly, these include examination of the surface features such as slope and stoniness, and boring with a bucket-type soil auger to reveal such soil characteristics as texture, structure, color, horizonal thickness, and pH. The sampled soil was then assigned the appropriate soil type name.

Soil pH.--A soil sample was taken at each grub population plot in the spring 1967 plantations (16 samples per plantation) and in the aldrin application plantings (30 samples per area). Each sample, taken with a soil core, was 3/4" in diameter and 12" long. The samples were brought into the laboratory, thoroughly mixed, made into a slurry, and read for pH using a Coleman Model 38 pH meter accurate to 0.05 pH.

Root Mass.--All roots 1/4" and less in diameter were collected from the cubic-foot soil plots during the grub population surveys. The 1/4" limit was imposed because observations by the author during earlier sampling indicated larger roots were not fed on by grubs. This also avoided unrealistic weights caused by large woody tree roots occurring in the plot.

These roots were brought into the laboratory, washed, oven-dried at 105°C. for 24 hours (or until no further weight loss occurred), and weighed in grams.

Vegetation.--The species of low-growing vegetation on the surface of each grub population plot were recorded, as were the species of trees and shrubs up to a distance of 100 feet from the plot. The following trees and shrubs were found:

yellow birch (*Betula alleghaniensis* Britton)
paper birch (*B. papyrifera* Marsh.)
sugar maple (*Acer saccharum* Marsh.)
red maple (*A. rubrum* L.)
silver maple (*A. saccharinum* L.)
box elder (*A. negundo* L.)
quaking aspen (*Populus tremuloides* Michx.)
big tooth aspen (*P. grandidentata* Michx.)
black cherry (*Prunus serotina* Ehrh.)
choke cherry (*P. virginiana* L.)
elm (*Ulmus americana* L.)
ironwood (*Ostrya virginiana* (Mill.) K. Koch)
oak (*Quercus spp.*)
apple (*Malus spp.*)
willow (*Salix spp.*)
beaked hazelnut (*Corylus cornuta* Marsh.)
Juneberry (*Amelanchier canadensis* (L.) Medic.)

The major low-growing vegetation found included:

bracken fern (*Pteridium aquilinum* (L.) Kuhn)
sweetfern (*Comptonia peregrina* (L.) Coult.)
wintergreen (*Gaultheria procumbens* L.)
strawberry (*Fragaria virginiana* Duchesne)
timothy (*Phleum pratense* L.)
red clover (*Trifolium pratense* L.)
hawkweed (*Hieracium aurantiacum* L.)
sheep sorrel (*Rumex acetosella* L.)
reindeer moss (*Cladonia rangiferina* (L.) Web.)
blueberry (*Vaccinium spp.*)
and several unidentified grasses, mosses and clubmosses.

The occasional low-growing vegetation is not listed.

## Soil Type Relationships

On the Hiawatha National Forest all the soil types planted were sands (lighter soils), but ranging from coarse to loamy fine sands. Since the soil scientists rate the soils as to their suitability for red pine productivity, this rating was used in Table 4 to arrange the soils. The mean white grub (all genera) and *Phyllophaga spp*. populations are included.

Many of the same soil types occur on both the Chequamegon and Nicolet National Forests and are discussed jointly. A variety of soil types from sands to silt loams are being planted. The results of the soil type determinations, arranged by potential red pine productivity, are presented in Table 5, with their corresponding grub (all genera) and *Phyllophaga spp*. populations.

The highest grub populations, all genera and *Phyllophaga spp*., occurred in the sands, loamy sands, and sandy loams. The plantations on the Hiawatha National Forest are all on sands and the populations of both all-genera grubs and *Phyllophaga spp*. grubs are generally high. There is no apparent relationship between soil type and grub population (Table 4) nor is there any relationship apparent between the potential red pine productivity of the soil and grub populations (Table 6).

The Chequamegon and Nicolet National Forests' plantations are on sands to silt loams. The highest populations of grubs (all genera) and *Phyllophaga spp*. occurred in the sands, loamy sands, and sandy loams. The major component of the populations is the genus *Serica*. The *Phyllophaga* populations are generally low, with the highest population occurring in a Crivitz Loamy Sand-Pence Sandy Loam area (Table 5). There is

Table 4.--Hiawatha National Forest's Soil Types with the Mean Grubs (All Genera) and the Mean *Phyllophaga* *spp*. Populations. Soil Types Arranged by Potential Red Pine Productivity.

| Potential Red Pine Productivity[a] | Soil Type(s) | Plantation | Mean Grubs per Cu.Ft. of Soil | Mean *Phyllophaga* per Cu.Ft. of Soil |
|---|---|---|---|---|
| Poor | Grayling Sand | ST | 0.00 | 0.00 |
| Fair to Poor | Rubicon Sand grading to Grayling Sand | FP | 1.12 | 0.63 |
| | Rubicon Sand | CL | 1.75 | 1.10 |
| | Rubicon Sand | T | 1.75 | 1.00 |
| Fair | Croswell Sand | ST | 1.31 | 0.56 |
| | Rubicon Sand, Croswell Sand | SL | 0.06 | 0.00 |
| | Rubicon Sand | ML | 1.81 | 1.25 |
| | Rubicon Sand | SB | 0.19 | 0.13 |
| Fair to Good | Rubicon Sand grading to Kalkaska Sand | LP | 2.38 | 1.75 |
| | | FD | 1.13 | 0.75 |
| | | H | 0.17 | 0.07 |
| | | MA | 0.33 | 0.23 |
| | Rubicon Sand grading to Croswell&Kalkaska Sands | R | 1.20 | 0.37 |
| Good to Excellent | Kalkaska Sand grading to Blue Lake Sand | TL | 0.50 | 0.25 |
| | Kalkaska Sand grading to Blue Lake Sand & Karlin Loamy Fine Sand | S | 2.33 | 1.20 |
| | Kalkaska Sand grading to Rousseau Fine Sand & Wallace Sand | MU | 1.33 | 1.33 |
| Excellent to Good | Rousseau Fine Sand | CR | 0.50 | 0.31 |
| | | SS | 0.81 | 0.69 |

[a]Soil types rated by G. Wigger, Soil Scientist.

Table 5.--Chequamegon and Nicolet National Forests' Soil Types with the Mean Grubs (All Genera) and the Mean *Phyllophaga* spp. Populations. Soil Types Arranged by Potential Red Pine Productivity.

| Potential Red Pine Productivity[a] | Soil Type(s) | Plantation | Mean Grubs per Cu.Ft. of Soil | Mean *Phyllophaga* per Cu.Ft. of Soil |
|---|---|---|---|---|
| Poor | Spirit Silt Loam | F II | 0.06 | 0.00 |
| Fair | Ahmeek Silt Loam | L IV | 0.19 | 0.19 |
| | Vilas Loamy Sand | W I | 1.19 | 0.13 |
| | | W II | 1.94 | 0.06 |
| | | W III | 0.94 | 0.19 |
| | | W IV | 0.94 | 0.06 |
| Fair to Good | Pence Sandy Loam, Padus Sandy Loam & Vilas Loamy Sand | HA IV | 0.50 | 0.19 |
| Good | Kalkaska Sand & Crivitz Loamy Fine Sand | E I | 0.56 | 0.00 |
| | | E III | 0.56 | 0.00 |
| | Crivitz Loamy Fine Sand & Pence Sandy Loam | L II | 0.88 | 0.75 |
| | Pence Sandy Loam | L I | 0.19 | 0.13 |
| Good to Excellent | Pence Sandy Loam & Padus Sandy Loam | HA II | 0.50 | 0.06 |
| | Padus Sandy Loam, Pence Sandy Loam & Iron River Loam | E II | 0.06 | 0.06 |
| | Stambaugh Silt Loam & Pence Sandy Loam | F I | 0.38 | 0.31 |
| | Stambaugh Silt Loam, Crivitz Loamy Fine Sand, Padus Sandy Loam & Spirit Silt Loam | X I | 0.13 | 0.00 |
| Excellent | Padus Sandy Loam & Iron River Loam | HA III | 0.31 | 0.06 |
| | Iron River Loam | HA I | 0.13 | 0.00 |
| | | G I | 0.06 | 0.06 |
| | | G II | 0.00 | 0.00 |
| Excellent to Poor[b] | Iron River Loam & Gaastra Silt Loam | L III | 0.13 | 0.13 |

[a]Soil types rated by S. Radtke, Soil Scientist.

[b]The majority of this plantation is on the excellent Iron River Loam but the soil type grades to the poor Gaastra Silt Loam in low areas.

Table 6.--Summary of Soil Types Ranked by Potential Red Pine Productivity and the Mean Grubs (All Genera) and the Mean *Phyllophaga spp.* Populations for the Hiawatha and Chequamegon and Nicolet National Forests.

| Soil Type | No. Observations | Mean Grubs per Cu.Ft. of Soil | Mean *Phyllophaga* per Cu.Ft. of Soil |
|---|---|---|---|
| | Hiawatha N.F. | | |
| Poor | 1 | 0.00 | 0.00 |
| Fair to Poor | 3 | 1.54 | 0.91 |
| Fair | 4 | 0.84 | 0.49 |
| Fair to Good | 5 | 1.00 | 0.63 |
| Good to Excellent | 3 | 1.39 | 0.93 |
| Excellent to Good | 2 | 0.66 | 0.50 |
| | Chequamegon and Nicolet N.F's | | |
| Poor | 1 | 0.06 | 0.00 |
| Fair | 5 | 1.04 | 0.13 |
| Fair to Good | 1 | 0.50 | 0.19 |
| Good | 4 | 0.55 | 0.22 |
| Good to Excellent | 4 | 0.27 | 0.11 |
| Excellent | 4 | 0.13 | 0.03 |
| Excellent to Poor[a] | 1 | 0.13 | 0.13 |

[a]The majority of this plantation is on the excellent Iron River Loam, but the soil type grades to the poor Gaastra Silt Loam in low areas.

no apparent relationship between potential red pine productivity and current grub populations.

## Soil pH Relationships

The results of the soil pH determinations appear in Table 7. In 16 of the 22 plantations measured, the median pH figures are within the 5.25 to 6.25 range discussed by Hammond (1948b). Within this range the *Phyllophaga* populations vary from 0.00 to 1.33 grubs per cubic foot of soil. The

Table 7.--Soil pH Determinations Related to the Mean *Phyllophaga spp.* Populations.

| Forest & District | Plantation[a] | pH Range | pH Median | Mean *Phyllophaga* per Cu.Ft. of Soil |
|---|---|---|---|---|
| CHEQUAMEGON N.F. | | | | |
| Washburn R.D. | W I | 5.1-5.6 | 5.35 | 0.13 |
| | W II | 4.9-5.6 | 5.25 | 0.06 |
| | W III | 5.1-5.8 | 5.45 | 0.19 |
| | W IV | 5.0-6.0 | 5.50 | 0.06 |
| Glidden R.D. | G I | 5.1-5.9 | 5.50 | 0.06 |
| | G II | 5.4-6.8 | 6.10 | 0.00 |
| Hayward R.D. | HA I | 5.0-5.7 | 5.35 | 0.00 |
| | HA II | 5.3-7.1 | 6.20 | 0.06 |
| HIAWATHA N.F. | | | | |
| Rapid River R.D. | ST | 4.9-5.7 | 5.30 | 0.00 |
| Manistique R.D. | MA | 4.8-5.6 | 5.20 | 0.23 |
| Munising R.D. | MU | 4.8-5.8 | 5.30 | 1.33 |
| Sault Ste. Marie R.D. | R | 4.7-5.7 | 5.20 | 0.37 |
| | H | 4.7-5.6 | 5.15 | 0.07 |
| | S | 4.9-7.7 | 6.30 | 1.20 |
| NICOLET N.F. | | | | |
| Eagle River R.D. | E I | 4.3-5.4 | 4.85 | 0.00 |
| | E II | 4.8-5.7 | 5.25 | 0.06 |
| | E III | 4.8-5.4 | 5.10 | 0.00 |
| Florence R.D. | F I | 5.5-7.2 | 6.35 | 0.31 |
| | F II | 5.3-6.4 | 5.85 | 0.00 |
| Laona R.D. | X I | 4.9-5.7 | 5.30 | 0.00 |
| Lakewood R.D. | L I | 5.1-6.6 | 5.85 | 0.13 |
| | L II | 5.3-6.4 | 5.85 | 0.75 |

[a]Sixteen samples taken in all plantations except R,H,S, MU, and MA, which had 30 samples.

highest mean *Phyllophaga* populations, 1.33 and 1.20 grubs per cubic foot of soil, are found in soils with median pH values of 5.30 and 6.30, respectively.

A simple linear regression line was calculated to show changes in the mean *Phyllophaga* populations associated with changes in the median pH level of the soil. The coefficient of determination ($r^2$) calculation indicates that only 5 per cent of the variation in *Phyllophaga* populations is associated with soil pH; thus the regression is not shown.

## Root Mass Relationships

The mean root mass per plantation varies from 49 grams to 178 grams per cubic foot of soil (Table 8). In the nine areas where no *Phyllophaga* were found the mean root mass ranged from 68 to 142 grams. Both plantations L II and FD had 0.75 *Phyllophaga* per cubic foot of soil, but the means of root mass per cubic foot were 56 grams and 140 grams, respectively. The three highest *Phyllophaga* populations, 1.75, 1.25, and 1.23, occurred in plantations with means of root mass of 76 grams, 126 grams, and 116 grams, respectively.

A simple linear regression and coefficient of determination ($r^2$) were calculated for the degree of association of mean root mass per cubic foot of soil with the mean *Phyllophaga* population. The $r^2$ is only 1.26 per cent.

A simple linear regression and a coefficient of determination ($r^2$) were also calculated for the association of damage index with the mean root mass per cubic foot of soil. The $r^2$ is 0.08 per cent.

Table 8.--Natural Vegetation Root Mass Determinations Related to the Mean *Phyllophaga spp.* Populations.

| Forest & District | Plantation[a] | Oven-dried Wt. in Gms. of Mean Root Mass per Cu. Ft. of Soil | Mean *Phyllophaga* per Cu. Ft. of Soil |
|---|---|---|---|
| CHEQUAMEGON N.F. | | | |
| Washburn R.D. | W I | 129 | 0.13 |
| | W II | 111 | 0.06 |
| | W III | 123 | 0.19 |
| | W IV | 148 | 0.06 |
| Glidden R.D. | G I | 169 | 0.06 |
| | G II | 70 | 0.00 |
| Hayward R.D. | HA I | 121 | 0.00 |
| | HA II | 67 | 0.06 |
| | HA III | 178 | 0.06 |
| | HA IV | 111 | 0.19 |
| HIAWATHA N.F. | | | |
| Sault Ste. Marie R.D. | R | 85 | 0.40 |
| | H | 80 | 0.17 |
| | S | 89 | 0.90 |
| Manistique R.D. | MA | 77 | 0.27 |
| | FD | 140 | 0.75 |
| | TL | 129 | 0.25 |
| | ML | 126 | 1.25 |
| | CR | 119 | 0.31 |
| Munising R.D. | MU | 116 | 1.23 |
| | LP | 76 | 1.75 |
| | FP | 86 | 0.63 |
| Rapid River R.D. | ST | 103 | 0.00 |
| | SL | 68 | 0.00 |
| NICOLET N.F. | | | |
| Eagle River R.D. | E I | 104 | 0.00 |
| | E II | 97 | 0.06 |
| | E III | 123 | 0.00 |
| Florence R.D. | F I | 76 | 0.31 |
| | F II | 88 | 0.00 |
| Laona R.D. | X I | 81 | 0.00 |
| Lakewood R.D. | L I | 103 | 0.13 |
| | L II | 56 | 0.75 |
| | L III | 49 | 0.13 |
| | L IV | 94 | 0.19 |
| | L V | 142 | 0.00 |

[a]Sixteen samples taken in all plantations except R, H, S, MA, and MU, which had 30 samples.

## Vegetational Relationships

The major species of adult host trees and shrubs and the low-growing vegetation found in the surveyed plantations are listed in Appendix Table C. The data are presented by percentage of plots with the tree species within 100 feet or with the low-growing vegetation on the one-square-foot-of-soil-surface plot. The incidental or occasional species are not included.

An examination of the data indicates that correlations may exist between the damage indexes for the plantations and the percentages of plots containing the specific vegetation, and between the mean *Phyllophaga* populations and percentage of plots containing the specific vegetation.

A simple correlation coefficient[1] was computed for each species of vegetation that appeared most likely to vary between plantations, and the damage indexes and the mean *Phyllophaga* populations for the plantations examined.

None of the correlations calculated was significant at the 10 per cent level. Food species data tested were all trees combined, quaking and big-tooth aspen combined, red maple, bracken fern, and wintergreen.

## Discussion

*Soil type*.--Soil type alone is of little value for identification of high-grub-hazard areas on the three forests surveyed. On the Hiawatha National Forest all the areas

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[1]Freese (1967) defines correlation coefficient as "a measure of the degree of linear association between two variables".

being planted were sands. On the basis of soil type all areas can be considered high hazard areas, even though the population surveys revealed that Phyllophaga populations vary. These variations in soil type and Phyllophaga populations do not appear to be related.

On the Chequamegon and Nicolet National Forests high grub populations were found in some plantations on sand and loamy sand soils. However, Phyllophaga populations are low in most areas. An occasional high Phyllophaga population can be expected in a plantation on a sandier soil, but cannot be predicted in advance.

The physical and chemical characteristics of the soils should be measured from the point of view of white grub habitat requirements. According to Speers and Schmiege (1961), grubs are sensitive to lack of moisture. Hammond (1954) reported that excessive moisture and high temperatures in spring and fall have caused high grub mortality. He also observed that well-drained, moderately warm, sod-covered light soils were preferred by egg-laying females. Hammond (1954) also reported the percentage of organic matter in the soils of his study area, and that low percentages provided less food for the grub population. Speers and Schmiege (1961) mentioned that the first food for new larvae is organic matter before they feed on live roots. All these factors remain to be evaluated, especially on the Hiawatha National Forest, where the grub damage to seedlings is the most serious of the forests studied.

Climatic factors, other than those mentioned in the literature above, should be investigated; these include frost depth, earliness of snow cover, and climatic history of the area.

Soil pH.--The low (5 per cent) coefficient of determination makes soil pH, over the range found in the surveyed plantations, of no value as an indicator of high-grub-hazard areas.

Root mass.--The very low coefficient of determination (1.26 per cent) for the mean root mass and the mean *Phyllophaga* populations makes root mass measurements useless in identifying high-grub-hazard areas. No relation between root mass and damage index was found ($r^2$=0.08 per cent).

Vegetation.--Although some *Phyllophaga* species have shown some adult food preferences, a wide variety of trees, shrubs, and weeds are fed on--enough to indicate that populations are probably rarely limited by lack of food. Most plantations today are being established on smaller acreages than in CCC days, but most of the literature on plantation grub populations deals with those former large areas of denuded land. Many of the present planting areas are bordered with, or are partly stocked with, oak, aspen, and paper birch--tree species on which adult *Phyllophaga* readily feed (Hammond 1948a; Craighead 1950; and Graham 1956).

Examination of the data (Appendix Table C) and computation of some correlation coefficients failed to reveal any associations between species of vegetation and numbers of

Phyllophaga. A study of the vegetation in and surrounding a proposed planting site will not aid in identifying high-grub-hazard areas with our present state of knowledge. Grub species identification and ecological requirements must be determined before success in rating planting sites can be achieved.

One other aspect of vegetation should be considered. Fleming (1957) noted that white grubs do not thrive in areas having clover or some other legumes. Hammond (1948a) also noted that legumes are rarely damaged and suggested that their roots may be tough and unattractive. Chamberlin and Callenbach (1943) credited lower egg-laying rates and higher larval mortality for the low grub populations in legumes. These findings prompted the recommendation to pilot test the use of legumes as a damage preventive measure.

Red clover was found in plantation L IV on the Lakewood Ranger District, Nicolet National Forest. The mean white grub population was 0.19 per cubic foot of soil and all specimens were Phyllophaga. The damage index was 1.25 and 8 per cent of the trees were scored 5 and assumed dead. Adult food trees and shrubs were plentiful and included paper birch, quaking and bigtooth aspen, willow, black and choke cherry, apple, and beaked hazelnut. The low-growing vegetation included grasses (especially timothy), hawkweed, and sheep sorrel, in addition to the clover.

In order to study the influence of the proximity of adult host trees and shrubs on the distribution of grubs, distances up to 100 feet from sample points to host vegetation were measured. Criddle (1916) showed that trees influence the size of grub populations up to about 1/8 mile (660 feet). Not enough survey areas had adult food plants in numbers sparse enough to prompt any statements about population distributions in relation to adult food. However, some indication of the effect that distance to food plants has on grub populations occurs in the Corner Lake (CR) plantation, Manistique Ranger District, Hiawatha National Forest.

The Corner Lake plantation is bordered on the North and West by aspen and paper birch, although none of the birch was within 100 feet of a sample point. Plots 4, 8, 12, and 16 were along the west edge of the plantation and plots 13, 14, 15, and 16 along the north edge. A clump of aspen suckers was present between plots 2 and 3.

A damage index was computed for each of the 16 plots as listed below. The overall mean damage index is 2.33.

| | | | |
|---|---|---|---|
| 1 - 1.65 | 5 - 1.60 | 9 - 2.15 | 13 - 1.45 |
| 2 - 4.30 | 6 - 1.05 | 10 - 3.25 | 14 - 3.35 |
| 3 - 2.75 | 7 - 1.40 | 11 - 1.65 | 15 - 1.95 |
| 4 - 1.90 | 8 - 2.50 | 12 - 3.40 | 16 - 2.85 |

Grubs were found in samples 2, 3, 12, 14, 15, and 16. All but plot 14 had one or more adult host trees within 100 feet of the sample point. Plot 15 occurred partially under the crown of a red pine tree. The grub feeding damage was heaviest on seedlings beyond the edge of the crown. Plot 9, although in the interior of the plantation, was 40 feet from a choke cherry. There is no apparent reason for the high damage index for plot 10.

Even though the statistical analysis failed to show importance of adult host trees, it appears from examination of these data that distance to adult host is important. However, most areas being planted now are not this open.

Comparisons of selected plantations.--Since the ecological and edaphic factors evaluated in this report failed to be of value in identification of high-grub-hazard areas, each proposed planting site in the future will have to be evaluated separately. Two pairs (four plantations) are selected here to illustrate the similarities in soil type and vegetation and differences in grub populations and feeding damage.

The first plantation considered is W II on the Washburn Ranger District, Chequamegon National Forest (Figure 13).The soil is Vilas Loamy Sand. The naturally occurring trees in the plantation are oak, bigtooth aspen, red maple, and paper birch. The low-growing vegetation is composed chiefly of grasses, blueberry, bracken fern, mosses and club mosses, strawberry, and wintergreen.

This combination of soil type and vegetation would rank high as expected *Phyllophaga* habitat, and considerable seedling mortality would be anticipated. The mean grub population is 1.94 per cubic foot of soil, but the mean *Phyllophaga* population per cubic foot is only 0.06. Mortality at the end of the first year was 9 per cent, with one-third of the dead trees showing signs of grub feeding on the roots.

The second plantation considered is the one at Muleshoe Lake (ML) on the Manistique Ranger District, Hiawatha National Forest (Figure 14). The soil is Rubicon Sand. The trees in and surrounding the area are paper birch, red maple, quaking

Figure 13.--Plantation W II. Washburn R.D., Chequamegon N.F.

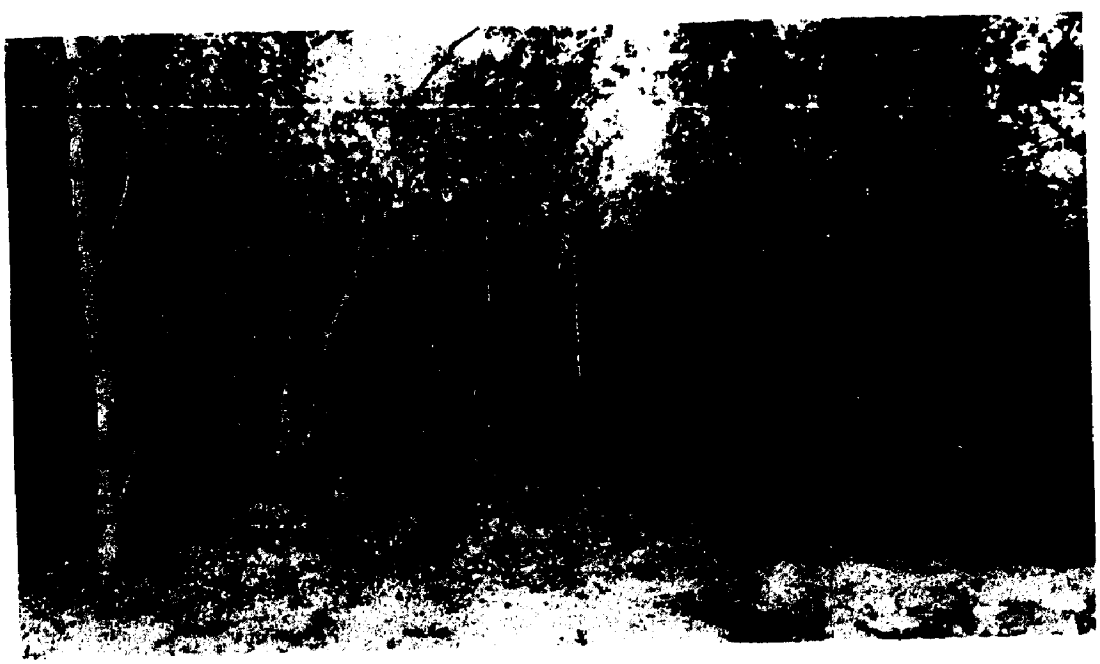


Figure 14.--Plantation ML. Manistique R.D., Hiawatha N.F.

aspen, and oak. The low-growing vegetation includes grasses, sweetfern, blueberry, bracken fern, reindeer moss, mosses and clubmosses, and wintergreen.

The white grub population is 1.81 grubs per cubic foot of soil, of which 1.25 per cubic foot are *Phyllophaga*. The damage index is 2.89. Of the seedlings examined 34 per cent were completely stripped of fibrous roots (Score 5) and assumed dead. The grub population and damage are higher than expected. This area is an underplanting with small openings. Much of the low-growing vegetation in these openings is reindeer moss, which is not considered a suitable larval food.

These two areas, W II and ML, would be expected to rank close together on a scale of probable tree loss. Both are typed KX (scrub oak) and both are on light soils. A higher number of aspen are found in the ML plantation and the openings in the stand are smaller. The W II plantation has more sod cover in its openings and would be expected to support a larger *Phyllophaga* population.

Graham (1956) discusses the history of Upper Michigan and northern Wisconsin as an influence on locations of grub populations. In Upper Michigan, sandy soils predominate. Large acreages of these soils were denuded by logging and fire, except for scattered stands of aspen and paper birch. In contrast, the soils and forest cover in Wisconsin were more diversified. The openings were much smaller. This may be the reason for the differences in *Phyllophaga* populations between the two areas.

The third plantation considered is LP on the Munising Ranger District, Hiawatha National Forest (Figure 15). The soil type is a Rubicon Sand grading to Kalkaska Sand. The trees and shrubs in and bordering the plantation are paper and yellow birch, red maple, quaking and bigtooth aspen, black cherry, and Juneberry. The low-growing vegetation is composed of grasses, blueberry, sheep sorrel, bracken fern, reindeer moss, and mosses and club mosses.

The white grub population is 2.38 grubs per cubic foot of soil, of which Phyllophaga is 1.75 per cubic foot. The damage index is 3.28 and 33 per cent of the seedlings examined were completely stripped of fibrous roots (Score 5).

The fourth plantation considered is Corner Lake (CR) on the Manistique Ranger District, Hiawatha National Forest (Figure 16). The soil type is Rousseau Fine Sand. The trees on and bordering the area are quaking aspen, bigtooth aspen, red maple, and choke cherry. The low-growing vegetation is composed of grasses, sweetfern, blueberry, sheep sorrel, bracken fern, reindeer moss, mosses and club mosses, and wintergreen. The mean white grub population is 0.50 per cubic foot of soil with a mean Phyllophaga population of 0.31 per cubic foot.The damage index is 2.33, with 1 per cent of the trees scored 5 and assumed dead.

Both plantations LP and CR are on the Hiawatha National Forest and are compared to show the variation that occurs on this forest, which is characterized by generally high white grub populations, principally Phyllophaga. Both plantations

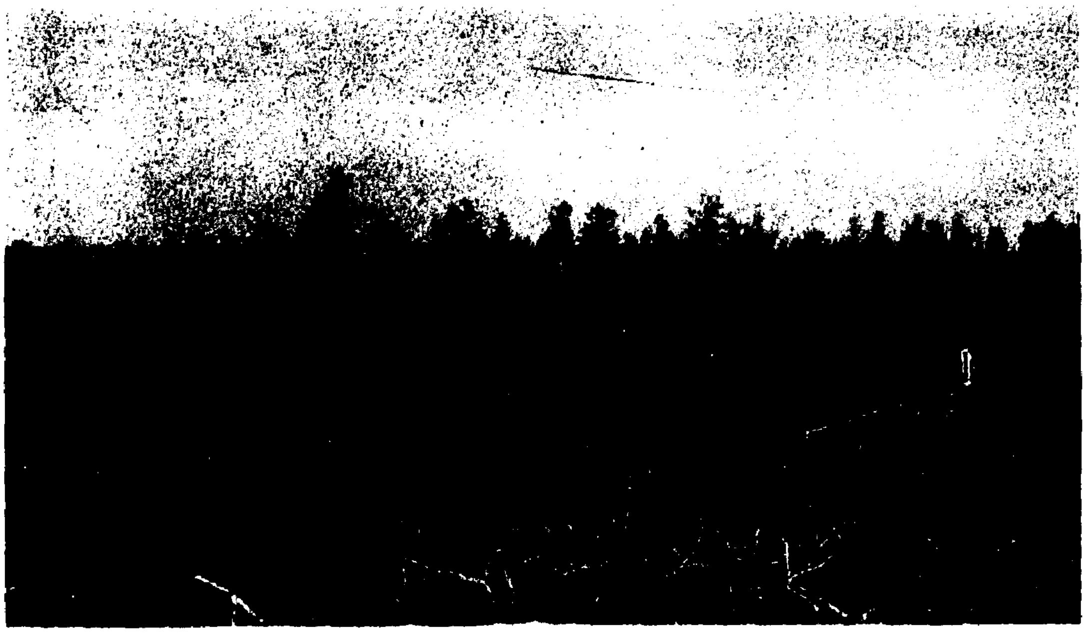


Figure 15.--Plantation LP. Munising R.D., Hiawatha N.F.

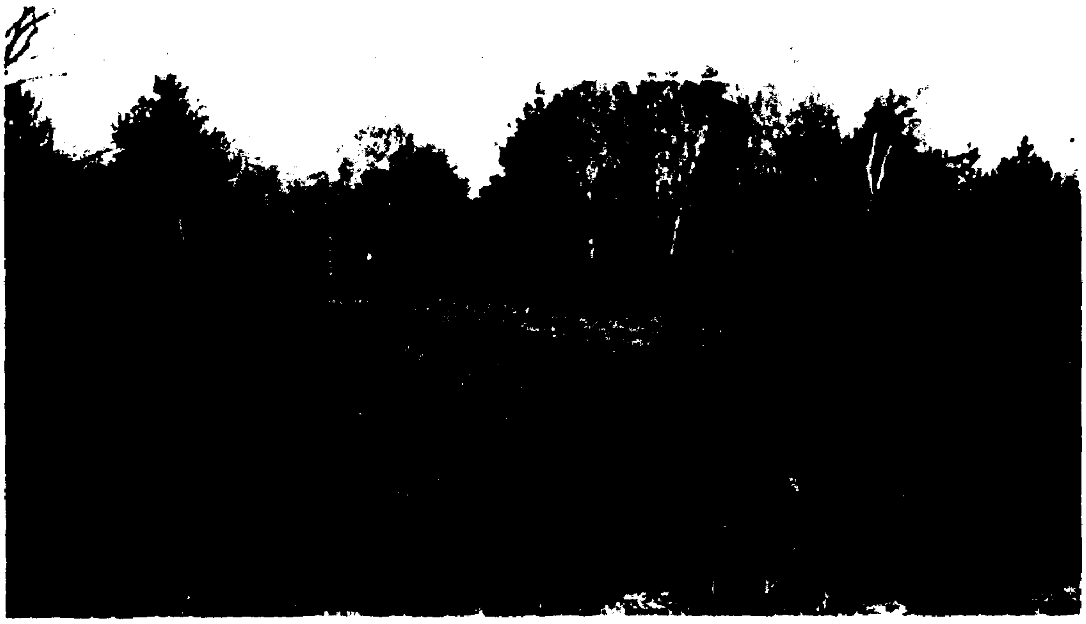


Figure 16.--Plantation CR. Manistique R.D., Hiawatha N.F.

are on sands. Both have paper birch and aspen on two or three boundaries. Plantation LP had a partial stand of Jack pine (*Pinus banksiana* Lamb.) with scattered aspen, white birch, and red maple. The Jack pine was removed prior to planting. The presence of Jack pine in the cover would be expected to reduce the grub population as Jack pine is not considered an adult host species.

Plantation CR is in an open area bordered by adult host trees and, according to the literature, is an ideal grub habitat (Graham 1956 and others). If the two areas were rated on the basis of present knowledge and without the benefit of a grub survey the expected degree of damage in each plantation would be reversed.

## EFFECTIVENESS OF CHEMICAL CONTROL APPLICATION TECHNIQUES

An aldrin solution applied to the seedlings' root system during planting has been recommended for chemical control of white grubs in forest plantations (Shenefelt and Benjamin 1955; Speers and Schmiege 1961). Benjamin _et al_. (1963) reported that 14,555 acres in Wisconsin were treated with a 1/2 per cent aldrin solution between 1957 and 1962. On the Hiawatha National Forest, almost 9,000 acres of pine plantations were treated with a 1 per cent aldrin solution during the period 1961-1966. Observations on the Hiawatha National Forest indicated that results had been erratic, and an evaluation of the control technique was deemed necessary.

Height growth of young red pine trees is reduced by white grub feeding on the roots. Shenefelt (1956) noted that at the end of the second growing season, aldrin-treated trees in his plots averaged about four-to-five inches taller than untreated trees. Shenefelt _et al_. (1954) reported significantly greater height attainment in treated trees after six growing seasons.

### Objectives

This part of the study was designed to evaluate effectiveness of the currently used technique of chemical control application and to test two new techniques.

## Methods and Materials

Plot design.--The evaluation was conducted in five plantations on the Hiawatha National Forest in Upper Michigan (Table 1,D).

A randomized complete block design replicated five times in each test planting was used to evaluate the chemical treatments. Each treatment was applied to 15 trees in six adjacent rows per block equalling 90 trees per block and 450 trees per planting. The treatments were as follows:

Treatment 1 - liquid aldrin (1 per cent active) applied at the time of planting, using the dispenser attached to the planting machine.

Treatment 2 - liquid aldrin (1 per cent active) applied immediately after planting, using the backpack pump and wand designed for the purpose.

Treatment 3 - granular aldrin (20 per cent active) applied at the time of planting, using the dispenser attached to the planting machine.

Treatment 4 - check plots (no aldrin application).

Application methods.--Treatment 1, liquid aldrin at planting, was applied by a dispenser attached to the planting machine. It is the currently used method of aldrin application. This device is a modification of the one described by Shenefelt et al. (1954 and 1955). Briefly, it consists of a pressurized tank containing the insecticide, a system of hoses containing a manually operated valve, and a nozzle located at the planting shoe. The valve is operated by either foot or knee action at the time the tree is placed in planting position. The soil immediately around the tree is sprayed with insecticide as the tree is being planted and before the trench is closed around the tree.

Treatment 2, liquid aldrin by hand, was applied with a backpack pump fitted with a long rod for insertion into the ground. The nozzle has three holes which dispense the insecticide into the soil in the vicinity of the tree roots.

Treatment 3, granular aldrin at planting, was applied with a dispenser attachment built onto one planting machine. This unit consisted of a non-pressurized hopper and system of tubes with a valve. Two tubes with flattened ends terminated in the vicinity of the shoe so that granules were deposited in two bands, one on each side of the seedling.

<u>Dosage rate</u>.--Shenefelt <u>et al</u>. (1954) recommended a dose of 8.5 ml of 1/2 per cent aldrin solution per seedling. Speers and Schmiege (1961) recommended an aldrin solution of 1/2 per cent to 1 per cent. A 1 per cent solution was used in this evaluation.

None of the application devices had a metering system. Each operator and piece of equipment dispensed a different amount of the chemical. The actual dosages for the treatments and areas are listed in Table 9.

<u>Planting methods and stock</u>.--The evaluation areas were planted in spring 1967 using production planting methods and experienced crews. Planting stock was run-of-the-nursery red pine 3-0 seedlings and 2-1 transplants. A forestry aide

applied the aldrin, using the backpack pump.

The plot trees to be planted using the alternate form of aldrin were skipped initially and planted later as the appropriate machine became available. The last shipment of planting stock was 2-1 transplants, and thus the skips had to be planted with this stock.

Table 9.--Aldrin Dosage Rates per Tree.

| | Treatment[a] | | | |
|---|---|---|---|---|
| Plantings | 1 | 2 | 3 | 4 |
| Raco | 13.7 ml. | 10.6 ml. | 9.3 Gm. | - |
| Highbanks Lake | 13.7 ml. | 10.6 ml. | 9.3 Gm. | - |
| Townhall | 13.7 ml. | 10.6 ml. | 9.3 Gm. | - |
| Bird Area | 5.8 ml. | 4.6 ml. | 9.3 Gm. | - |
| Townline Lake | 5.8 ml. | 3.7 ml. | 9.3 Gm. | - |

[a]Treatment 1 - liquid aldrin by machine - 1% active
Treatment 2 - liquid aldrin by hand - 1% active
Treatment 3 - granular aldrin by machine - 20% active
Treatment 4 - no aldrin---check plots

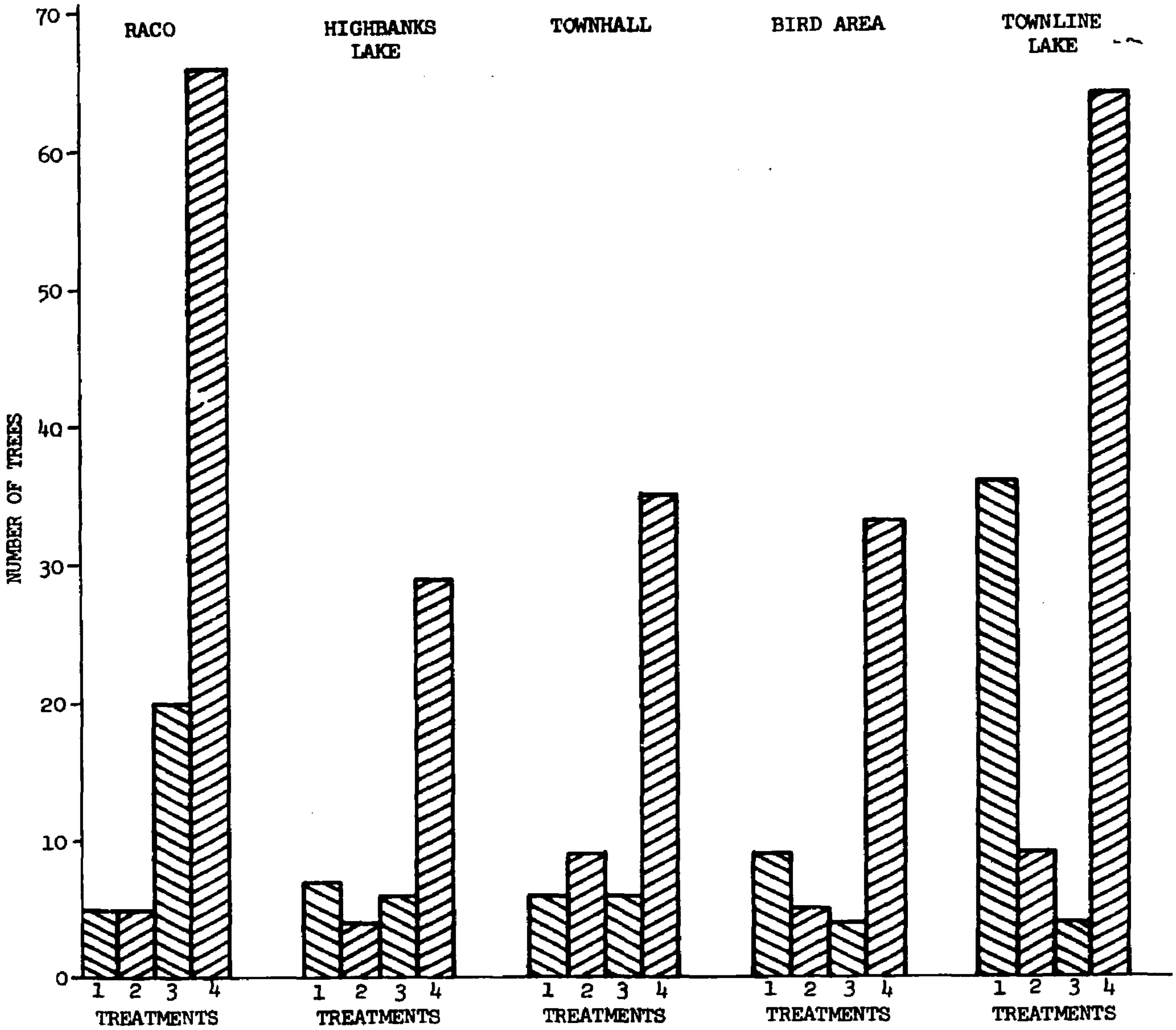
<u>Damage survey</u>.--Trees in the treated plots were surveyed at the end of the first growing season (fall 1967). Dead trees were dug and the amount of root damage scored. A sample of ten living trees per treatment replicate were randomly selected, dug, and root-scored. A mortality survey was conducted in spring 1968 (one year after planting).

In fall 1968 (16 months after planting) ten trees per treatment replicate were randomly selected, dug, root-scored-and tallied by condition. Dead trees in each plot, which were not included in the survey sample, were also dug, root-scored, and tallied separately.

Growth measurement.--Height growth was measured in four aldrin application plantings as an indicator of sub-lethal grub feeding. The current year's growth was measured to the nearest tenth of an inch at the end of the first and second growing seasons after planting. Measurement of only the new growth instead of total tree height avoided the errors caused by shifting and settling soil, and differences in planting depth.

## Results and Discussion

The mortality survey results are presented in Appendix Table B 3. The highest mortality and greatest number of trees with grub feeding damage, especially those with heavy damage (scores 4,5), occurred in Treatment 4 (no-aldrin plots). The bar graph (Figure 17) compares the numbers of dead trees receiving heavy feeding damage (scores 4,5) in each treatment. The data are the totals from the three mortality surveys (fall 1967, spring 1968, fall 1968), and include the mortality occurring the first 16 months after planting. The data do not include trees that had been heavily damaged but had not turned brown by the time of the survey. Examination of the data on trees selected at random, regardless of above-ground condition (fall 1968 living and dead survey in Appendix Table B 3), reveals that additional trees had been heavily damaged but were not dead at the time of survey. The fate of these




Treatment 1 - liquid aldrin by machine - 1% active
Treatment 2 - liquid aldrin by hand - 1% active
Treatment 3 - granular aldrin by machine - 20% active
Treatment 4 - no aldrin---check plots

Figure 17.--Numbers of Heavily Damaged Dead Trees (Scores 4,5) in Aldrin Application Plantings at End of Second Growing Season.

trees cannot be determined since they were destroyed in the survey, but most likely at least those trees with their entire fibrous root systems removed would have been found dead in the next survey.

The survey data were grouped into seven comparisons for statistical analysis. These groupings appear in the left-hand column of Appendix Table D 1 and are: (1) all damaged dead trees (scores 2-5), (2) all damaged living trees (scores 2-5), and (3) all heavily damaged living trees (scores 4,5) at the end of the first growing season; (4) all damaged dead trees (scores 2-5) and (5) all heavily damaged dead trees (scores 4,5) accumulated through fall 1968 survey; (6) all damaged randomly selected living and dead trees (scores 2-5) and (7) all heavily damaged randomly selected living and dead trees (scores 4,5) from the fall 1968 survey.

Each planting (Raco, Townhall, Bird Area, Townline Lake, and Highbanks Lake) in each comparison was subjected to an analysis of variance (F test). This test was used to determine: (1) if significant differences among treatments had occurred and (2) if the differences which had occurred were within the aldrin treatments, or were between the aldrin treatments and untreated controls. The Duncan range test was also used to make all possible comparisons of the means of the data. The results are summarized in Appendix Table D 1.

Tests of the fall 1967 data on all damaged dead trees (scores 2-5) showed no significant differences among treatments except in the Townhall data. Here only Treatment 3 had significantly fewer damaged dead trees than Treatment 4.

No significant differences were found in the damaged living tree data when the full range of damage (scores 2-5) was tested. No significant differences were found, except in Townhall data, when only heavily damaged living trees (scores 4,5) were used. Here both Treatments 1 and 2 had significantly fewer trees with root scores of 4 and 5 than did Treatment 4.

Data of the accumulated damaged dead trees (scores 2-5) and accumulated heavily-damaged dead trees (scores 4,5) showed significant differences in each test planting except Highbanks Lake, where a difference was found only when heavily damaged trees alone were considered. Thus, differences became apparent at the end of two growing seasons that were not apparent at the end of the first season. In all plantings significantly more trees in the no-aldrin control plots (Treatment 4) were dead and damaged than in the aldrin treated plots, indicating that any of the three aldrin application techniques used reduced the numbers of damaged trees. Only in the Townline Lake planting was one chemical treatment more effective in reducing numbers of all damaged (scores 2-5) and heavily damaged (scores 4,5) dead trees. There liquid aldrin applied by machine (Treatment 1) gave poorer protection than granular aldrin (Treatment 3) and liquid aldrin applied by hand (Treatment 2). The low dosages of liquid aldrin used in this planting probably accounted for the poorer protection in Treatment 1, but this was overcome in Treatment 2 probably by the better placement of the chemical possible with hand application.

The data shows that when trees are randomly selected regardless of above-ground condition, and only the heavily damaged trees (scores 4,5) are analyzed, significant differences are found between the various chemical application treatments and the control but not among the chemical treatments.

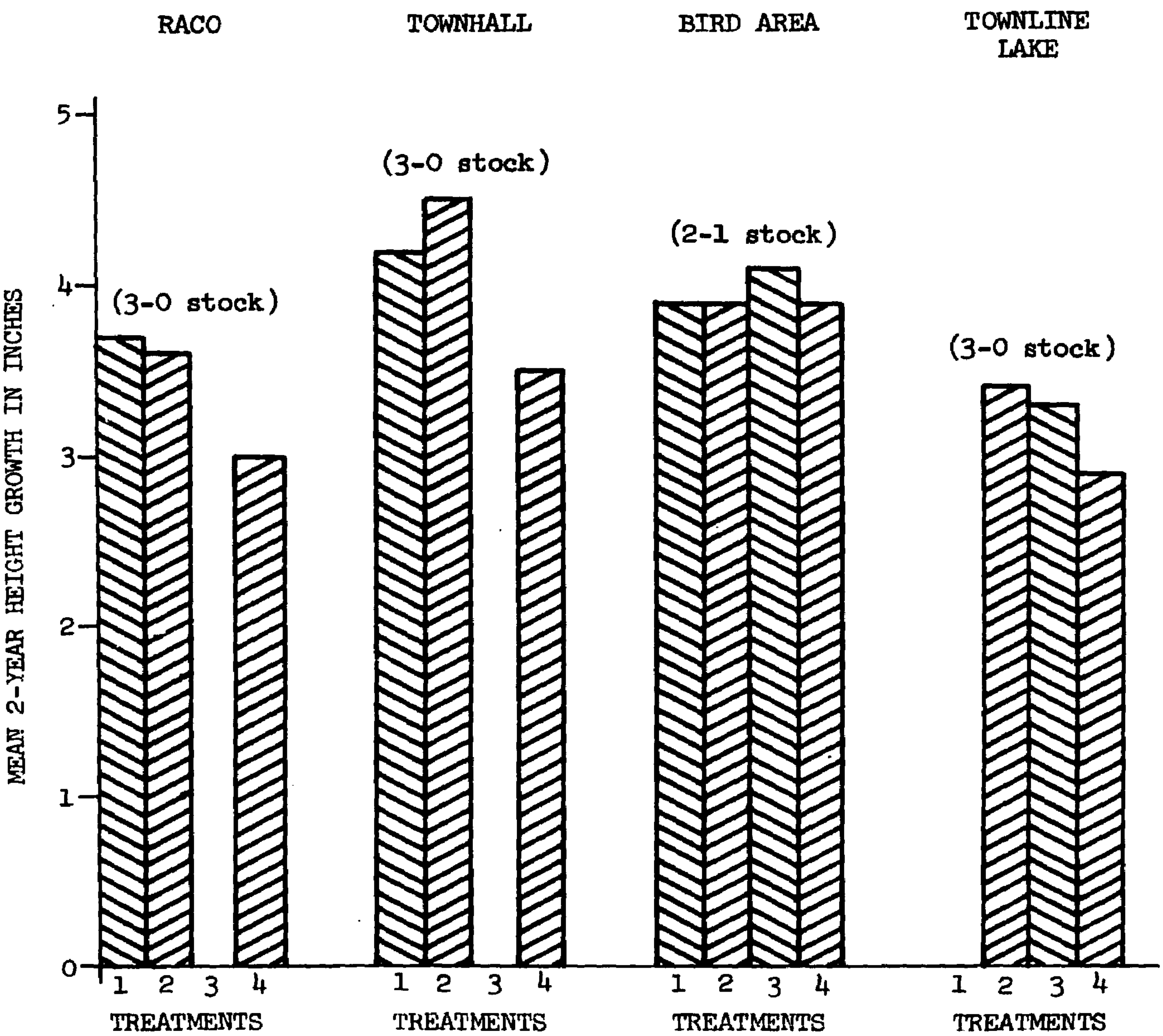
All aldrin application techniques tested gave protection to the seedlings when compared with no chemical treatment. No one application technique appears significantly better than another up to the time of the last survey (fall 1968).

The results of the current-height-growth measurements are presented in a bar graph (Figure 18), and show the mean growth since planting (two growing seasons) for like stock in each planting. The treatments shown in Raco, Townhall, and Townline Lake plantings are on 3-0 stock and the Bird Area was planted entirely with 2-1 stock.

An analysis of variance and, where appropriate, Duncan range tests were used to determine significant differences in height growth. Analyses were made for the new growth each year and for the two-year growth since planting. The results are summarized in Appendix Table D 2.

No significant differences were found in height growth data at the end of the first growing season except in the Raco planting, where the aldrin-treated trees had grown significantly more than the untreated trees.

Significant differences were found between treatments and control in three of the four areas when the second-growing-season (1968) data and the combined-two-year-growth data were analyzed. The treated trees had grown significantly more than the untreated controls (Treatment 4). No significant




Treatment 1 - liquid aldrin by machine - 1% active
Treatment 2 - liquid aldrin by hand - 1% active
Treatment 3 - granular aldrin by machine - 20% active
Treatment 4 - no aldrin---check plots

Figure 18.--Comparison of Mean Height Growth of Like Growing Stock in Aldrin Application Plantings.

differences in heights were found among the aldrin treatments.

It appears that in addition to tree mortality, feeding by white grubs causes reduced height growth in surviving untreated trees. The actual reduced growth is in terms of inches at this stage of a plantation's life, but the ultimate effect, if any, cannot be measured or predicted at this time.

## SUMMARY AND CONCLUSIONS

White grubs (Coleoptera, Scarabaeidae) are the soil-inhabiting stages of the May (or June) beetle and related genera. The grubs feed on a variety of roots, including red pine, causing mortality in young plantations. Studies of their damage, habitat, and control are reported here. Various aspects of these studies were conducted in 1967 and 1968 in one- and two-year-old red pine plantations on the Hiawatha National Forest in Upper Michigan and the Chequamegon and Nicolet National Forests in northern Wisconsin.

White grub population surveys were conducted, with the following six genera found: Phyllophaga, Serica, Diplotaxis, Dichelonyx, Aphodius, and Geotrupes. The mean grub population was 0.77 grubs per cubic foot of soil with a range from 0 to 2.38. Members of the genus Phyllophaga were most abundant with a mean of 0.43 grubs per cubic foot of soil and a range of 0 to 1.75.

Feeding damage surveys revealed that from 1 per cent to 86 per cent of the red pine seedlings were fed on; the damage indexes ranged from 1.04 to 3.88 (minimum 1.00; maximum 5.00).

Regression analyses show that the genus Phyllophaga is the most damaging group of grubs. The relationships between damage index and the mean Phyllophaga populations per cubic foot of soil, and between percentage of trees damaged and the mean Phyllophaga populations per cubic foot of soil are not straight line relationships but rather are curvilinear. Coefficients of determination ($r^2$'s) of .66 and .65, respectively, were obtained for predicting damage index and percentage of trees damaged from the mean Phyllophaga populations per cubic foot of soil. Initially a rapid increase in both damage index and percentage of trees damaged occurs with a small increase in Phyllophaga. The curves become relatively fixed at about 1.3 Phyllophaga per cubic foot of soil, with a damage index of 3 and about 63 per cent of the trees damaged.

Several authors have indicated that 0.5 grubs per cubic foot of soil is a damaging population. These data show that with a population of 0.5 Phyllophaga per cubic foot of soil a damage index of 2.50 could be expected, with a corresponding damage to 59 per cent of the trees. With a population of 0.1 Phyllophaga per cubic foot of soil,a damage index of 1.50 could be expected, with 25 per cent of the trees damaged. The large standard errors indicate that considerable variation in damage associated with a given Phyllophaga population could be expected.

The use of a Phyllophaga feeding index improved the $r^2$'s to .78 for predicting damage index and .70 for predicting percentage of trees damaged. The feeding indexes ranged from 8 to 12 for the Chequamegon National Forest, 0 to 16 for the Nicolet National Forest, and 0 to 218 for the Hiawatha National Forest.

The linear relationship between percentage of trees

The linear relationship between percentage of trees damaged and damage index is very strong ($r^2=.89$). A good estimate of the damage index can be obtained from the percentage of trees damaged data, especially when more than 10 per cent of the trees are damaged.

The highest grub populations (all genera) and highest Phyllophaga populations were found on the Hiawatha National Forest. The most severe damage was there also. This Forest should expect high grub populations and feeding damage to occur generally over the Forest.

Although high grub populations occurred on the Washburn Ranger District of the Chequamegon National Forest, the major component of the population was the genus Serica; the red pine damage was low. On the basis of this survey, serious damage is not expected on this Forest.

The grub populations and feeding damage were low on the Nicolet National Forest, with the exception of one plantation on the Lakewood Ranger District having predominantly Phyllophaga grubs. This Forest can expect occasional damage caused by white grub feeding in a few areas.

One purpose of this study was to seek a system by which high-grub-hazard areas could be recognized during pre-planting site inspections. The ecological factors evaluated were soil types, soil pH, amount of root mass available (larval food), and species of vegetation available for adult food.

Soil types were not a good indicator of locations having high grub, especially Phyllophaga spp., populations. All the soils being planted to red pine on the Hiawatha

National Forest are sands. The grubs (all genera) and *Phyllophaga* populations are variable in any soil type but it appears that the better the soil for red pine production the higher the grub population might be.

On the Chequamegon and Nicolet National Forests the soil types vary from sands to silt loams. Grub populations are low in most plantations. The high grub populations on the Washburn Ranger District of the Chequamegon National Forest and Lakewood Ranger District of the Nicolet National Forest occur in sandier soils.

Soil pH was of no value as an aid to identifying areas of high grub (all genera) or *Phyllophaga* populations among the areas tested. Only 5 per cent of the variation in *Phyllophaga* populations can be attributed to the differences in soil pH.

Similarly root mass is of no value, as only 1.26 per cent of the variation in *Phyllophaga* populations can be attributed to the amount of root mass in the soil.

Attempts to correlate *Phyllophaga* populations and amount of grub feeding damage with the availability of adult food failed to be significant at the 10 per cent level.

No system for identification of high-grub-hazard areas was found.

Tests for effectiveness of the aldrin application techniques revealed that significantly less damage occurred in the aldrin-treated plots than in the check plots during the first 16 months after planting. None of the application methods used was superior to the others. In spite of the aldrin, some feeding damage and mortality occurred in the treated plots.

Significant differences were also found in the mean annual height growth of the trees. The untreated trees grew significantly less the second growing season, and also when the combined two-year growth was tested. No differences in height growth were found among the various treatment application methods.

## RECOMMENDATIONS

Of the three national forests surveyed, white grub damage is most serious on the Hiawatha National Forest, and the recommendations to the land managers are primarily for that Forest. Recommendations are also made to research and forest pest control organizations.

The LAND MANAGER should consider the following recommendations:

1. Collect impact data (such as tree mortality, growth and monetary losses) which can be used to arrive at a dollars-and-cents evaluation of the magnitude of the problem. Impact information is necessary for research and pest control organizations to set priorities in their work planning.

2. Since grub populations, especially Phyllophaga spp., are widely distributed over the Hiawatha National Forest, the Land Manager should consider planting to a closer (probably 6' X 6') spacing in initial plantings, and all three forests should consider closer spacing when filling-in or re-planting areas having grub-caused losses. This practice will prevent moderate losses from destroying a plantation

and will avoid the need for some costly fill-in and re-plant operations.

3. The Hiawatha National Forest land managers should consider initiation of administrative studies of: (1) complete ground preparation, such as rock-raking, as a means of larval control, (2) chemically killing the low-growing vegetation to prepare planting scalps, and (3) killing adult food trees and shrubs by use of herbicides, girdling, or other means, to reduce the adult insect population. The last operation should be conducted at least three years in advance of planting.

RESEARCH should plan the following studies:

1. In cooperation with Pest Control personnel, identify the grub species complex, and determine length of life cycles, recognition of instars, and brood development.

2. Screen new chemical agents, as presently there is no chemical control available. In addition, search for biological control agents, such as "milky disease". Test these for grub control in forest plantations.

3. Study the impact of root feeding on tree mortality and growth loss, and on the susceptibility of damaged trees to attack by secondary insects and

diseases, such as aphids, root rot, and the presently unidentified swellings on some seedling stems.

4. In cooperation with the Forest's Soil Scientist and Pest Control personnel, study ways of identifying and describing high-grub-hazard areas by studying such factors as climate, microclimate, and water table.

5. Develop a furrow survey technique and relate the number of grubs, especially Phyllophaga spp., per unit of furrow to number of grubs per cubic foot of soil, and thus to seedling damage.

FOREST PEST CONTROL should undertake the following:

1. Survey proposed planting sites on the Hiawatha National Forest for Phyllophaga spp. populations and relate these to expected seedling damage. Areas with high Phyllophaga spp. populations should be reserved as suitable areas for pilot testing the various control and prevention measures recommended above.

2. Pilot test new chemical and biological control agents as they become available.

3. Pilot test the use of clovers or other legumes as damage prevention measures. In areas where complete cultivation is not possible test whether

legumes in the planting furrow will give a satisfactory degree of protection to the trees.

4. Pilot test use of baits as a rapid grub survey technique.

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# APPENDICES

APPENDIX A

IDENTIFICATION OF WHITE GRUBS

Field Key to the More Common Lake States White Grubs[1]

1. Anal slit V- or Y-shaped. . . . . . . . . . . . . . . 2

   Anal slit transverse, may be curved or bow-like . . 7

2. Antennae and legs each with 3 segments. . . . <u>Geotrupes</u>

   Antennae and legs with 4 segments each. . . . . . . 3

3. Anal slit Y-shaped with stem ½ as long as an arm. Raster with 2 short, longitudinal, parallel palidia (Figure A 4c) . . . . . . . . <u>Macrodactylus</u>

   Not as above. . . . . . . . . . . . . . . . . . . . 4

4. Anal slit Y-shaped with stem only slightly shorter, equal to, or much longer than arm . . . . . . . 5

   Anal slit V- or Y-shaped. If Y-shaped then stem much shorter than arm. Palidia present. Ventral anal lip with a longitudinal groove or cleft (Figure A 2a) . . . . . . . . . . <u>Phyllophaga</u>

5. Stem of Y much longer than arm. Raster with a single, transverse, slightly curved, comb-like palidium which is just anterior to the ventral anal lobes (Figure A 3a). . . . . . . . . . . . <u>Serica</u>

   Not as above. . . . . . . . . . . . . . . . . . . . 6

6. Stem of Y-shaped anal slit slightly shorter than arm. Raster lyriform (Figure A 4b) . . . <u>Dichelonyx</u>

   Stem of Y-shaped anal slit equal in length to arm. Raster with an oblique palidium resembling a moustache anterior to each lower anal lobe (Figure A 3b) . . . . . . . . . . . . . . . <u>Diplotaxis</u>

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[1]Abridged from a collection of keys and descriptions by Ritcher, P. O. 1966.

7. Palidia present . . . . . . . . . . . . . . . . . . . . 8

Palidia absent. . . . . . . . . . . . . . . . . . . . 9

8. Palidia slightly diverging posteriorly; septula oblong; 5 to 12 pali in each palidium . <u>Strigoderma</u>

Palidia slightly diverging posteriorly; septula oblong; 16 to 25 pali in each palidium (Figure A 4a) . . . . . . . . . . . . . . . <u>Anomala</u>

9. Lower anal lobe emarginate and partially divided into 2 or sometimes 4 lobes (Figure A 4f) . <u>Aphodius</u>

Not as above. . . . . . . . . . . . . . . . . . . . . 10

10. Raster with teges consisting of a broad patch of moderately short, hamate setae with curved tips, which covers the caudal half of the area between the lower anal lip and the caudal margin of the abdominal segment. Lower anal lip covered with similar hamate setae and with a caudal fringe of 18 to 35 long, cylindrical setae (Figure A 4d) . . . . . . . . . . . . . . . . . . . . <u>Cotalpa</u>

Raster with a broad teges of 34 to 50 rather short, flattened, slightly curved setae, which extends slightly less than half the distance from the anterior margin of the lower anal lip to the posterior margin of abdominal segment 9. Lower anal lip covered with setae similar in shape to those of the teges and with a caudal fringe of 20 to 40 long setae (Figure A 4e) . . . . . <u>Aphonus</u>

Raster with a sub-triangular teges of about 50 short, flattened, slightly curved setae. Lower anal lip covered with a similar number of similar setae and a caudal fringe of 7 to 11 long slender setae . . . . . . . . . . . . . . . <u>Ligyrus</u>

## Glossary[1]

caudal--of or pertaining to the anal end of the insect body.

emarginate--notched; with an obtuse, rounded or quadrate section cut from a margin.

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[1]Definitions from Torre-Bueno, J. R. de la. 1950.

hamate--furnished with hooks, or bent like a hook.

lyriform--lyre-shaped; cut into several transverse segments, and gradually enlarging toward the extremity.

palidium--(pl. palidia)--in scarabaeoid larvae, a group of pali arranged in a single row, or two or more rows, either medianly placed across the venter in front of the lower anal lip, or paired and extending forward and inward from one of the ends of the anal slit, or paired and extending straight, arcuately or obliquely forward from inside of one of the ends of the anal slit; the pali are usually recumbent with the apices directed toward the septula; the palidium may have one to many rows of pali.

raster--in scarabaeoid larvae, a complex of definitely arranged bare places, hairs and spines on the ventral surface of the last abdominal segment, in front of the anus; divided into septula, palidium, and other parts.

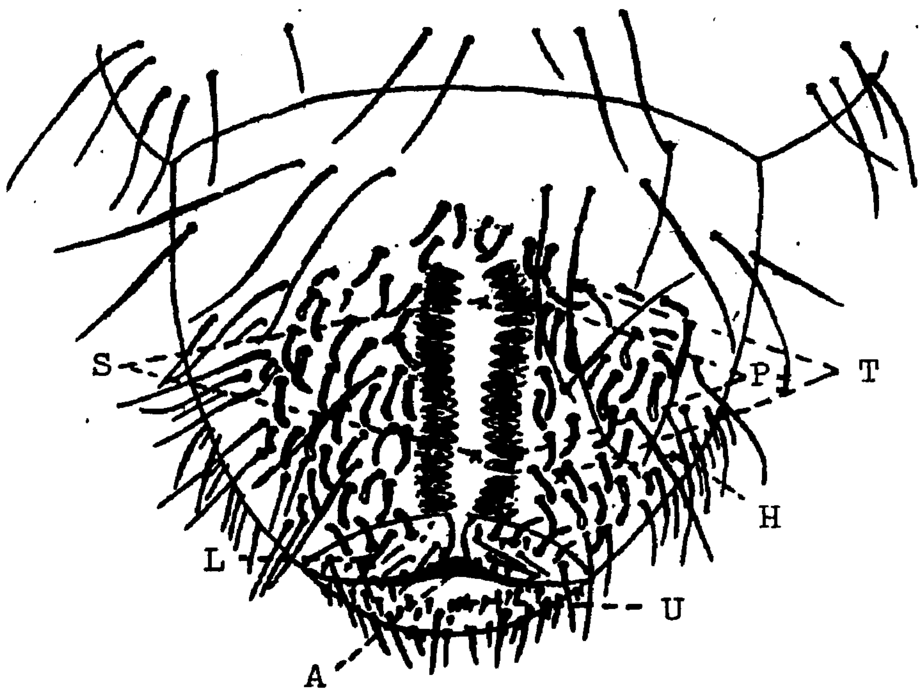
septula--in scarabaeoid larvae, a narrow bare region of the raster between a single transverse palidium and the base of the lower anal lip, or between a pair of oblique palidia diverging backward to the end of the anal slit, or between a pair of backward diverging, or parallel, or curved palidia to inside the ends of the anal slit.

setae--hollow structures developed as extensions of the epidermal layer; commonly known as hairs.

teges--in scarabaeoid larvae, a continuous, dense or sparse, patch of hooked or straight, larger or minute, outward pointing or erect setae, occupying the hind part, or almost the whole, of the tenth abdominal venter when the palidium is absent; or single and transverse, or paired, longitudinal and short; occasionally divided toward the head into two parts with a median intect field, the campus, between; a component of the raster.

venter--the under surface of the abdomen.

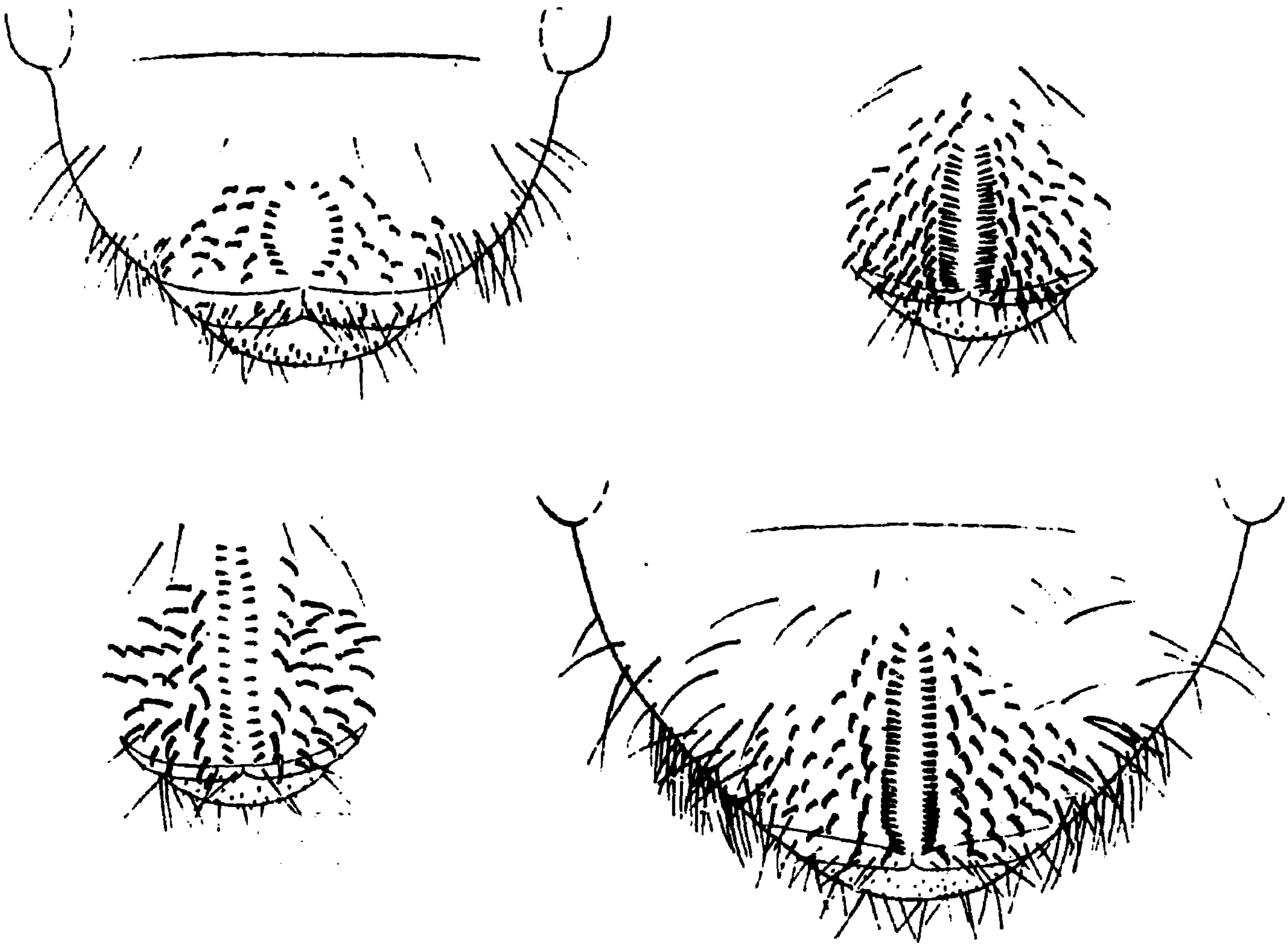
# Illustrations




A--anal slit
H--setae
L--lower anal lip
P--palidium

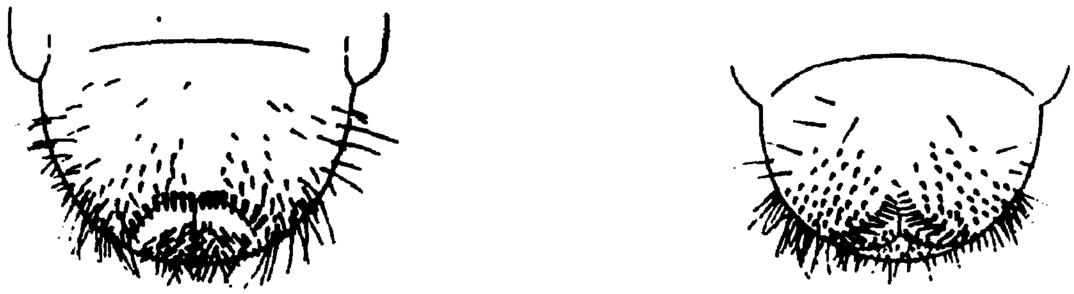
S--septula
T--teges
U--upper anal lip

Figure A 1.--Diagrammatic View of Venter of 10th Abdominal Segment of Phyllophaga Larvae with Important Features Identified. (After Böving 1942.)



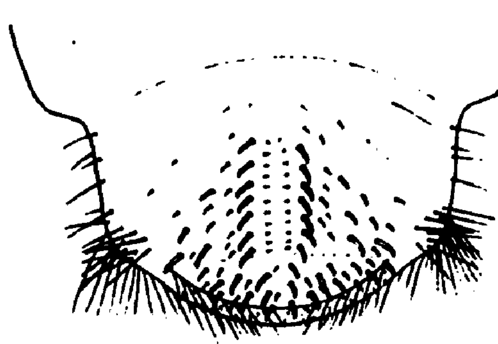
a--Phyllophaga spp.

Figure A 2.--Members of This Group May Cause Serious Damage. (Illustrations after Ritcher 1966.)

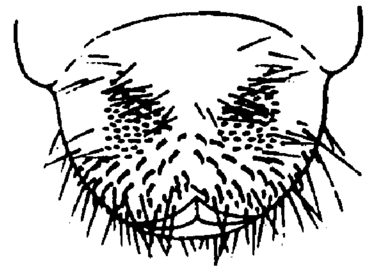


a--Serica spp.    b--Diplotaxis spp.

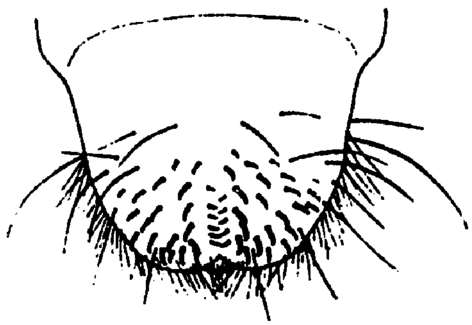
Figure A 3.--Members of This Group May Cause Moderate Damage. (Illustrations after Ritcher 1966.)



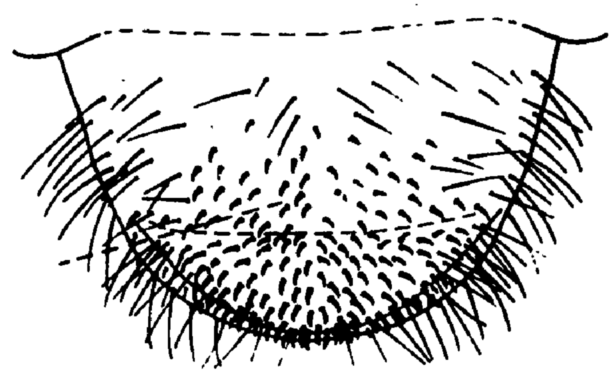
a--*Anomala* spp.



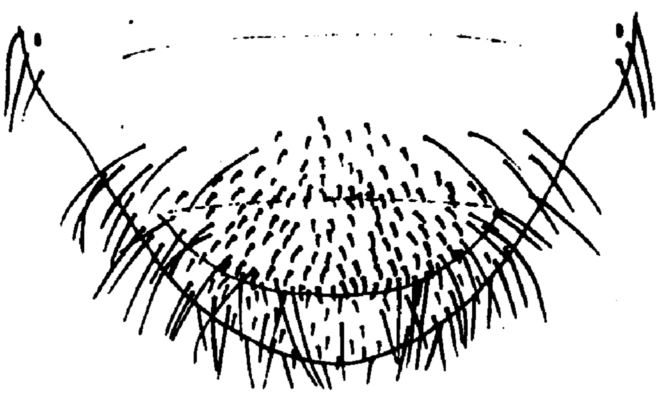
b--*Dichelonyx* spp.



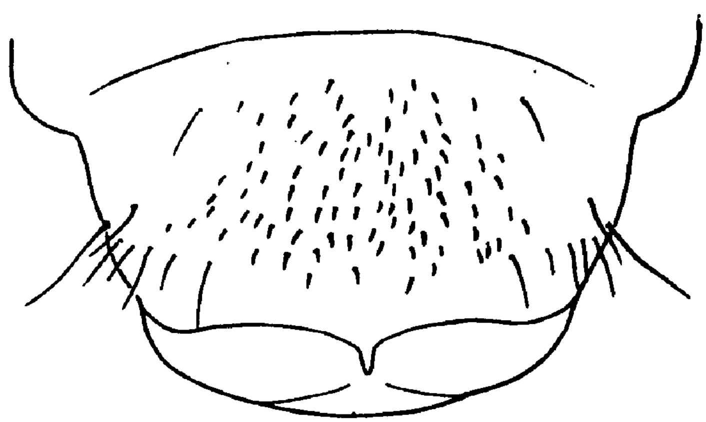
c--*Macrodactylus* spp.



d--*Cotalpa* spp.



e--*Aphonus* spp.



f--*Aphodius* spp.

Figure A 4.--Members of This Group May Cause Light or No Damage. (Illustrations after Ritcher 1966.)

APPENDIX B

RESULTS OF GRUB DAMAGE AND POPULATION SURVEYS

Table B 1.--Grub Damage Survey Spring 1967 Plantations.

| Forest & District | Plantation | Season Examined | No.[a] Dead Trees | Root Scores 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|---|---|
| CHEQUAMEGON N.F. Washburn R.D. | W I | S '68 | 16 | 11 | 0 | 1 | 1 | 3 |
| | W II | S '68 | 29 | 20 | 0 | 5 | 0 | 4 |
| | W IV | S '68 | 19 | 15 | 1 | 0 | 0 | 3 |
| HIAWATHA N.F. Rapid River R.D. | ST | F '67 | 2 | 2 | 0 | 0 | 0 | 0 |
| | | S '68 | 10 | 10 | 0 | 0 | 0 | 0 |
| | | F '68 | 7 | 4 | 0 | 0 | 1 | 2 |
| | | Total | 19 | 16 | 0 | 0 | 1 | 2 |
| NICOLET N.F. Lakewood R.D. | L II | F '67 | 31 | 7 | 0 | 0 | 0 | 24 |
| | | S '68 | 28 | 4 | 0 | 0 | 3 | 21 |
| | | F '68 | 14 | 6 | 0 | 1 | 0 | 7 |
| | | Total | 73 | 17 | 0 | 1 | 3 | 52 |

[a]In each plantation 320 trees were examined. Only dead trees were dug and root-scored for white grub feeding damage.

Table B 2.--Grub Damage Survey Spring 1968 Plantations.

| Forest & District | Plantation | No. Dead Trees[a] | Root Scores 1 | 2 | 3 | 4 | 5 | % Trees Damaged | Damage Index |
|---|---|---|---|---|---|---|---|---|---|
| CHEQUAMEGON N.F. Hayward R.D. | HA III | (7) | 266 (4) | 16 | 24 | 8 (1) | 6 (2) | 17 | 1.35 |
| | HA IV | (26) | 257 (18) | 14 (1) | 22 (2) | 15 (2) | 12 (3) | 20 | 1.47 |
| HIAWATHA N.F. Rapid River R.D. | SL | (17) | 311 (14) | 7 (1) | 0 | 1 (1) | 1 (1) | 3 | 1.04 |
| Manistique R.D. | FD | (38) | 52 (1) | 14 | 27 | 56 (1) | 171 (36) | 84 | 3.88 |
| | TL | (9) | 228 (5) | 10 | 23 (2) | 25 (1) | 34 (1) | 29 | 1.83 |
| | ML | (7) | 129 (5) | 22 | 33 | 27 | 109 (2) | 60 | 2.89 |
| | CR | (10) | 160 (3) | 36 | 38 (1) | 32 | 54 (6) | 50 | 2.33 |
| | MA | (3) | 7 | 7 | 18 | 14 | 4 (3) | 86 | 3.02 |
| Munising R.D. | LP | (16) | 90 (5) | 18 | 32 | 73 (2) | 107 (9) | 72 | 3.28 |
| | FP | (34) | 187 (22) | 15 (1) | 45 (4) | 42 (3) | 31 (4) | 42 | 2.11 |
| | MU | (9) | 13 | 6 | 5 | 15 (1) | 11 (8) | 74 | 3.10 |
| Sault Ste. Marie R.D. | R | (9) | 21 (1) | 10 | 6 (1) | 3 | 10 (7) | 58 | 2.42 |
| | S | (5) | 21 (1) | 11 | 9 | 5 (1) | 4 (3) | 58 | 2.20 |
| NICOLET N.F. Lakewood R.D. | L III | (1) | 272 (1) | 21 | 6 | 8 | 13 | 15 | 1.34 |
| | L IV | (1) | 283 | 20 | 45 (1) | 28 | 25 | 37 | 1.25 |
| | L V | (3) | 304 | 16 (3) | 18 | 8 | 0 | 13 | 1.08 |

[a]In each plantation 320 trees were examined. All these trees were dug, regardless of whether they were living or dead, and their roots scored for white grub feeding damage. Numbers in () indicate trees dead at time of survey.

Table B 3.--Damage Surveys of Aldrin Application Plantings.

| Area | Season | TC[a] | Treatment 1 | | | | | | Treatment 2 | | | | | | Treatment 3 | | | | | | Treatment 4 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Root Scores | | | | | T[b] | Root Scores | | | | | T[b] | Root Scores | | | | | T[b] | Root Scores | | | | | T[b] |
| | | | 1 | 2 | 3 | 4 | 5 | | 1 | 2 | 3 | 4 | 5 | | 1 | 2 | 3 | 4 | 5 | | 1 | 2 | 3 | 4 | 5 | |
| Raco CCC Camp | F '67 | D | 10 | 0 | 4 | 0 | 0 | 14 | 8 | 0 | 0 | 3 | 0 | 11 | 8 | 0 | 1 | 0 | 2 | 11 | 4 | 0 | 3 | 0 | 7 | 14 |
| | S '68 | D | 2 | 1 | 0 | 0 | 0 | 3 | 1 | 0 | 1 | 0 | 1 | 3 | 5 | 0 | 1 | 0 | 1 | 7 | 5 | 1 | 0 | 2 | 9 | 17 |
| | F '68 | D | 8 | 1 | 1 | 2 | 3 | 15 | 5 | 2 | 2 | 0 | 1 | 10 | 16 | 4 | 1 | 9 | 8 | 38 | 5 | 1 | 4 | 2 | 46 | 58 |
| | | S | 20 | 2 | 5 | 2 | 3 | 32 | 14 | 2 | 3 | 3 | 2 | 24 | 29 | 4 | 3 | 9 | 11 | 56 | 14 | 2 | 7 | 4 | 62 | 89 |
| | F '67 | L | 42 | 4 | 3 | 1 | 0 | 50 | 37 | 8 | 1 | 2 | 2 | 50 | 46 | 1 | 2 | 1 | 0 | 50 | 34 | 6 | 1 | 5 | 4 | 50 |
| | F '68 | L& | 36 | 10 | 2 | 2 | 0 | 50 | 36 | 6 | 6 | 2 | 0 | 50 | 38 | 4 | 5 | 2 | 1 | 50 | 21 | 10 | 6 | 3 | 10 | 50 |
| | | D | | | (1) | | | | | | | (1) | | | (2) | | | (1) | (1) | | (1) | | (1) | | (7) | |
| Town-hall | F '67 | D | 17 | 0 | 2 | 0 | 2 | 21 | 9 | 0 | 3 | 0 | 3 | 15 | 10 | 0 | 0 | 0 | 0 | 10 | 16 | 0 | 5 | 0 | 5 | 26 |
| | S '68 | D | 2 | 0 | 0 | 0 | 1 | 3 | 1 | 0 | 0 | 1 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 9 | 11 |
| | F '68 | D | 13 | 3 | 1 | 1 | 2 | 20 | 8 | 3 | 2 | 2 | 3 | 18 | 8 | 3 | 2 | 1 | 5 | 19 | 7 | 1 | 0 | 2 | 19 | 29 |
| | | S | 32 | 3 | 3 | 1 | 5 | 44 | 18 | 3 | 5 | 3 | 6 | 35 | 18 | 3 | 2 | 1 | 5 | 29 | 24 | 2 | 5 | 2 | 33 | 66 |
| | F '67 | L | 44 | 4 | 2 | 0 | 0 | 50 | 40 | 5 | 4 | 0 | 1 | 50 | 39 | 6 | 1 | 3 | 1 | 50 | 31 | 7 | 3 | 3 | 6 | 50 |
| | F '68 | L& | 39 | 8 | 2 | 0 | 1 | 50 | 29 | 9 | 11 | 1 | 0 | 50 | 25 | 15 | 5 | 2 | 3 | 50 | 21 | 11 | 9 | 5 | 4 | 50 |
| | | D | (2) | | | | (1) | | (2) | | (1) | | | | | | (1) | | (3) | | (1) | | | (1) | (3) | |
| Bird Area | F '67 | D | 1 | 0 | 2 | 0 | 0 | 3 | 6 | 0 | 0 | 0 | 3 | 9 | 3 | 0 | 0 | 0 | 1 | 4 | 7 | 0 | 1 | 0 | 4 | 12 |
| | S '68 | D | 2 | 0 | 0 | 0 | 0 | 2 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 2 | 4 |
| | F '68 | D | 4 | 1 | 0 | 0 | 9 | 14 | 0 | 0 | 0 | 1 | 1 | 2 | 2 | 0 | 0 | 0 | 3 | 5 | 0 | 0 | 1 | 1 | 26 | 28 |
| | | S | 7 | 1 | 2 | 0 | 9 | 19 | 7 | 0 | 0 | 1 | 4 | 12 | 5 | 0 | 0 | 0 | 4 | 9 | 9 | 0 | 2 | 1 | 32 | 44 |
| | F '67 | L | 39 | 4 | 3 | 2 | 2 | 50 | 44 | 2 | 2 | 2 | 0 | 50 | 43 | 5 | 2 | 0 | 0 | 50 | 34 | 5 | 2 | 2 | 7 | 50 |
| | F '68 | L& | 19 | 13 | 14 | 2 | 2 | 50 | 17 | 17 | 12 | 2 | 2 | 50 | 29 | 12 | 8 | 1 | 0 | 50 | 7 | 7 | 18 | 14 | 4 | 50 |
| | | D | | (1) | | | (1) | | | | | | (1) | | | | | | | | | | | | (3) | |

| | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Town-line Lake | F '67 | D | 0 | 0 | 1 | 0 | 2 | 3 | 6 | 0 | 3 | 0 | 4 | 13 | 12 | 0 | 1 | 0 | 0 | 13 | 5 | 0 | 3 | 0 | 5 | 13 |
| | S '68 | D | 0 | 0 | 1 | 1 | 4 | 6 | 3 | 0 | 0 | 0 | 2 | 5 | 4 | 0 | 0 | 0 | 0 | 4 | 1 | 0 | 1 | 2 | 9 | 13 |
| | F '68 | D | 2 | 0 | 1 | 2 | 27 | 31 | 1 | 0 | 0 | 2 | 1 | 4 | 4 | 0 | 0 | 2 | 2 | 8 | 2 | 0 | 1 | 5 | 43 | 51 |
| | | S | 2 | 0 | 3 | 3 | 33 | 40 | 10 | 0 | 3 | 2 | 7 | 22 | 20 | 0 | 1 | 2 | 2 | 25 | 8 | 0 | 5 | 7 | 57 | 77 |
| | F '67 | L | 28 | 6 | 2 | 9 | 5 | 50 | 29 | 8 | 6 | 4 | 3 | 50 | 27 | 6 | 3 | 10 | 4 | 50 | 24 | 0 | 5 | 7 | 14 | 50 |
| | F '68 | L& D | 19 | 7 | 13 | 7 | 4 (2) | 50 | 28 (1) | 10 | 8 | 4 (1) | 0 | 50 | 27 | 7 | 13 | 1 | 2 (1) | 50 | 13 | 6 | 5 | 15 (1) | 11 (8) | 50 |
| High-banks Lake | F '67 | D | 2 | 0 | 3 | 0 | 3 | 8 | 4 | 0 | 2 | 0 | 2 | 8 | 15 | 0 | 0 | 0 | 0 | 15 | 11 | 0 | 1 | 0 | 7 | 19 |
| | S '68 | D | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 2 | 3 | 0 | 0 | 0 | 0 | 6 | 6 |
| | F '68 | D | 4 | 0 | 1 | 1 | 3 | 9 | 2 | 1 | 0 | 0 | 1 | 4 | 2 | 0 | 0 | 2 | 2 | 6 | 2 | 0 | 0 | 1 | 15 | 18 |
| | | S | 7 | 0 | 4 | 1 | 6 | 18 | 6 | 1 | 2 | 0 | 4 | 13 | 18 | 0 | 0 | 2 | 4 | 24 | 13 | 0 | 1 | 1 | 28 | 43 |

TC[a]=tree condition; D=dead; S=sum; L=living; L&D=living and dead. Ten living trees (L) per treatment per block were randomly selected after mortality had been tallied. Ten living and dead trees (L&D) per treatment per block were randomly selected before the dead trees had been tallied. Number in () is number of trees that were dead. This mortality is included in dead trees F '68 also.

T[b]=total trees.

Table B 4.--Grub Population Surveys.

| Forest & District | Plantation | Year Survey | All Grubs | | Grubs By Genera: Phyllophaga | | | Serica | | | Diplotaxis | Dichelonyx | Aphodius | Geotrupes | Other | Damaged[b] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | No. | Mean[a] | No. | Mean[a] | % | No. | Mean[a] | % | No. | No. | No. | No. | No. | No. |
| CHEQUAMEGON N.F. | | | | | | | | | | | | | | | | |
| Washburn R.D. | W I | 1967 | 19 | 1.19 | 2 | 0.13 | 11 | 15 | 0.94 | 79 | 0 | 1 | 0 | 0 | 1 | 0 |
| | W II | 1967 | 31 | 1.94 | 1 | 0.06 | 3 | 22 | 1.38 | 71 | 0 | 6 | 0 | 0 | 1 | 1 |
| | W III | 1967 | 15 | 0.94 | 3 | 0.19 | 20 | 12 | 0.75 | 80 | 0 | 0 | 0 | 0 | 0 | 0 |
| | W IV | 1967 | 15 | 0.94 | 1 | 0.06 | 7 | 12 | 0.75 | 80 | 0 | 0 | 0 | 1 | 1 | 0 |
| Glidden R.D. | G I | 1967 | 1 | 0.06 | 1 | 0.06 | 100 | 0 | 0.00 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | G II | 1967 | 0 | 0.00 | 0 | 0.00 | 0 | 0 | 0.00 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Hayward R.D. | HA I | 1967 | 2 | 0.13 | 0 | 0.00 | 0 | 0 | 0.00 | 0 | 0 | 2 | 0 | 0 | 0 | 0 |
| | HA II | 1967 | 8 | 0.50 | 1 | 0.06 | 13 | 7 | 0.44 | 88 | 0 | 0 | 0 | 0 | 0 | 0 |
| | HA III | 1968 | 5 | 0.31 | 1 | 0.06 | 20 | 3 | 0.19 | 60 | 0 | 1 | 0 | 0 | 0 | 0 |
| | HA IV | 1968 | 8 | 0.50 | 3 | 0.19 | 38 | 4 | 0.25 | 50 | 0 | 0 | 1 | 0 | 0 | 0 |
| HIAWATHA N.F. | | | | | | | | | | | | | | | | |
| Sault Ste. Marie R.D. | Raco (CCC Camp) | 1967 | 30 | 1.00 | 12 | 0.40 | 40 | 11 | 0.37 | 37 | 0 | 3 | 0 | 0 | 2 | 2 |
| | | 1968 | 36 | 1.20 | 11 | 0.37 | 31 | 15 | 0.50 | 42 | 6 | 2 | 0 | 0 | 2 | 0 |
| | Highbanks Lake | 1967 | 7 | 0.23 | 5 | 0.17 | 71 | 1 | 0.03 | 14 | 0 | 0 | 0 | 0 | 1 | 0 |
| | | 1968 | 5 | 0.17 | 2 | 0.07 | 40 | 3 | 0.10 | 60 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Townhall | 1967 | 29 | 0.97 | 27 | 0.90 | 93 | 0 | 0.00 | 0 | 0 | 0 | 0 | 0 | 1 | 1 |
| | | 1968 | 70 | 2.33 | 36 | 1.20 | 51 | 7 | 0.23 | 10 | 0 | 0 | 27 | 0 | 0 | 0 |
| Manistique R.D. | Bird Area | 1967 | 10 | 0.33 | 8 | 0.27 | 80 | 1 | 0.03 | 10 | 0 | 0 | 0 | 0 | 0 | 1 |
| | | 1968 | 10 | 0.33 | 7 | 0.23 | 70 | 0 | 0.00 | 0 | 2 | 1 | 0 | 0 | 0 | 0 |
| Munising R.D. | Townline Lake | 1967 | 41 | 1.37 | 37 | 1.23 | 90 | 3 | 0.10 | 7 | 0 | 0 | 0 | 0 | 0 | 1 |
| | | 1968 | 40 | 1.33 | 40 | 1.33 | 100 | 0 | 0.00 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Rapid River R.D. | ST-Stonington | 1967 | 0 | 0.00 | 0 | 0.00 | 0 | 0 | 0.00 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | SL-Sleepy Sentinel | 1968 | 1 | 0.06 | 0 | 0.00 | 0 | 1 | 0.06 | 100 | 0 | 0 | 0 | 0 | 0 | 0 |

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Manistique R.D. | FD-Fishdam River | 1968 | 18 | 1.13 | 12 | 0.75 | 67 | 6 | 0.38 | 33 | 0 | 0 | 0 | 0 | 0 | 0 |
| | TL-Thunder Lk. Rd. | 1968 | 8 | 0.50 | 4 | 0.25 | 50 | 4 | 0.25 | 50 | 0 | 0 | 0 | 0 | 0 | 0 |
| | ML-Muleshoe Lake | 1968 | 29 | 1.81 | 20 | 1.25 | 69 | 6 | 0.38 | 21 | 0 | 1 | 0 | 2 | 0 | 0 |
| | CR-Corner Lake | 1968 | 8 | 0.50 | 5 | 0.31 | 63 | 2 | 0.13 | 25 | 1 | 0 | 0 | 0 | 0 | 0 |
| | SB-Steuben Burn | 1968 | 3 | 0.19 | 2 | 0.13 | 67 | 1 | 0.06 | 33 | 0 | 0 | 0 | 0 | 0 | 0 |
| | CL-Camp 41 Lake | 1968 | 35 | 1.75 | 22 | 1.10 | 63 | 12 | 0.60 | 34 | 1 | 0 | 0 | 0 | 0 | 0 |
| Munising R.D. | LP-Lonesome Pine | 1968 | 38 | 2.38 | 28 | 1.75 | 73 | 7 | 0.44 | 18 | 3 | 0 | 0 | 0 | 0 | 0 |
| | FP-Flattop Pine | 1968 | 18 | 1.12 | 10 | 0.63 | 56 | 8 | 0.50 | 44 | 0 | 0 | 0 | 0 | 0 | 0 |
| Sault Ste. Marie R.D. | SS-Soo Spurr | 1968 | 13 | 0.81 | 11 | 0.69 | 85 | 2 | 0.13 | 15 | 0 | 0 | 0 | 0 | 0 | 0 |
| | T-FR 3144 | 1968 | 28 | 1.75 | 16 | 1.00 | 57 | 11 | 0.69 | 39 | 1 | 0 | 0 | 0 | 0 | 0 |
| St. Ignace R.D. | ST-FR 3124 | 1968 | 21 | 1.31 | 9 | 0.56 | 43 | 11 | 0.69 | 52 | 0 | 0 | 0 | 1 | 0 | 0 |
| NICOLET N.F. | | | | | | | | | | | | | | | | |
| Eagle River R.D. | E I | 1967 | 9 | 0.56 | 0 | 0.00 | 0 | 5 | 0.31 | 55 | 0 | 0 | 0 | 0 | 0 | 4 |
| | E II | 1967 | 1 | 0.06 | 1 | 0.06 | 100 | 0 | 0.00 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | E III | 1967 | 9 | 0.56 | 0 | 0.00 | 0 | 8 | 0.50 | 89 | 0 | 1 | 0 | 0 | 0 | 0 |
| Florence R.D. | F I | 1967 | 6 | 0.38 | 5 | 0.31 | 83 | 1 | 0.06 | 17 | 0 | 0 | 0 | 0 | 0 | 0 |
| | F II | 1967 | 1 | 0.06 | 0 | 0.00 | 0 | 0 | 0.00 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| Laona R.D. | X I | 1967 | 2 | 0.13 | 0 | 0.00 | 0 | 1 | 0.06 | 50 | 0 | 1 | 0 | 0 | 0 | 0 |
| Lakewood R.D. | L I | 1967 | 3 | 0.19 | 2 | 0.13 | 67 | 1 | 0.06 | 33 | 0 | 0 | 0 | 0 | 0 | 0 |
| | L II | 1967 | 14 | 0.88 | 12 | 0.75 | 86 | 1 | 0.06 | 7 | 0 | 0 | 0 | 0 | 0 | 1 |
| | L III | 1968 | 2 | 0.13 | 2 | 0.13 | 100 | 0 | 0.00 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | L IV | 1968 | 3 | 0.19 | 3 | 0.19 | 100 | 0 | 0.00 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | L V | 1968 | 0 | 0.00 | 0 | 0.00 | 0 | 0 | 0.00 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

[a]Mean insects per cubic foot of soil. All plantations had 16 plots except Raco, Highbanks Lake, Townhall, Bird Area, and Townline Lake, which had 30, and Camp 41 Lake, which had 20.

[b]The damaged larvae are included in the total grubs and grubs-per-cubic-foot-of-soil figures, but could not be identified to genus.

# APPENDIX D

## VEGETATION IN SURVEYED PLANTATIONS

Table C.--Low-Growing Vegetation on Surface of One-Cubic-Foot Plots, and Trees and Shrubs within 100 Feet of Plots.

| Forest & District | Plantation | Mean Phyllophaga | Percentage of Plots with: Trees and Shrubs[a] within 100 feet | | | | | | | Low-growing Vegetation[a] | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | a | b | c | d | e | f | g | h | i | j | k | l | m | n | o | p |
| CHEQUAMEGON N.F. | | | | | | | | | | | | | | | | | | |
| Washburn R.D. | W I | 0.13 | 0 | 56 | 100 | 0 | 13 | 0 | 0 | 25 | 75 | 0 | 0 | 44 | 0 | 0 | 5 | 0 |
| | W II | 0.06 | 31 | 31 | 100 | 0 | 6 | 0 | 0 | 0 | 56 | 0 | 0 | 44 | 0 | 6 | 50 | 0 |
| | W III | 0.19 | 19 | 56 | 100 | 0 | 75 | 0 | 0 | 6 | 63 | 0 | 0 | 44 | 0 | 0 | 75 | 0 |
| | W IV | 0.06 | 63 | 69 | 88 | 6 | 63 | 0 | 6 | 25 | 38 | 6 | 0 | 38 | 0 | 19 | 69 | 0 |
| Glidden R.D. | G I | 0.06 | 21 | 40 | 0 | 14 | 70 | 0 | 21 | 0 | 0 | 36 | 0 | 40 | 0 | 40 | 21 | 0 |
| | G II | 0.00 | 37 | 0 | 0 | 0 | 0 | 0 | 19 | 0 | 0 | 6 | 0 | 0 | 0 | 19 | 0 | 0 |
| Hayward R.D. | HA I | 0.00 | 88 | 38 | 0 | 31 | 0 | 13 | 13 | 0 | 13 | 13 | 0 | 44 | 0 | 75 | 38 | 0 |
| | HA II | 0.06 | 0 | 6 | 0 | 0 | 25 | 0 | 0 | 0 | 0 | 0 | 0 | 44 | 0 | 25 | 13 | 0 |
| | HA III | 0.06 | 75 | 88 | 6 | 25 | 94 | 38 | 44 | 0 | 0 | 0 | 0 | 6 | 0 | 38 | 6 | 0 |
| | HA IV | 0.19 | 100 | 38 | 0 | 81 | 56 | 31 | 50 | 0 | 0 | 6 | 0 | 38 | 0 | 38 | 0 | 0 |
| HIAWATHA N.F. | | | | | | | | | | | | | | | | | | |
| Manistique R.D. | MA | 0.23 | 17 | 0 | 0 | 77 | 0 | 0 | 0 | 0 | 20 | 17 | 43 | 30 | 70 | 3 | 10 | 0 |
| | FD | 0.75 | 100 | 100 | 0 | 25 | 81 | 0 | 0 | 0 | 6 | 0 | 13 | 31 | 19 | 0 | 44 | 0 |
| | TL | 0.25 | 75 | 94 | 0 | 0 | 31 | 0 | 13 | 0 | 13 | 19 | 38 | 88 | 0 | 13 | 50 | 0 |
| | ML | 1.25 | 94 | 81 | 100 | 0 | 6 | 0 | 0 | 6 | 63 | 0 | 0 | 19 | 31 | 0 | 13 | 0 |
| | CR | 0.31 | 50 | 13 | 0 | 6 | 0 | 0 | 0 | 13 | 63 | 0 | 56 | 19 | 13 | 0 | 6 | 0 |
| | SB | 0.13 | 65 | 38 | 38 | 69 | 0 | 0 | 81 | 0 | 19 | 0 | 63 | 13 | 6 | 6 | 6 | 0 |
| | CL | 1.10 | 70 | 15 | 75 | 5 | 20 | 0 | 0 | 15 | 45 | 10 | 10 | 10 | 20 | 5 | 15 | 0 |
| Munising R.D. | MU | 1.33 | 63 | 67 | 0 | 90 | 0 | 13 | 13 | 0 | 17 | 77 | 67 | 100 | 33 | 0 | 0 | 0 |
| | LP | 1.75 | 81 | 94 | 0 | 0 | 38 | 100 | 0 | 0 | 63 | 0 | 38 | 38 | 50 | 0 | 0 | 0 |
| | FP | 0.63 | 100 | 81 | 0 | 0 | 0 | 19 | 0 | 0 | 56 | 0 | 13 | 50 | 31 | 0 | 0 | 0 |
| Sault Ste. Marie R.D. | R | 0.40 | 27 | 20 | 43 | 0 | 37 | 27 | 0 | 27 | 20 | 10 | 67 | 43 | 40 | 3 | 7 | 0 |
| | H | 0.07 | 53 | 53 | 57 | 0 | 37 | 0 | 20 | 3 | 50 | 0 | 10 | 27 | 10 | 0 | 3 | 0 |
| | S | 1.20 | 0 | 0 | 0 | 83 | 0 | 10 | 13 | 0 | 0 | 90 | 10 | 3 | 13 | 0 | 0 | 0 |
| | SS | 0.69 | - | - | - | - | - | - | - | 0 | 0 | 100 | 69 | 13 | 50 | 0 | 0 | 0 |
| | T | 1.00 | - | - | - | - | - | - | - | 0 | 0 | 88 | 75 | 13 | 31 | 0 | 0 | 0 |
| St. Ignace R.D. | ST | 0.56 | - | - | - | - | - | - | - | 0 | 0 | 100 | 31 | 6 | 6 | 0 | 0 | 0 |
| Rapid River R.D. | ST | 0.00 | 6 | 0 | 88 | 0 | 0 | 0 | 0 | 13 | 50 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | SL | 0.00 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 | 56 | 0 | 0 | 0 | 0 | 0 | 13 | 0 |

| | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| NICOLET N.F. | | | | | | | | | | | | | | | | | | |
| Eagle River R.D. | E I | 0.00 | 81 | 81 | 0 | 13 | 63 | 38 | 0 | 0 | 69 | 0 | 0 | 75 | 0 | 6 | 94 | 0 |
| | E II | 0.06 | 87 | 25 | 0 | 69 | 13 | 56 | 44 | 19 | 31 | 0 | 0 | 65 | 6 | 0 | 19 | 0 |
| | E III | 0.00 | 100 | 44 | 0 | 69 | 6 | 19 | 6 | 31 | 69 | 6 | 0 | 56 | 0 | 0 | 63 | 0 |
| Florence R.D. | F I | 0.31 | 56 | 6 | 0 | 0 | 0 | 6 | 31 | 0 | 0 | 63 | 0 | 0 | 0 | 50 | 0 | 63 |
| | F II | 0.00 | 100 | 0 | 0 | 25 | 0 | 0 | 31 | 0 | 0 | 6 | 0 | 0 | 0 | 25 | 0 | 0 |
| Laona R.D. | X I | 0.00 | 100 | 6 | 0 | 100 | 0 | 6 | 88 | 0 | 0 | 6 | 0 | 19 | 0 | 56 | 6 | 6 |
| Lakewood R.D. | L I | 0.13 | 38 | 6 | 6 | 50 | 19 | 19 | 0 | 50 | 0 | 0 | 0 | 44 | 0 | 6 | 13 | 0 |
| | L II | 0.75 | 50 | 0 | 0 | 62 | 6 | 0 | 13 | 44 | 0 | 0 | 0 | 12 | 0 | 13 | 0 | 38 |
| | L III | 0.13 | 13 | 0 | 0 | 6 | 6 | 0 | 0 | 0 | 0 | 50 | 6 | 0 | 0 | 13 | 0 | 44 |
| | L IV | 0.19 | 31 | 50 | 0 | 75 | 38 | 0 | 44 | 0 | 0 | 69 | 6 | 0 | 0 | 0 | 0 | 63 |
| | L V | 0.00 | 100 | 13 | 19 | 100 | 25 | 19 | 100 | 0 | 0 | 13 | 0 | 31 | 0 | 31 | 0 | 38 |

[a] a = aspen
b = red maple
c = oak
d = cherry
e = white birch
f = Juneberry
g = willow
h = sweet fern
i = blueberry
j = hawkweed
k = sheep sorrel
l = bracken fern
m = reindeer moss
n = strawberry
o = wintergreen
p = clover

## APPENDIX D

## STATISTICAL TESTS ON RESULTS OF ALDRIN APPLICATION PLANTINGS

Table D 1.--Analysis of Variance Tests for Damaged Trees in Aldrin Application Plantings.

| Comparison | Area | F Test: Treatment | F Test: Within Treatments | F Test: Treatment vs. Control | Duncan Range Test |
|---|---|---|---|---|---|
| Damaged Dead Trees (Scores 2-5) End of First Growing Season (Fall '67) | Raco | n.s. | | | |
| | Townhall | * | n.s. | ** | 4-3 ** 2-3 n.s. 1-3 n.s.<br>4-1 n.s. 2-1 n.s.<br>4-2 n.s. |
| | Bird Area | n.s. | | | |
| | Townline Lk. | n.s. | | | |
| | Highbanks Lk. | n.s. | | | |
| Damaged Living Trees (Scores 2-5) End of First Growing Season (Fall '67) | Raco | n.s. | | | |
| | Townhall | n.s. | | | |
| | Bird Area | n.s. | | | |
| | Townline Lk. | n.s. | | | |
| | Highbanks Lk.[a] | - | | | |
| Heavily Damaged Living Trees (Scores 4-5) End of First Growing Season (Fall '67) | Raco | n.s. | | | |
| | Townhall | * | n.s. | ** | 4-1 * 3-1 n.s. 2-1 n.s.<br>4-2 * 3-2 n.s.<br>4-3 n.s. |
| | Bird Area | n.s. | | | |
| | Townline Lk. | n.s. | | | |
| | Highbanks Lk.[a] | - | | | |
| Damaged Dead Trees (Scores 2-5) Accumulated F '67, S'68, F '68 | Raco | ** | n.s. | ** | 4-2 ** 3-2 n.s. 1-2 n.s.<br>4-1 ** 3-1 n.s.<br>4-3 * |
| | Townhall | ** | n.s. | ** | 4-3 ** 2-3 n.s. 1-3 n.s.<br>4-1 ** 2-1 n.s.<br>4-2 * |
| | Bird Area | ** | n.s. | ** | 4-3 ** 1-3 n.s. 2-3 n.s.<br>4-2 ** 1-2 n.s.<br>4-1 * |
| | Townline Lk. | ** | * | ** | 4-3 ** 1-3 ** 2-3 n.s.<br>4-2 ** 1-2 *<br>4-1 * |
| | Highbanks Lk. | n.s. | | | |

Table D 1 (cont'd.)

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Heavily Damaged Dead Trees (Scores 4-5) Accumulated F '67, S '68, F '68 | Raco | ** | n.s. | ** | 4-1 ** 4-2 ** 4-3 ** | 3-1 n.s. 3-2 n.s. | 2-1 n.s. |
| | Townhall | ** | n.s. | ** | 4-1 ** 4-3 ** 4-2 ** | 2-1 n.s. 2-3 n.s. | 3-1 n.s. |
| | Bird Area | ** | n.s. | ** | 4-3 ** 4-2 ** 4-1 ** | 1-3 n.s. 1-2 n.s. | 2-3 n.s. |
| | Townline Lk. | ** | * | ** | 4-3 ** 4-2 ** 4-1 * | 1-3 ** 1-2 * | 2-3 n.s. |
| | Highbanks Lk. | * | n.s. | ** | 4-2 * 4-3 * 4-1 * | 1-2 n.s. 1-3 n.s. | 3-2 n.s. |
| Damaged Randomly Selected Living & Dead Trees (Scores 2-5) F '68 | Raco | n.s. | | | | | |
| | Townhall | n.s. | | | | | |
| | Bird Area | ** | n.s. | ** | 4-3 ** 4-1 * 4-2 n.s. | 2-3 * 2-1 n.s. | 1-3 n.s. |
| | Townline Lk. | n.s. | | | | | |
| | Highbanks Lk.[a] | - | | | | | |
| Heavily Damaged Randomly Selected Living & Dead Trees (Scores 4-5) F '68 | Raco | ** | n.s. | ** | 4-1 ** 4-2 ** 4-3 ** | 3-1 n.s. 3-2 n.s. | 2-1 n.s. |
| | Townhall | n.s. | | | | | |
| | Bird Area | ** | n.s. | ** | 4-3 ** 4-2 ** 4-1 ** | 1-3 n.s. 1-2 n.s. | 2-3 n.s. |
| | Townline Lk. | ** | n.s. | ** | 4-3 ** 4-2 ** 4-1 ** | 1-3 n.s. 1-2 n.s. | 2-3 n.s. |
| | Highbanks Lk.[a] | - | | | | | |

n.s.=not significant
* =significant at 5% level
** =significant at 1% level

[a]No living trees dug at Highbanks Lake

Table D 2.--Analysis of Variance Tests for Height Growth in Aldrin Application Plantings.

| Area | Data[a] | F Test: Treatment | F Test: Within Treatments | F Test: Treatment vs. Control | Duncan Range Test |
|---|---|---|---|---|---|
| Raco | 1967 | * | n.s. | * | 1-4 ** 1-2 n.s.<br>2-4 * |
| | 1968 | ** | n.s. | ** | 1-4 ** 1-2 n.s.<br>2-4 * |
| | Sum | ** | n.s. | ** | 1-4 ** 1-2 n.s.<br>2-4 * |
| Townhall | 1967 | n.s. | | | |
| | 1968 | * | n.s. | ** | 2-4 ** 2-1 n.s.<br>1-4 * |
| | Sum | * | n.s. | ** | 2-4 ** 2-1 n.s.<br>1-4 * |
| Townline Lk. | 1967 | n.s. | | | |
| | 1968 | ** | n.s. | ** | 2-4 ** 2-3 n.s.<br>3-4 * |
| | Sum | * | n.s. | ** | 2-4 ** 2-3 n.s.<br>3-4 * |
| Bird Area | 1967 | n.s. | | | |
| | 1968 | n.s. | | | |
| | Sum | n.s. | | | |

n.s. = not significant
* = significant at 5% level
** = significant at 1% level

[a]New growth measured at end of each growing season. Height of trees surviving two years added for total growth since planting.