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IMPACT OF REDHEADED PINE SAWFLY, NEODIPRION LECONTEI
(FITCH), ON YOUNG RED PINE PLANTATIONS

presented by

Robert Dean Averill

has been accepted towards fulfillment
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Louis F Wilson
Major professor

Date November 14, 1977

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IMPACT OF REDHEADED PINE SAWFLY, *NEODIPRION LECONTEI* (FITCH), ON YOUNG RED PINE PLANTATIONS

By

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ABSTRACT

IMPACT OF REDHEADED PINE SAWFLY, NEODIPRION LECONTEI (FITCH), ON YOUNG RED PINE PLANTATIONS

By

Robert Dean Averill

The concept of forest insect impact is presented utilizing the redheaded pine sawfly, a serious defoliator of young red pine trees 1 to 5 meters tall. Impact is defined as being composed of two components: (1) ecological--the cumulative net effects of the insect on the total forest site and areas off site, and (2) socio-economic--the value judgments and/or decision criteria established by management objectives. Impact is a dynamic variable, and a function both of change in the forest condition and of the criteria established for particular management objectives.

Six intensive study plots ranging from ¼ to 1 acre in size were established in the Manistee National Forest near Boon, Michigan. Each plot differed in soil, topography and vegetation. Additional red pine plantings in Lower and Upper Michigan, Wisconsin, New York, and Ontario, Canada, were censused for sawfly damage and site quality.

Three site classes of resistance to sawfly were identified based on soil development and disturbance, competing vegetation in

the rooting zone of red pine, and suitability for red pine growth. Site resistance class I (SRC-I) was most resistant to physical change by the sawfly whereas SRC-III was most susceptible to change and SRC-II was intermediate to change induced by the sawfly.

Sawfly egg cluster density was lowest on SRC-I and highest on SRC-III. Survival of larvae was significantly lower on SRC-I than the other two classes; survival was not significantly different between the other classes.

Infested trees had egg clusters distributed as follows: terminal 8.6%, terminal and top whorl 36.1%, remainder of tree 63.9%. Tree height varied between 0.13 and 4.89 m during the course of study. Trees shorter than 0.6 m were not attacked, and in attacked trees over 3.0 m all egg clusters were distributed in the terminal and upper whorl. The sawfly preferred to oviposite on trees between 1.2 and 2.4 m tall. On better soils the sawfly ate more foliage than on poorer soils. Tree mortality occurs with a mean of 96.5% defoliation. Growth loss was related to tree height and terminal length. Terminal growth loss from sawfly was significantly different between classes but terminal defoliation was not.

Tree survival was 68% on SRC-III lands prior to the sawfly outbreak. The sawfly caused 54% tree mortality during the study. On SRC-I and SRC-II lands the sawfly caused tree mortality of 2 and 4%, respectively.

Egg parasitism was significant and the larval parasite, Exenterus amictorius (Panzer), was discovered for the first time on this sawfly and was the most significant larval parasite.

Impact models were developed showing the relationship of host vigor to both tree growth and sawfly dynamics by site resistance classes. Identifiable physical changes to multiple use management objectives were incorporated into the models to allow calculation of impact to each management objective and to determine if the overall impact is positive or negative. A risk rating guide was developed for use in the field to rate both proposed red pine planting sites and existing plantations to sawfly damage. Equations are presented for red pine growth and determination of future product yield of sawfly attacked trees.

Dedicated to

Clarence Campbell Averill

ACKNOWLEDGMENTS

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My sincerest appreciation is extended to Dr. Louis Wilson, who has guided and inspired my efforts throughout my graduate program. The invaluable aid of my committee members, Dr. Donald White, Dr. Victor Rudolph, Dr. Stanley Wellso, and Dr. Richard Fowler, in providing helpful suggestions and constructive criticism is appreciated.

Finally, special thanks to my wife, Sue, for her encouragement and patience during this period of graduate study.

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INTRODUCTION

The redhead pine sawfly, *Neodiprion lecontei* (Fitch), is an important defoliator of young hard pines in eastern North America (Benjamin 1955) where it is particularly destructive to red pine, *Pinus resinosa* Ait., and jack pine, *P. banksiana* Lamb. It also feeds on eastern white pine, *P. strobus* L., Scotch pine, *P. sylvestis* L., Austrian pine, *P. nigra* Arn., and to a lesser degree other species of pines planted in the vicinity of the primary hosts.

This sawfly occurs in colonies of 100 or more insects and is a voracious feeder that readily strips small (1 to 5 m) trees of all or some of their foliage. Consequently, numerous trees may be killed or deformed during an outbreak. In the Lake States about 11.9 million acres are planted or seeded to red or jack pine, and approximately 44,000 acres of national forest plantations there have received chemical suppression measures in an attempt to manage this insect (Fowler 1973). The sawfly has destroyed thousands of acres of pine on state and private land where suppression measures have not been taken. Severe outbreaks did not occur until the advent of the widespread reforestation projects early in this century. Since then, the most notable Lake States outbreaks occurred in 1936-1940, 1946-1948, 1957-1960, and 1968-1973.

Current emphasis on ecological matters and the benefit-cost analyses of forest protection require that the land managers have better data on sawfly impact from which to draw their management decisions. This study was conducted to provide a data base for forest managers to enable them to better understand the impact of this sawfly in young red pine plantations. To accomplish this, data were recorded in red pine plantations infested with the sawfly during the 1968-1973 outbreak.

Objectives

The major objectives of this study are to:

1. identify and determine the important biological and ecological parameters that are important for the survival of the redheaded pine sawfly and its host;
2. develop a workable model of redheaded pine sawfly impact on red pine using these parameters; and
3. propose guidelines (based on impact data analyses) for managing this sawfly in red pine plantations.

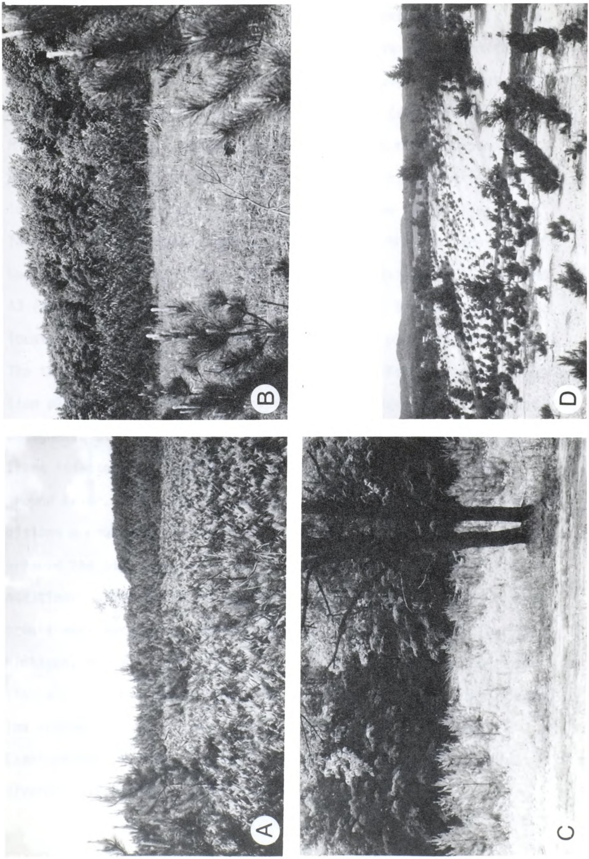
Study Areas

The Manistee National Forest, Michigan, was undergoing an outbreak of the redheaded pine sawfly during the 1968-1973 infestation at the time this research was begun. Three study areas (Table 1, Figure 1) in young red pine plantations were selected in the spring of 1971 and 1972, based on a survey of sawfly-infested areas (Millers 1971). All areas were open plantings on sandy soils with level to gently rolling topography. Edges were bordered by mixed

TABLE 1.--Location and tree data of redheaded pine sawfly study areas in Michigan, at the peak of defoliation (spring 1971).

Plot	Location	Number of Trees	Mean Height (m)	Mean Defoliation (%)
A1	T. 22 N., R. 11 W., Sec. 34 NE	364	1.6	20.4
A2	T. 22 N., R. 11 W., Sec. 34 NE	300	1.6	24.2
A3	T. 22 N., R. 11 W., Sec. 27 SE	664	1.5	16.6
B1	T. 22 N., R. 11 W., Sec. 28 NE	349	1.4	12.5
C1	T. 22 N., R. 11 W., Sec. 11 SW	594	0.7	1.5
C2	T. 22 N., R. 11 W., Sec. 11 SW	763	0.6	1.5

Figure 1. Sawfly infested areas: (A) study plot A3 bracken fern pocket; (B) study plot A3 bracken fern pocket with dead trees (spring) after outbreak; (C) study plot B1 along hardwoods; (D) highly disturbed sandy site.



hardwood stands or open fields. Trees were planted about 6 x 6 ft. apart. Ground cover consisted mostly of grasses and intermittent pockets of bracken fern, *Pteridium aquilinum* (L.) Kuhn, sweet-fern, *Comptonia peregrina* (L.) Coult., and bare soil (sand blows). Miscellaneous forbs, lichens, and sedges were a minor component. Six study plots, destined for intensive research, were established in the three plantations. Plot size varied from .25 to 1 acre. A large private plantation called "Anderson" had three of the plots because of diversity of terrain. These were designated A1, A2, and A3 (Table 1). A second planting on USDA Forest Service land, located near the Boon Fire Tower contained one plot designated B1. The two additional plots were established in a Forest Service plantation planted by the Daughters of the American Revolution (DAR) and designated C1, and C2. Plots were set up specifically to include trees infested with sawflies, different terrain, and different ground cover. Three plot maps representing all types of field conditions encountered are depicted in Figures 2, 3, and 4. To broaden the scope and geographical area represented by this study, additional plantations with a history of redheaded pine sawfly outbreaks were surveyed in August 1972. Plantations in Lower and Upper Michigan, Wisconsin, New York, and Ontario, Canada, were examined (Table 2). Plantation locations were provided by Forest Service and the appropriate State and Provincial forestry organizations. Examinations consisted of recording data on insect populations, diversity of terrain, and soil profiles.

TABLE 2.--Location of additional redheaded pine sawfly plots examined in red pine plantations in eastern North America.

State or Province	County	Location	
UNITED STATES			
MI	Benzie Co.	T. 27 N., R. 12 W., Sec. 16 NE	
MI	Benzie Co.	T. 28 N., R. 13 W., Sec. 35 SW	
MI	Houghton Co.	T. 47 N., R. 36 W., Sec. 31 NE	
MI	Houghton Co.	T. 27 N., R. 38 W., Sec. 26	
MI	Houghton Co.	T. 47 N., R. 38 W., Sec. 26 E½	
MI	Mackinac Co.	T. 43 N., R. 1 W., Sec. 35 S½	
MI	Mackinac Co.	T. 41 N., R. 4 W., Sec. 14	
MI	Mackinac Co.	T. 42 N., R. 4 W., Sec. 31 NW	
MI	Mackinac Co.	T. 43 N., R. 5 W., Sec. 3 NE	
MI	Mackinac Co.	T. 43 N., R. 3 W., Sec. 20 SW	
MI	Mackinac Co.	T. 43 N., R. 3 W., Sec. 20 NE	
MI	Mackinac Co.	T. 43 N., R. 3 W., Sec. 18	
MI	Wexford Co.	T. 21 N., R. 12 W., Sec. 18	
MI	Wexford Co.	T. 21 N., R. 11 W., Sec.'s 3,4,9, & 10	
MI	Wexford Co.	T. 22 N., R. 11 W., Sec. 13 SE	
WI	Menominee Co.	T. 30 N., R. 16 E., Sec. 26 NW	
WI	Menominee Co.	T. 20 N., R. 16 E., Sec.'s 3,4,9, & 10	
NY	St. Lawrence Co.	Stockhom Township Block 33	
NY	St. Lawrence Co.	near Canton	
NY	St. Lawrence Co.	south of Stockhom Center	
CANADA			
Ontario	Simcoe Co.	Vespra Twp.	Concession 1 Lots 34 & 35
Ontario	Simcoe Co.	Flos Twp.	Concession 2 Lots 26 & 27
Ontario	Frontenac Co.	Oso Twp.	Concession 3 Lot 26
Ontario	Frontenac Co.	Hinchinbrooke Twp.	Concession 5 Lot 9
Ontario	Lanark Co.	Bathurst Twp.	Concession 4 Lot 16

Figure 2. Red pine plot A3 showing distribution pattern of trees defoliated by redheaded pine sawfly larvae in 1971. White = 0.9% defoliation; spot = 10-90% defoliation; black - 91-100% defoliation. Delimited areas SC-I, SC-II, SC-III are site class divisions. Fern refers to bracken fern occupying SC-III class. SC-I and SC-III areas had grasses and forbs.

Lower graph portrays a profile of defoliation pattern and tree heights by rows for a cross section of trees through the midsection of the plot.

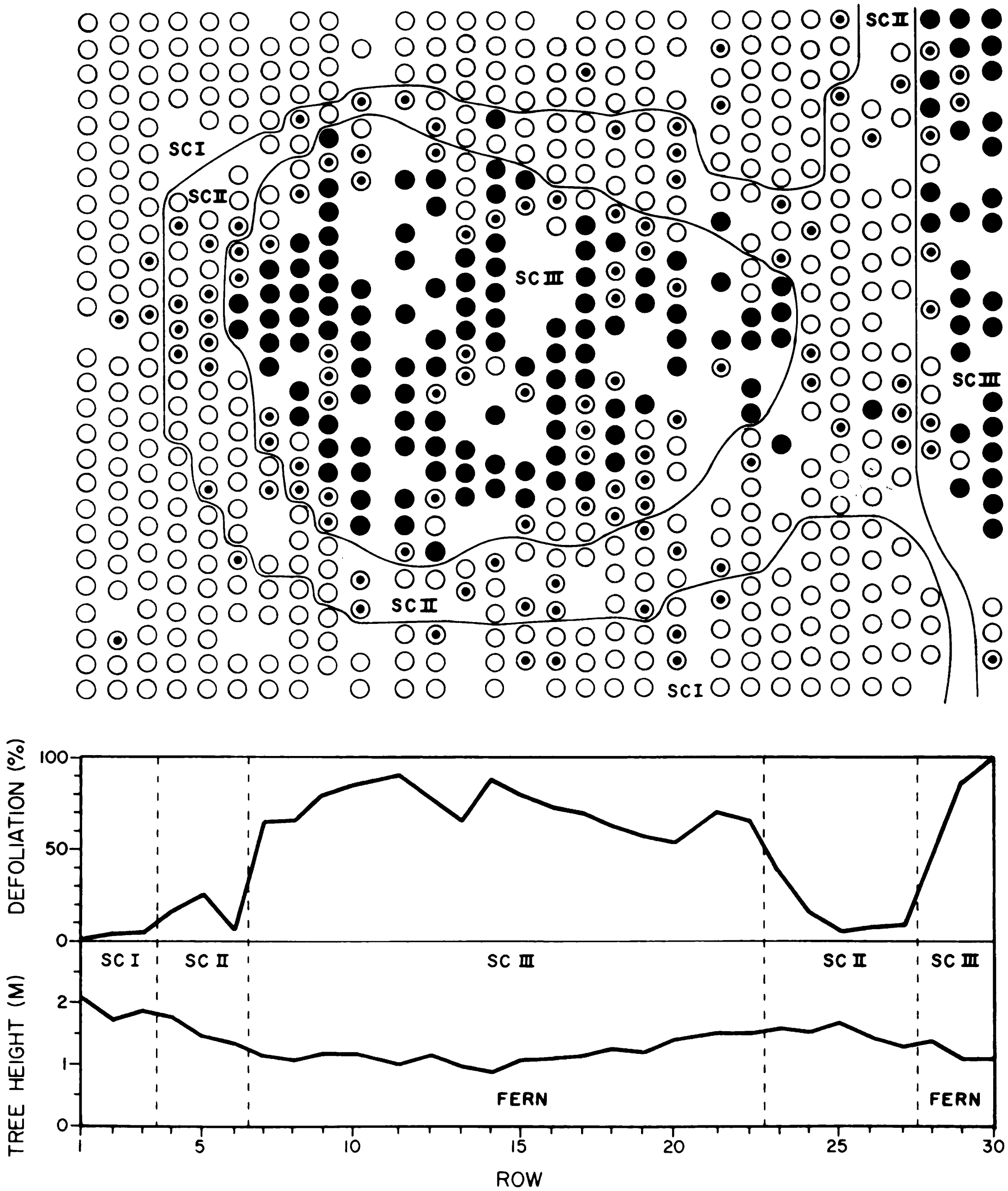

SC I
SC II
SC III
DEFOLIATION (%)
TREE HEIGHT (M)
FERN
ROW
100
50
0
2
1
0
1
5
10
15
20
25
30

Figure 3. Red pine plot A1 showing distribution pattern of trees defoliated by redheaded pine sawfly larvae in 1971. White = 0-9% defoliation; spot = 10-90% defoliation; black = 91-100% defoliation. Squares represent jack pine trees. Deliminated areas SC-II, SC-III are site class divisions. Fern refers to bracken fern occupying one SC-III area. Sand indicates a sand blow in the other SC-III area. The SC-II area had grasses and forbs.

Lower graph portrays a profile of defoliation pattern and tree heights by rows for a cross section of trees through the midsection of the plot.

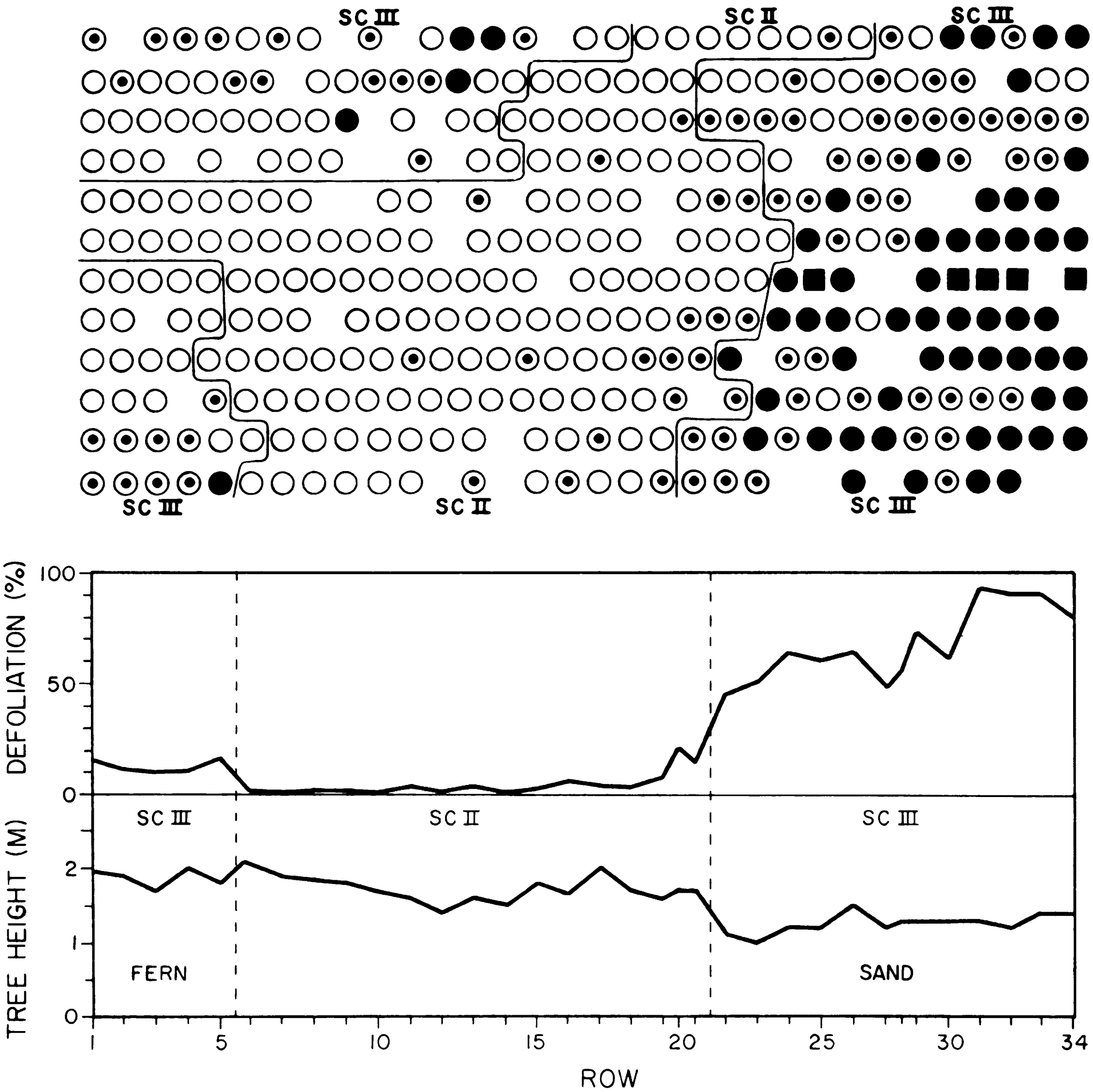
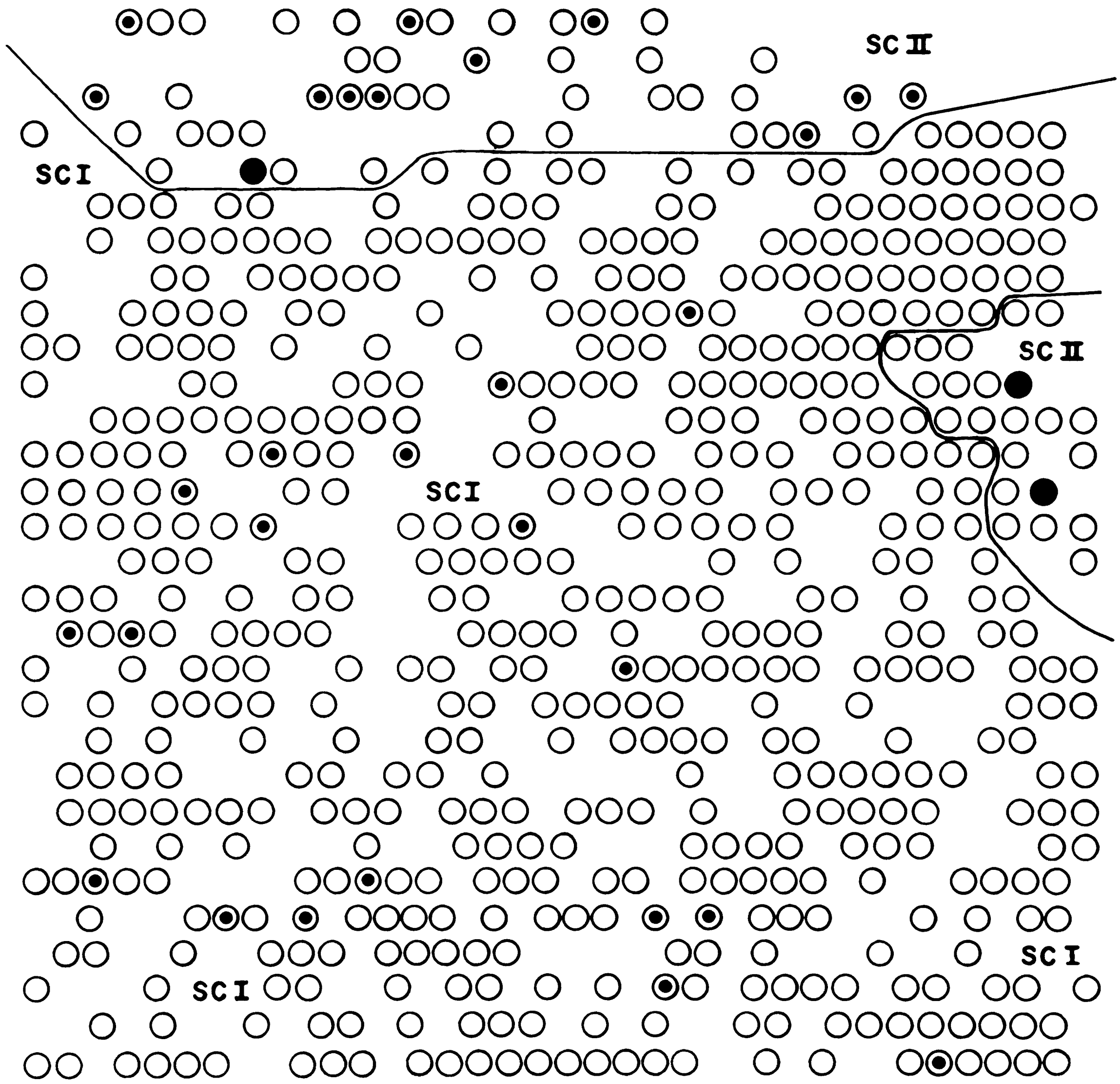

SC III
SC II
SC III
SC III
SC II
SC III
DEFOLIATION (%)
100
50
0
SC III
SC II
SC III
TREE HEIGHT (M)
2
1
0
FERN
SAND
1
5
10
15
20
25
30
34
ROW

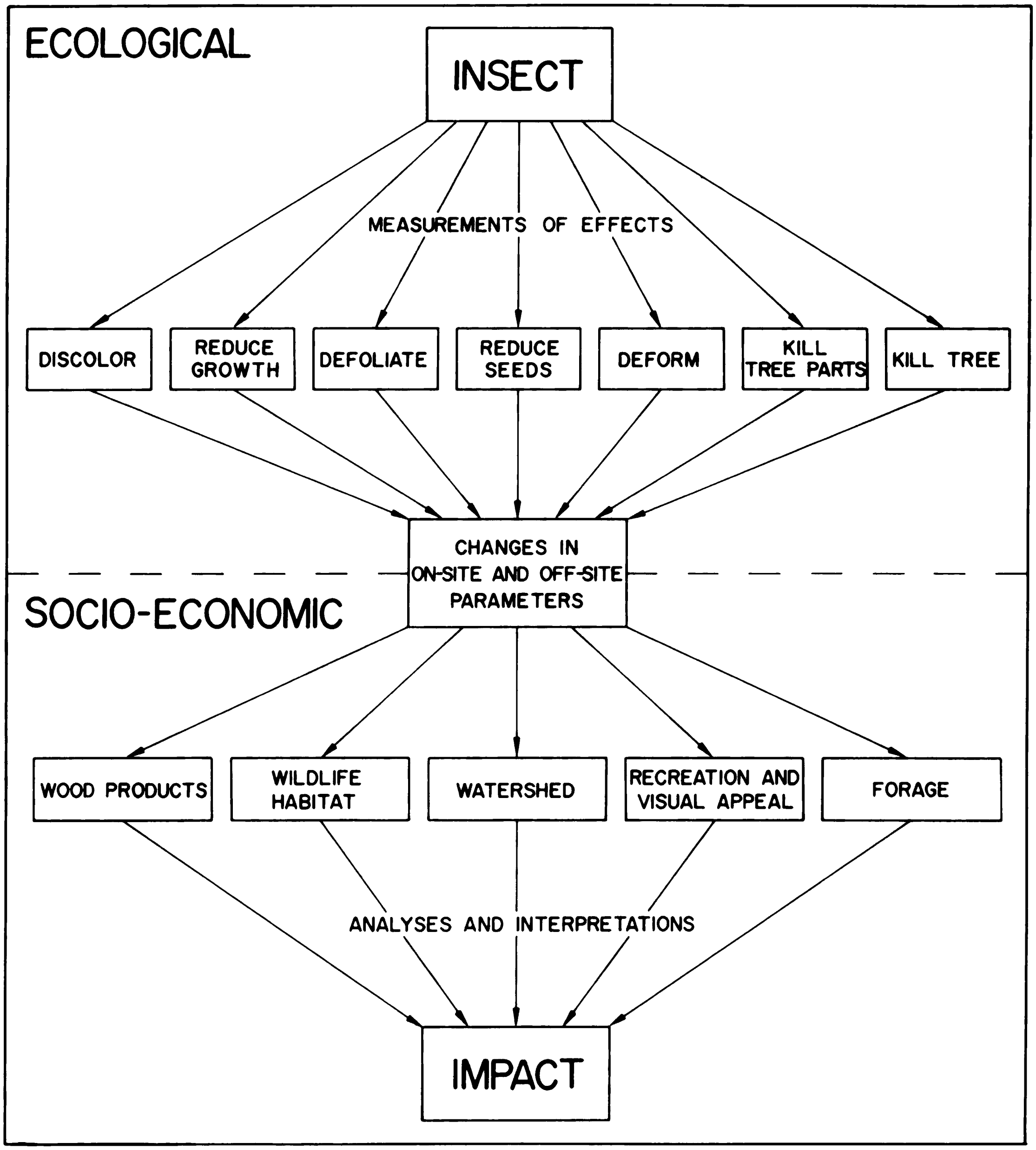
Figure 4. Red pine plot C1 showing distribution pattern of trees defoliated by redheaded pine sawfly larvae in 1971. White = 0.9% defoliation; spot = 10-90% defoliation; black = 91-100% defoliation. Delimited areas SC-I and SC-II are site class divisions.


SC II
SC I
SC II
SC I
SC I
SC I

Definition and Concept of Impact

The impact of an insect population feeding on the host trees can be broadly defined as the cumulative net effects of the insect which results in modification of management activities for specified forest resource uses and values (USDA 1972). More specifically, impact has two components: (1) ecological--the cumulative net effects of the insect on the total forest site and areas offsite; and (2) socio-economic--the value judgments and/or decision criteria established by management objectives (Figure 5). The ecological component is based on physical changes to the tree and site caused by insect activity (e.g., discolored branches, dead trees, dense ground cover). However, the on-site physical changes may be of such magnitude as to initiate off-site changes as well (e.g., erosion, water recharge, etc.). The socio-economic component is essentially man's reaction to these changes and is the most difficult component to appreciate and understand. What the ecological effects imply depends upon the management objectives and values at stake, and man's goals differ by degree and change frequently. Suppose a land manager has a well defined objective for a particular parcel of land he manages. If the objective is primarily timber production then insect injury might have a subtractive effect. However, for wildlife there may be an additive effect and no effect at all for watershed. Also, widespread insect-caused mortality could be considered beneficial in an overmature forest, and thus have a large additive effect, while one insect falling in a person's coffee when in a campsite could have nearly as great a subtractive effect.

Figure 5. Generalized model of impact from an insect.


ECOLOGICAL
INSECT
MEASUREMENTS OF EFFECTS
DISCOLOR
REDUCE GROWTH
DEFOLIATE
REDUCE SEEDS
DEFORM
KILL TREE PARTS
KILL TREE
CHANGES IN ON-SITE AND OFF-SITE PARAMETERS
SOCIO-ECONOMIC
WOOD PRODUCTS
WILDLIFE HABITAT
WATERSHED
RECREATION AND VISUAL APPEAL
FORAGE
ANALYSES AND INTERPRETATIONS
IMPACT

Impact, then is a dynamic variable, and a function both of change in forest stand condition and of the criteria established for particular management objectives. Both components are measurable but the socio-economic one cannot be fully assessed until the ecological one is understood. To do this, the ecosystem must be examined and the insect effects measured directly. There are several ways to do this. For instance, Waters (1969) advocates a life table approach to the insect's host to provide a complete ledger of tree growth and losses. Stage (1973), however, suggests a simpler tree-by-tree basis. Geographic and other approaches have also been tried (Vyse 1971; Myers et al. 1971). The approach of this study was to isolate the major ecological components, examine them and their interactions, and then propose various interpretations based on important socio-economic parameters.

Components of Sawfly Impact

Three major elements of the ecological component of impact are apparent for a forest feeding insect--the insect, the tree, and the physical environment they both occupy. These elements affect each other and are so interdependent that a change in one causes a change in the other two. They must be examined independently and in combination to identify the specific components which relate most to impact. These components should provide the base data for a definitive model relative to redheaded pine sawfly management.

THE INSECT

The redheaded pine sawfly is the principal component of the impact story as it is the direct instrument of injury, and the initiator of changes in the tree-environment components. A goal is to reduce populations of the sawfly through forest management practices so that undesirable impacts are minimized and desirable ones are maximized. To do this one must have a thorough understanding of the insect's behavior and of the constraints which limit its populations.

Life History of the Sawfly

The life cycle of the redheaded pine sawfly in the Lake States is reviewed briefly for understanding the forces acting upon it and its association with the tree and environment.

The sawfly is usually univoltine. However, second generation adults occasionally emerge in the southern portion of its range (Benjamin 1955). The sawfly spends the winter as a prepupa in a cocoon spun in the needle litter or soil beneath its host tree. Pupation occurs in the spring as the weather warms. Adults emerge in late June and early July; mating and oviposition occur shortly thereafter. The female oviposits on the previous year's needles of the host. She makes the initial egg slit at the base of the needle and then moves distad making more incisions. She averages 8 eggs per needle and 116 eggs per cluster on red pine (Benjamin 1955).

Larvae emerge 3-4 weeks later. First instar larvae feed on the needles from which they emerge, removing only small portions of each. Second instar larvae move to adjacent new or old needles and eat all but the vascular tissues--producing a bottle-brush appearance. The remaining three feeding larval instars consume the entire needle and additionally nibble on tender bark tissues. If food becomes limiting the larvae leave the tree and search for nearby hosts to complete feeding. During larval migration they may starve, desiccate, or be preyed upon. Once satiated on foliage, the larvae again shed their exoskeletons and become non-feeding eonymphs which move to the ground. There they spin cocoons and become prepupae. Unless stimulated to pupate which occurs only rarely in the northern states, most of these overwinter in the cocoons in diapause. Some prepupae remain for 2 or more years in diapause before pupation.

Distribution of the Sawfly by "Site Classes"

The abundance and distribution of sawfly egg clusters and larval colonies were examined to determine if the sawflies preferred particular trees or locations of trees within a stand. Egg clusters were censused on every tree in every plot during June and larval colonies were counted during July each year from 1971-1973. Number of colonies varied considerably between plots and much of this variation was due to the choice of plot size. The peak year of the infestation was 1971 for the sawfly population in most areas followed by an abrupt decline in 1972 (Table 3). Only the Boon Tower planting (B1) peaked in 1972 and still had a sawfly population in 1973. A decline was expected by 1972 for this outbreak because the

TABLE 3.--Number of sawfly egg clusters and larval colonies by plots and years.

Plot	1971		1972		1973	
	Egg Clusters	Larval Colonies	Egg Clusters	Larval Colonies	Egg Clusters	Larval Colonies
A1	320	147	6	3	0	0
A2	243	89	4	0	0	0
A3	532	160	17	4	0	0
B1	-	-	191	97	48	20
C1	104	81	60	32	0	0
C2	63	12	27	19	0	0

sawfly has predictably been cyclic in the past. However, the reason for the complete collapse in 1973 in the study areas is uncertain.

Because the plots were chosen to differ widely in soil types and vegetation it was soon noticed that the sawfly was considerably more abundant in some locations than others. By examining tree growth and site conditions of the plots (see Tree and Site sections), three separate site classes (SC-I, SC-II, SC-III) were discriminated. The site classes were characterized as follows:

SC-I: relatively undisturbed soils in which the A_2 horizon is visible. Competitive plants not present or sparse. Ground cover composed of grasses, lichens, mosses, and miscellaneous forbs.

SC-II: disturbed soils with the A_2 horizon faintly present or shallow with the top 20 cm of the soil profile containing less fine sand and organic matter than SC-I. Light array of competitive plants such as bracken fern and/or some roots from nearby hardwoods in the root zone of the red pine. More than half the ground surface occupied by grasses, lichens, mosses, and miscellaneous forbs.

SC-III: soil highly disturbed or eroded. There are three recognized conditions here. In the first, usually the upper 20 cm of solum is missing and the lower B horizon or parent material, C horizon, is exposed on the surface. These areas are typical sand blows and devoid of ground cover. In the second, competitive plants, such as bracken fern, grow profusely and form thick mats just below the soil surface. In the third situation, the area has hardwood roots present and abundant within the rooting zone of the red pine.

By using these criteria the boundaries for the site classes were established in each of the study plots (for examples see Figures 2, 3, and 4).

The insect population was related directly to these classes--the lowest number of insects were found on SC-I trees and the greatest number were on SC-III trees except for plot B1 (Tables 4 and 5). Some stands had all three site classes and thus had the greatest variation of insect infestation. For example, all three classes are present in plot A3 (Figure 2) and populations there were 0.34 egg clusters per tree for SC-I, 0.92 for SC-II, and 2.38 for SC-III trees. Plots A1 and B1 were represented by SC-II and SC-III areas (Figure 3). The DAR planting appeared to be a much better site overall than the other plantings and plot C2 was classed as all SC-I with 0.08 egg clusters per tree. Plot C1 had 0.13 egg clusters per tree on SC-I and 0.52 on SC-II (Table 4).

Distribution of the Sawfly within Trees

The within tree distribution of egg clusters was examined to determine the number of colonies per tree and possible preference of adults for oviposition sites. The number and location of colonies on the tree in conjunction with tree size are variables that must be considered to determine damage and impact to the tree.

Anderson plantation plots A1 and A3 were studied because they contained the most insects and the most variation in tree size at the peak of the outbreak. Egg clusters and larval colonies were tallied for each tree as to location by terminal (leader shoot), upper whorl (leader and laterals) and lower whorls.

TABLE 4.--Sawfly egg population for each study plot by site classes at the peak of the outbreak (1971).

Plot	Mean Number Egg Clusters per Tree		
	SC-I	SC-II	SC-III
A1	-	0.73	1.25
A2	0.53	1.73	2.31
A3	0.34	0.92	2.38
B1*	-	0.64	0.42
C1	0.13	0.54	-
C2	0.08	-	-

*Peaked in 1972.

TABLE 5.--Sawfly larval population for each study plot by site class at peak of the outbreak (1971).

Plot	Mean Number Larval Colonies per Tree		
	SC-I	SC-II	SC-III
A1	-	0.27	0.64
A2	0.21	0.58	1.23
A3	0.13	0.26	0.69
B1*	-	0.49	0.32
C1	0.08	0.57	-
C2	0.02	-	-

*Peaked in 1972.

The sawfly population varied from 0 to 20 egg clusters and 0 to 11 larval colonies (measured when half grown) per tree. On infested trees, the terminal shoot had 8.6%, the first whorl (terminal included) had 36.1% and the rest of the tree had 63.9% of the egg clusters. However, the numbers of egg clusters per tree and their distribution varied considerably relative to tree size. Very small stunted trees under 0.6 m tall appeared to be unattractive to the sawfly and thus were not attacked. All trees larger than 0.6 m tall were attacked and those 1.2 to 2.4 m tall were preferred (Figure 6). The number of egg clusters in the upper whorl related directly to tree size--the taller the tree, the greater the percentage of egg clusters (Figure 7).

Consumption of Foliage by the Sawfly

The number of sawfly larvae and the amount of foliage consumed or destroyed by them must be known to adequately interpret actual or potential damage to the tree. Colonies were selected from all the research plots and from several other plantings in the vicinity of Boon, Michigan. Seventy colonies were tagged on trees that had little previous defoliation so the insects would not run out of food and wander away. The colonies averaged 48 larvae (range 3 to 487) when selected in the beginning of the third instar. Defoliation was measured as length (cm) of linear branch foliage consumed upon completion of feeding. Needle lengths were measured from several trees and locations and found not to vary significantly. The regression of foliage consumed in cm (Y) on number of larvae (X) is $Y = 28.56 + 1.93X$ ($SE = 61.86$, $r = .89$).

Figure 6. Frequency of egg clusters for various locations on trees by tree size for plots A1 and A3 combined.

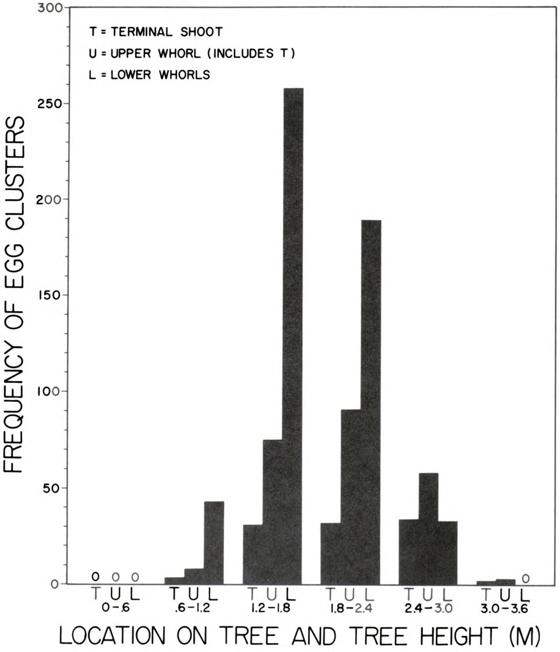
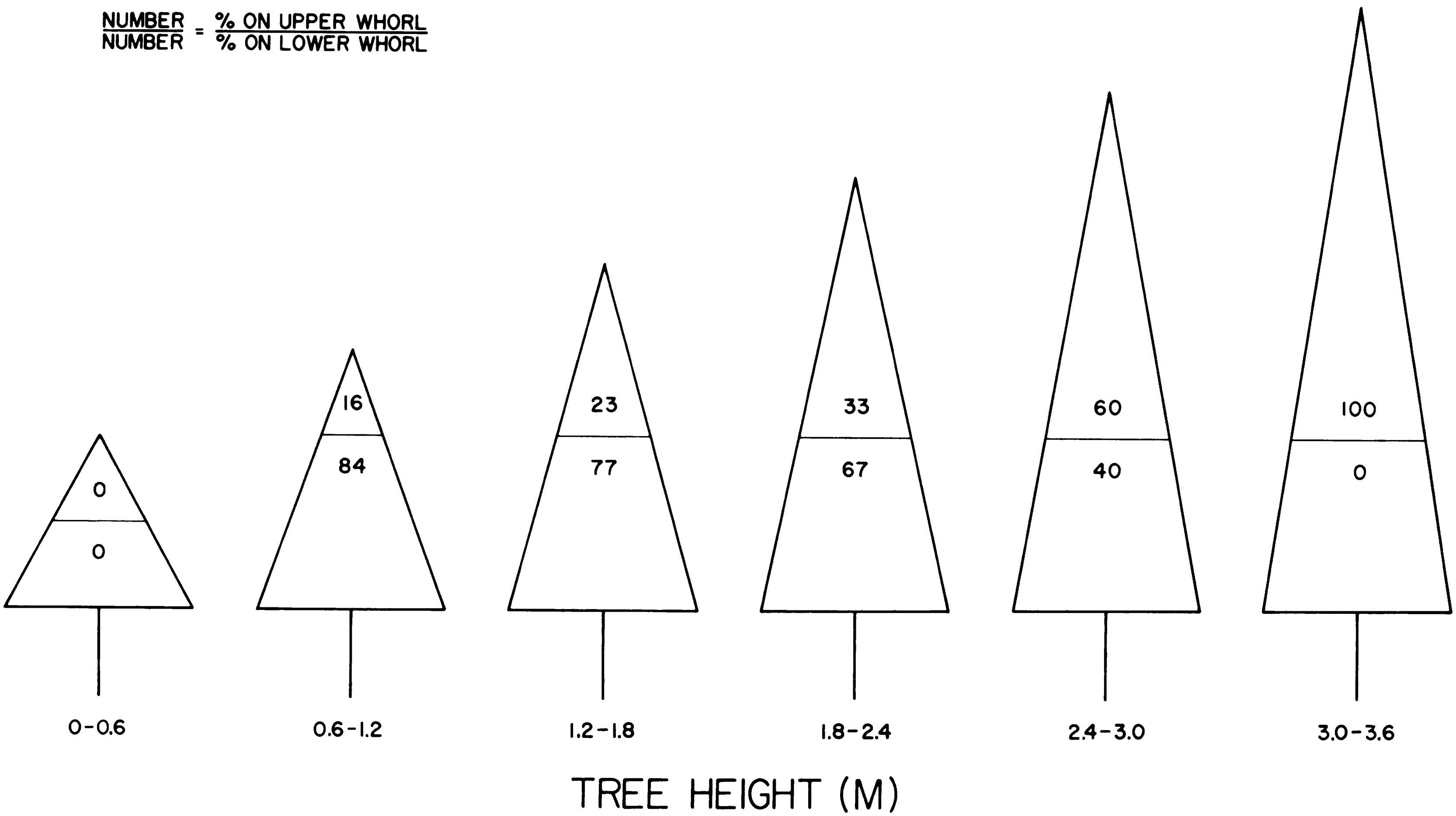

T = TERMINAL SHOOT
U = UPPER WHORL (INCLUDES T)
L = LOWER WHORLS
FREQUENCY OF EGG CLUSTERS
0
50
100
150
200
250
300
0 0 0
0
T U L
0 - .6
T U L
.6 - 1.2
T U L
1.2 - 1.8
T U L
1.8 - 2.4
T U L
2.4 - 3.0
T U L
3.0 - 3.6
LOCATION ON TREE AND TREE HEIGHT (M)

Figure 7. Percentage of egg clusters for upper whorl (upper number) and for all lower whorls (lower number) on various sized trees for plots A1 and A3 combined.

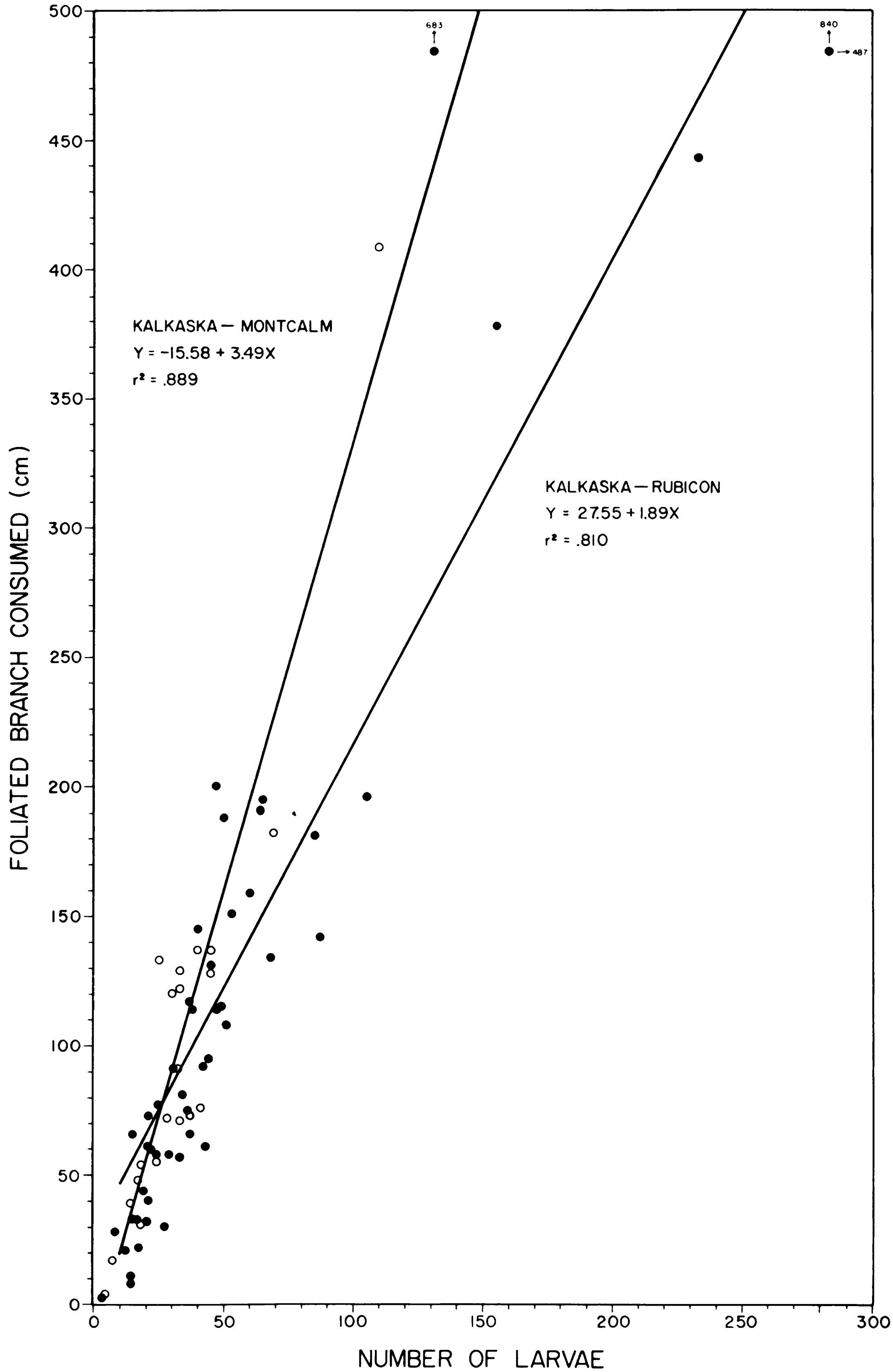

NUMBER / NUMBER = % ON UPPER WHORL / % ON LOWER WHORL
0
0
16
84
23
77
33
67
60
40
100
0
0-0.6
0.6-1.2
1.2-1.8
1.8-2.4
2.4-3.0
3.0-3.6
TREE HEIGHT (M)

Larvae in the DAR plots (C1, C2) consumed more foliage per insect than in other plots. The only apparent differences were site class and soil. DAR plots had Kalkaska integrating to Montcalm sand, while all the others had Kalkaska integrating to Rubicon. When regression equations were computed and covariance analyses made on their slopes the differences were significant at the .05 level (Figure 8). An average of 3.02 cm of foliated branch was consumed by each larva in the DAR plots and 2.53 cm for each larva in the other plots. The reason for these differences is unknown but a nutrient deficiency may have been responsible. In terms of colonies this means that the sawfly larvae in the DAR plots ate about one-fifth more foliage than those in the other plots or 23.5 cm more. Though relatively a small difference this could be important when the trees are small, several sawfly colonies inhabit the same tree, or the sawflies are concentrated on the upper whorl.

Defoliation within stands was also measured to determine the amount and location of damage. Estimates of defoliation were made each year for each tree in each plot and recorded after larval feeding as percentage of foliage missing (5% intervals) on the terminal shoot (leader) and the entire tree.

Whole tree defoliation was distinctly related to site classes--the greatest defoliation was on SC-III trees and the least on SC-I trees (Figures 2 and 3, upper graph). In all plots where SC-III trees occurred, defoliation exceeded 90% per tree for about half of the trees (Figures 2 and 3, diagram), and nearly all of these had the leaders fully defoliated as well. Recall that SC-III

Figure 8. Red pine foliage consumed by sawfly larvae on trees growing on different soil series.



500
450
400
350
300
250
200
150
100
50
0
0
50
100
150
200
250
300
683
840
487
KALKASKA — MONTCALM
Y = −15.58 + 3.49X
r² = .889
KALKASKA — RUBICON
Y = 27.55 + 1.89X
r² = .810
FOLIATED BRANCH CONSUMED (cm)
NUMBER OF LARVAE

sites also have the bulk of the insect population and contain the shortest trees on the average within each plot (Figures 2 and 3, lower graph). Defoliation over 90% rarely occurred on SC-I and SC-II trees. Most trees on these sites were defoliated less than 10% which is insignificant to tree growth unless leaders are defoliated. Of the trees attacked on SC-I and SC-II sites only 3 and 10% of the leaders respectively were injured sufficiently to cause deformity or growth loss during the peak of the outbreak.

Factors Limiting the Sawfly

Some of the limiting factors which affect sawfly populations were examined, but a complete population dynamics study was not made because the study was begun at the peak of the outbreak, and shortly thereafter the population began to decline. However, some factors which seemed to modify the sawfly's behavior and survival were noted. Partial life tables were prepared based on the major biological components discovered in the plots.

Egg and larval survival was studied in 1972 and 1973, in the Anderson and Boon Tower plantings. Egg clusters were selected on mean sample trees and followed through eclosion. Numbers of living larvae were tallied at the peak of each instar until the larvae left the host to pupate. Barriers were placed around several trees to contain the last instar wandering sawflies. These barriers were made of strips of 6" wide tin formed into a circle and sunk into the ground. The exposed portions covered with a sticky material kept most of the larvae from escaping.

Survival varied considerably between 1972 and 1973 (Table 6). Egg survival was 65% in 1972 and 36% in 1973. The egg parasite Closterocerus cinctipennis Ashm. was the most abundant agent and killed 85% of the eggs in some clusters and was the primary cause of mortality in both years. Larval survival varied also between the two years, but the causes were not investigated. Some of the larvae were parasitized but larval mortality from parasites rarely occurs because the parasites do not kill the insects until they are in the cocoon stage.

Nine species of parasites were reared from cocoons (Table 7). Benjamin (1955) noted 58 species of parasites and predators from N. lecontei. Perilampus hyalinus Say, which is a hyperparasite of diptera such as Spathimergenis spp., was the most common insect emerging from the cocoons. It contributed 16% mortality and the Spathimergenis erecta-aurifrons complex added an additional 3%. Benjamin (1955) also reported Perilampus as being common in 1948 and 1949 in Lower Michigan. Exenterus nigrifrons Roh., E. diprionis Roh., and E. amictorius Panzer were the next most common parasites. E. amictorius contributed 6% mortality. This European ichneumonid was introduced several times into Eastern Canada between 1933 and 1949 to control diprionid sawflies. The first record of it in Michigan was from Emmet Co. in July 1959. Besides being a parasite of N. lecontei, it also is established in N. swainei Midd. (McLeod 1972), N. sertifer Geoff. (Lyons 1964), and Diprion similis Htg. (Mertins and Coppel 1968). The higher rate of parasitization of E. amictorius compared to native Exenterus species suggests that it

TABLE 6.--Partial life tables for the redheaded pine sawfly in the Boon Tower Plantation in 1972 and 1973.

Age Interval	Number Alive At Beginning of Lx	Mortality Dx	Dx as Percentage of Lx	Survival (%) Within x
1972				
Egg	113	39	35	65
Instar I, II	74	7	9	91
Instar III	67	3	4	96
Instar IV	64	5	8	92
Instar V	59	-	-	-
1973				
Egg	106	68	64	36
Instar I, II	38	1	3	97
Instar III	37	5	14	86
Instar IV	32	23	72	28
Instar V	9	-	-	-

TABLE 7.--Partial life table for the redheaded pine sawfly during the cocoon stage in Anderson Plantation in 1972.

Age Interval x	Factor Responsible for Dx	Number Alive At Beginning of Lx	Mortality Dx	Dx as Percentage of Lx	Survival (%) Within x
Cocoon		522			
	Perilampus hyalinus		81	16	84
	Spathimeigenis spp.		15	3	97
	Exenterus amictorius		29	6	94
	E. diprionis		6	1	99
	E. canadensis		3	0.6	99.4
	Pleolophus basizonus		3	0.6	99.4
	Endasys subclayatus		1	0.2	99.8
	Mastrus aciculatus		1	0.2	99.8
	Parasite larvae (undetermined		21	4	96
	Disease (unknown)		33	6	94
	Other		24	5	95
	Male Sawflies (emerged)	138	24	18	82
	Female Sawflies (emerged)	66	31	47	53
	Sawflies in diapause	282	-	-	-
	Survival rate males	.22			
	Survival rate females	.07			

may be replacing them in the ecosystem. This appeared to be the case with its introductions against N. swainei (McLeod 1972).

An unknown disease killed about 6% of the cocooned insects, and undetermined factors killed 5% more.

More male sawflies emerged than females (Table 7). Also, a large number diapaused overwinter.

The survival of the sawfly by site classes was also examined on all plots in 1971. Egg clusters were marked and followed through eclosion. Larvae were tallied at the beginning of eclosion and just before leaving the tree to pupate.

Initial observations showed that egg clusters on SC-I trees contained more dead eggs than those on SC-II and SC-III trees. Part of the mortality was from more abundant egg parasitization, but most was from another but unidentified cause. Larval mortality was also higher on SC-I trees by about 20%. Mean percentage survival for the site classes were: SC-I, 41.3%, SC-II, 56.4%; and SC-II, 52.3%. Survival on SC-I trees were significantly ($P < .05$) lower than SC-II and SC-III trees, using Duncan's multiple range test. Survival on SC-II and SC-III trees were not significantly different from each other.

THE TREE

The tree is subject to considerable modification by its environment and from the insect parasitic on it. As a part of the understanding of impact, one must learn how the tree grows under various conditions relative to soil, water availability, and competitive factors. One must also learn how the tree is further modified by the sawfly so its damage can be assessed in terms of impact.

Some research is available which is useful in these studies of red pine growth. Fortunately, red pine grows with little variation under uniform site conditions because its heritability of growth rate variation is low (Yao et al. 1971). Soil has much more influence on red pine growth than heritability. Soil factors regulating red pine growth have been studied by Hannah (1967) and Van Eck and Whiteside (1963). Neary et al. (1972) and White (1958) reported on growth relations to competition for available moisture.

Important tree data relative to impact are presented here.

Tree and Stand Dynamics

Tree height measurements and mortality were recorded throughout the study for all trees in all study plots. The plantations contained even-aged trees but the ages of the plantations varied from 5 to 9 years. Trees ranged in height from 0.13 m to 3.20 m at the beginning of the study and grew to 0.29 m to 4.89 m by its completion. Mean growth of all stands plotted over age showed a linear relationship (Figure 9). When soil type was considered the height-over-age relationship was linear. Trees growing on Kalkaska soils integrating to Montcolm gave a better growth over-age relationship ($Y = 62.20 + 25.90$ (age); $r^2 = .850$) than Kalkaska integrating to Rubicon ($Y = -101.93 + 32.7$ (age); $r^2 = .990$). (See site section for details of soil types.) Growth during the study was curtailed significantly only in the C2 plot. This was due to frost which killed some of the new growth in 1972 and not from sawfly damage. Tree heights by plots indicate that the Anderson plantation had the tallest and oldest trees, the Boon Tower plantation had intermediate sized trees, and the DAR plantation had the shortest trees (Figure 10). The frost injury in plot C2 is evident as an abrupt change in the slope of the curve (Figure 9, white discs; and Figure 10).

Tree heights varied significantly by site classes before, during, and after the sawfly outbreak (Figure 11). Trees on site class I were the tallest trees and remained dominant throughout the study. Site class III trees were highly suppressed and remained the shortest throughout the study. The sawfly accounted for a portion of the reduced growth by defoliating the leader and other portions of the trees. Site class II trees were intermediate in growth and frequently occurred in a transition zone between SC-I and SC-III trees.

Tree stocking in the Anderson plantation was examined before, during, and after the sawfly outbreak and summed as a life

Figure 9. Red pine tree height plotted over age for all study plots combined. (White discs are DAR plots which were frost injured.)

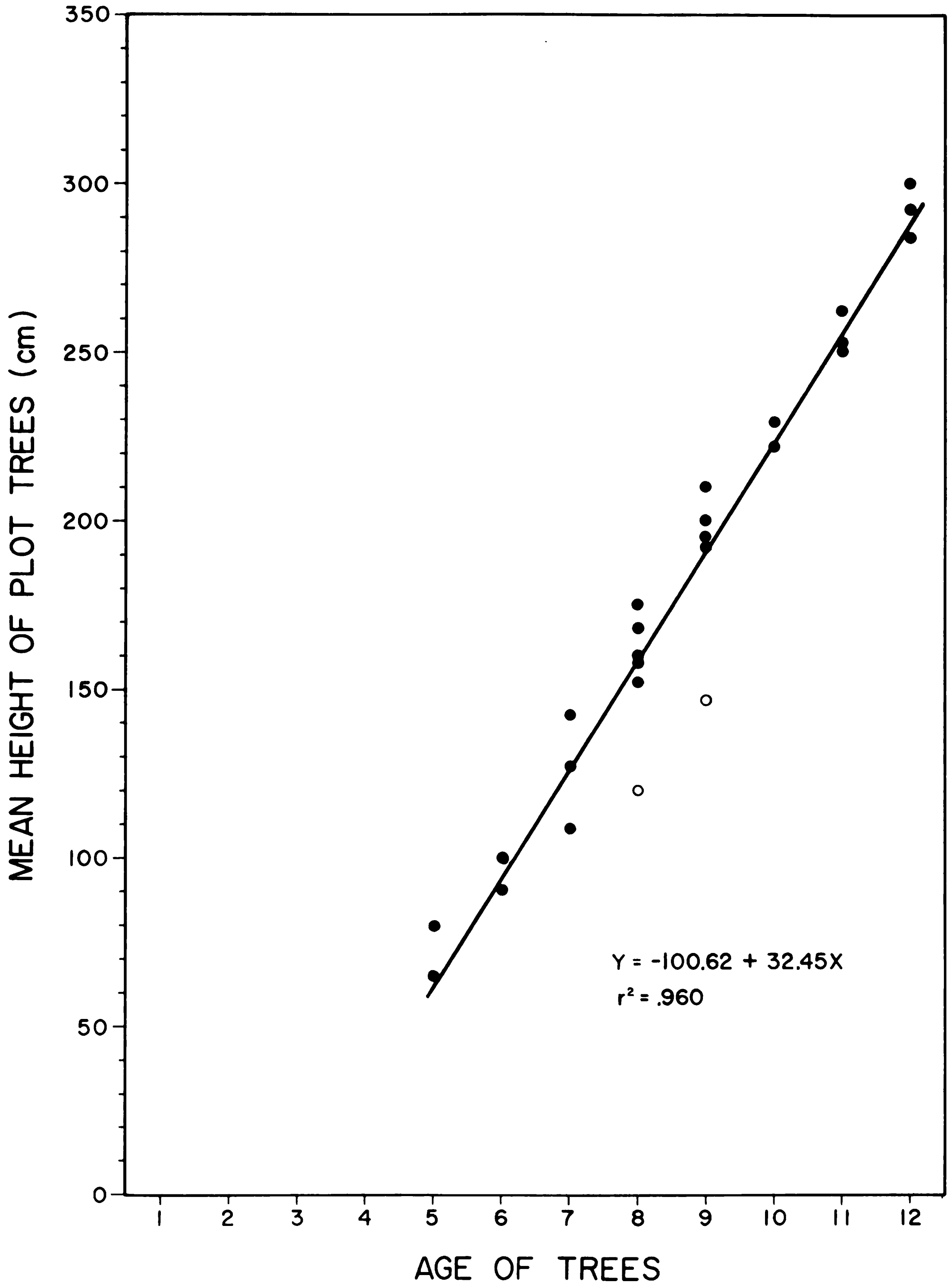

350
300
250
200
150
100
50
0
MEAN HEIGHT OF PLOT TREES (cm)
1
2
3
4
5
6
7
8
9
10
11
12
AGE OF TREES
Y = -100.62 + 32.45X
r² = .960

Figure 10. Red pine heights plotted over years for each study area.

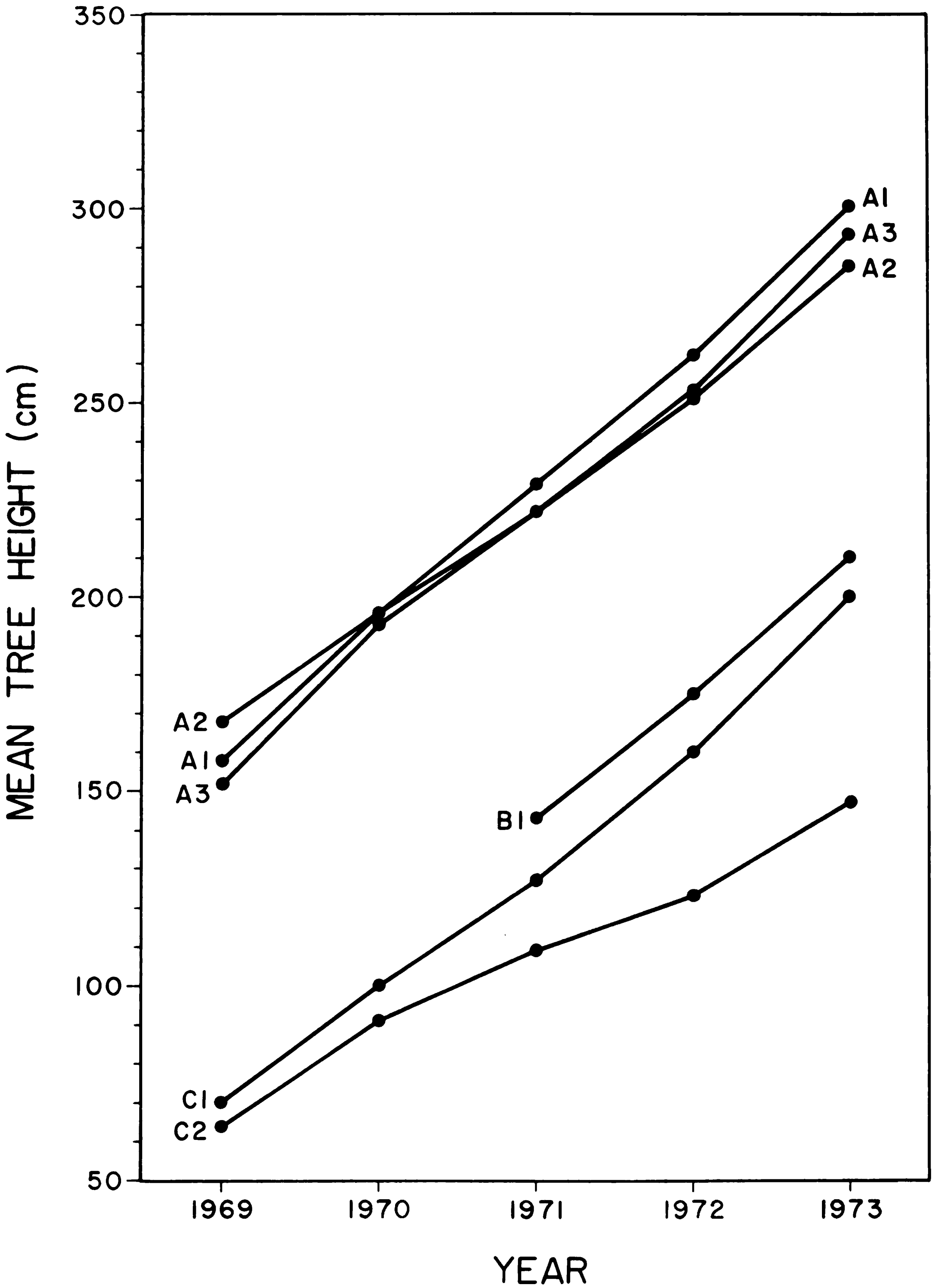

350
300
250
200
150
100
50
MEAN TREE HEIGHT (cm)
A1
A3
A2
A2
A1
A3
B1
C1
C2
1969
1970
1971
1972
1973
YEAR

Figure 11. Mean tree height plotted over years by site classes for plot A3.

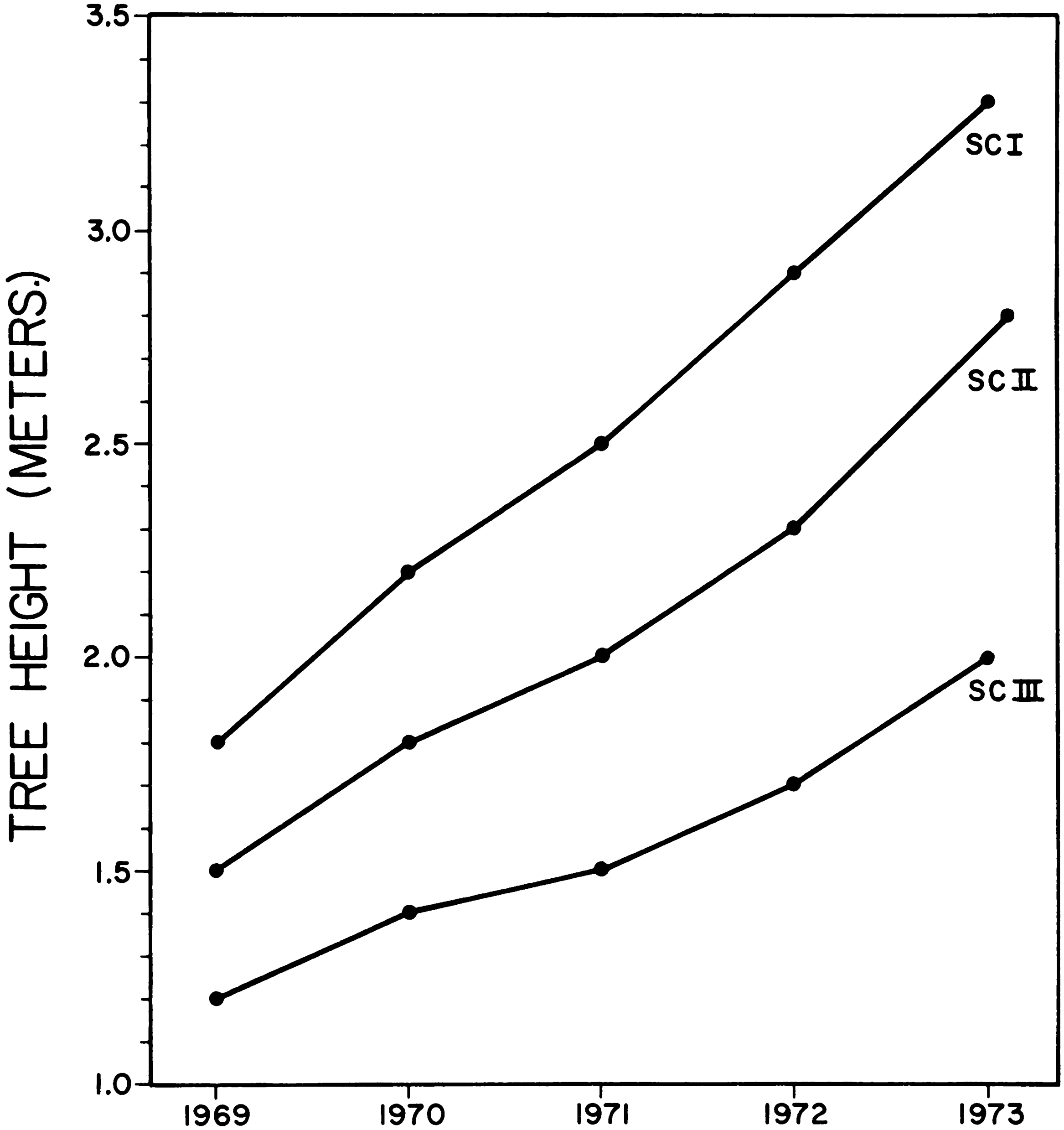

TREE HEIGHT (METERS)
3.5
3.0
2.5
2.0
1.5
1.0
1969
1970
1971
1972
1973
SC I
SC II
SC III

table by site classes (Table 8). Pre-outbreak mortality was highest in site class III areas and lowest in site class I areas. The exact cause of pre-outbreak mortality was not determined, but most of it was probably due to poor survival following planting. All trees that died from the study period were killed by the sawfly. Survival of trees on site class I were nearly unchanged by the outbreak and site class II trees changed only slightly. Very heavy mortality occurred on site class III trees (Table 8), and most of those surviving were badly defoliated or deformed by the end of the outbreak.

Damage Effects from Defoliation

The degree of damage an insect causes is the primary ingredient of its impact. The degree and location of defoliation were examined on the terminal shoot and the entire tree to understand damage as it related to tree deformity and mortality. Univoltine populations of the redheaded pine sawfly feed in July and August in Michigan. At this time the new foliage has fully expanded and the larvae fed on both old and new foliage. The upper whorls are preferred for oviposition and colonies elsewhere on the trees often migrate upwards to the leader while feeding (Benjamin 1955) so there is a high probability that the leader will be defoliated. If the leader dies from defoliation, then a growth loss and/or deformity will result. The magnitude of the growth loss and deformity increases as the uppermost whorl and succeeding lower whorls die. If not sufficiently recovered at thinning time or harvest, the tree may be regarded as a cull.

TABLE 8.--Life table of red pine trees in the Anderson plantation plots combined.

Site Class	Period of Interval x	Alive at (Tx)*	Mortality (Dx)	Dx as % of Tx	% Survival Rate Within x
I	Pre-Outbreak	382	22	6	94
	Outbreak	360	1	2	98
	Post-Outbreak	359			
					Percent Survival = 93
II	Pre-Outbreak	499	71	14	86
	Outbreak	428	15	4	96
	Post-Outbreak	413			
					Percent Survival = 83
III	Pre-Outbreak	795	256	32	68
	Outbreak	539	293	54	46
	Post-Outbreak	246			
					Percent Survival = 31

*Pre-outbreak is the original stocking, outbreak is stocking in 1969, and post-outbreak is stocking in 1974.

In the spring of 1971, the 1970 terminal lengths were measured to the nearest centimeter. Growth of the terminals was measured each year including 1973; the end of the outbreak.

Defoliation caused by the sawfly was estimated at the same time the growth measurements were made. Defoliation that occurred in 1970 or earlier was estimated in the spring of 1971 before larval eclusion. The final estimates were made the summer of 1973 after all feeding was completed. Estimates of terminal defoliation and whole tree defoliation were made separately.

Estimates of the percentage of foliage missing from the tree were made to the nearest 10%. Each year two people estimated the defoliation while viewing the tree from opposite sides. The method used was to keep dividing the defoliation class in half until one 10% increment level was included. For example, assume the tree was 10% defoliated. The first estimate then is the tree defoliated greater or less than 50%--less in this example. The next estimates are greater or less tahn 25%; then 12%; then 6%. In this case the defoliation is less than 12% but greater than 6%. Ten is the only tens unit in the class, therefore the defoliation was estimated at 10%. When the evaluators disagreed the process was repeated and the differences reconciled.

Dead trees were recorded in the spring of 1971 as those died in 1970 or died earlier. Those that died in 1969 or earlier had shed all their foliage and had deteriorated to the point where cause and year of mortality could not be determined.

Degree of defoliation varied considerably between plots, between locations within the plots, and between locations on the tree. Overall, the mean terminal defoliation ranged from 0 to 30.8% and the mean whole tree defoliation ranged from 0.4 to 84.2% for the study plot areas (Table 9).

Some red pine mortality occurred in all study areas during the years of the sawfly outbreak which ended in 1972. No trees died in 1973 the year after the outbreak. Percentage mortality varied from 1 to 40% per study plot by the end of the outbreak (Table 10). About 90% of all mortality, however, occurred in site class III areas (Figures 2, 3).

Heavy defoliation in one year or severe partial defoliations in several years that sum up to a heavy defoliation kills red pine. Two and sometimes 3 years are needed on some trees to reach sufficient defoliation for mortality. Mean amount of defoliation resulting in death of the trees was 94.8 ± 0.8 (S.E.) % for SC-I trees, 97.4 ± 0.6% for SC-II trees, and 96.5 ± 0.2% for SC-III trees. There was no significant difference between these site class means so the overall mean for all areas was 96.5 ± 0.2%. Nearly all trees defoliated 90% or less survived the outbreak, though those with higher percentages of defoliation lost considerable growth and were usually distorted. On lightly defoliated trees, growth loss occurred only if the leaders were defoliated. Leaders were more frequently attacked by the sawfly and more heavily defoliated as the population increased and defoliation of the tree increased (Figure 12).

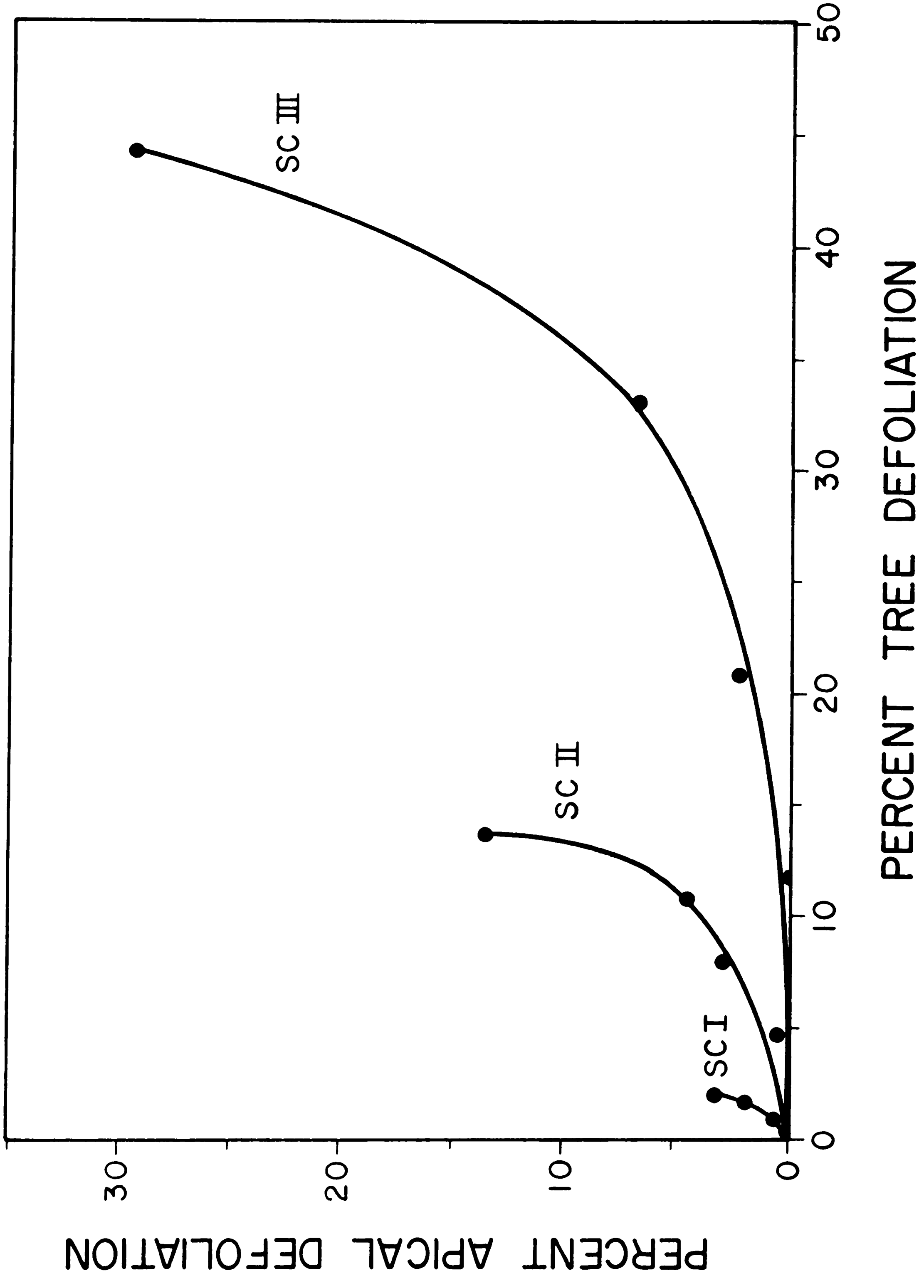
TABLE 9.--Mean apical and whole tree defoliation by year in all study plots in Michigan.

Plot	Location	1970 $\overline{X}$ % ± S.D.	1971 $\overline{X}$ % ± S.D.	1972 $\overline{X}$ % ± S.D.	1973 $\overline{X}$ % ± S.D.
A1	Leader	15.4 ± 31.0	4.9 ± 18.2	0.47± 6.1	0
	Tree	20.4 ± 30.7	13.8 ± 21.8	9.7 ± 17.3	6.2 ± 12.4
A2	Leader	20.2 ± 32.3	2.4 ± 11.9	0	0
	Tree	24.2 ± 30.9	14.8 ± 22.0	10.5 ± 19.0	7.0 ± 11.5
A3	Leader	13.6 ± 30.2	2.8 ± 14.8	0	0
	Tree	16.6 ± 29.2	11.6 ± 22.2	7.1 ± 16.4	4.2 ± 11.7
B1	Leader	-	30.8 ± 36.9	6.8 ± 24.2	0.5 ± 6.4
	Tree	-	84.2 ± 32.4	11.2 ± 24.2	5.6 ± 16.2
C1	Leader	2.9 ± 15.3	2.6 ± 14.5	0.8 ± 8.9	0
	Tree	1.5 ± 7.1	2.3 ± 8.5	1.4 ± 7.2	0.5 ± 4.2
C2	Leader	2.5 ± 14.0	1.5 ± 10.6	0.7 ± 7.1	0
	Tree	1.5 ± 8.7	1.4 ± 6.6	0.9 ± 4.0	0.4 ± 2.4

TABLE 10.--Red pine mortality during the sawfly outbreak by study plots in Michigan.

Plot	Live Trees at Pre-Outbreak	Number of Trees Killed in:					Live Trees at Post-Outbreak	Percent Mortality
		1968-69	1970	1971	1972	1973		
A1	364	43	10	3	0	0	308	15
A2	300	106	6	1	0	0	180	40
A3	664	107	3	8	0	0	526	21
B1	337	0	0	17	10	0	310	8
C1	595	1	3	1	1	0	589	1
C2	763	2	4	3	1	0	753	1

Figure 12. Relationship of leader defoliation to whole tree defoliation.


PERCENT APICAL DEFOLIATION
PERCENT TREE DEFOLIATION
SC I
SC II
SC III
0
10
20
30
40
50

Leader mortality was not only dependent upon the degree of defoliation but also upon the degree of defoliation of the rest of the tree. Trees with less than 70% total defoliation required 95% or more apical defoliation to cause leader mortality. However, trees with more than 70% total defoliation had leaders die when they were more than 90% defoliated.

In order to determine the effect that apical defoliation has on future growth, trees were selected in 1970 which had light total defoliation but varying degrees of apical defoliation. Eighty trees were picked from among the three available site classes (I, II, III) in the Anderson Plantation plots. Also 80 check trees were chosen that were similar in size and defoliation except the apical portion was not injured. A total of 160 trees were examined and terminal growth was measured on each tree in each year from 1970 to 1973 to see if defoliation modified growth.

Mean terminal defoliation varied per tree but did not differ significantly between site classes. Thus the same average amount of defoliation occurred in each group of trees. Growth of the leader, however, varied between site classes both before and after defoliation. The main reason for growth differences before defoliation was because tree height varied by site classes and leader length is related to tree height. Leader growth, however, was retarded from defoliation. By 1973 at the end of the outbreak defoliated leaders were significantly (t-test) shorter than comparable undefoliated leaders (Table 11).

TABLE 11.--Mean tree heights per each study plot by site classes at pre- and post-outbreak periods.*

Plot	No. Trees	Tree Height (meters S.E.)**		
		SC-I	SC-II	SC-III
Pre-Outbreak				
A1	364	-	1.74 ± .03	1.46 ± .03
A2	300	1.67 ± .04	1.56 ± .03	1.59 ± .05
A3	664	1.84 ± .02	1.48 ± .02	1.16 ± .02
B1	337	-	1.56 ± .03	0.95 ± .04
C1	595	0.71 ± .01	0.60 ± .03	-
C2	763	0.64 ± .01	-	-
Post-Outbreak				
A1	308	-	3.38 ± .06	2.52 ± .07
A2	180	3.08 ± .08	2.65 ± .06	2.40 ± .07
A3	526	3.34 ± .04	2.65 ± .01	1.96 ± .04
B1	310	-	2.27 ± .05	1.26 ± .05
C1	589	2.72 ± .02	1.83 ± .09	-
C2	753	1.46 ± .02	-	-

*Pre-outbreak is 1969 for all plots except B1 in 1971. Post-outbreak is 1973 for all plots.

**Dashed areas in table indicate that site class was absent from the plot.

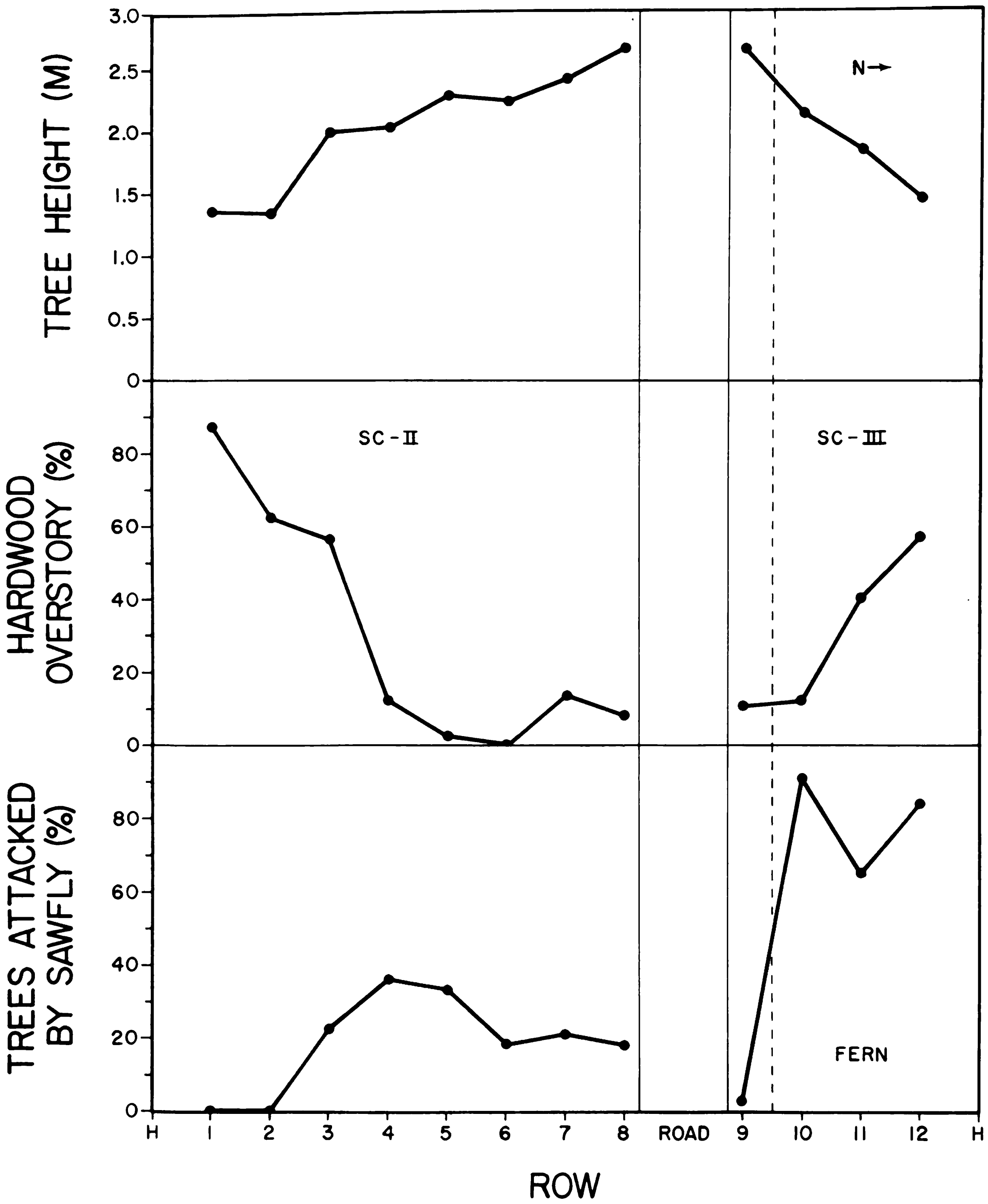
Leaders that were severely defoliated died the next season. A dead top resulted in one or more lateral shoots taking dominance the next year. These trees had a prominent crook or forked top.

Competition

Each plot was examined to see if the red pine was competing with other vegetation and to learn how this might affect the insect population. The growth of red pine varied considerably within some plots and heights were influenced the greatest where there was competing vegetation. This was most obvious where red pines were growing adjacent to hardwoods (red maple et al.) or where they were growing within patches of bracken fern. Plot B1 (Boon Tower), a long narrow planting 12 rows wide and established between two mature hardwood stands, was chosen to examine the effects of competing vegetation. Tree height measurements taken before the peak of the outbreak show trees considerably shorter along the hardwood edges compared to those elsewhere. Further, tree height by rows was related inversely to percentage of hardwood overstory (Figure 13). Mean tree height was 2.04 m ± 0.46 S.D., and the shortest trees in rows 1, 2, and 12 were shorter by one S.D. Apparently the hardwoods were directly competing with the red pines and thus influenced their growth significantly--at least in the first three rows from each edge.

The insect population was highest along the north edge (rows 10, 11, 12) of the planting. Trees within these three rows were designated an SC-III site, whereas the remaining area was an

Figure 13. Red pine plot B1 showing mean tree heights, hardwood overstory, and trees attacked by sawflies, by rows in 1972. SC-I, SC-II refer to site classes. Fern refers to bracken fern.


TREE HEIGHT (M)
3.0
2.5
2.0
1.5
1.0
0.5
0
N→
HARDWOOD OVERSTORY (%)
80
60
40
20
0
SC-II
SC-III
TREES ATTACKED BY SAWFLY (%)
80
60
40
20
0
FERN
H
1
2
3
4
5
6
7
8
ROAD
9
10
11
12
H
ROW

SC-II site. This was consistent with population levels in other plots--the SC-III sites had the most insects and generally the smallest trees. In this instance some very short trees (rows 1 and 2) along the south edge of the planting were free from insects (Figure 13). This is unusual but may have been due to the heavy shading from the hardwoods, or some microclimatic factor. Benjamin (1955), however, reported the sawfly preferred shaded trees for oviposition.

Though red maple, Acer rubrum L. and other trees competed with red pine, young black cherry (Prunus serotina Ehrh.) trees scattered among the planting did not appear to do so. Root examinations showed that the maple roots occupied the same zone as the red pine while the cherry roots were below the red pine. Further, the cherry roots did not form dense mats as maple roots did.

Red pine growth was also noticeably affected from competing ground cover (Table 11) especially in areas where bracken fern formed dense mats within plots such as in A1 and A3 (Figures 2 and 3). In these pockets, rhizome and root mats filled the upper horizons of soil in the tree root zone. Tree height differences were usually dramatic at the interfaces where the fern patch ended and grasses, forbs, or lichens covered the ground. Plants other than bracken fern did not appear to have an effect on tree height.

Apparently, both hardwoods and bracken fern are competitive to young red pines and growth loss in red pine is likely due to a reduction in available moisture.

THE SITE

Site, or the location in the environment which the tree and sawfly inhabit, is the modifying component of impact. It sets the constraints or boundaries of the development and interactions of and between the insect and the tree. Certain aspects of the site were examined to seek those parameters important for sawfly impact.

The literature suggested that site quality and availability of water to the tree often affects populations of sawflies and other defoliators. For example, Gremal'skii (1961) summarizing the Russian work on the resistance of pine stands to defoliator pests, concluded that mass breeding occurs only in stands containing physiologically weakened trees. He noted causes of nutritional deficiency where survival rates with some insect pests was higher when fed foliage from weakened stands. White (1952) showed that *N. lecontei* larvae died after briefly feeding on jack pine seedlings grown on fertile nursery soil, whereas larvae on naturally reproduced seedlings taken from the forest and grown on unfertilized soil completely defoliated the host. Schwenke (1962), who studied the sawfly *Diprion pini* (L.) on trees growing on good and poor sites, found that survival rate and size of larvae was greater on trees from poor sites. He suggested that the unfavorable water balance in poor sites increased the sugar content of the needles which is probably the major limiting site factor for forest growth. He

further remarked that any suitable measure of site (direct or indirect) is, in effect, an estimate of soil moisture relationships.

Soil Structure and pH

The soils in the study plots and in other sawfly infested areas were examined to see if soil type or water holding capacity of the soil was related to the development of the tree and the size of the insect population. Two personnel of the Soil Conservation Service[1] examined and classified the research plots to soil series. They classified plots A1, A2, A3, and B1 as being composed of soil in the Kalkaska integrating to Rubicon phases. Plots C1 and C2 were soils of the Kalkaska integrating to Montcalm phases. Interpreting from Hannah's (1967) soil classification system, the DAR Plantation (C plots) soils are more productive for red pine than those of the Anderson or Boon Tower plantings. The data agree with this.

Local soil types were determined in plots A1 and C1 by digging soil pits in sawfly attacked and non-attacked areas. A 4-inch bucket soil auger was used to determine the solum characteristics between sawfly attacked and non-attacked sites in the other plots as well as the locations visited during the extensive survey conducted in Michigan, Wisconsin, New York, and Ontario, Canada. Variation in soil texture, soil depth, and pH were examined for key differences. The pH was measured using a Hellige-Truog soil reaction test kit.

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[1]Soil scientists, SCS, Cadillac, Michigan.

Gross site requirements for red pine are well documented. Wilde et al (1964) considers 10% silt plus clay to be the minimum fine particle ratio for adequate growth. On soils heavier than sandy loams, silt and clay have an adverse effect on red pine growth since they tend to restrict permeability and aeration (Van Eck and Whiteside 1963). In lower Michigan soils formed in deep sands, productivity is also related to soil profile development. Hannah (1967) found a positive correlation between site index and the depth of the A and B horizons. At least 45-50 cm of reasonably permeable, fairly well aerated soil is necessary for normal red pine development. Below that depth, if the soil is compacted, very coarse, or calcareous, growth decreases after 25 years (Van Eck and Whiteside 1963). On the other hand, if the soil below 45 cm is medium-to-fine textured, the growth rate is likely to be rapid (White and Wood 1958). The influence of soil moisture, according to Stoeckler and Linstrom (1950), masks the influence of nutrients, possibly because higher nutrient levels are associated with finer textured soils. Excessive soil compaction can restrict root development (Armson and Williams 1960). Stone et al. (1954) describe growth and survival of red pine in imperfectly and poorly drained soils. Best growth for red pine is associated with a soil pH of 4.5 to 6.0 (Wilde and Iyer 1962). A recent review of forest site quality evaluations by Carmean (1975) suggests an integrated approach to determining forest site quality.

In some locations (Table 12, Appendix A) the sawfly was exploiting sites of low quality for red pine. Red pine growing in

TABLE 12.--Site parameters of redheaded pine sawfly infestations within plots examined in North America.

Plot No. (See Appendix	Moisture Regime	Soil Texture	Soil Reaction (pH)	Ground Cover	Other
1	dry	coarse			Sandblow
2	dry	medium			
3	moist	medium			Abandoned farmstead
4	dry	medium			Frost pocket
5	moist	medium		dense sod	Frost pocket
6	dry	coarse			
7	dry	medium			Limestone and rock outcrops
8	wet	fine	8.0		
9	dry	fine		braken fern	Limestone and rock outcrops
10	wet	medium	7.0		
11	dry	medium	7.0		Frost pocket
12	moist	fine		dense sod	
13	dry	coarse			
14	dry	coarse			Sandblow
15	dry	coarse			Overburden
16	dry	coarse			
17	moist	medium			Abandoned farmstead
18	wet	coarse			
19	moist	coarse		hardwood edge	
20	dry	coarse			
21	moist	medium			Compacted soil
22	moist	fine	7.5		
23	dry	coarse			Overburden
24	wet	fine			
25	dry	medium			
A1	dry	coarse	6.5		Sandblow
A2	dry	coarse	6.5		Sandblow
A3	dry	coarse	6.5	braken fern	
B1	dry	coarse	6.5	hardwood edge	
C1	moist	medium	6.2		Eroded
C2	moist	medium	6.2		Frost pocket

saldblows where the top soil was no longer present and the subsoil lacked a fine textured layer or color bands and red pine growing in poorly drained clay soils with a pH greater than 7.0, represented the extreme ends of the available moisture spectrum in which the trees were severely damaged by the sawfly. In the former situation, the lack of a suitable moisture holding capability and in the latter condition the excessive moisture holding capability represent sites where the establishment of red pine is not recommended (Bell 1971).

The more pronounced the soil change between sawfly attacked and non-attacked sites within a plantation the more discrete was the damaged area. Other soil conditions which provided discrete pockets of sawfly activity were composed of soils severely compacted from old road grades and overburden soil (Table 12). In two instances the pocket effect of short trees and sawfly activity was adjacent to abandoned farm building foundations. These were rectangular pockets, suggesting that a prior cropping activity left the soil in poor condition.

Within the study plots there was a definite gradation of soil characters between the three site classes that were set up (SC-I, SC-II, SC-III). For instance, in plot A1, the solum characteristics (Table 13) in the non-attacked portion of SC-I suggests a more productive site by the presence of a leaching or A2 horizon and a somewhat deeper soil with narrow texture and color bands than SC-III, which underwent severe sawfly attack. A more strongly developed upper B occurs in SC-I also. Portions of the SC-III upper B horizon were irregularly and strongly cemented in some locations. These

TABLE 13.--Solum characteristics for plot A1, SC-I (non-attacked) and SC-III (severely attacked) areas.

Site Class	Horizon	Depth (cm)	Color	pH	Texture
I	A1	0-20	10YR 4/1	6.0	Coarse sand, loose
	A2	20-28	7.5YR 6/2	6.0	Coarse sand
	Bir	28-30	2.5YR 3/2	5.0	Fine to medium sands, friable
	B2	30-60	7.5YR 5/8	6.0	Coarse sand, weakly cemented
	B3	60-80	7.5YR 5/6	6.0	Coarse sand
	C	80+	7.5YR 7/6	6.5	Coarse sand
	Texture bands (¼" thick) and color bands 48-60"				
III	Ap	0-22	10YR 3/1	6.5	Coarse sand, loose
	Bir	22-25	10YR 2/2	6.0	Coarse sand
	B2	25-43	5.0YR 4/6	5.0	Coarse sand, cemented variously
	B3	43-70	7.5YR 6/8	5.0	Coarse sand
	C	70+	7.5YR 7/4	7.0	Coarse sand

visible differences between SC-I and SC-III within plot A1 suggest that water and nutrients would be least available for red pine growth in the SC-III area. The growth response of the trees within the site classes reflect this difference in available moisture.

In plot A3 the difference between SC-I and SC-III was more subtle in soil characters (Table 14). Depth to the C horizon was 13 cm greater in SC-III. Both site classes show a less strongly developed soil profile than in plot A1. The principle difference occurred because there was a thick mat of bracken fern in A3 which competed with trees for moisture on a somwhat poorer site.

In plot C1, the major soil difference between SC-I and SC-II sites was the light top soil erosion in the SC-II area. There was a more coarse textured and thinner Ap horizon in SC-II.

Plot B1 was atypical in the degree of erosion and compaction. The road through the plot was previously a railroad grade. Just south of the plot the terrain sloped upward with a tree cover of maple. The soil on this slope has a very prominent A2 horizon. About 3 rows (6-7 m) into the planting the A2 horizon ceased and was replaced by an irregular bordered Ap-like horizon over the Bir. In the central portion of the plot, running north and south, is an area of compacted soil. South of the pine stand the compacted layer follows a course up the slope indicative of an old trail. Sawfly damage within the plot was more strongly aggregated within the compacted area south of the roadway. The compacted portion within the plot lacked an A2 horizon whereas south of the plot the trail had a narrow A2 horizon. Perhaps the sawfly was showing preference for an

TABLE 14.--Solum characteristics for plot A3, SC-I (non-attacked) or SC-III (severely attacked) areas.

Site Class	Horizon	Depth (cm)	Color	pH	Texture
I	Ap	0-20	7.5YR 5/2	6.5	Coarse sand, loose
	Bir	20-25	2.5YR 3/4	6.0	Coarse sand
	B	25-45	7.5YR 5/6	5.0	Coarse sand
	C	45+	7.5YR 7/6	5.5	Coarse sand
III	Ap	0-22	7.5YR 3/2	6.5	Coarse sand, loose
	Bir	22-28	2.5YR 3/4	6.0	Coarse sand
	B	28-58	5.0YR 4/8	5.0	Coarse sand
	C	58+	7.5YR 8/4	5.5	Coarse sand

area where man had disturbed the soil profile in the past. North of the roadway within plot B1 the Ap horizon was evident to the hardwood tree line where the A2 horizon again became evident. Thick bracken fern between the hardwoods and roadway created severe competition for pine growth and this area was classified as SC-III.

Throughout Wexford County where sawfly activity was present on the Kalkaska integrating to Rubicon soil the most dominent soil character difference between attacked and non-attacked sites was the presence of the A2 horizon in the non-attacked portion and its absence or only slight development in the attacked areas. In these areas the sawfly pocket activity pattern was less discernible. Growth differences between attacked and non-attacked trees was also less noticeable. The degree of development of the A2 horizon probably reflects subtle differences in moisture and nutrients available for red pine growth. The sawfly may respond to the affects these have on the trees. With a shift toward less precipitation, trees occupying coarse textured SC-III areas could become stressed sooner than those occupying SC-I. Conversely, on SC-III areas that are imperfectly to poorly drained, increased precipitation could place red pine into a stressed condition sooner than on SC-I. SC-II represents a transition zone in susceptibility to sawfly attack. The degree of damage within this zone is probably dependent on the duration and intensity of the droughty or excessive precipitation period.

The data suggest that within plantations of red pine, those trees that are attacked heaviest by the sawfly (site class III areas) are characterized by one or more of the following:

1. Depth of parent material is significantly less (t-test $P < .01$) in attacked than non-attacked sites (mean 51 cm difference).
2. Soil pH in the upper 23 cm of the solum tends to be slightly acid to slightly alkaline on the attacked site (mean 7.0, range 6.5 to 8.0). The non-attacked sites tend to be more acid (mean 6.2, range 6.0 to 6.5).
3. Attacked sites may be composed of overburden soil and/or may be more compacted.
4. Soil texture is coarser on attacked sites and textural banding, when present, is less well developed.
5. On heavier soils attacked sites are imperfectly to poorly drained.

Attacks in red pine plantations where there was no discernable pocket activity, as occurs in portions of Canada, were limited to those sites which had rocky outcroppings present and where the soil depth varied from 10 to over 75 cm to bedrock. Sawfly attacks on these sites were not as aggregated nor related to tree size or depth to bedrock (Table 12, Appendix A).

Precipitation

The historical records of sawfly activity and weather records were examined to determine whether sawfly outbreaks were

related to annual precipitation. The review of past outbreaks was done cautiously, since no standards exist and interest in the sawfly varied over time as did the number of or quality of reports. However, by piecing together such subjective statements as "increasing," "decreasing," "static," and "widespread" as well as the number of reports filed each year, the relative density of the sawfly was determined over time. When populations became damaging, suppression efforts were conducted. Fowler (1973) provided a review of when and where chemical suppression was conducted against the sawfly on the national forests in the Northeastern Forest Service Region. Reports on file at the St. Paul Field Office[2] and by Benjamin (1955) were reviewed for incidence of sawfly in Michigan from 1935 to 1971. Based on these reports, each year's population was classified as endemic, a local outbreak, or a widespread outbreak.

The effect of various climatic factors either individually or in combinations is not fully understood. Thus, the Palmer method of drought index numbers was chosen to represent the intensity of drought and wet periods. These index numbers, given by Strommen et al. (1969), are a function of accumulated weighted differences between actual precipitation and the precipitation requirement, where the requirement depends on: carryover of previous moisture, evapotranspiration, moisture recharge and runoff that is appropriate for the area being investigated.

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[2]U.S.D.A. Forest Service, St. Paul, Minnesota.

developed to provide index numbers and thus permit comparing particular periods of interest with the average climatic conditions for the area. The index values are accumulative.

Drought severity is usually discussed in four classes: mild, moderate, severe, and extreme by the Weather Bureau and the U.S. Department of Agriculture. Palmer (1965) arbitrarily assigned a drought index value of -4.0 to the accumulated monthly index values for the driest periods on record that he studied and called the class extreme. He divided the lesser accumulated monthly index values equally into drought index values of -1.0 mild, -2.0 moderate, and -3.0 severe. Conversely, values of +1.0 to +4.0 were assigned to describe wetter than normal periods.

Michigan is divided into 10 climatic divisions to provide as much climatic homogeneity as possible to the users of the system. The redheaded pine sawfly has historically been a problem in the four northern divisions: West Upper, East Upper, Northwest Lower, and Northeast Lower.

Red Pine growth is correlated with precipitation (Neary et al. 1972). They showed a positive correlation between the amount of rainfall during July-September (the period of bud set), plus the following May and June (the period of water uptake) and annual bud length growth. To correlate both precipitation and sawfly with the host, Palmer Index values were used in the following manner. For each year analyzed, the average value for the months of April, May, and June, the period of moisture uptake and sawfly oviposition, was added to the previous years average value for July, August, and

September, the period of larval activity as well as bud set. These values were then plotted over years along with the population density for each climatic division (Figures 14 and 15).

It is evident in viewing these figures that the data fluctuates in both directions from the "normal" or 0 Palmer Index values and they generally are associated with population releases. Populations usually collapse when the index values move back toward 0. The least amount of climatic variation occurs in the Northeastern Lower Division, and this division historically has been affected by sawfly the least, only local outbreaks are recorded.

The mean Palmer's Index values for each climatic division were plotted over broad categories of sawfly population density (Figure 16). Because of the larger variations associated with climatic data and the subjective evaluation of sawfly density, no absolute predictions can be made from the relationship. However, there is a strong relationship showing that endemic (very low) populations occur during moist periods, local (limited area) populations generally occur during wet or near normal years, and widespread (large area) populations occur during drier periods. Analysis of variance of endemic and widespread values on Palmer's Index showed a highly significant difference ($< .01$, $F_{1,100} = 8.5$). The historical records did not provide information as to whether a given outbreak was on a wet or dry site. However, based on the extensive survey it appears reasonable to assume that outbreaks during the more moist years were associated with imperfectly to poorly drained soils. It

Figure 14. Sawfly populations and Palmer's Index values for the period 1935-1973 for the northeast and northwest regions of Michigan's Lower Peninsula.

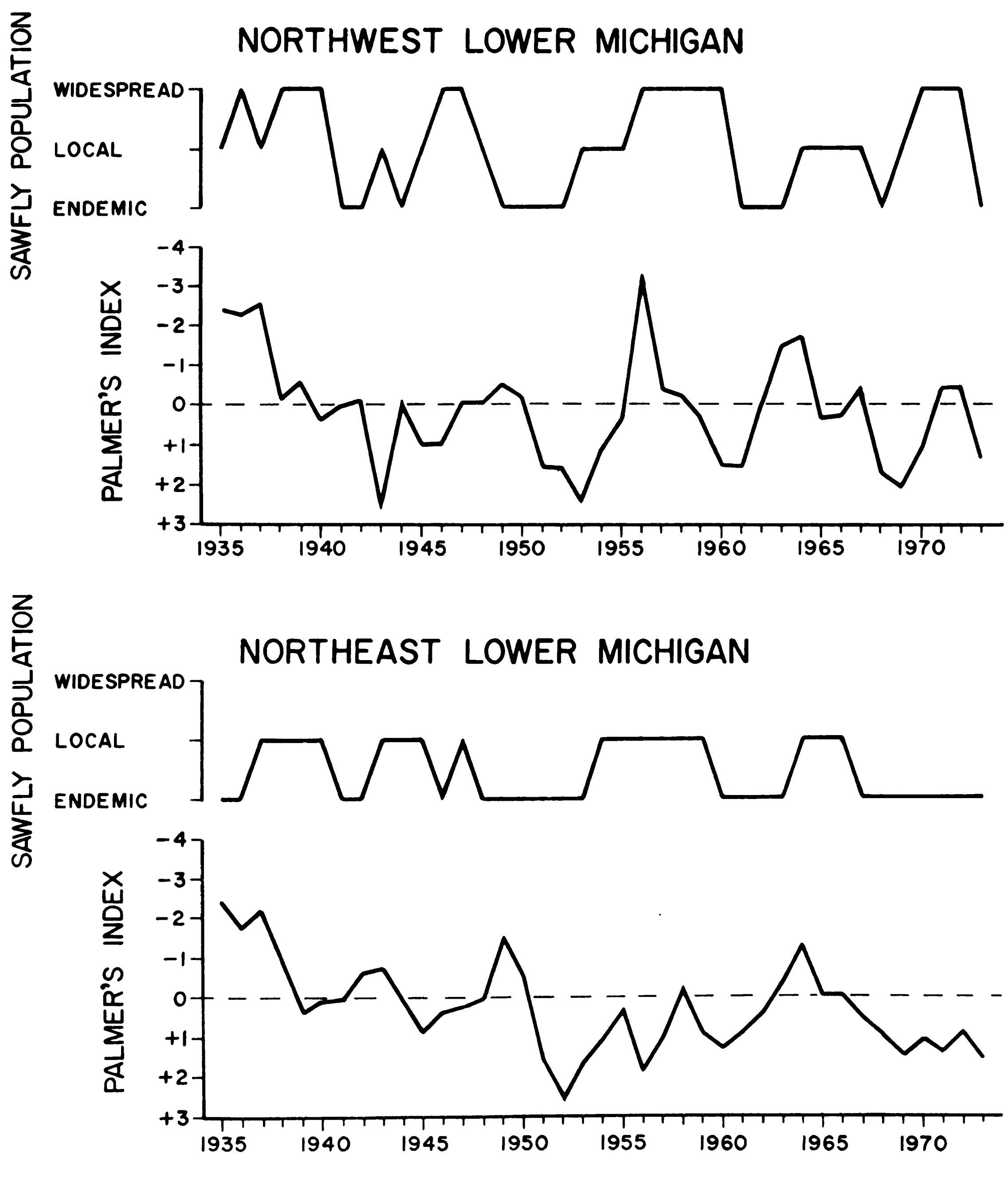
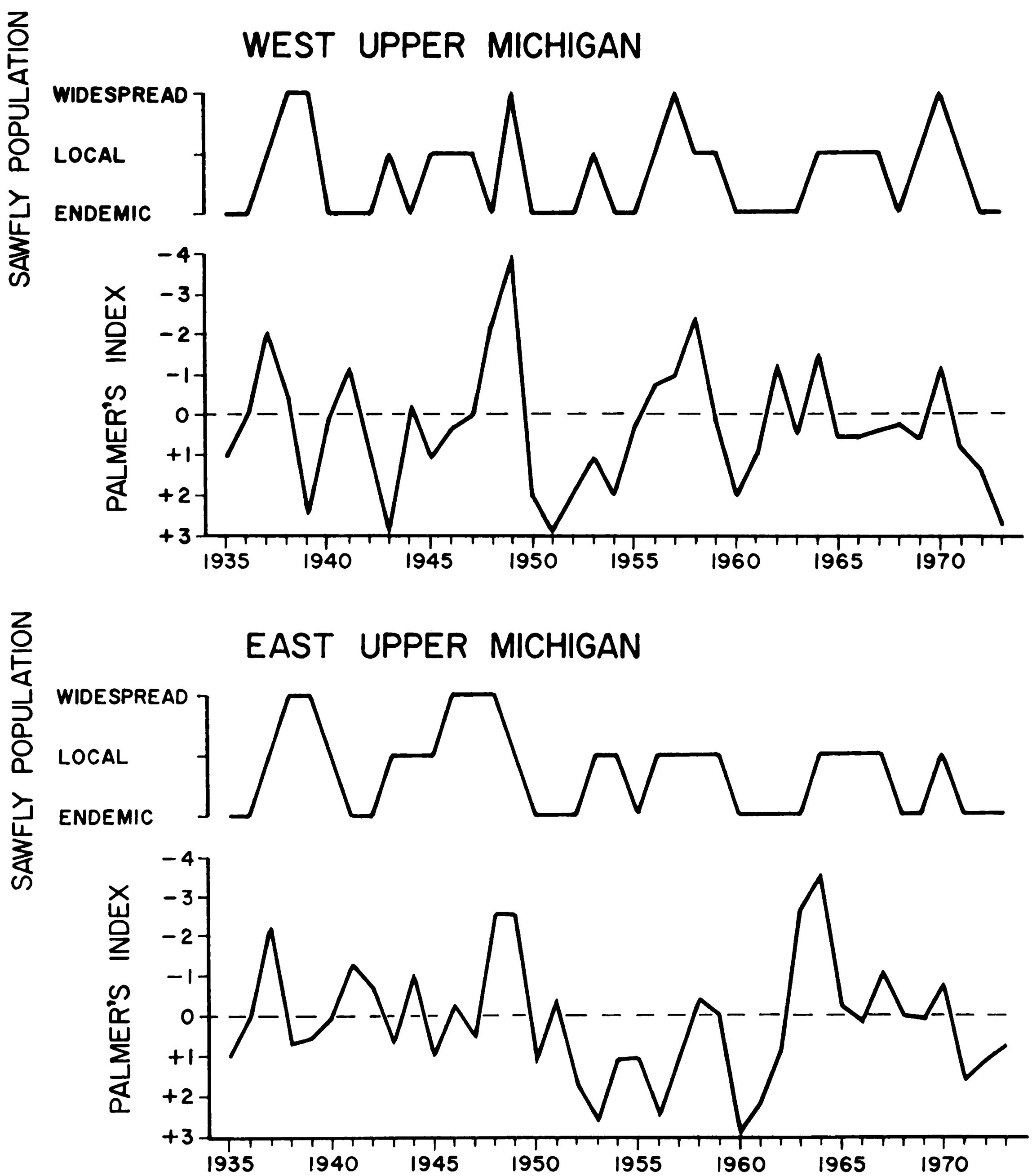

NORTHWEST LOWER MICHIGAN
SAWFLY POPULATION
WIDESPREAD
LOCAL
ENDEMIC
PALMER'S INDEX
-4
-3
-2
-1
0
+1
+2
+3
1935
1940
1945
1950
1955
1960
1965
1970
NORTHEAST LOWER MICHIGAN
SAWFLY POPULATION
WIDESPREAD
LOCAL
ENDEMIC
PALMER'S INDEX
-4
-3
-2
-1
0
+1
+2
+3
1935
1940
1945
1950
1955
1960
1965
1970

Figure 15. Sawfly populations and Palmer's Index values for the period 1935-1973 for the west and east regions of Michigan's Upper Peninsula.



WEST UPPER MICHIGAN
SAWFLY POPULATION
WIDESPREAD
LOCAL
ENDEMIC
PALMER'S INDEX
-4
-3
-2
-1
0
+1
+2
+3
1935
1940
1945
1950
1955
1960
1965
1970
EAST UPPER MICHIGAN
SAWFLY POPULATION
WIDESPREAD
LOCAL
ENDEMIC
PALMER'S INDEX
-4
-3
-2
-1
0
+1
+2
+3
1935
1940
1945
1950
1955
1960
1965
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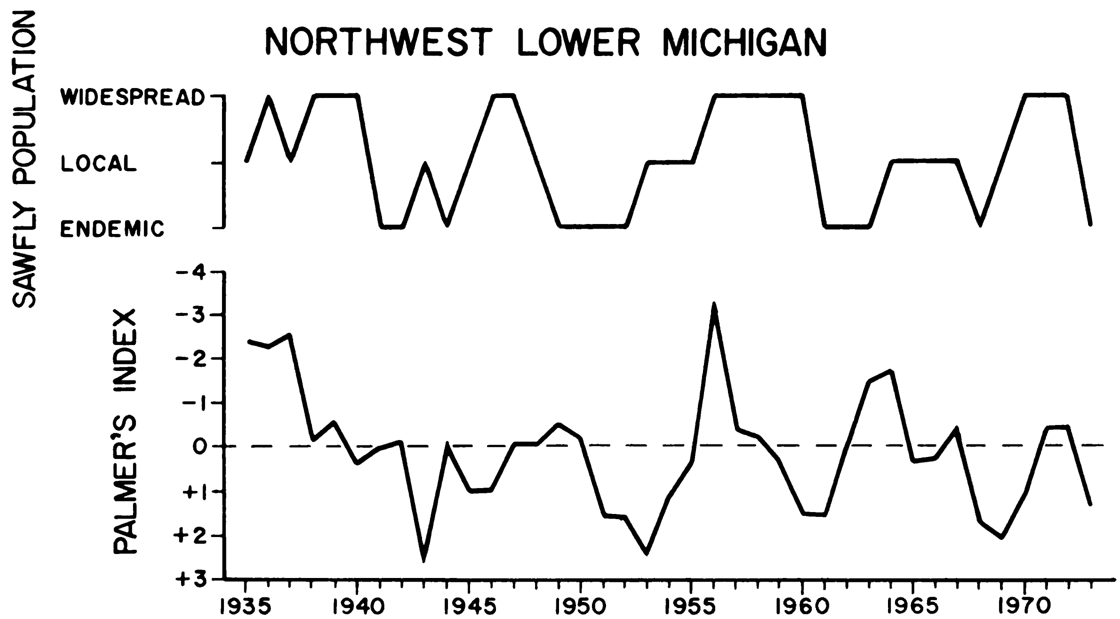
NORTHWEST LOWER MICHIGAN
SAWFLY POPULATION
WIDESPREAD
LOCAL
ENDEMIC
PALMER'S INDEX
-4
-3
-2
-1
0
+1
+2
+3
1935
1940
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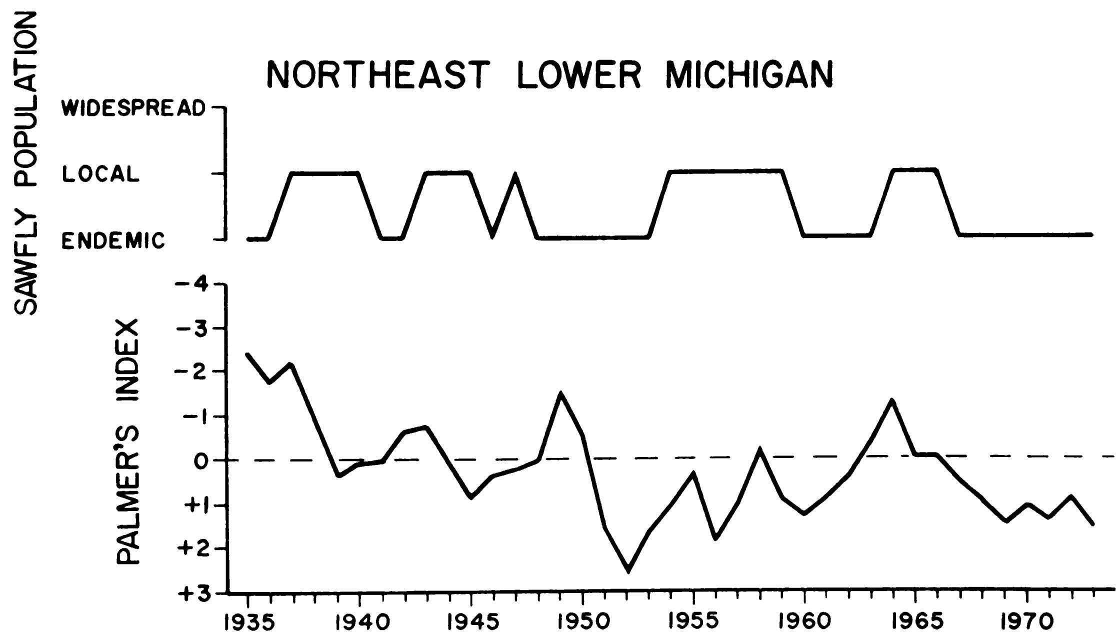
NORTHEAST LOWER MICHIGAN
SAWFLY POPULATION
WIDESPREAD
LOCAL
ENDEMIC
PALMER'S INDEX
-4
-3
-2
-1
0
+1
+2
+3
1935
1940
1945
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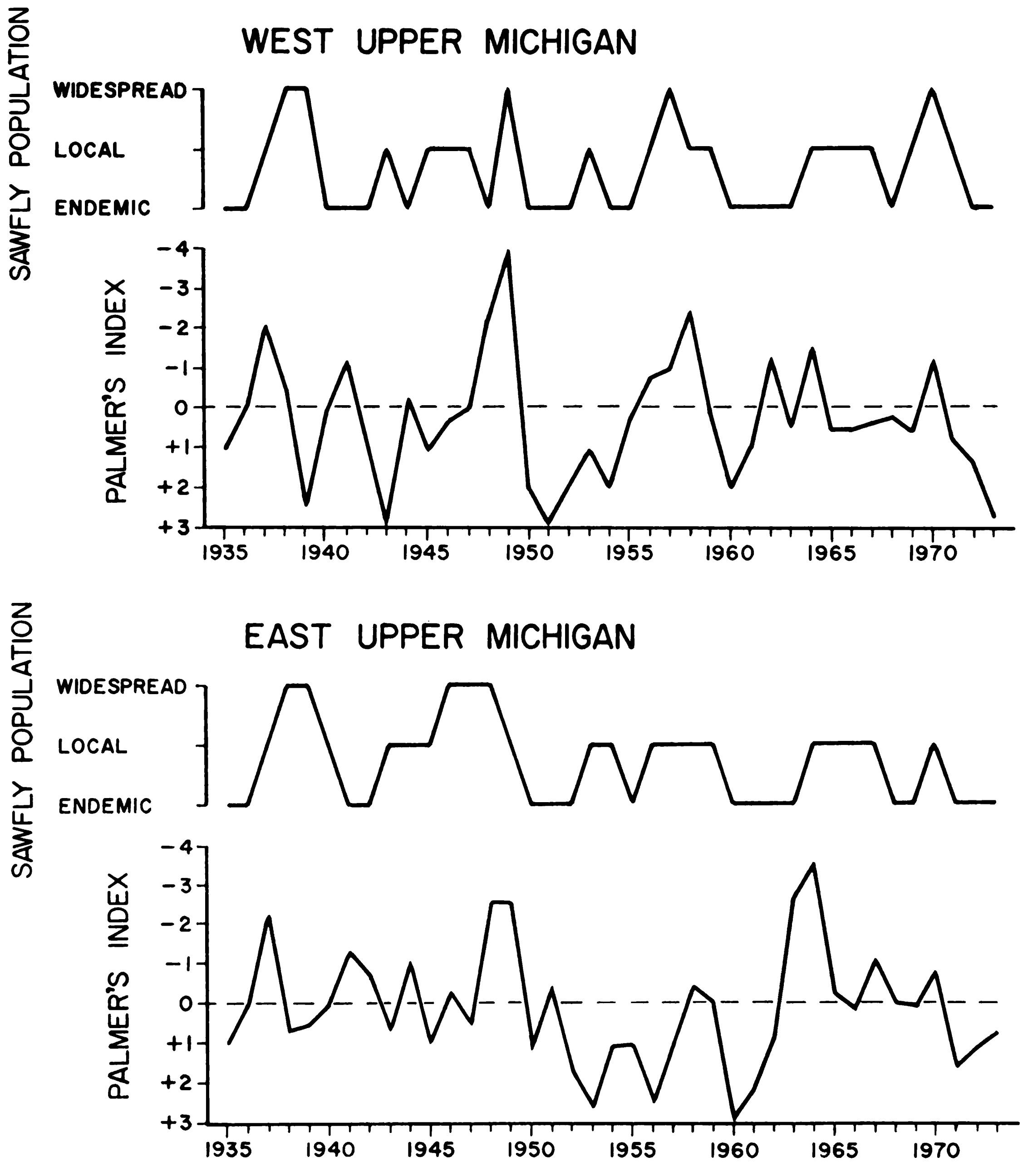
1965
1970

Figure 15. Sawfly populations and Palmer's Index values for the period 1935-1973 for the west and east regions of Michigan's Upper Peninsula.


WEST UPPER MICHIGAN
SAWFLY POPULATION
WIDESPREAD
LOCAL
ENDEMIC
PALMER'S INDEX
-4
-3
-2
-1
0
+1
+2
+3
1935
1940
1945
1950
1955
1960
1965
1970
EAST UPPER MICHIGAN
SAWFLY POPULATION
WIDESPREAD
LOCAL
ENDEMIC
PALMER'S INDEX
-4
-3
-2
-1
0
+1
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1935
1940
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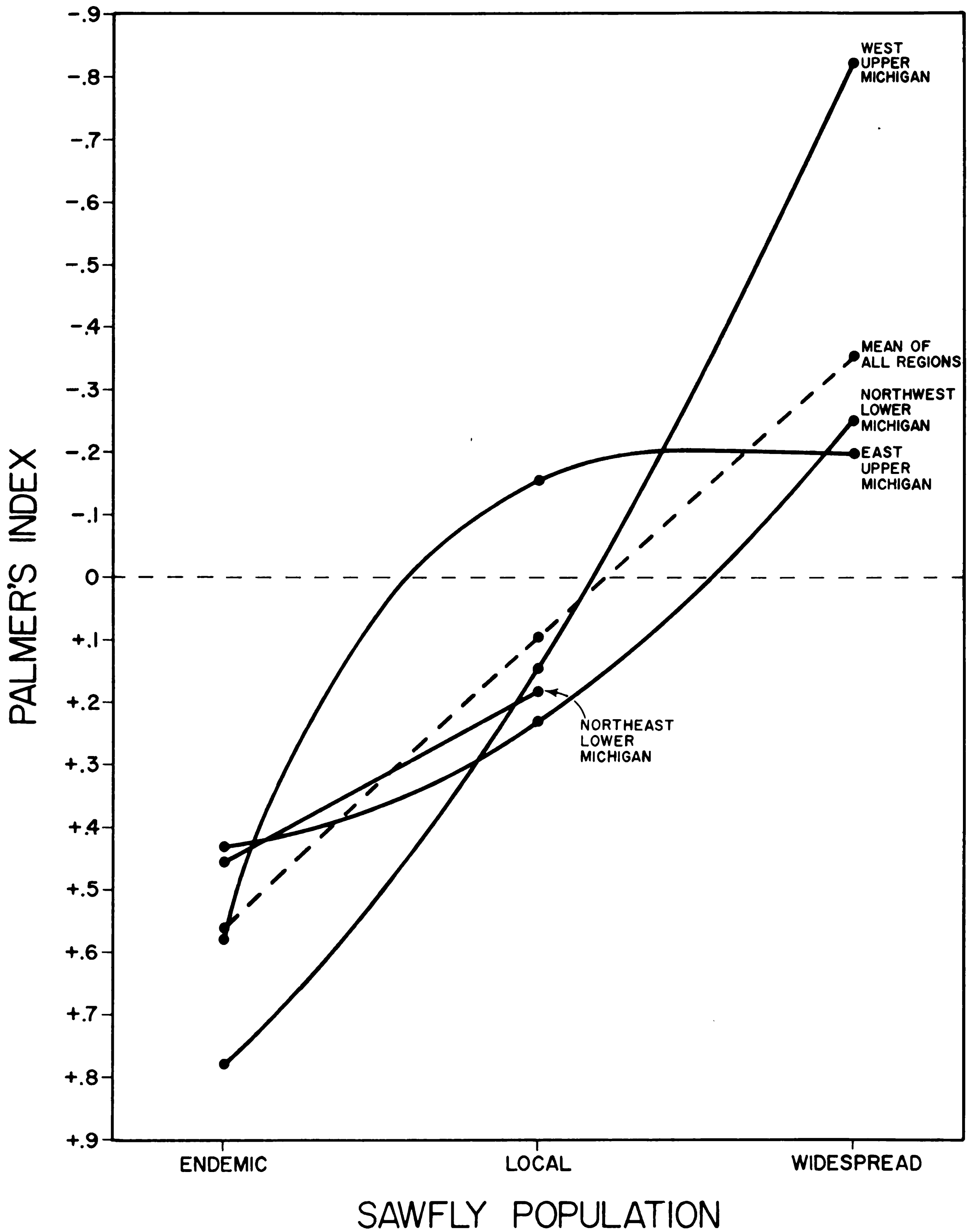
Figure 16. Relationship of mean Palmer's Index values to populations of sawfly in Michigan by regions. (The northeast lower Michigan region did not have widespread population densities.)


-.9
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-.6
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-.4
-.3
-.2
-.1
0
+.1
+.2
+.3
+.4
+.5
+.6
+.7
+.8
+.9
PALMER'S INDEX
WEST UPPER MICHIGAN
MEAN OF ALL REGIONS
NORTHWEST LOWER MICHIGAN
EAST UPPER MICHIGAN
NORTHEAST LOWER MICHIGAN
ENDEMIC
LOCAL
WIDESPREAD
SAWFLY POPULATION

appears that there is utility in the Palmer's Index for predicting outbreaks of this insect.

DISCUSSION

The Redheaded pine sawfly injures, and may kill, portions of or all or a tree by removal of both new and old foliage. Trees that survive sawfly attack may exhibit crooks, multiple stems or branch deformity. The studies indicate that within a plantation the sawfly is strongly influenced by microsite conditions which the land manager can recognize. The land shows a capability to support various levels of sawfly population which inflict varying degrees of change to an established planting.

Tree vigor appears to be the pivotal element on which the insect host-site ecosystem revolves. Stressed red pines are injured much more by the sawfly than are those growing well. The sawfly apparently prefers to attack shorter trees within a planting and tree height is one measure of vigor as well as an indicator of the relative productivity of the soil on which a tree is growing. Soil productivity is influenced by its nutrient content and its ability to hold moisture. When nutrients and/or available moisture becomes limiting to red pine, the trees become stressed. Three different site classes were identified which exhibited increasing susceptibility to sawfly which will henceforth be called site resistance classes (SRC-I, SRC-II, SRC-III) to distinguish them from standard site class terminology. Each site resistance class, because of its soil quality and moisture holding capability, is indicative

of the potential to provide stressed growing conditions for red pine which are then subject to sawfly attack.

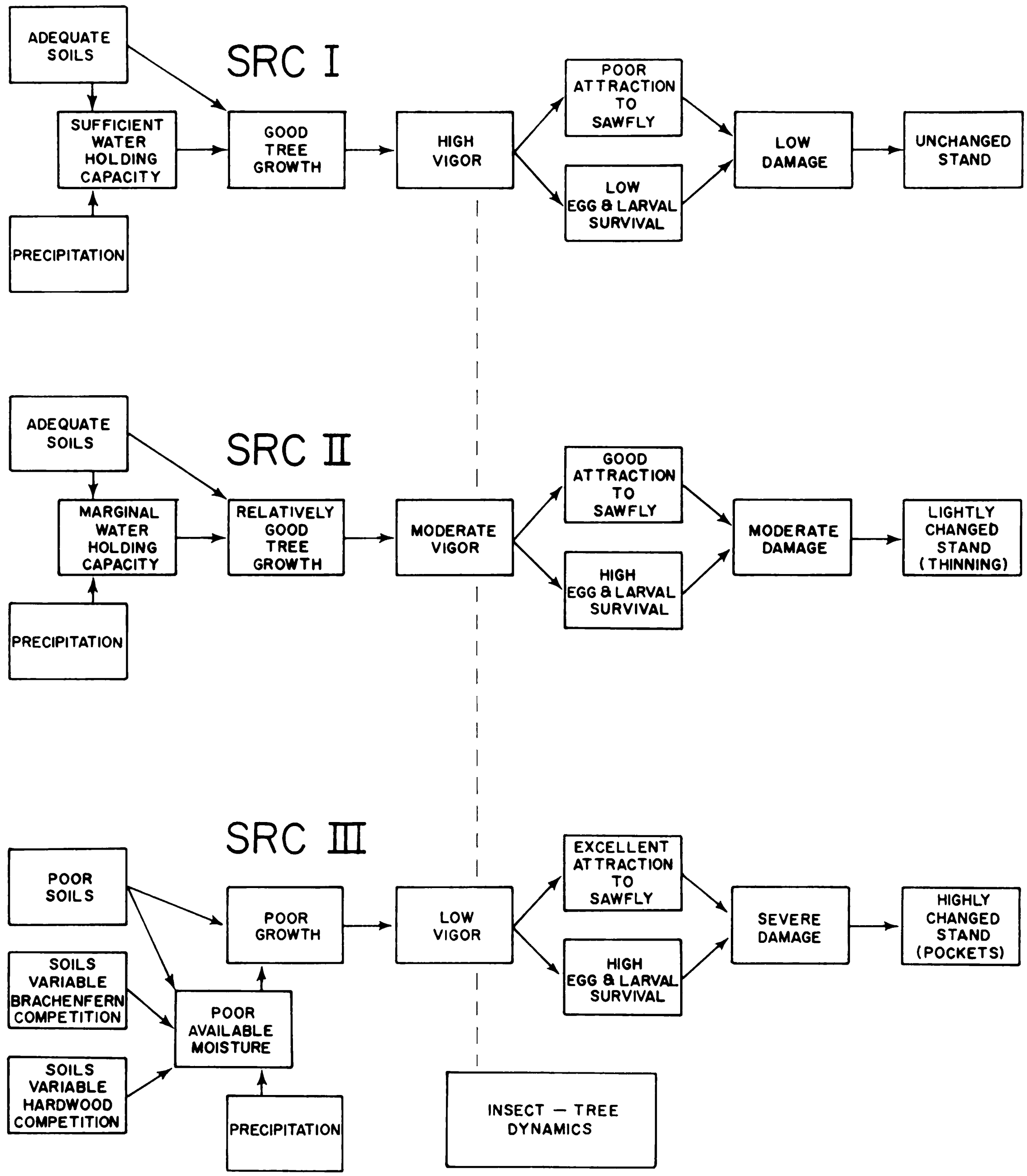
The data obtained in this study can be compiled in a model of sawfly impact.

Ecological Model of the Redheaded Pine Sawfly

Sufficient information is available to construct a basic ecological model of the sawfly. The model is based on the differences between the three site resistance classes and major interrelationships between the insect, tree, and the environment (Figure 17).

Site resistance Class I (SRC-I) is highly resistant to the sawfly. It contains adequate soils for growing red pine. There the soils are relatively undisturbed or have a visible leaching (A_2) zone. Also, these soils frequently have a B horizon which contains texture bands or well developed color bands. Bracken fern, if present at all, is sporadic; hardwood roots are rarely present in the same zone as red pine roots. In other words, there is, in general, little competition for available moisture from other sources. The amount of water received by the trees is adequate and the soil has sufficient water holding capacity. Overall, SRC-I contributes sufficient nutrients and water for good red pine growth and the trees maintain high vigor as exhibited by their form, color, and annual growth. Even dry periods, which affect tree growth and vigor to some degree, do not weaken these trees enough to make them more attractive to the sawfly. Thus, these sites consistently produce red pine that have a lower attraction for the sawfly. Further,

Figure 17. Ecological model of the redheaded pine sawfly.


SRC I
ADEQUATE SOILS
SUFFICIENT WATER HOLDING CAPACITY
PRECIPITATION
GOOD TREE GROWTH
HIGH VIGOR
POOR ATTRACTION TO SAWFLY
LOW EGG & LARVAL SURVIVAL
LOW DAMAGE
UNCHANGED STAND
SRC II
ADEQUATE SOILS
MARGINAL WATER HOLDING CAPACITY
PRECIPITATION
RELATIVELY GOOD TREE GROWTH
MODERATE VIGOR
GOOD ATTRACTION TO SAWFLY
HIGH EGG & LARVAL SURVIVAL
MODERATE DAMAGE
LIGHTLY CHANGED STAND (THINNING)
SRC III
POOR SOILS
SOILS VARIABLE BRACHENFERN COMPETITION
SOILS VARIABLE HARDWOOD COMPETITION
POOR AVAILABLE MOISTURE
PRECIPITATION
POOR GROWTH
LOW VIGOR
EXCELLENT ATTRACTION TO SAWFLY
HIGH EGG & LARVAL SURVIVAL
SEVERE DAMAGE
HIGHLY CHANGED STAND (POCKETS)
INSECT — TREE DYNAMICS

the larvae exhibit some anabiosis, as survival is lower on SRC-I trees. Perhaps these trees are insufficient in some nutrient needed for optimum larval growth. The little feeding that does occur causes only slight damage so that stand change is barely perceptible. There is seldom more than sporadic branch or leader mortality and whole tree mortality is rare. The stand, thus remains nearly unchanged and injured trees rapidly outgrow the effects of the sawfly (Figure 17).

Site resistance class II (SRC-II) is more susceptible to the sawfly than SRC-I (Figure 17). The site contains adequate soils for nutrients but the upper solum is usually disturbed. The A_2 horizon is only weakly developed and the B horizon lacks the degree of development found in SRC-I soils. Bracken fern, when present, forms small clumps and hardwoods, at most, compete for only a small portion of the available moisture. On Kalkaska integrating to Rubicon phase soils the subtle difference between SRC-I and SRC-II is often only exhibited in the degree of development of the A_2 horizon. At best, SRC-II soils have marginal water holding capacity and are sensitive to changes in precipitation. Extended drought can sufficiently weaken some of the trees making them more attractive to the sawfly. Normal and moist years, however, provide relatively good growth and moderate vigor. The SRC-II site is transitional between SRC-I and SRC-III but tree growth in most years is more like SRC-I trees. The sawfly is attracted to SRC-II trees more than to SRC-I trees, especially in dry years when the trees are stressed. Foliage appears adequate for high larval survival so damage from each colony

is maximized. The sawfly attacks the trees almost randomly or along margins of SRC-III areas, where there is both a strong edge effect and more marginal soil properties. This attack site is not unusual as other sawflies exhibit the same phenomenon in pine plantations (Wilson 1975). This means, however, that damage may be concentrated in certain portions of a stand. Resulting damage is usually moderate; scattered trees or ones along edges are injured. Defoliation occurs on apical portions of the trees and on entire trees. Tree mortality occurs but the degree varies by location and amount of stress imposed upon the tree during the outbreak. The little damage from mortality modifies the stand slightly as a light scattered thinning of usually the weakest trees.

Site resistance class III (SRC-III) is highly susceptible to the sawfly (Figure 17). Some degree of resistance occurs only in the most vigorous trees on this site, and these are usually on islands with better site conditions. In certain instances the soils may be poor in nutrients, pH, and water holding capacity due to previous practices. They may be severely eroded (sandblows), highly compacted, or composed of coarse overburden soils. In other instances the soils are more variable and may even normally be adequate in nutrients and pH, but moisture availability is poor because of competition from bracken fern on hardwood roots. Both form dense mats of roots in the red pine rooting zone so that any trend toward dryness greatly stresses the trees. Trees in this class are generally stressed in both normal and moist years and persistently respond by poor height growth, poor form, and off-color

foliage. Their vigor is always low. The sawfly definitely prefers trees on this category and egg and larval survival is maximal, as there appears to be no anabiotic effect on them. Some attractant, such as a terpene violatilized in abundance when the tree is highly stressed, may be important to adult attraction. Terpenes are known to attract pine insects (Wright and Wilson 1972). Whatever the factor, the sawfly population appears to be released when poor available moisture is further reduced and drought occurs. Damage becomes severe in SRC-III areas. The attacked trees are small with many sawflies on each of them, so mortality is rapid and widespread. Most surviving trees become greatly stunted and severely deformed. The stand becomes highly modified by the end of an outbreak. Rows of trees are missing along hardwood edges and small to large pockets open up where poor soils or competing bracken fern occurs. Stands with larger or numerous areas of SRC-III may be almost completely depleted of trees. Also, the larger and more numerous the SRC-III areas are in a planting the more SRC-II zones bordering them will be since SRC-II is transitional in nature. Some trees on the SRC-II area will also be damaged or destroyed. The implications of the impact of sawfly damage for various degree of site resistance areas in a stand are discussed in the socio-economic model section.

Population Dynamics Model of the Sawfly Ecosystem

There are many factors which interact to bring about a sawfly outbreak that results in severe host damage. Some of these factors can be manipulated so that sawfly populations will be arrested before

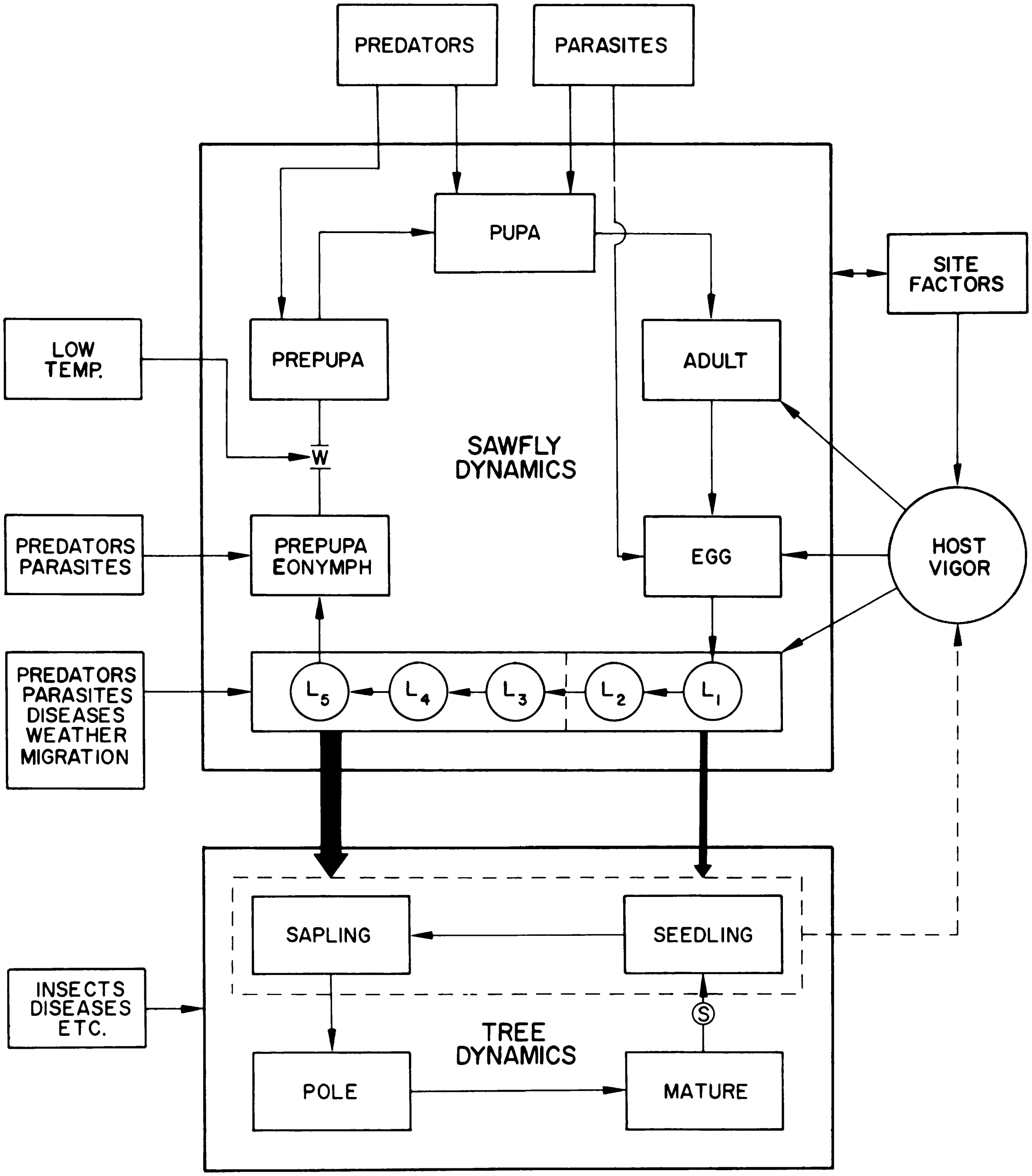
intolerable damage occurs. Such factors can be examined through an insect-tree population dynamics model (Figure 18).

Using host vigor again as the pivotal point of the system the ecological and dynamics models can be interlinked (Figures 17, 18). Host vigor as noted before, determines the attraction of the female sawfly to the tree, and some degree of survival of the egg and larval stages. Vigor in turn is regulated mostly by site conditions. Thus, any input that improves the site or one that improves the tree so that it is better able to utilize the site, will hamper the sawfly population. Certain treatments such as fertilization or irrigation of poor sites can improve tree growth and increase vigor but such practices may currently be impractical. However, such treatments will be a part of forest management in intensive culture regimes in the future. Trees can be bred for more efficient site utilization, although red pine has particularly low genetic variability. Even planting practices such as root depth might be modified to improve water availability to the roots. Competitive plants such as bracken fern might be thinned or destroyed prior to planting to provide more moisture to the trees.

The sawfly, too, has many constraints or factors that limit its populations in most years (Figure 18). Some of these might be manipulated once a thorough population dynamics and key factor analysis has been made, and key factors, other than host vigor, are isolated.

A few of the limiting factors were observed in this study. For instance, a large portion of the egg population can be destroyed

Figure 18. Population dynamics model of the redheaded pine sawfly--red pine ecosystem. (Host vigor [in circle] links this model to the ecological model.) W = winter, S = Seed, L_1 to L_5 = larval instars.


PREDATORS
PARASITES
PUPA
SITE FACTORS
LOW TEMP.
PREPUPA
ADULT
W
SAWFLY DYNAMICS
PREDATORS PARASITES
PREPUPA EONYMPH
EGG
HOST VIGOR
PREDATORS PARASITES DISEASES WEATHER MIGRATION
L5
L4
L3
L2
L1
SAPLING
SEEDLING
INSECTS DISEASES ETC.
S
TREE DYNAMICS
POLE
MATURE

by an egg parasite, but more parasitization occurs on site resistance class I. Perhaps parasite populations could be increased in SRC-III areas by habitat improvements. Increased parasitization has occurred following the cultural increase of adult feeding hosts of parasites of the European pine shootmoth, (Rhyacionia buoliana (Schiff.)), (Syme 1966). Similarly, there are many parasites, predators, and diseases that influence the larval and pupal stages of the sawfly. Rodents, which feed on sawflies in the cocoon stage, prefer certain habitats and are thus more effective in some localities. Low winter temperatures, perhaps during periods of sparse snow cover, could reduce the sawfly population. This, however, would be difficult to regulate.

Also, the Northeastern Region of the lower peninsula of Michigan has traditionally had low populations of the sawfly, even when outbreaks are occurring elsewhere. Site relationships do not appear to be better, yet something appears to be regulating the insect population. Perhaps some factor in the insect dynamics might be revealed in future studies to better understand this phenomenon, and use it to the detriment of the insect.

Socio-economic Model

Public and some privately held forest lands are managed for a multiple of uses. Thus, multiple-use management implies managing for more than one purpose, though only one may dominate at a particular location. While disagreement exists between parties practicing and criticizing this concept, it is obvious and generally agreed upon, that management must consider the whole ecosystem in which

they are tasked (Figure 19). Management objectives, in terms of quantified outputs, are what the sawfly is affecting. Without management objectives then, impact as defined herein, does not exist. Crosby (1977) points out that damage and value protection is goal oriented in his recent guide to the appraisal of fire in the forest ecosystem. He translated broad USDA Forest Service goals into general objectives to point out the diverse values that are at risk in fire protection. The same holds true for damage and value protection from the redheaded pine sawfly. Without translating management goals into quantified management objective outputs, it is impossible to calculate with a reasonable degree of precision the socioeconomic effects of an insect in the forest environment.

Management objectives affected by the sawfly are associated-both on the sites where the sawfly is physically present and off these sites. Timber, wildlife, recreation and visual quality, forage for game and livestock, water and soil are all products of a forest ecosystem which may have management objectives that the sawfly may effect (Figure 19). The degree of the effect is tempered by the site resistance class on which the sawfly activity occurs.

An impact risk rating guide based on expected physical change to tree form by SRC, was developed. To risk rate a plantation to impact from this sawfly the percent occupied by each SRC is first determined using soil-site selections in Figure 20 as a guide. All combinations of site resistance class are possible except SRC-I and SRC-III because SRC-II is transitional between these two classes. Risk is predicted from Figure 21 by comparing the dominent SRC

Figure 19. Socio-economic impact model of redheaded pine sawfly.

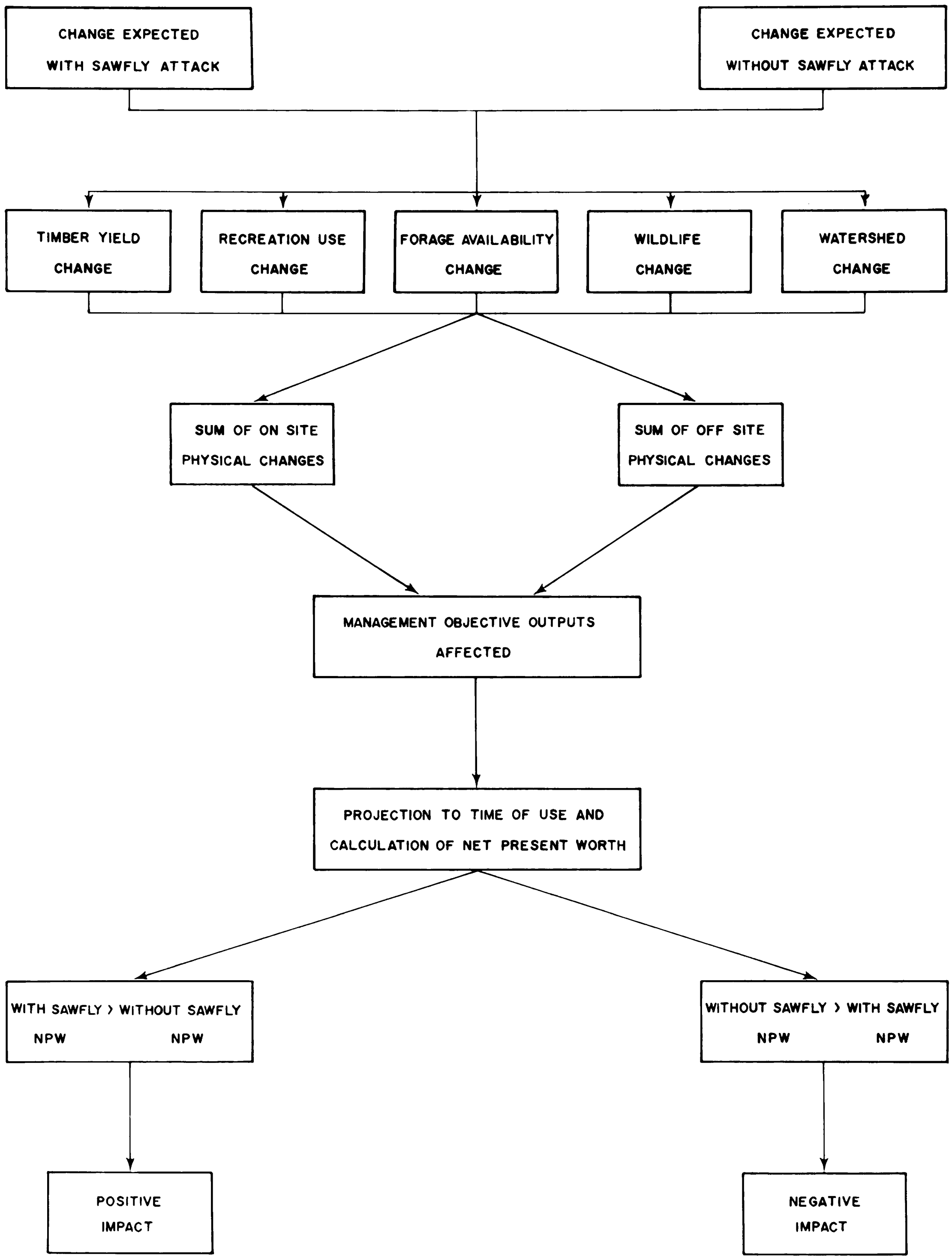

CHANGE EXPECTED WITH SAWFLY ATTACK
CHANGE EXPECTED WITHOUT SAWFLY ATTACK
TIMBER YIELD CHANGE
RECREATION USE CHANGE
FORAGE AVAILABILITY CHANGE
WILDLIFE CHANGE
WATERSHED CHANGE
SUM OF ON SITE PHYSICAL CHANGES
SUM OF OFF SITE PHYSICAL CHANGES
MANAGEMENT OBJECTIVE OUTPUTS AFFECTED
PROJECTION TO TIME OF USE AND CALCULATION OF NET PRESENT WORTH
WITH SAWFLY NPW > WITHOUT SAWFLY NPW
WITHOUT SAWFLY NPW > WITH SAWFLY NPW
POSITIVE IMPACT
NEGATIVE IMPACT

Figure 20. Soil-moisture and tree growth relative to site resistance classes.

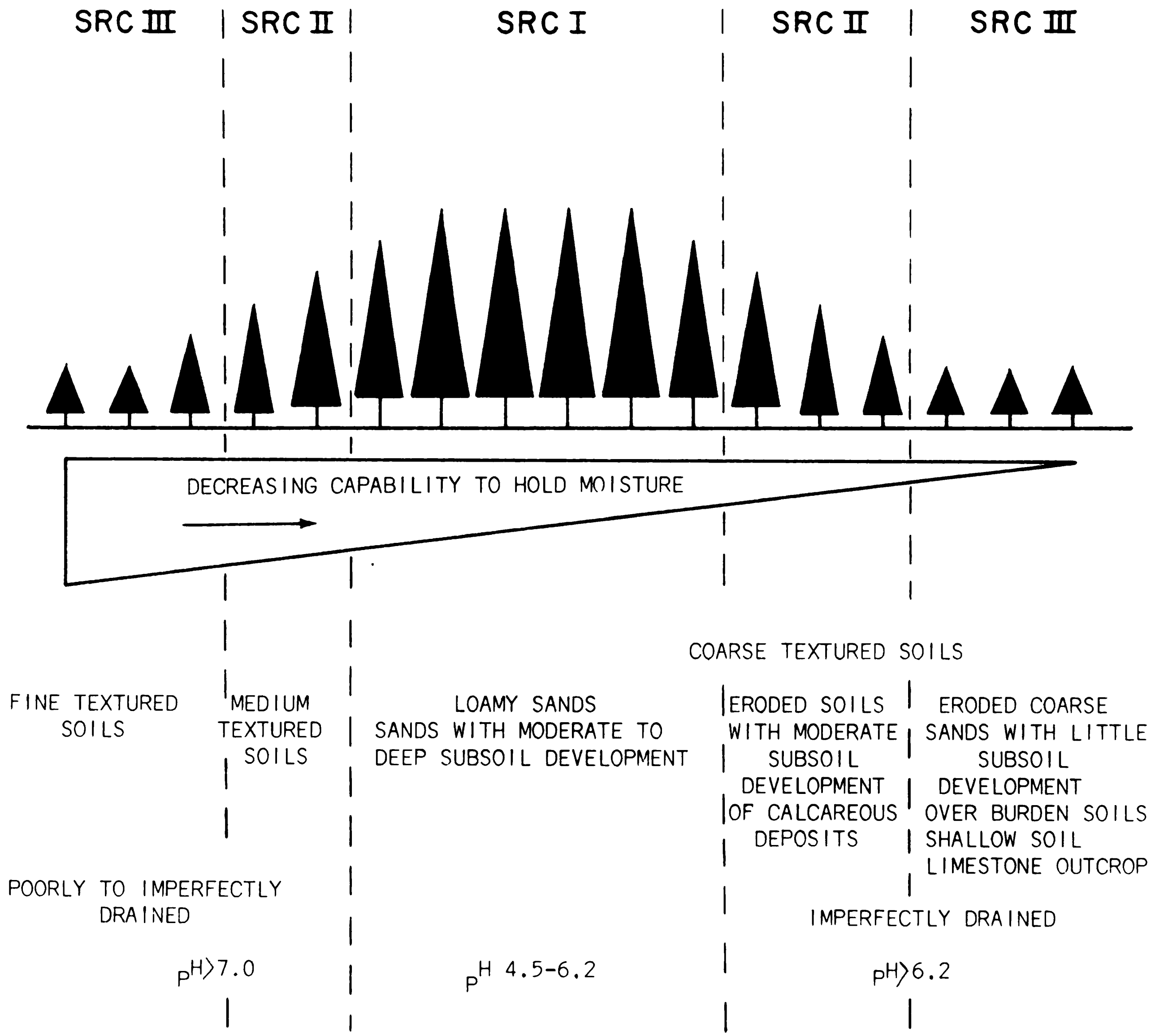
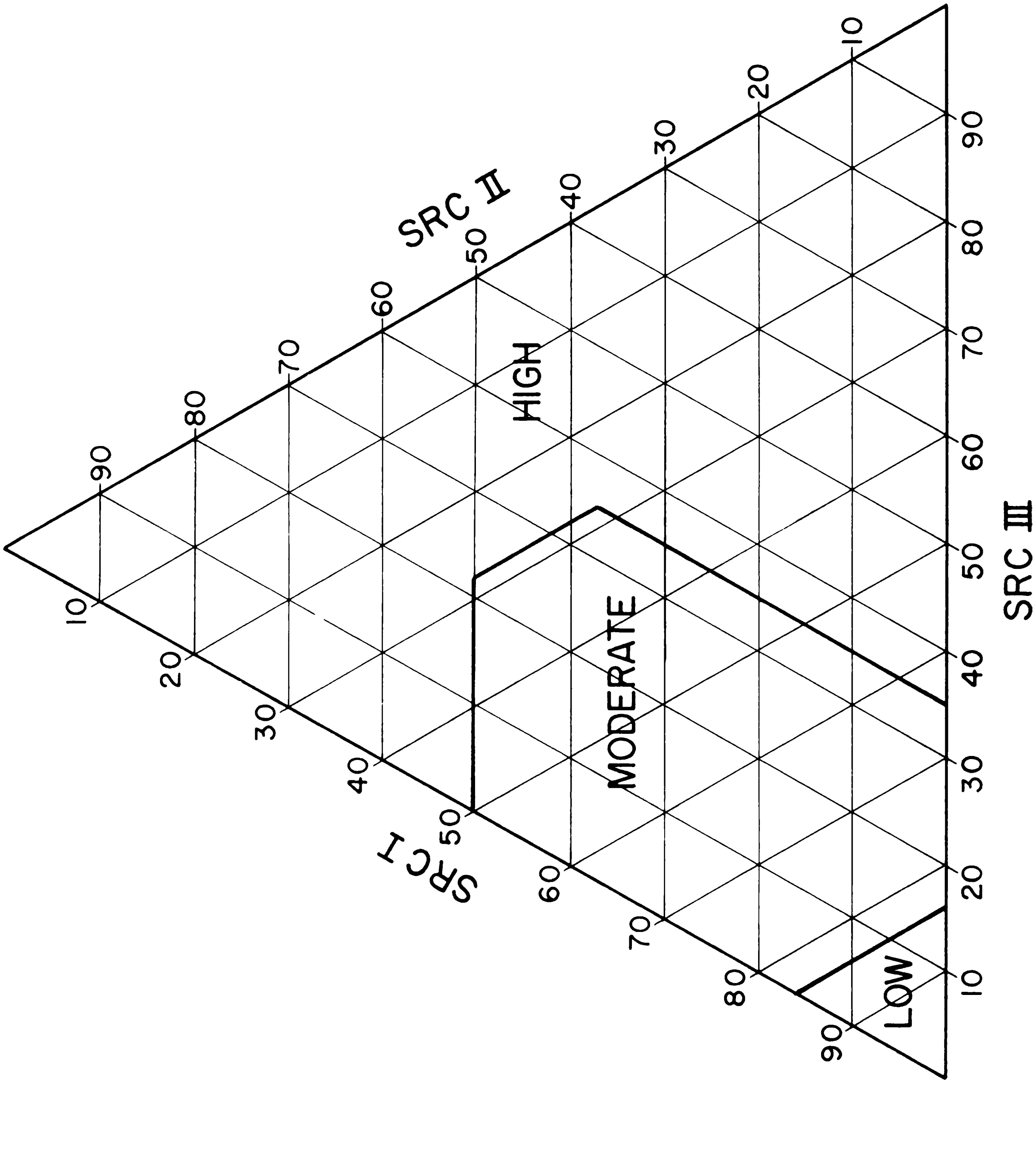

SRC III
SRC II
SRC I
SRC II
SRC III
DECREASING CAPABILITY TO HOLD MOISTURE
FINE TEXTURED SOILS
MEDIUM TEXTURED SOILS
LOAMY SANDS
SANDS WITH MODERATE TO DEEP SUBSOIL DEVELOPMENT
COARSE TEXTURED SOILS
ERODED SOILS WITH MODERATE SUBSOIL DEVELOPMENT OF CALCAREOUS DEPOSITS
ERODED COARSE SANDS WITH LITTLE SUBSOIL DEVELOPMENT OVER BURDEN SOILS SHALLOW SOIL LIMESTONE OUTCROP
POORLY TO IMPERFECTLY DRAINED
IMPERFECTLY DRAINED
pH>7.0
pH 4.5-6.2
pH>6.2

Figure 21. Risk rating guide for redheaded pine sawfly impact in red pine plantations.


SRC I
SRC II
SRC III
HIGH
MODERATE
LOW
10
20
30
40
50
60
70
80
90

percentage first with the second highest class percentage. This puts the risk at low, moderate, or high.

The degree of risk is related to the importance of the management objectives for the plantation. Used as a decision guide, it allows both the entomologist and the land manager to prioritize their concern toward this insect. Plantations with a high risk rating warrant annual detection surveys as well as a quantification of management objective outputs desired. Plantations with moderate risk ratings which are especially valuable to the manager should be treated as high risk plantations.

The socio-economic model is designed to be used at the level the user desires to determine impact by tree, SRC, or by stand. This flexibility is necessary to assist the user in determining the level of impact for his particular case. Trees, if not attacked successfully by the sawfly, are free of injury. Even though they are not injured their role in relation to the management objectives may be affected due to change brought about by the sawfly on attacked trees. Successfully attacked trees may be lightly defoliated with no resultant deformity, or they may be defoliated to the extent that the tree is deformed, or killed. In each instance the change may result in an increase, decrease or maintenance of the management objectives associated with the tree, SRC or stand. Obviously the degree of impact is associated with how well the management outputs are identified. Comments in the following sections show how the sawfly impact can affect these management objectives.

Timber

In the Lake States, red pine is valued for its use in wood products and often is the major concern in the management of a forest. Observations on tree growth and the relative soil productivity of the SRC rating system indicate that SRC-III has the potential to produce trees up to 50 feet tall at age 50 (site index 50), whereas SRC-I has a site index value over 60. Manthy et al. (1964) show that site index 50 red pine stands can expect to have a financial yield for pulpwood rotations of less than 3% and sawlog rotations yield between 2.7 and 5.3%. Site index 60 red pine stands will return financial yields for pulpwood rotations from less than 2.5 to 4.6% and sawlog rotation yield between 2.9 and 6.9%. At the end of our study, stocking of SRC-III lands had been reduced to 31% of the original stocking level with 54% of the mortality attributable to the sawfly. If 50% of the future merchantable volume is lost due to the sawfly then the financial yield on SRC-III lands will range between 1.3 and 2.6% based on the assumptions used by Manthy et al. (1964).

To evaluate sawfly change to a timber objective the output from the ecological model needed for input into the socio-economic model is density loss and quality change in the trees. Data was taken to evaluate the potential timber product change. The value of a stand in terms of wood products is expressed in volume and quality. For red pine, desirable sawlog stocking is 100-150 evenly spaced trees per acre (cooley 1973). These trees are kept on the stump the full rotation (70-110 years). Trees not selected, will be

harvested at varying ages for pulp, posts, poles, and some dimensional lumber. This allows for a mixture of products. Should the manager be interested in liquidating his stumpage at a younger age, he foregoes future products from that rotation. Thus, the management situation described is one of the more complex in timber products derived from the stand. Since the sawfly attacks trees that are not yet merchantable, a method is needed to predict the future value with and without insect attack.

One means of evaluating future potential value and assigning value lost to sawfly is by distinguishing tree categories. These are: potential select sawlog (S); potential pulp or intermediate product (P); and cull (C) from other sources. S and P represent trees with future monetary worth while C has no future timber worth. The trees in this study had been outplanted a minimum of three years when they were scored in late 1971. By comparing each tree with its nearest neighbors for height, form, color, and defect other than sawfly, it was possible to decide whether a potential crop tree (S or P) existed. Trees were graded in the following numeric system:
1 = salwog; 2 = sawlog sawfly degraded; 3 = pulp; 4 = pulp sawfly degraded; 5 = cull, and 6 = dead. Trees were first scored ignoring the sawfly effects, but relying on height and branch form, in comparison to its neighbors. Sawfly degrade categories were then added if it looked like the sawfly was going to prevent the tree from maintaining its potential due to defoliation. Generally the taller better formed trees were placed in the S-category, though not always to insure that 150 or more trees per acre could be kept for sawlogs.

The influence of sand blows and bracken fern on tree height and quality limited potential products based on the fact that trees outside these areas would, in a few years, overcome and suppress some of the pocket activity. This made selection for S-trees in these pockets difficult since the sites were producing few to choose from. In the fall of 1973, the trees were rescored and all trees were placed in categories 1, 3, 5 or 6. Mean tree values by site resistance class and plots are shown in Table 15. Mean changes ranged from 0.155 to 0.367 within plots. Mean change by site resistance class increased with increasing susceptibility to sawfly. SRC-I increased 0.236 units, SRC-II increased by 0.294 units and SRC-III increased by 0.354 units. Recall that an increasing number means a decrease in value.

Knowledge of the future tree quality under varying levels of sawfly defoliation is important to a timber manager in determining what course of action should be taken against a sawfly population. The equation for predicting future tree quality is predicted on a mixed pulp-sawtimber management objective where thinning would principally be from below. Modifications to this management scheme as well as validation of our tree response must wait a future volume study of the plots. The equation developed for future tree quality is: FTQ = present tree quality + site resistance class + percent defoliation + lateral takeover. Mathematically this was: $FTQ = .734 + .738_{x_1} - .031_{x_2} + .014_{x_3} + .350_{x_4}$. The value .734 is the slope of the regression. The statistics are given in Table 16. The standard error of estimate was 0.823. Present tree quality and

TABLE 15.--Future product potential of red pine in study plots and by site class resistance.

Plot	Mean Tree Value ± S.E.		Change
	Pre-sawfly	Post-sawfly	
A1	3.129 ± .08	3.426 ± .08	0.297
A2	3.643 ± .01	4.010 ± .01	0.367
A3	2.985 ± .07	3.220 ± .07	0.235
B1	2.779 ± .07	3.029 ± .08	0.250
C1	2.410 ± .05	2.568 ± .05	0.155
C2	2.329 ± .05	2.696 ± .05	0.367
SRC I	2.286 ± .03	2.522 ± .03	.236
SRC II	2.582 ± .04	2.876 ± .05	.294
SRC III	4.288 ± .06	4.642 ± .06	.354

TABLE 16.--Future product potential prediction statistics for red pine attacked by redheaded pine sawfly.

Analysis of Variance (AOV) for Overall Regression					
	Sum of Squares	Degrees of Freedom	Mean Square	F	Sig.
Regression	3,134.0	4	783.5	1,155.7	.01
Error	1,642.0	2,422	0.68		
TOTAL	4,776.0	2,426			

Multiple correlation Coefficients: R2 = .656 R = .810

Standard Error of Estimate: 0.823

Variable	Regression Coefficient	Standard Error of Coefficient	F.	Sig.	Partial Correlation Coefficient
Constant	.734	.051	205.9	.01	.28
Present Tree Quality (x_1)	.738	.014	2,594.5	.01	.72
SRC (x_2)	-.031	.03	1.12	.29	-.02
High Defoliation (x_3)	.014	.001	211.9	.01	.28
Lateral Takeover (x_4)	.35	.029	141.5	.01	.23

Site Resistance Class is used as previously described. The non-significance of SRC in this equation suggests site as the common cause affecting correlation between the other variables. Sixty-six percent of the variation in future tree quality is explained by the variables used (r^2 value).

Mean values of present tree quality, high defoliation and site resistance class for the six intensive study plots were used to develop a future stand value equation. The future stand value prediction equation was: FSV = .07258 + 1.1034 (present stand value) + .0009 (high defoliation) - .0565 (site resistance class). The adjusted multiple correlation coefficient is .975. The small sample size resulted in none of the regression coefficients being significant at $P < .05$. On the basis of available stand data it is the best possible at this time. It does point out the importance of available moisture and present stand value in relation to red-headed pine sawfly.

Tree mortality on SRC-I and SRC-II lands was not great enough to affect future sawlog harvest. It is reasonable to assume a slight reduction of pulp yield where extensive tree deformity occurs. In any event, future timber yield on SRC-I and SRC-II lands will probably be more affected by the type of silvical prescription applied to the stand than the sawfly. Since the sawfly is more successful on the shorter trees a thinning from above would tend to lengthen the time period to attain equal volume had they not been attacked. If this recovery period was longer than the reentry period for the stand, a measurable volume loss due to sawfly may be

present. A thinning from below will result in the sawfly attacked trees being removed early in the rotation which results in maximizing their present worth.

In determining volume from a stand the forester generally selects dominant or co-dominant trees to measure volume for the stand estimate. A stand with a high ratio of SRC-III land scattered within it may be overestimated in terms of productivity. If the SRC-III land is more aggregated the forester will recognize this and must either adjust his sampling or delete the SRC-III land from the manageable base due to its lack of timber productivity. Based on this study it appears that a real loss to the timber output is negligible when the manager recognizes the real productivity of the site.

Spraying pesticides to control sawflies to protect only timber value on SRC-III lands which have a financial return of less than 3% does not appear to be an attractive investment, since the pesticide spray costs invested in a bank paying a 5% interest would be more attractive.

Wildlife

Openings and forest edge provide a diversity of niches that many animals need. Utilization of these niches is dependent on an available population to occupy suitable habitat. Wildlife habitat potential would be enhanced by the sawfly on SRC-III areas where openings are created. SRC-I and SRC-II are only slightly modified by the sawfly so habitat enhancement from openings is not great.

On SRC-III sand blows it may be necessary to establish vegetation other than conifers to fully exploit their useability. The sawfly presents an opportunity for the land manager to utilize these openings in an effective manner to meet his wildlife objectives. In other words, the sawfly can have a positive effect on the environment in SC-III areas if wildlife management is an objective.

Forage for Wildlife and Livestock

Suitable forage for grazing animals occurs on the wetter SRC-III areas. Some of the SRC-III areas were sandblows and in order to utilize these sites for forage production, rehabilitation of the site to support forage is necessary.

Visual Quality

Each forest landscape scene has identifiable character, variety and deviation or degree of contrast (USDA 1973). It is generally recognized that a visually varied landscape is more likely to be appealing than a landscape which lacks variety. The visual variety is regulated by four elements which compete for dominance: form, line, color, and texture. The redheaded pine sawfly introduces variety into the landscape which is unacceptable to some people due to the psychological impact of introducing dying or partially killed plant materials. However, by staying within the elements which compose a landscape one can say that the sawfly increases the variety of these elements.

As defoliation increases, the texture of the tree canopy increases. Each defoliated branch may become a sharp line increasing

the other elements also. An increase in color results from the reddish-brown denuded branches which subsequently become a subdued gray. The "bottle brush" effect of small larvae feeding provides a unique variation in form, line, color and texture which only these larvae are capable of introducing into the landscape. The presence of larval colonies enhances the color yellow on trees. The form of the landscape may also be modified where sawfly caused tree mortality results in "pockets" in the landscape. Along the plantation edge this usually results in an undulating border.

As sawfly activity increases or as the distance between the viewer and sawfly activity is decreased, increasing contrast results. Depending on the visual management objective associated with the SRC mixture in the landscape, the sawfly may benefit or cause a loss in the objective.

Visitor Use

If the visual quality of an area becomes socially unacceptable to the user due to sawfly activity, visitor use may decline. On private lands this could reduce property value temporarily, which if for sale would be a negative impact to the property owner but a benefit to the buyer in dollars saved. The length of reduced use of real value would be dependent on the duration and intensity of the sawfly activity as well as the quality of alternative use areas that former users can compare.

Water Yield and Quality

Since sawfly caused tree mortality was slight on SRC-I and SRC-II areas any increase in moisture as the result of loss of tree cover would probably be rapidly utilized by competing vegetation, enhancing their later growth. On SRC-III areas the potential increase in water yield is increased by the high sawfly caused tree mortality. On imperfectly to poorly drained areas this may result in a slight rise in the water table which may increase the physical area of stress on adjacent red pine. On coarse textured sites, the loss of tree cover from sawfly would tend to increase the rate of water movement through the soil.

Water quality would probably only be affected, if a pesticide was used against the sawfly to control its activity. The effect and duration of water quality change would largely depend on the pesticide selected for use.

Soil Productivity

Red pine is often planted to stabilize eroded sandy soils. The development of spodazols is highly dependent on organic matter decomposition that will develop acid soils and other substances of great solvent capacity as well as sufficient moisture to develop marked leaching. Loss of red pine cover on sand blows due to sawfly effect could have a negative effect in meeting soil protection/ enhancement objectives on SRC-III areas. On SRC-I and SRC-II areas where the tree cover is not lost, sawfly frass deposited on the soil surface is probably broken down faster and becomes more quickly

involved in the soil forming process than do needles which fall to the soil surface.

Social Well Being

When a person encounters an insect feeding on a tree his response may range from non-interest to high excitement and concern. Perhaps more often than not, his concern is with the welfare of the tree and not necessarily the insect. The level of concern is tempered by who owns the trees, how many insects are present, and their view of the world around them. Light infestations of sawflies usually receive less notice than heavy infestations. Thus, the greater the insect density per tree and physical area occupied by the insect population the greater will be the concern. Fear of what may happen if the insect is not immediately destroyed results in emotional feelings that are not necessarily productive for the individual or to the community to which he belongs.

By evaluating the redheaded pine sawfly effect to the management objectives the physical effects can be separated from the emotional response.

Summary

Determining the net socio-economic impact of the redheaded pine sawfly requires a comparison of the physical change expected with or without sawfly attack (Figure 19). The sum of the on-site (within plantation) and off-site (external to plantation) physical change can be calculated. These physical changes were expressed from the management objective outputs and their change. The outputs

were then projected to their time of use and valued in units or dollars. An output consisting of sawfly present, or not, must be in like units of measure, though different outputs can be expressed in different units. The output values are then discounted to the present at an appropriate interest rate. The difference in the two values represents the present value of the sawfly as negative impact (cost) if the without sawfly is greater than with sawfly and positive impact (benefit) if with sawfly is greater than without sawfly. Much of the decision making process is subjective because actual monetary values cannot be readily assigned to the sawfly affects, yet a decision must be made if the impact of the sawfly is expected.

RECOMMENDATIONS

Forest managers should evaluate proposed red pine planting sites prior to establishment. Areas that have a high risk due strictly to soil productivity should have the management objectives considered carefully and insure they are within the land's capability to meet them. Plantations already established should be risk rated. Those plantations with a high risk should be identified to the proper forest pest management personnel so that they may assist in developing management objectivew with minimal risk to sawfly attack.

Forest pest management personnel should utilize the models developed to assist land managers in determining sawfly risk to their red pine plantations as well as assisting in identifying management objectives which this sawfly may adversely affect. Annual detection surveys in high risk, high valued plantations should be established to maximize early detection of outbreaks especially during droughty periods. Where control of the sawfly is considered, the value protected is the expected loss. The value protected must be greater than the cost of protection to be economically efficient.

Forest researchers should initiate studies which integrate the physiological aspect of host vigor to more closely define its relationship to sawfly attack. They should seek the amount of moisture stress and nutrient level necessary in the soil and host plant for successful attack and feeding by the redheaded pine sawfly.

Also they might search for the factors that serve to attract the sawfly during adult dispersal.

The redheaded sawfly goes unnoticed for many years in an area then suddenly explodes to damaging levels. A better understanding of its population levels is necessary in order to minimize the fluctuations in population density. The relationship of site and suitable habitat for the parasites of redheaded pine sawfly should be investigated to understand what requirements are necessary to allow rapid parasite response change to their host.

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APPENDIX

APPENDIX A

LOCATION AND SITE VARIATION BETWEEN ATTACKED AND NON-ATTACKED PORTIONS OF REDHEADED PINE SAWFLY DAMAGED RED PINE PLANTATIONS EXAMINED IN THIS STUDY

Plantation Number:

1. Michigan, Benzie Co. T27N R14W Sec 16 NE SW

   Attacked Area: sand blow; C horizon on surface

   Non-Attacked Area: Kalkaska series, with Ap A_2 Bir, C horizons

   Comments: Jack pine reproduction in sand blow under attack by sawfly. Bracken fern pockets present. Sawfly fed primarily in the sand blow and bracken fern pockets. Site similar to plot A2.

2. Michigan, Benzie Co. T28N R13W Sec 35 SW SW

   Attacked Area: medium sand in A and B horizons. C horizon at 36" of medium sand and some gravel.

   Non-Attacked Area: Litter layer ½" thick; A_2 horizons of evident between 2 and 5" A and B horizons of medium sand; II C layer at 38" of medium sand and gravel.

3. Michigan, Houghton Co. T47N R36W Sec 31 NE

Attack Area: Medium and coarse sands to 55", with a fine sand band between 35 to 38". Rock layer at 55". This spot is in an old farmyard of unknown prior use. Poor survival of redpine within the farmyard area.

Also attacks in this plantation on medium and coarse sands with soil becoming rocky at 32-35" tree growth is averaging 12" year; defoliation up to 40% of some trees.

Non-Attack Area: Medium and fine sand with rock at 35" average growth 18-20" year.

Note: Numerous frost pockets in this stand, many containing scleroderris infested trees.

4. Michigan, Houghton Co. T47N R38W Sec 26 NE NE

Attack Area: 0-7" medium and coarse sand, 7-28" coarse sand and rocks 1-4" in size, 42-48" fine sand and clay, 48" and 52" fine tectural banding and medium sand with some clay. Frost pocket, scleroderris present. 13" average growth per year past 4 years.

Non-Attacked Area: 0-36" fine sand, 36" and 48", texture bands of fine sand, very fine sand and some clay; no scleroderris present. 26" average growth per year past 4 years.

5. Michigan, Houghton Co. T47N R38W Sec. 26 E1/2NE1/8

Attack Area: Weakly cemented Bir at 11", 26-30" fine sands. Dense sod layer where light sawfly attacks have occurred. Located in a frost pocket with scleroderris present.

Non-Attack Area: Same as the attack area in soil characteristics but lacking sod development. Average growth is 22" per year the past 4 years in the attacked and non-attacked portions.

6. Michigan, Mackinac Co. T43N R1W Sec 36 S1/2

Attack Area: #1 - coarse sand, C horizon 56"

#2 - Coarse sand, Bhir-12-18", C horizon 54"

Non-Attacked Area: #1 - medium and coarse sand, color bands up to 1¼" thick and cemented between 52 and 64", C horizon - 64"

#2 - 12-16" fine sand, ¼" color bands between 52 and 64", C horizon 64"

Comments: Sprayed for sawfly 1971, average tree growth/year 1969-71 attacked 16", non-attacked 22", stand height average 8', pockets up to 20' x 20'.

7. Michigan, Mackinac Co. T41N R4W Sec 14

Attack Area: 4 to 6" to limestone rock, fine sandy loam soil

Non-Attack Area: Ap fine sandy loam 7-30" B horizons of clay loam 30" and C horizon of clay loam.

7. Comments: 1 colony present in 1973, trees on shallow soils range from 3-9' tall, non-attacked areas trees average 20' tall.

8. Michigan, Mackinac Co. T42N R4W Sec 31 NW

Attack Area: Ap loam, 7" and imperfectly drained clay loam grading to clay pH: Ap = 8.0, C = 8.0

Non-Attack Area: Ap loamy sand, 16" and sandy clay. pH: Ap 6.8, C = 8.0.

Comments: Sprayed for sawfly in 1969, attack area growth/year 1969-71 averages 6", trees 3' tall and yellowish in color. Non-attack area growth/year 1969-71 averages 18", trees 8' tall with no yellowing; best site in plantation tree growth is averaging 24" year, trees about 15' with good color. Sawfly active along south edge of stand.

9. Michigan, Mackinac Co. T43N R5W Sec 3 NE

Attack Area: Shallow soil 4-6" deep to rock with some limestone present. Clay soil, rock outcrops throughout attack area.

Non-Attack Area: 0-22" fine and medium sands, pH: Ap 6.5 Bir 7.0 22-45" sandy clay, C-45".

Comments: In SW corner of plantation a bracken fern mound about ½ acre in size on overburden soil 12-24" deep with a sawfly colony. NE of this bracken fern

9. clump is another area with sawfly activity. Soil is well developed spodozol 26" deep to limestone bed-rock, shootmoth in this area.

10. Michigan, Mackinac Co. T43N R3W Sec 20 SW

Attack Area: C horizon at 20-23", pH: Ap 7.0, C 8.0, soil grades from loamy sand in Ap, medium sand in B and a sandy clay C.

Non-Attack Area: C horizon at 23", pH 6.0-6.5 in A and B horizons, 8.0 in C. Soil grades from sandy loam in Ap medium sands in B to clay-sand in C.

Comments: The attack area is a moist site with Balsam fir invading, attack area has a high number of trees with forks, growth of 6-12" year, stocking is 100 trees/ac. In the non-attacked area stocking is 350-400 trees/ac. Growth averages 18" year. Some old sawfly attack evident but no damage noted, balsam fir also invading the non-attacked portions.

11. Michigan, Mackinac Co. T43N R3W Sec 20 NE

Attack Area: Ap, 0-5", B, 0-10", B_2 5-10", C 10" +; pH, Ap 6.5, B 7.5, B_2 8.0, C 8.0. Ap of medium and fine sand other horizons of fine sand (fine bead sand).

11. Non-Attack Area: Ap 0-9", Bhir 11-17", B_2 17-34", C 34" and pH Ap 6.0, B 6.5, C 7.8 (well developed Rubicon like soil)

Comments: Attack area growth/year 12" trees 4-5' tall, Non-attack area growth/year 20" trees 10' tall. This is a very variable stand in its soil and tree growth. Frost pockets with past sawfly activity. Hardest hit area is in SE corner where a 1½ acre pocket has a few deformed trees remaining growing on shallow (<8" to limestone and gravel) covered by a B like horizon - possibly an old gravel pit, remaining trees growing on a weekly developed Rubicon like soil (no Bhir cemented though).

12. Michigan, Mackinac Co. T43N R3W Sec 18

Attack Area: C at 45¼ clay soil

Non-Attack Area: C at 54" sandy clay loam

Comments: Redpine growth is excellent, poor or has died. Frost heaving occurs here. Heavy sod throughout plantation.

13. Michigan, Wexford Co. T21N R12W Sec 18

Redpine plantation established in 1940, sprayed for sawfly in 1948. Well developed. Grayling series soil. No "pocket" evidence of sawfly, small holes here and there but stocking is adequate - down to 4 x 4' in places. Trees up to 8" dbh

13. basal area up to 210 sq. ft. Jack pine on west side of plantation has spotty stocking and dbh is only 3-3½" with poor survival in frost pocket. May have been where sawfly was doing damage in 1948.

14. Michigan, Wexford Co. T21N R11W Sec 3, 4, 9, 10
Plantation established 1940, sprayed for sawfly in 1948, attacked areas probably were in sand blow areas and gullies where present red pine dbh is 3" and site index is 50-55. The eroded areas are now stabilized. Basal area on the better developed soils (color bands, between 45 and 60" C horizon 60" - Kalkaska series) ranges from 160 to 210 dbh ranges from 7.2 - 9.1" SI is 70 +.

15. Michigan, Wexford Co. T22N R12W Sec 13 SE SE¼
Attack Area: (in a draw) overburden 0-28", C 28", + of sand and gravel.
Non-Attack Area: Overburden and Ap 0-14", Bir 14-24", B_2 24-42", B_3 42-51", C 51" and medium sands in Ap and B layers, fine sand in C, soil moist at 2" +.
Comments: The Valders till is about 8' from the surface as evidenced by a road cut opposite the plantation. Trees were planted in 1969. Sawfly attacked only a few trees in the gulley. On the surface the plantation appears to be a good site for sawfly, however, the moisture situation appears favorable due to

the clay till which may extend under most of this plantation.

16. Wisconsin, Menominee Co. T30N R16E Sec 26 NW¼

Attack Area: C horizon at 20" medium sands with coarse sand and gravel at 20". Attack in the SE corner of the stand on a 7-10% slope leading to a pothole.

Non-Attack Area: 0-39" medium sand; ½" pink cemented sand band at 49" dark color gand with some fine sand present at 64". Some portions of the non-attacked area with rock present at 48".

17. Wisconsin, Menominee Co. T20N R16E Sec 3, 4, 9, 10

(Sprayed in 1969 with Malathion)

Attack Area: A and B horizon of medium and fine sand 40" + color band 1" wide, poor tree survival in a 100 x 200' plot that may have been an old garden in the farmstead. Stand partially burned in 1971. Average growth 21" per year 1971 and 1972.

Non-Attack Area: A and B horizon of medium and fine sand; 2" wide sandy clay bands at 50" and 62"; average growth 24" per year in 1971 and 1972.

18. New York, St. Lawrence Co. Stockholm Township Block 33

Attack Area: C horizon at 32"; ortstein layer between 11 and 18"; medium sands. Mottling below 20", water table at 53".

Non-Attack Area: none

Note: An 11 acre plantation sprayed in 1967 to control sawfly.

19. New York, St. Lawrence Co. (near Canton)

Attack Area: C horizon at 24" medium and coarse sands.

Non-Attack Area: C horizon at 32" texture bands between 16" and 25".

Note: Attacks heaviest along hardwood edge where root competition is evident, attacks also in raspberry thickets.

20. New York, St. Lawrence Co. (south of Stockholm Center)

Attack Area: 4-6" to rock, medium and coarse sands.

Non-Attack Area: Medium and coarse sands; compacted at 25", at 32" sandy clay and large rocks encountered.

Note: Scattered attacks throughout this 5 acre mixed red and Scotch pine planting. Sawfly appears to be just building up, non-attacked area represents the "best" portion of the stand.

21. Ontario, Canada, Simcoe Co. Vespra Twp. Concession 1, Lots 34, 35

Attack Area: C horizon at 40", limestone rocks at 38-40", weak color bands between 20 and 38"; trees 4-6' tall.

Non-Attack Area: C horizon at 59", ½" wide texture bands between 25 and 51", wavy clay band between 51 and 58"; trees 10-15' tall.

Note: A 100 acre red pine plantation managed for sawlogs attacked by sawfly in 1968, treated with a virus in 1971. Attack pockets up to 1/5 acre in size. Appears that a road went through a portion of the stand (sawfly attacked area) as the soil is lightly compacted and evidence of a road exists going into the stand.

22. Ontario, Canada, Simcoe Co. Flos Twp. Concession 2, Lots 26, 27

Attack Area: C horizon at 18", silty clay loam; imperfectly drained' pH in Ap 7.5; trees 2-6' tall.

Non-Attack Area: C horizon at 40" of sand and gravel; color bands between 10 and 40" of sandy loam; pH Ap 7.0; trees 6-15' tall.

23. Ontario, Canada, Frontenac Co. Oso Twp. Concession 3, Lot 26

Attack Area: #1 - Overburden soil from adjacent road out.

#2 - medium and coarse sand less than 16" to C horizon

Non-Attack Area: Variously developed spodosol over 16" to C horizon.

24. Ontario, Canada, Frontenac Co., Hinchinbrooke Twp., Concession 5, Lot 9

Attack Area: Silty loam soil, imperfectly drained; C horizon at 36"

Non-Attack Area: Loamy sand; textural bands between 34 and 42"; C horizon at 48"; well developed spodosol.

Note: Scattered population of sawfly in this 10 acre red pine stand; no apparent pocket activity.

25. Ontario, Canada, Lanark Co., Bathurst Twp., Concession 4, Lot 16

Scattered attacks by sawfly on redpine planted on rock outcrop, shallow sandy soil, abandoned farmland. Trees growing over 15" year, general tendency for the shorter trees to be attacked, although no pattern is evident.