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WHITE PINE REGENERATION IN MICHIGAN: EVALUATION OF WHITE PINE
WEEVIL AND WHITE PINE BLISTER RUST EFFECTS

By

Linda K. Williams

A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE

Entomology Department

2002

ABSTRACT

WHITE PINE REGENERATION IN MICHIGAN: EVALUATION OF WHITE PINE WEEVIL AND WHITE PINE BLISTER RUST EFFECTS

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Eastern white pine (*Pinus strobus* L), once a major component of Michigan forests, was mostly removed by statewide logging and subsequent wildfires in the 1800's. Re-establishment of white pine by planting have been hindered by a native insect, the white pine weevil (Coleoptera: Curculionidae, *Pissodes strobi* Peck) and an exotic disease, white pine blister rust (*Cronartium ribicola* Fischer). Identifying silvicultural practices that effectively control white pine weevil and limit white pine blister rust occurrence is important for future regeneration efforts. Differences in weevil incidence, white pine blister rust occurrence, and tree growth were evaluated by in northern Michigan. Thirty-eight percent of all the white pine trees surveyed for this study had no apparent defects. About 40% of trees in natural stands were free of defects compared with 20% of trees in planted stands. White pine blister rust occurred on only 0.07% of trees examined. A study of weevil survival rates and parasitism rates found significantly higher numbers of weevils and parasitized larvae in open grown white pine trees. White pine seedlings were established in areas of Upper and Lower Michigan to collect long-term data on pest incidence and tree growth in stands of different densities and species composition.

ACKNOWLEDGMENTS

Thanks to Dr. Deborah G. McCullough, Michigan State University (MSU) Entomology department, for planting the seed of graduate school in my mind way back when I took her FOR/ENT 407 class as an undergraduate, and for being my major professor throughout this project. Thank you to my committee members, Dr. Donald O. Dickmann and the late Dr. Carl W. Ramm from MSU Dept. of Forestry, and Dr. Robert Haack from the USDA Forest Service, though we only had one committee meeting throughout my time in this program I appreciated the input. Thank you Roger Mech, Michigan Department of Natural Resources (DNR), for hiring me for so many summers as a pest scout and allowing me to discover that forest health was the area I wanted to pursue as a career which led me towards this graduate degree. Interestingly enough I need to thank the Michigan DNR for not being able to hire me as a full time employee, I probably never would have come back to school if that had happened. Thank you to Frank Sapio (Michigan DNR) for encouraging me to go back to school and keeping it at the forefront of my mind, and for helping to secure research funding from the Michigan DNR.

Dr. Ray Miller from the Upper Peninsula Tree Improvement Center (UPTIC) deserves many thanks for coordinating the large white pine planting in the spring of 1998. Additional people who helped with the planting at this site were Brad Bender, Kile Zuidema, Zac Fairchild, Kirsten Fondren, Joe Zeleznik, Randy Klevicas, and Mickey Trimner. Thanks to Randy Kevicas and Paul Bloese from the MSU Tree Research Center (TRC) for planting all those white pine in the nursery beds at the TRC and lifting

and root pruning them when we were ready to plant. Thanks go out to Greg Kowalewski from W. K. Kellogg Forest, and the Michigan DNR for planting white pine on their respective lands. A big thank you to all the forest managers who helped me with my requests for white pine stands in their areas.

Thank you Kirsten Fondren for listening to me after I got some of those manuscripts back from Deb and could hardly read my original words because of all the red ink on the page. Additionally Deb, thanks for that red ink on my various writing drafts, this has made me a much better writer than when I started, though the process was painfully slow I know.

I need to thank my brother, Ben Williams, for doing chores for me all the times that I was gone for one or two weeks at a time collecting data, only to come home for a weekend, and then be off again for more data collection. And thank goodness for my horses for all the times that I just needed to not think about white pine. Thanks to my mom, Susan Williams, for the look of amazement on her face when I told her I was going to go back to school. Thanks to my dad, Gary Williams, for being so proud of my going back to school, and I can't believe all his friends aren't sick of hearing about my research.

Thank you Brad Bender for tutoring Anne Henderson and myself on the operation of WinDendro. Also Brad, thanks for making all those core mounts ... who knew I'd need so darned many feet of board for those little cores. Thanks to Anne Henderson for all the time she spent with those little cores at UPTIC, at the hotel, and back at MSU. The Fox River Hotel in the tiny town of Seney in Michigan's Upper Peninsula deserves a thank you. It was an excellent place to stay, and I stayed there for many nights in the summer of 1999 and they never failed to bring me bugs for identification.

Thank you to the Wisconsin DNR for hiring me before I even had my degree, and for allowing me to finish my research in the summer of 1999. Also thanks for understanding that all of my spare time (plus some) during the first few months of my new job was spent on my thesis. And finally I'd like to thank the makers of Tylenol and aspirin.

My graduate education and research would not have been possible without the financial support from the McIntire-Stennis Cooperative Forestry Resource Program through the MSU Forestry Department, the Michigan Department of Natural Resources Forestry Division, and the Michigan State University Hutson Endowment.

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INTRODUCTION

Eastern white pine (*Pinus strobus* L.) is one of North America's most valuable tree species (Lehrer 1982), and was once a major component of Michigan forests. Statewide logging and subsequent fires removed much of this timber resource and the seed source needed for regeneration. Efforts to re-establish white pine in the forests of Michigan and other Great Lakes states in past years have been hindered by problems caused by white pine weevil (Coleoptera: Curculionidae, *Pissodes strobi* (Peck)) and white pine blister rust (*Cronartium ribicola* (Fischer)).

White pine weevil is an insect native to North America (Marty and Mott 1964). White pine weevil adults emerge in May from overwintering sites, mate, and begin to feed and lay eggs on the terminal leader of young white pine that are usually less than 4.6 m (15 ft) tall (Jaynes 1958, Marty and Mott 1964, Dixon and Houseweart 1982). Eggs hatch and larvae feed in the phloem of the terminal leader from June through August, progressing through four instars (Marty and Mott 1964). Damage from larval feeding causes the current year growth to wilt and die, and can destroy the previous two to four years of growth of height growth (Marty and Mott 1964). When the terminal leader dies, lateral branches that take over dominance can cause a crook or fork in the stem (Gross 1985). Damage caused from repeated attacks create what are commonly known as stagheaded, pasture, or cabbage trees (Harman and Kulman 1967).

Parasitoids may be an important source of mortality for some white pine weevil populations. Effects of parasitoids on white pine weevil populations have been examined previously. Few studies related weevil survival and parasitoid abundance to site or stand

characteristics. Harman and Kulman (1968) found that open-grown stands were most suitable for weevil development, but were also associated with high levels of parasitism in Virginia. No similar studies have been conducted in the Lake States.

White pine blister rust is a pathogen that originated in Asia and was introduced to the United States in 1910, and accidentally imported into Michigan on white pine seedlings in 1917 (Mandenberg 1933). White pine blister rust can be devastating and result in dead branches or whole tree mortality. White pine blister rust requires a secondary host, *Ribes spp.*, to complete development (Kroeber 1941). Blister rust occurs in geographically localized areas where humidity, air currents, host species, and other conditions are suitable (Liebhold et al. 1995). Blister rust hazard zones were created for the Lake States in 1961 and silvicultural recommendations were developed in an attempt to minimize blister rust damage to white pine (Van Arsdel 1961, Anderson 1973).

Determining which silvicultural practices provide control of white pine weevil damage and limit blister rust occurrence is important to successfully regenerate white pine. Many early silvicultural experiments were limited by small sample size or a lack of replication, making the results applicable to a very limited area. We initiated a long-term study of various planting methods using replicated experimental designs, to evaluate white pine growth, survival, and insect and disease incidence. An important part of these plantings is to provide demonstration sites for forest managers and private landowners interested in planting white pine for biological diversity or sawlog production.

This thesis includes a formal literature review of white pine silviculture and regeneration, and the biology and impacts of white pine weevil, and white pine blister rust. Chapter 1 focuses on my survey of existing white pine stands in Northern

Michigan. Objectives were to 1) determine incidence of white pine weevil and white pine blister rust, 2) quantify growth rates of white pine trees in these stands, and 3) relate weevil damage, blister rust incidence and growth rates to site and stand characteristics. Chapter 2 addresses a study of the effect of parasitoids on weevil survival in four stands of young planted white pine in Michigan's Upper Peninsula. Chapter 3 is a detailed record of four methods of white pine plantings to establish long-term research and demonstration sites which occurred in Michigan from 1997-2001.

LITERATURE REVIEW

By

Linda Williams

Eastern White Pine

Until statewide logging in the mid to late 1800's, Michigan was covered with 150 to 170 billion board feet of standing pine timber (Maybee 1976). Eastern white pine (*Pinus strobus* L.) trees, often 125 to 170 feet tall, made up a major portion of this pine cover (Maybee 1976). After most trees were removed by logging, fires swept across much of the state, starting in 1871, and removed much of the remaining white pine and the seed source from Michigan forests (Utley et al 1906). Once assumed to be in endless abundance, white pine is now a minor forest component through much of its original range (Buchert 1994).

The natural range of eastern white pine includes southeastern Canada, the Lake States, the northeastern states, and the Appalachian Mountains as far south as Georgia (Marty and Mott 1964). The climate over the range of white pine is typically cool and humid (Burns and Honkala 1990). White pine is a major component of five Society of American Foresters (SAF) forest cover types: red pine (Type 15), white pine-northern red oak-red maple (Type 20), eastern white pine (Type 21), white pine-hemlock (Type 22), white pine-chestnut oak (Type 51) (Wendel 1980). White pine also occurs in 23 other SAF forest cover types as a minor component (Wendel 1980).

White pine may function as a pioneer species; a climax species on relatively dry, sandy soils; a long-lived successional species; or a component of climax forests throughout its range. Natural stands of white pine rarely stagnate because a

differentiation into crown and diameter classes usually occurs due to differences in vigor, age, and microsite (Wilson and McQuilkin 1965). Dominance is more pronounced on relatively high quality sites, at greater stand densities, and in natural stands compared to plantations (Wilson and McQuilkin 1965).

White pine can be found on a variety of sites, growing on nearly all soils within its range, and can compete well with sod and other ground cover (Wilson and McQuilkin 1965, Gross 1985). It grows best on well-drained sandy soils of low to medium site quality, where it can easily outcompete other woody species, can be managed effectively and economically, and where there is relatively little hardwood competition (Lancaster 1984, Mader 1985, Burns and Honkala 1990). White pine also grows on fine sandy loams and silt-loam soils when there is no hardwood competition, such as old fields and pastures, burns, and blow downs (Burns and Honkala 1990). White pine can occasionally be found on clay soils or poorly drained soils with surface mounds. It can be productive on these sites, but is usually found as individual trees or in small groups (Mader 1985). White pine is of moderate shade tolerance and is able to regenerate under an overstory (Baker 1949).

White pine is monoecious, meaning that each tree has both male strobili and female flowers (Krugman et al 1974). Flowering generally occurs between May and June (Burns and Honkala 1990). Good seed years are thought to occur every 3 to 5 years, though there can be much longer periods of time between good seed crops (Burns and Honkala 1990). Recent reductions in seed crops throughout the range of white pine may be due in part to white pine cone beetle (*Conophthorus coniperda* (Schwarz)) (Coleoptera: Scolytidae) which feeds on the immature seeds as the cone matures (Burns

and Honkala 1990). Most seeds are dispersed within one month of cone maturity (Burns and Honkala 1990). Clearcutting during or just after a heavy seed crop can result in well stocked stands on light soils (Burns and Honkala 1990).

Bare mineral soil is not necessary for white pine seed germination; seeds can germinate and survive on both disturbed and undisturbed litter layers (Balmer and Williston 1983). Full exposure to sunlight, moist mineral soil, moss, or a short grass cover of light to medium density are favorable seedbeds (Wilson and McQuilkin 1965). Unfavorable seedbeds for white pine seed include dry mineral soil, pine litter, lichen, and very thin or very thick grass cover (Wilson and McQuilkin 1965). Overstory shade resulting from a shelterwood cut provides good protection during the early stages of growth (Wilson and McQuilkin 1965). In the seedling stage, white pine is very susceptible to competition because its height growth is slow compared to most of its associates, but once it reaches the sapling stage, its ability to compete is greatly improved (Wilson and McQuilkin 1965). Root grafting occurs in white pine stands regardless of stand age, soil characteristics, or drainage (Bormann 1962). White pine does not reproduce vegetatively under natural conditions (Heimbürger 1955).

White Pine Weevil Biology

White pine weevil (Coleoptera: Curculionidae, *Pissodes strobi* (Peck)) is native to North America (Marty and Mott 1964), and was once considered three separate species based on geographic region and associated host trees (Hopkins 1911, Manna and Smith 1959, Smith 1962, Smith and Sudgen 1969). Previous classification listed *Pissodes strobi* (Peck) as preferring Eastern white pine from northeastern North America, *Pissodes engelmannii* (Parry) preferring Engelmann spruce (*Picea engelmannii* Parry) from the

northern rocky mountains, and *Pissodes sitchensis* (Hopkins) preferring Sitka spruce (*Picea sitchensis* (Bong.) Carr.) from the northwest pacific coast region. These populations are now considered to be a single species called *Pissodes strobi* (Peck) though host preference varies across regions in North America (Hopkins 1911, VanderSar et al 1977, Alfaro and Borden 1985). White pine weevil is considered a serious pest of Sitka spruce in northwestern North America where it is commonly called Sitka spruce weevil (Alfaro et al 1984) and white pine in the East where it is referred to as white pine weevil (Marty and Mott 1964). Other species which white pine weevil will infest include jack pine (*Pinus banksiana* Lamb.), Scotch pine (*Pinus sylvestris* L.), pitch pine (*Pinus rigida* Mill.), red spruce (*Picea rubens* Sarg.), Norway spruce (*Picea abies* L. Karst), white spruce (*Picea glauca* Moench), and occasionally balsam fir (*Abies balsamae* (L.) Mill.), hemlock (*Tsuga canadensis* (L.) Carr.), and lodgepole pine (*Pinus contorta* Dougl.) (Peirson 1922, MacAloney 1930, Craighead 1950, Wallace and Sullivan 1985, Alfaro 1996).

White pine weevil adults overwinter in the duff layer, emerge in May, mate, and begin to feed on the terminal leader (Jaynes 1958, Marty and Mott 1964, Dixon and Houseweart 1982). Adult weevils are 4.5 to 6 mm long, oval, and brown with irregular spots of brown and white scales on the elytra. Up to 200 eggs, each about 1.5 mm in diameter, are laid by each female. Eggs are laid in feeding punctures starting at the top of the leader and progressing down as the adult female weevil feeds along the terminal, with one egg laid in each feeding puncture (Silver 1968, McMullen and Condrashoff 1973). Eggs hatch in 10 to 14 days (Peirson 1922). Larvae feed downward in the phloem of the terminal leader from June through August, progressing through four instars, or molts

(Marty and Mott 1964). Larvae are small, legless, white grubs that reach 7 mm in length by the final instar. Late instar larvae enter the stem pith and pupate within an elliptical area lined with sawdust and small wood chips called a chip cocoon (Dixon and Houseweart 1982, Wallace and Sullivan 1985). Only 5 to 10% of eggs initially laid will develop successfully to adult emergence (Taylor 1929a). In late September, new adults emerge and feed on the current-year shoots until the weather gets cool and then go into hibernation (Wallace and Sullivan 1985).

Site and stand conditions can have major effects on white pine weevil populations. Complete or partial overstory shade, for example, can deter white pine weevil oviposition and feeding in several ways. Wallace and Sullivan (1985) found that weevils selected the stoutest, most vigorous leaders, and avoided leaders with diameters less than 4 mm. Larger diameter terminal leaders are rarely found in shaded stands (Sullivan 1961). Stout leaders also have thicker bark. Weevils prefer leaders with a bark thickness of 1.8–2.2 mm but will infest leaders with bark thickness of 0.8–2.5 mm (Wallace and Sullivan 1985). Bark temperatures of terminal leaders are lower on white pine grown in the understory compared to open grown white pine (Sullivan 1961). Lower temperatures limit feeding and oviposition by adult weevils and hinder the development of larvae (Wallace and Sullivan 1985). Overstory trees may distort the visual response that adult weevils have to terminal leader silhouettes, making it difficult for them to find suitable terminal leaders (Peirson 1922, VanderSar and Borden 1977, Taylor et al 1996). Harman and Kulman (1969) proposed that high levels of shading could affect the chemical properties of the terminal leader, thus making it less attractive for adult feeding, though no studies of this topic were located in the literature. Weevils

overwintering in shaded stands suffered higher mortality rates than those in open stands because high moisture levels and cool temperatures persist later into the spring (Wallace and Sullivan 1985). Overwintering mortality has been described as a key mortality factor of white pine weevil populations in white pine and may cause up to 92% mortality of overwintering adult weevils (Dixon and Houseweart 1986, Bellocq and Smith 1996).

Attack by white pine weevil can negatively affect white pine growth and form. Because adult weevils are not strong flyers, they usually seek out trees that are less than 4.6 m (15 ft) in height (Wallace and Sullivan 1985). Feeding by larvae effectively girdles the terminal leader causing the current years growth to wilt and die (Marty and Mott 1964, Wallace and Sullivan 1985). White pine weevil damage in the early years of a tree's growth occurs in the lower 4.9 m (16 ft) of the stem. This section of the stem is the economically valuable butt log if the tree is to be harvested for timber. Up to four years of terminal leader growth can be destroyed by a white pine weevil attack which reduces the average height growth of a tree (Marty and Mott 1964).

When the terminal leader dies, a lateral branch will attempt to take over dominance, and can cause a crook in the stem (Wilson and McQuilkin 1965, Brace 1971, Gross 1985), or two or more lateral branches may compete for dominance resulting in a forked stem (Harman and Kulman 1967). Damage caused by white pine weevil can result in up to a 40% loss in final lumber volume, and board quality reductions of 1 to 3 grades (Waters et al. 1955, Ferguson and Kingsley 1972, Alfaro 1982, Alfaro 1995). Trees that are injured several times may have numerous crooks and forks in the stem. Trees with multiple leaders are commonly called stagheaded, pasture, or cabbage trees and are of little value for lumber. Repeatedly attacked trees may be unable to compete

with surrounding vegetation, may be overtopped, and may eventually be killed by suppression (Alfaro and Borden 1985).

Controlling Damage from White Pine Weevil

Management to reduce damage from white pine weevil can be divided into three categories: chemical, silvicultural, and biological.

Chemical control: Currently no biological insecticides are available for control of white pine weevil and few conventional chemical insecticides are economical and effective for forest application (de Groot 1985, Bellocq and Smith 1996). Using chemical pesticides to control white pine weevil is especially difficult because the larvae and pupae are protected within the terminal leader. Permethrin and methoxychlor were evaluated by de Groot et al (1995) for controlling white pine weevil in young jack pine stands. After two years of spraying, only 1-3% of leaders were damaged by weevil compared to 9-13% of the leaders damaged in control plots (de Groot and Helson 1993, de Groot et al 1995). This result showed that it is possible to control white pine weevil with chemical insecticide, though this may not be economically or environmentally practical on large forested acreage.

Silvicultural control: Determining which silvicultural practices effectively control white pine weevil, while providing acceptable growth rates and quality white pine products, is important to land managers who would like to plant white pine. There are two commonly accepted silvicultural practices for regeneration of white pine to limit weevil damage: 1) maintain high densities of pines to cause injured trees to straighten more quickly, and 2) maintain partial shading of young trees with a hardwood overstory to reduce the frequency of weevil attack (Marty and Mott 1964). A third option of

planting white pine in a hardwood clearcut or burn to establish a mixed species, even-aged stand, has potential but has not been well evaluated.

Planting white pine at a high density in open areas, without an overstory, can limit the amount of residual damage from white pine weevil though it does not limit the frequency of attack. Graham (1918) and MacAloney (1930) showed that high density stands sustained low amounts of deformity, even though attack rates were high, because lateral branches re-established dominance quickly after the terminal leader was killed due to the high competition for light in dense stands. Pure stands of white pine seldom stagnate because of inherent variations in vigor and trees will continue to compete for dominance after a successful weevil attack (Burns and Honkala 1990).

Several previous studies have evaluated the effectiveness of establishing high-density white pine stands. Early works suggested that high density planting (e.g. 7407 trees per hectare (Tpha), 3000 trees per acre (TPA)) may produce small-crowned trees which can limit diameter growth (Tarbox 1924, Cline and Lockard 1925, Steill 1979). Pure tracts of white pine may also be favorable for the buildup of other pest populations (Cline and Lockard 1925). White pine plantations in Maine and New Hampshire which were established by seeding (29,630 seeds/ha, 12,000 viable seeds/acre) were compared to those that were planted at a 1.8 x 1.8 m (6 x 6 ft, 2990 TPha, 1210 TPA) spacing (Graber 1988). At 18 years old, the seeded stand had 8,464 TPha (3,428 TPA) and the planted stand had 2,612 TPha (1,058 TPA). Trees in seeded stands were similar in height to planted trees but had smaller diameters at breast height (dbh), smaller branches, and showed fewer stem defects from weevil damage than planted trees. Multiple leaders resulting from white pine weevil attack occurred on only 10% of the heavily stocked

seeded trees compared with 85% of the trees in the planted areas (Graber 1988). Stiehl (1979) examined a white pine plantation in Ontario that had been planted at a 0.66 x 0.66 m (2.2 x 2.2 ft, 22,239 TPha, 9,000 TPA) spacing. When the stand was 19 years old, the trees were 7.5 m (24.6 ft) tall and 60% of the trees had escaped weeviling, but only half of all trees planted were still surviving (Stiehl 1979). Additionally, the dense stocking can cause heavy mortality in the intermediate and suppressed classes (Stiehl 1979).

In a study of white pine stands in Wisconsin, Pubanz (1996) concluded that maintaining tree vigor was key in minimizing effects of weevil in open grown trees. Similarly, Norway spruce grown in Quebec on better sites were able to recover from white pine weevil damage more quickly than plantations on poor sites, limiting the amount of defect found on trees on better sites (Archembault et al 1993). Brace (1971) noted that larger sawlogs provided more opportunities for sawyers and mills to minimize the damage caused by weevil and to maximize the grade of boards produced.

Establishing white pine under an overstory can also reduce the amount of damage from white pine weevil (Stiehl and Berry 1985, Wallace and Sullivan 1985, Katovich and Morse 1992, Taylor et al 1996). Trees grown in the understory, even with only 25% crown cover, experienced about 10% of the frequency of weevil attack that trees grown in the open experienced (Belyea and Sullivan 1956, Sullivan 1961). Stiehl and Berry (1985) found that stands in full light sustained twice as much weevil damage as stands in 50% light. In Virginia, Harman and Kulman (1968), investigated different methods of white pine regeneration in relation to successful development of white pine weevil larvae to adult emergence. They found that understory trees were least favorable to the successful weevil development. In Ontario, white pine weevil damage was reduced when

white pine was grown under an overstory of deciduous species (Stiell 1979). Wallace and Sullivan (1985) also found that white pine grown under deciduous species had fewer weevil defects, and Schultz (1989) reported no evidence of white pine weevil occurrence in white pine planted under birch in Wisconsin. Studies of understory planted Sitka spruce (Alfaro and Omule 1990), and white spruce (Taylor et al 1994) also showed lower levels of white pine weevil infestation than open plantations of the same species. Some silvicultural studies have found that white pine saplings can survive in the understory for up to 30 years and still respond well to release, indicating that white pine is well suited for regeneration in the understory (Goebel and Cool 1968, Berry 1982, Kelty and Entcheva 1994).

Although white pine is moderately shade tolerant (Baker 1949, Spurr and Barnes 1980, McRae et al 1994, Wetzal and Burgess 1994) and can survive well in the understory, some studies point out disadvantages to regenerating white pine in the understory. Trees grown in the understory tend to grow more slowly than trees grown in open plantations (Stiell and Berry 1985, Barbara and Kelty 1994). White pine will tolerate up to 80% shade, but tree growth decreases as shade increases (Freeman and VanLear 1977, Balmer and Williston 1983). Stiell and Berry (1985) found that trees in 75% shade took five times longer to reach 5.2 m than trees grown in the open. Logan (1956, 1959, 1962) found that acceptable levels of weevil damage could be achieved under 50 – 75% shade, while still maintaining adequate growth rates. White pine less than 30 years old with at least one-third of their height in live crown respond well to release, but response declines proportionately with increasing age and decreasing crown length (Burns and Honkala 1990). Another disadvantage of planting under an overstory

is that overstory trees must be thinned and eventually removed after the white pine has grown past the height of being susceptible to weevil attack (MacAloney 1930). Removal of the overstory creates the opportunity for damage to the understory white pine, and for windthrow of residual trees following the harvest (MacAloney 1930, Cline and Lockard 1925).

Regenerating white pine in even-aged mixed species stands can be beneficial because of the high stem density which causes white pine to re-establish dominance quickly to compete for light resources. A study of white pine planted in a hardwood clearcut as an even-aged mixed species stand, was conducted by Patterson and Aizen (1989) who found that only 3.5% of these white pine had evidence of weevil damage. Herbicide treatment was needed to control hardwood sprouts and seedlings to prevent the white pine trees from being overtopped, out-competed, and eventually killed (Patterson and Aizen 1989). Wilson and McQuilkin (1965) noted that against strong competitors such as aspen, oak, and maple, white pine usually failed to gain a place in the upper canopy and eventually died. The study by Patterson and Aizen (1989) was discontinued because the white pine died from being overtopped by hardwoods when herbicide use on the hardwoods was discontinued.

Biological control: Effectiveness of natural control of white pine weevil populations by parasitoids or other natural enemies has not been well studied. Biological control of white pine weevil was considered vitally important by Plummer and Pillsbury (1929), since white pine weevil is a native insect they considered it unlikely that natural control could be artificially increased beyond existing levels. A variety of parasitoids are able to utilize the various life stages of white pine weevil. Peirson (1922) suggested that the

highest percentage of parasitism occurred during the pupal stage and that nearly 50% of pupae could be parasitized in some years. Emergence of adult weevils, in a study of infested Engelmann spruce leaders, was very low (mean of 1 adult/leader), suggesting that parasitoids can play an important role in regulating the population of weevils (VanderSar 1978). VanderSar (1978) and Nealis (1998) found that many parasitoids of weevil larvae complete their life cycles within the terminal leader, overwinter in the damaged terminals, and emerge in the spring when adult weevils begin to lay eggs.

Harman and Kulman (1967) compiled a list of parasites and predators of white pine weevil, but reported that many of the studies were from the late 1800's, and few were thorough, quantitative studies. MacAloney (1932) reared 29 species of parasitic insects from white pine terminal leaders infested by white pine weevil in the New England states. The most common externally feeding parasitic insects include *Lonchaea corticus* Taylor (Diptera: Lonchaeidae) (Plummer and Pillsbury 1929, MacAloney 1932, VanderSar 1978), *Eurytoma pissodis* Gir. (Hymenoptera: Eurytomidae) (Graham 1926, MacAloney 1932, Harman and Kulman 1967, Stevenson 1967, VanderSar 1978), and *Bracon pini* Muesebeck (Hymenoptera: Braconidae) (MacAloney 1932, Harman and Kulman 1967, Stevenson 1967, VanderSar 1978). The most common internally feeding parasites include *Doryctes* sp. (Hymenoptera: Braconidae) (MacAloney 1932), *Coeloides pissodis* Ashmead (Hymenoptera: Braconidae) (MacAloney 1932), *Dolichometus terebrans nubilipennis* Viereck (Hymenoptera: Ichneumonidae) (Harman and Kulman 1967, Stevenson 1967, VanderSar 1978), and *Rhopalicus pulchripennis* Crawford (Hymenoptera: Pteromalidae) (Harman and Kulman 1967, Stevenson 1967, VanderSar 1978). Additional parasites of white pine weevil are *Labena grallator* Say

(Hymenoptera: Ichneumonidae), *Exeristes comstockii* Cresson (Hymenoptera: Ichneumonidae), *Eurytoma tylodermatis* Ashmead (Hymenoptera: Eurytomidae), *Eurytoma tomici* Ashmead (Hymenoptera: Eurytomidae), *Eupelmus pini* Taylor (Hymenoptera: Eupelmidae), *Coeloides pissodis* Ashmead (Hymenoptera: Braconidae), *Calliephialtes nubilipennis* Ashmead (Hymenoptera: Ichneumonidae), and *Spathius sp.* (Hymenoptera: Braconidae) (Barnes 1928a 1928b, Taylor 1929a 1929b). Nealis (1998) reported that decreases in the number of white pine weevils that survived to adult emergence corresponded to increased numbers of a dipteran external parasite (*Lonchaea corticus*) which is found throughout the range of white pine weevil (Alfaro and Borden 1980). Plummer and Pillsbury (1929) found that *L. corticus* caused 50% mortality during the larval stage. Other parasites of white pine weevil may be of relatively minor importance in controlling weevil populations when compared to *L. corticus* (Kenis et al. 1996).

White Pine Blister Rust Biology

White pine blister rust is a fungal pathogen that originated in Asia and was introduced to the United States in 1910, and to Michigan in 1917, on white pine seedlings from nurseries in France and Germany (Mandenberg 1933, McIntyre and Boyer 1964). White pine blister rust is highly virulent throughout the range of white pine and trees are susceptible from the seedling stage through maturity (Wilson and McQuilkin 1965). White pine blister rust infection can result in dead branches, stem cankers, and tree mortality. Sporulation of the fungus occurs on white pine in the spring, producing aeciospores which infect *Ribes spp.*, the secondary host for white pine blister rust (Kroeber 1941). During the summer, urediospores are produced on one *Ribes* plant and

blown to another *Ribes* plant, where they again cause infection (Kroeber 1941). In the fall, the fungus releases windblown teliospores from the underside of *Ribes* leaves, which then infect pine needles. For spores to successfully infect pine needles, the needles must be wet, air temperatures must be between 10 – 16° C (50 - 60° F), and relative humidity must exceed 97% for at least 48 h (Anderson 1973).

Blister rust is found in geographically localized pockets where appropriate weather conditions occur frequently (Liebhold et al. 1995). Blister rust infections also occur more often near the ground because moisture and temperature conditions favorable for rust inoculation occur there frequently (Charleton 1963). White pine grown under partial shade receives some protection from blister rust since little dew forms under the canopy, limiting the time when rust spores can germinate (Stearns 1992). Schultz (1989) reported no evidence of white pine blister rust occurrence in white pine planted under birch in Wisconsin.

Controlling White Pine Blister Rust

The first blister rust infection on naturally regenerated white pine in Michigan was discovered in 1928 (McIntyre and Boyer 1964). Public Act 313, created in 1929, gave the Commissioner of Agriculture power to pursue control of blister rust by destroying diseased pine or *Ribes* plants (Mandenburger 1933). By 1930 Michigan had begun a program to eradicate cultivated European black currant (*Ribes nigrum* L.). This program was replaced in 1932 by a regional blister rust control program (McIntyre and Boyer 1964). The Federal Unemployment Relief programs, begun in 1933, funded large scale *Ribes* removal and by 1937 much of the black currant had been eliminated throughout the region (McIntyre and Boyer 1964). However, by 1947 all of Michigan's

83 counties were known to have blister rust present on native *Ribes* plants (McIntyre and Boyer 1964). The *Ribes* eradication program was discontinued in the mid to late 1900's.

The Lake States were divided into blister rust hazard zones in 1961 and silvicultural recommendations were developed to minimize blister rust in low and moderate hazard zones, and to restrict planting in high hazard zones (Figure 1) (Van Arsdel 1961, Anderson 1973). Current methods for controlling white pine blister rust include pruning branches with cankers from trees, planting in low risk areas, and planting blister rust resistant seedlings.

White pine blister rust control by pruning the lower branches can be successful (Brown 1972) because environmental factors limit most blister rust cankers to within 1.8 m of the ground (Van Arsdel et al 1956, Van Arsdel et al 1961). Pruning of all lower branches, compared to pruning only infected branches, was three times more effective in preventing white pine blister rust infections in white pine in Wisconsin (Lehrer 1982). Lehrer (1982) suggests that pathological pruning of all lower branches could be used as the sole control measure in low and medium hazard zones with or without *Ribes* eradication, and could be used in the high hazard zones as a supplement to *Ribes* eradication for control of white pine blister rust.

A study to try to enhance blister rust resistance in western white pine was started in the late 1940's (Bingham 1983) and these seedlings have shown possible resistance when compared with non-resistant seedlings. Kwan-Soo et al (2001) found that susceptible families of eastern white pine had larger and rounder stomata than resistant stocks which may be a trait that can be selected for. Resistance to blister rust continues to be studied and may be an important tool in future plantings.

Study Importance

Interest in white pine regeneration in the Lake States has recently experienced a resurgence (Stine and Baughman 1992). There is relatively little information about white pine weevil and what stand conditions are associated with good tree growth and low occurrence of weevil damage. There are currently no comprehensive integrated pest management strategies for blister rust control in white pine stands (Lehrer 1982). White pine is a valuable timber species and the information from this study could be used to establish silvicultural guidelines for white pine regeneration in the state of Michigan.

The overall objectives of this study were to evaluate the existing white pine resource in northern Michigan, determine frequency and extent of damage from white pine weevil and white pine blister rust, and relate this information to site and stand characteristics (results in chapter 1). A short term study on the effect of parasitoids on weevil survival was conducted in four plantations of young white pine in Michigan's Upper Peninsula and is discussed in chapter 2. Part of this project was also aimed at exploring regeneration methods for white pine, and providing demonstration sites for managers interested in planting white pine. A record of objectives and methods of these long-term research and demonstration sites is included as chapter 3.

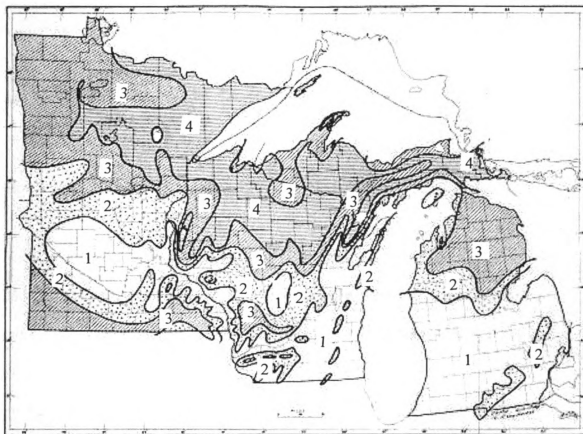


Figure 1. White pine blister rust hazard zones (Van Arsdel 1975). Zone 1 = little control required, no hazard; Zone 2 = minor controls required, low hazard; Zone 3 = modified standard controls required, moderate hazard; Zone 4 = augmented control required, high hazard.

CHAPTER 1

EVALUATION OF DAMAGE FROM WHITE PINE WEEVIL AND WHITE PINE BLISTER RUST IN WHITE PINE STANDS IN MICHIGAN

Introduction

Until widespread logging during the late 1800's, Michigan was covered with an estimated 150 to 170 billion board feet of pine, and eastern white pine (*Pinus strobus* L.) comprised a major portion of that pine cover (Maybee 1976). Efforts to re-establish white pine in Michigan and much of the Lake States region have been hampered by damage from white pine weevil (*Pissodes strobi* (Peck)) (Coleoptera: Curculionidae), which can reduce volume and quality of lumber, and white pine blister rust (*Cronartium ribicola* (Fischer)) which can cause tree mortality. A better understanding of the site and stand conditions, and silvicultural practices that limit damage from these pests while providing acceptable growth rates is needed in Michigan.

In the spring, white pine weevil adults lay eggs in feeding sites along the terminal leader of young white pine trees. Eggs hatch and larvae feed in the phloem of the terminal leader from June through August, then pupate within a chip cocoon under the bark. New adults emerge about two weeks later and feed until the weather gets cool. Adults overwinter at the base of the tree under the duff layer (Wallace and Sullivan 1985). Feeding by white pine weevil larvae can kill two to three years of terminal leader growth. This injury to the tree often results in overall reduced growth rate, and crooked,

forked, or multiple leaders in the main stem, which can reduce the amount of useful lumber when the tree reaches maturity.

The two most commonly accepted practices for regeneration of white pine to limit the amount of damage the tree sustains from weevil attack include establishing white pine plantations with a high stem density, and planting white pine under an overstory. High density planting in open areas with no overstory is thought to encourage injured white pine to re-establish apical dominance more quickly because of competition for light. Open grown trees have faster growth rates than trees in the understory, enabling them to recover from weevil injury more quickly, which also reduces the severity of the defect (Marty and Mott 1964). A disadvantage of planting large blocks of a single tree species, however, is that monocultures can be severely affected by outbreaks of pest populations (Cline and Lockard 1925).

Alternatively, maintaining partial shading of young trees with a hardwood overstory can reduce the frequency of weevil attack. Partial shading deters white pine weevil oviposition and feeding by limiting terminal leader diameters to sizes rejected by weevils (Wallace and Sullivan 1985), lowering leader temperatures and raising relative humidity to levels unfavorable to weevil activity (Sullivan 1961), and distorting visual responses of adult weevils (Peirson 1922, VanderSar and Borden 1977, Taylor et al. 1996). White pine stands growing under 50% crown cover had only half the amount of weevil damage as stands planted in full sunlight (Stiell and Berry 1985). Some disadvantages of partial shading are relatively slow growth of shaded trees in the understory (Stiell and Berry 1985), reduced diameter growth even when height may not be adversely affected (Stiell 1979), and substantial mortality due to competition can

occur (Stiell 1979). Also, overstory trees must eventually be removed (MacAloney 1930), which can cause damage to understory trees.

White pine blister rust was first found in Michigan in 1917 but was probably introduced earlier (Mandenburger 1933). The disease originated in Asia and was imported to Michigan on white pine seedlings from nurseries in France and Germany (Mandenburger 1933). White pine blister rust infections can result in dead branches, stem cankers, or tree mortality. White pine blister rust requires *Ribes* sp. to complete its development. An extensive *Ribes* eradication program was executed throughout Michigan in the early 1900's in an effort to eliminate the secondary host for the pathogen. The Lake States were divided into blister rust hazard zones in 1961 based on weather patterns. Silvicultural recommendations based on site and stand characteristics were developed to minimize blister rust damage in the low and intermediate hazard zones and white pine planting was discouraged in high hazard zones (Van Arsdell 1961, Anderson 1973). Current recommendations include pruning cankered limbs, planting in low risk areas, planting at high densities, planting under an overstory, and planting blister rust resistant seedlings. Concern about blister rust has greatly limited the amount of white pine planted in the Lake States (Nicholls and Anderson 1977).

White pine has regenerated naturally in stands throughout Michigan, but there have been relatively few efforts to restore large tracts of white pine forest by land managers due to the presumed problems with white pine weevil and white pine blister rust. The overall goals of this study were to evaluate existing white pine stands in Michigan to determine incidence and severity of damage from white pine weevil and white pine blister rust, and to relate pest incidence to site and stand characteristics.

Specific objectives of this study were to 1) evaluate differences in white pine weevil damage and white pine blister rust occurrence between open-grown and understory white pine stands on public lands in northern Michigan, and 2) assess relationships between white pine weevil damage, white pine blister rust damage, tree growth, and site and stand characteristics.

Methods

Stand selection: Stands were selected at random for this study by querying the inventory databases of the Michigan Department of Natural Resources (Michigan DNR), the United States Department of Agriculture (USDA) Forest Service, and by direct requests of forest managers for stands with a white pine cover type or white pine understory. The Highplains region in Michigan's Lower Peninsula, and Dickinson and Luce regions in the Upper Peninsula were selected for this study from a Regional Landscape Ecosystem classification because of the abundance of white pine cover type on these land types (Albert 1995).

In the Highplains district, soils were sandy and excessively well-drained. Elevation was 177 – 526 m, and the landforms were described by Albert (1995) as high plateau and outwash plains. The Dickinson district had sandy soils, with some loamy sands. The elevation is 183 – 396 m with outwash plains, sandy ridges, conifer swamps, and till plains as the primary landforms (Albert 1995). Luce district, at an elevation of 183 – 378 m, had sand, loamy sand, and some organic soils. Landforms in this district consisted of broad poorly drained embayments, beach ridges and depressions, sand spits, and sand dunes.

White pine stands included in this study were required to be ≥ 5 years old, ≥ 1.2 ha (three ac) in size and have $\geq 50\%$ of the basal area in white pine. Ninety-six stands were selected randomly from a list of stands meeting the above criteria. I surveyed 43 stands in the Highplains district (seven were open-grown plantations), eight stands in the Dickinson district (one was an open-grown plantation), and 45 stands in the Luce district (13 were open-grown plantations). Stand locations are listed in Appendix 1 and mapped in Figure 1. Stands were visited, mapped, and the method of regeneration (natural or planted) was recorded. Stands in which silvicultural activities were performed in the last 10 years were excluded from the survey to prevent data from being confounded by recent management activities such as selection cuts. White pine stands within each of the three ecological regions were classified by tree size class (seedling/sapling, poletimber, sawtimber) and stand area (2.02 – 4.04, 4.05 – 20.23, 20.24+ ha, or 3-10, 11-50, 51+ ac). Site index and stand year of origin were acquired from the Michigan DNR and USDA Forest Service inventory databases. Table 1 summarizes the characteristics of the 96 surveyed stands.

Stand and Tree Variables: Site, stand, and tree characteristics were measured using a combination of circular and linear plots to ensure that stand conditions were well represented. Circular plots, 0.01 ha each, were established in each stand at the rate of one plot per 4.04 ha (10 ac), with a minimum of three plots and a maximum of seven plots per stand. A 20.1 m (one chain) buffer strip around the edge of the stand was not sampled to eliminate potential edge effects. Plots were randomly located in the stand using a numbered grid overlayed on the stand map and randomly drawn numbers to determine where plots would be established. Linear plots, 100 m x 1 m, were established in a

randomly chosen direction, starting at the edge of each circular plot, so that there were equal numbers of circular and linear plots per stand.

Variables measured in each circular plot included trees/ha, tree age, percentage crown closure (measured with a spherical densiometer), and topography (flat, rolling, hilly). Additional variables measured in circular plots included diameter at breast height (dbh), total height, bole height (height to first live branch), and dominance class for all trees with dbh >2.54 cm.

To estimate age of white pine trees and assess radial growth, one increment core was taken at 0.3 m (one ft) above ground level from at least one randomly chosen white pine in each circular plot. Cores were mounted, sanded to a very fine finish, and reviewed under a dissecting microscope for any false rings, narrow rings, missing rings, and partial rings to be sure that growth and age were estimated as accurately as possible. Cores were then placed on a flatbed scanner and assessed using an image analyzer and WinDendro (Regen Instruments Inc.) software to determine the width of annual growth rings. Mean annual increment was calculated by taking the average of the annual growth over the life of the tree. When testing natural vs. planted stands for mean annual increment differences the sawtimber sized stands were eliminated from analysis since there were no sawtimber sized planted stands.

In linear plots, I evaluated only white pine trees that were encountered within the 100 x 1 m strip. Variables measured in linear plots included dbh, total height, bole height (height to first live branch), and dominance class.

White Pine Weevil Damage: Additional variables were collected from white pine trees in both circular and linear plots to assess weevil damage. These variables included

number of defects in the main stem, number of lateral branches competing for dominance, and whether a dead leader was visible. A stem defect was any deformity in the stem that caused the stem to crook or fork and for this study I assumed that all crook or fork defects were due to weevil injury. Number of stem defects were recorded within three areas on the stem depending on distance from the ground: 0–2.4 m, 2.5–4.9 m, and 5.0+ m (0–8 ft, 8.5–16 ft, and 16+ ft, respectively). This grouping of defects enabled me to delineate defects within the first log (basal log), second log, and the remaining portion of the stem.

Branch angle of the upper two whorls of branches was visually estimated on all white pine trees in the circular plots. Preliminary sampling of branch angle using a protractor on the upper quarter of the branches on young trees determined that my visual estimation was accurate to within ± 10 degrees of the actual branch angle.

White Pine Blister Rust Damage: Each white pine tree in all circular and linear plots was examined for evidence of blister rust infections. When symptoms were present, I determined height and location of the infection, (main stem or branch, and height from ground), tree health (live, declining, dead), and amount of *Ribes* sp. in the plot (percentage of ground cover within the plot). Evidence used to determine if a tree was infected included sporulating cankers (orange-yellow blisters), pycnia (yellow-brown blisters) on the canker, or mature cankers bordered by a yellowish discoloration of bark at the canker margin and resin flow down the stem (Nicholls and Anderson 1977).

Statistical Analysis: Data were tested for normality using the Shapiro-Wilkes test. The data were normal and no transformations were necessary. I determined stand-level averages for average number of total defects per tree, and average numbers of defects per

2.4 m (8 ft) section (0-2.4 m, 2.5-4.9 m, 5.0+ m) using white pine data from circular and linear plots. I also calculated stand-level percentages of trees with 0, 1, 2, 3, and 4 or more defects per tree. Results are reported for tests run on both the average numbers of defects per 2.4 m stem section and the percentage of trees with numbers of defects.

Analysis of variance was used to test stand level means (calculated from individual tree data) to evaluate differences in the number of weevil-related stem defects, radial growth rates, and blister rust frequency between 1) regeneration type (planted vs. naturally regenerated), 2) ecological regions (Highplains, Dickinson, Luce), 3) stand area categories (2.02–4.04, 4.05–20.23, 20.24 + ha), 4) tree size classifications (seedling/sapling, poletimber, sawtimber) 5) crown closure and 6) site index class. Each stand was assigned to a site index class based on the specific site index of that stand. Single tree data (rather than stand level means) were used to assess differences in the number of stem defects per tree among dominance classes. There were no significant differences in average number of defects from white pine weevil among the three ecological regions ($F=0.29$, $df=2,92$, $p=0.751$), so the data were pooled for subsequent analyses. One outlier was removed for tree growth analyses. This outlier had greater than 8 mm of average annual radial growth, was a dominant/co-dominant seedling/sapling planted stand in the Highplains district, and significantly changed the results when left in the data. SAS statistical software was used for all analyses with alpha set at 0.05.

Results

Characteristics of Surveyed Stands: A total of 4,293 white pine trees in 96 stands (Figure 1), were surveyed in 1998 and 1999. Data were collected from a total of 307

circular plots (averaging 5.6 ± 0.240 white pine trees per plot) and 307 linear plots (averaging 8.4 ± 0.341 white pine trees per plot). Naturally regenerated stands were more common than plantations in all three districts (Table 1) because relatively little planting of white pine has occurred on public lands. I assessed a total of 3,205 white pines in 75 naturally regenerated stands, and 1,088 white pines in 21 planted stands. Twenty-seven stands (28% of surveyed stands) were 2.0 – 4.0 ha in size, 40 stands (42% of surveyed stands) were 4.1 – 20.2 ha in size, and 29 stands (30% of surveyed stands) were 20.2 ha or larger in size. A total of 42 stands were classified (according to inventory data) as seedling/sapling, 38 stands were poletimber, and 26 were classified as sawtimber. The seedling/sapling sized stands that I surveyed had a mean DBH of 11.8 ± 0.24 cm (4.6 ± 0.10 in), poletimber stands were 17.7 ± 0.26 cm (7.0 ± 0.10 in) DBH, and sawtimber stands had a mean DBH of 25.4 ± 0.51 cm (10.0 ± 0.20 in).

There were similar numbers of naturally regenerated stands surveyed in each of the three stand area categories, while nearly half of the planted stands surveyed were in the 4.1 – 20.2 ha size category (Table 1). Naturally regenerated surveyed stands were evenly distributed between seedling/sapling and poletimber sized classes, with slightly fewer stands in the sawtimber class. There were no sawtimber sized planted stands surveyed since there were few to choose from and none met the selection criteria; most planted stands surveyed were in the seedling/sapling size class. The 43 stands surveyed in the Highplains district were evenly distributed among stand size classes, while in the Dickinson district there were no sawtimber stands included in my survey. Luce district had the highest number of planted trees surveyed compared to the other districts. The range of site indices for naturally occurring stands and planted stands were similar but the

mean site index (SI) of planted stands was slightly higher than that of naturally regenerated stands, and the Highplains district had a slightly higher average site index than the other districts (Table 2). Dickinson district had the greatest crown closure, with a mean of 84.4%, though differences among regions were not significant ($F=1.09$, $df=2,93$, $p=0.340$). Stands in the poletimber sized class had a mean crown closure of 81.9%, which was slightly higher than other classes, but differences were not significant ($F=1.52$, $df=2,93$, $p=0.224$). Eighty-eight percent of surveyed stands had topography that I classified as flat, 9% had rolling terrain, and 3% I considered hilly. Stand level data are found in Appendix I.

Tree Growth: Planted trees had significantly greater mean annual increments (mean annual radial growth) than trees in natural plantations ($F=11.31$, $df=1,274$, $p\leq 0.001$) (Table 3). There were no significant differences in growth among stands related to topography ($F=1.69$, $df=2,340$, $p=0.187$), crown ratio ($F=1.56$, $df=1,330$, $p=0.213$), district ($F=0.19$, $df=2,340$, $p=0.829$), stand area ($F=0.40$, $df=2,340$, $p=0.672$), or site index ($F=2.0$, $df=3,259$, $p=0.122$) (Table 3). Percentage crown closure significantly affected radial growth rates ($F=5.75$, $df=1,330$, $p\leq 0.001$) (Table 3). Radial growth was significantly greater in stands with 90 percent crown closure as compared to stands with 60 and 70 percent crown closure (Table 3), although radial growth rates within each crown closure class varied considerably (Figure 2). Since these results were counter-intuitive I re-analyzed the crown closure data and separated it by stand size class (seedling/sapling, poletimber, sawtimber). This separation of the data showed that in the seedling sapling size class there were significant differences ($F=2.97$, $df=3,115$, $p=0.035$). The 60% crown closure class of seedling/sapling stands had the greatest

growth rates (3.0 ± 1.09) but due to the high standard error it was not significantly different. The greatest growth rate, at 2.7 ± 0.25 , was found in the 90% crown closure class. Crown closure class was not a significant factor in mean annual increment for poletimber sized stands ($F=0.12$, $df=3,153$, $p=0.951$) or sawtimber stands ($F=1.58$, $df=3,64$, $p=0.202$).

Tree size class was also significantly related to radial growth rates. Mean annual increment in seedling/sapling sized stands and poletimber sized stands were not significantly different from each other but both had significantly greater radial growth rates than sawtimber sized stands (Table 3) ($F=18.29$, $df=2,340$, $p \leq 0.001$). As expected, dominance class also had a significant affect on radial growth. Sapling and dominant/co-dominant trees had significantly greater growth rates than intermediate or suppressed classes of trees ($F=28.37$, $df=4,338$, $p \leq 0.001$) (Table 5).

White Pine Weevil

Thirty-eight percent of all the white pine trees surveyed for this study had no apparent defects. Trees with one defect accounted for 27% of all trees surveyed, 16% had two defects, 9% had three defects, and 10% of the white pines had four or more defects per tree. The percentage of trees with defects was higher in planted stands than in naturally regenerated stands. There were 42% of trees in natural stands that were free of defects compared with 20% of trees in planted stands. Only 7% of trees in natural stands had four or more defects while 22% of trees in planted stands had more than four defects. Crook was the most common defect, occurring in 62% of trees surveyed. Forking, or

multiple leaders, occurred in 10% of surveyed trees and was more common in planted stands than naturally regenerated stands.

District: Fifty-one percent of the white pine trees in Dickinson district, 33% of white pines in the Highplains district, and 38% of the trees in Luce district had no apparent defects. Only 1% of Dickinson district white pines, 13% of the trees in Highplains, and 9% of Luce district trees had more than 4 defects per tree. There were no significant differences among the three ecological regions (Dickinson, Highplains, and Luce districts) in average number of defects per tree for any of the 2.4 m (8 ft) stem sections (Table 4). The percentage of trees per stand with 0, 1, 2, 3, or 4+ defects per tree also did not differ significantly among the districts (Table 5).

Regeneration Type: Planted trees had significantly more defects per tree on average than trees in stands that regenerated naturally (Table 4). One planted stand in the Highplains district had a very high average of 10.1 weevil defects per tree; most stand averages were not so high. There were significantly greater average number of defects per planted stand ($F=7.03$, $df=1,94$, $p=0.009$), average defects in the basal stem section (0-2.4 m) ($F=12.02$, $df=1,94$, $p\leq 0.001$), and in the 2.5-4.9 m stem section of planted stands ($F=6.5$, $df=1,94$, $p=0.012$) when compared to naturally regenerated trees (Table 4). Average number of defects in the upper stem section (greater than 5.0 m) were also greater in planted stands but differences were not significant ($F=0.99$, $df=1,94$, $p=0.321$). When examining the differences among log sections the naturally planted stands had significantly greater numbers of defects in the second log section compared to the upper sections and the basal log section of the tree ($F=3.84$, $df=2,222$, $p=0.023$) (Table 4). There were no differences among log sections in the planted stands.

Only 20% of planted trees in planted stands were free from defects compared to 42% of naturally regenerated pines. Naturally regenerated stands had a significantly higher percentage of trees with no defects ($F=6.39$, $df=1,94$, $p=0.013$) (Table 4). Planted and natural stands were not statistically different in the percentage of trees with one defect per tree ($F=0.21$, $df=1,94$, $p=0.648$), two defects per tree ($F=0.80$, $df=1,94$, $p=0.375$), and three defects per tree ($F=1.08$, $df=1,94$, $p=0.302$) (Table 5). Nearly four times as many planted trees had four or more defects (22%) compared with 6% of naturally regenerated trees with four or more defects. The percentage of trees with four or more defects was significantly higher in planted stands than in natural stands ($F=6.71$, $df=1,94$, $p=0.011$) (Table 5).

Stand Area: In the largest stands (4.1 – 2.2 ha), 33% of the trees were defect free, while 41% and 38% in medium sized stands and small stands, respectively, of trees were defect free. Trees with four or more defects were most common in small stands. On average, 19% of trees in small stands had four or more defects and 6% of trees in medium sized stands and 10% of trees in large stand areas had four or more defects.

Average number of defects per tree did not significantly differ among stand area categories ($F=0.65$, $df=2,92$, $p=0.524$) (Table 4). Average number of defects per stem section was also not significantly affected by stand area for the basal log (0 - 2.4 m) ($F=1.01$, $df=2,92$, $p=0.370$), the second log (2.5 - 4.9 m) ($F=0.84$, $df=2,92$, $p=0.434$), or the upper sections of the tree (5.0+ m) ($F=0.44$, $df=2,92$, $p=0.643$) (Table 4). Similarly, stand area had no significant affect on the percentage of trees with no defects ($F=0.68$, $df=2,93$, $p=0.507$), one defect per tree ($F=2.49$, $df=2,93$, $p=0.088$), two defects per tree

($F=1.03$, $df=2,93$, $p=0.361$), three defects per tree ($F=0.54$, $df=2,93$, $p=0.586$), or four or more defects per tree ($F=1.28$, $df=2,93$, $p=0.284$) (Table 5).

Tree Size Class: There were no significant differences in average number of defects per tree among seedling/sapling, poletimber, and sawtimber sized stands ($F=1.72$, $df=2,92$, $p=0.185$) (Table 4). In the basal stem section (0–2.4 m), seedling/sapling sized stands had significantly more defects than sawtimber stands ($F=6.83$, $df=2,93$, $p=0.002$) (Table 6), but differences between trees in poletimber stands and seedling/sapling or sawtimber stands were not significant (Table 4). Average numbers of defects was not significantly affected by stand size class for the second stem section (2.4–4.9 m) or the upper stem sections (5.0+ m) (Table 4). There were significantly greater average numbers of defects in the second log of Poletimber sized stands compared to the upper sections and basal log section ($F=7.51$, $df=2,111$, $p=0.001$) (Table 4). Seedling/sapling and sawtimber sized stand average defects were not significantly different among log sections.

Trees in sawtimber sized stands consistently had fewer defects than seedling/sapling and poletimber stands (Table 5). Seedling/sapling, poletimber, and sawtimber sized stands did not significantly differ in the percentage of trees with no defects ($F=2.44$, $df=2,93$, $p=0.093$), one defect ($F=1.15$, $df=2,93$, $p=0.320$), and two defects ($F=1.66$, $df=2,93$, $p=0.196$). The percentage of trees with three defects was marginally significantly greater in the seedling/sapling and poletimber sized classes compared to sawtimber classes ($F=3.09$, $df=2,93$, $p=0.050$). Percentage of trees with four or more defects per tree was marginally insignificant among size classes ($F=3.07$, $df=2,93$, $p=0.051$) though sawtimber sized stands were substantially different from seedling/sapling sized stands (Table 5).

Dominance Class: Overall average number of defects per tree significantly differed among trees of different dominance classes ($F=25.93$, $df=3$, $p\leq 0.001$). Mean number of defects per tree in the dominant/co-dominant class were significantly greater than intermediate, suppressed, and seedling/sapling classes; the intermediate class had significantly higher defects than the suppressed, and seedling/sapling classes, and the suppressed class had significantly more defects than the sapling class (Table 4). Average numbers of defects in the basal stem section (0–2.4 m) were not significantly different among any of the dominance classes ($F=1.29$, $df=3$, $p=0.256$). Number of defects per tree in the second stem section (2.5–4.9 m) were significantly higher for trees in the dominant/co-dominant class ($F=19.23$, $df=3$, $p\leq 0.001$) than for other classes; the intermediate class had significantly more defects than the suppressed, and the sapling classes, and the suppressed dominance class had significantly more defects than the sapling class (Table 4). The average number of defects in the upper stem sections (5.0+ m) was also significantly affected by tree dominance class ($F=53.95$, $df=3$, $p\leq 0.001$). Once again there were significantly higher numbers of defects in the upper stem section of the dominant/co-dominant class than intermediate, suppressed, and sapling dominance classes; the intermediate class had significantly higher defects than the suppressed, and the sapling classes, and the suppressed class had significantly more defects than the sapling class (Table 4).

Dominant/co-dominant ($F=75.01$, $df=2,7491$, $p\leq 0.001$) and intermediate ($F=30.44$, $df=2,1818$, $p\leq 0.001$) trees had significantly greater average numbers of defects in the second log section compared to the upper sections and the basal log section (Table 4). Suppressed ($F=44.29$, $df=2,2883$, $p\leq 0.001$) and sapling classed trees ($F=57.68$,

df=2,660, $p \leq 0.001$) had significantly greater numbers of defects in the basal log section compared to the other sections of the tree (Table 4)

Crown Closure: Percentage crown closure was grouped into 10-percent classes for analysis. There were no significant differences in the mean number of defects per stem section among crown closure classes (Table 4) or in the percentage of trees with any category of defect among the crown closure classes (Table 5).

Site Index: Site index was not a significant factor in the overall average number of defects per tree, the average number of defects in the basal log (0 – 2.4 m), the second log (2.5 – 4.9 m), or the top portions of the tree (5.0 m and higher). Site index was also not significant when examining the percentage of trees per stand with no defects, one, two, three, or four or more defects per tree.

White Pine Blister Rust

Only 0.7% of the white pine trees I surveyed had symptoms of white pine blister rust. Six stands (11 trees) with blister rust were located in Luce district and three stands (12 trees) were located in Highplains district; stands are shown by red dots in Figure 1. Defects occurred on the main stem of 22 of the 23 infected trees and all trees with stem cankers were declining. Height from the ground to the visible infection ranged from 1.2 - 11.6 m (4 - 38 ft) with an average of 3.4 m (11 ft). All but four of the cankers were located within the basal log of the tree. Dominant/co-dominant trees accounted for 10 of the infected trees (43%) there were four intermediate trees that were infected, and nine suppressed trees (39%) which had blister rust infections. No *Ribes* plants were found within my plots, or noted within the stands which were surveyed. There were no

significant differences in white pine blister rust occurrence among regeneration type, district, stand area, tree size class, and tree dominance class.

Discussion

Tree Growth

I expected that tree dominance class would have a strong relationship to mean annual increment (mean annual radial growth) . As expected, I found that dominant/co-dominant trees had significantly greater mean annual increments than the other dominance classes, although the range of radial growth was substantial for all dominance classes. Saplings also had very high rates of radial growth. Rapid growth rates in these two classes of trees could enable trees to recover rapidly from white pine weevil attacks, allowing the tree to begin putting on clear wood sooner than other dominance classes. Additionally, I found that mean annual increment of trees in stands classified as poletimber and seedling/sapling showed greater growth rates than trees in stands classified as sawtimber. Since there were no sawtimber sized planted stands the naturally regenerated sawtimber sized stands were removed from analysis of planted and natural and the results showed that planted trees in this study had growth rates that were 25% greater than naturally regenerated stands. My results support research by Stiel and Berry (1985) and Barbara and Kelty (1994) that showed greater growth rates in open planted trees.

Mean annual increment was greatest in stands where percentage crown closure was in the 80 – 90%. Vigorous rapidly growing stands could achieve high crown closure rates more quickly than other less vigorously growing stands and may account for this

result. After considering those results to be counterintuitive I analyzed the data again and separated it into stand size classes. Although the data still showed that the greatest growth rates were in the 90% crown closure classes this was only significant in the seedling/sapling size class. Puettmann and Saunders (2001) found similar results where seedlings growing in areas of high competition showed smaller growth loss due to herbivory than seedlings with little or no competition.

As expected there were no differences in mean annual increment among the stand area classifications or among topography designations. For this study there were three stand area categories and it was not expected that larger or smaller stands would show lesser radial growth rates as trees will achieve their growth rate regardless of the area of that particular stand. I used three topography descriptions for this study (flat, rolling, hilly) and this seemed adequate for what little topography Michigan has. Although there was no significant differences among topography categories if a similar study was carried out in an area with more variable terrain in radial growth rates could be affected.

I hypothesized that trees on sites with higher site indices should have a greater mean annual increment than trees on low quality sites, but in this study site index did not strongly affect radial growth rates. The stands with higher site indices did show greater mean annual increment than poorer stands but it was not significant.

White pine weevil

District: I originally hypothesized that white pine weevil damage might differ among the three districts surveyed due to differing management practices but I found that similar amounts of damage was similar across the districts selected for this study. Although there was a higher percentage of trees in Highplains district with four or more defects per

tree, I believe that this was due to the higher numbers of planted stands located in this district and the overall higher numbers of weevil defects associated with these stands. All areas were sandy, with moderate to extreme climate according to district description. It would appear from the results of this study that Michigan's white pine resource is affected by white pine weevil equally as much regardless of the location of the stands and that the ecological regions are not useful in trying to determine white pine weevil prevalence. Since I only sampled three of Albert's (1995) ecological districts there were many districts that were not sampled, so these conclusions may not be applicable to the other districts in Michigan.

Regeneration Type: I hypothesized that planted stands would have greater amounts of damage attributable to white pine weevil than naturally regenerated stands due to the attractiveness of a large concentration of acceptable terminal leaders located in a single area. My results supported my hypothesis and showed that planted trees have significantly greater numbers of weevil defects as well as greater percentages of trees within the stand with defects. Although it would at first appear that this should discourage land managers from planting white pine, I would disagree. The planted stands surveyed were mostly pure white pine stands established with no overstory. Historically, there were few other planting choices for land managers, since planting in the understory or establishing even-aged mixed species stands have only recently become accepted practices. Also, as noted, there were no planted stands in the Luce District in the seedling/sapling size class due to very limited recent plantings of white pine. Future studies which have the benefit of examining underplanted or even-aged mixed species planting may find very different results than this study. Additionally, high numbers of

defects does not always mean that the trees have no lumber value. Some research (Stiell and Berry 1985, Barbara and Kelty 1994) indicates that open grown trees have superior growth rates over understory planted trees and they may more quickly outgrow any defects (Graham 1918, MacAloney 1930), and my research supports this as well.

Stand Area: I hypothesized that smaller stands would be more difficult for white pine weevil to find and that larger stands would appear more attractive to weevils. My results showed that the area of the stand made no difference in the number of defects per tree. Larger stands and oddly shaped stands would tend to have more edge and edge trees were not sampled in this research. The interior of stands of any size, however, will have similar amounts of damage according to my results.

The data for percentage of trees with defects shows that small areas had the most trees with no defects per tree as well as the largest percentage of trees with four or more defects per tree, but once again these results were not significant. This means that stands in the smallest area class had some trees that were severely damaged by weevil but that there were also many trees that appeared undamaged that would be future crop trees. Based on my data there seems to be no reason to choose any particular stand area on the basis of expected weevil damage.

Tree Size Class: The overall average number of defects per tree was not significantly different among the tree size classes in this study. But, since the basal log is the most valuable part of the tree, it is useful to note that sawtimber sized stands had significantly fewer defects in the basal log than seedling/sapling sized stands. This could simply demonstrate that the trees are able to recover from the defect and begin putting on clear wood between the time that the tree is injured as a seedling/sapling and when it reaches

sawtimber status. Tree dissection would be needed to confirm this, but was not done for this study.

Additionally, sawtimber sized stands had the lowest percentages of trees with three or four defects per tree, thus, better quality crop trees were more common in sawtimber sized stands. Not knowing the silvicultural history of the stands makes it difficult to determine if this result was due to the tree's ability to eventually grow over defects or if it was due to past harvesting practices that removed the more badly damaged trees.

Dominance Class: I hypothesized that dominant/co-dominant trees would have greater numbers of defects per tree due to the more desirable size of the terminal leader as the tree developed. My hypothesis was supported by the data showing that the dominant/co-dominant trees had the greatest number of defects on average per tree compared to all other dominance classes. This result is consistent with weevil preference for stout leaders and less preference for smaller leaders of suppressed trees (Wallace and Sullivan 1985).

I found that dominant/co-dominant and intermediate trees had significantly greater numbers of defects in the second log section. This would seem to indicate that the tree was not as attractive to the weevil during the first years of its life until it reached 4.9 m. Suppressed and sapling classes had greater defects in the basal log but this would seem to make sense due to suppressed and sapling trees not being as tall or as old as some of the dominant/co-dominant trees.

Crown Closure: The percentage of crown closure in a stand was not a significant factor related to the average number of defects in a tree or the percentage of trees with any number of defects. I had originally hypothesized that trees in stands with greater crown

closure would have fewer defects. This result would seem to indicate that shading does not affect weevil attacks. However, the measurements of crown closure were not taken at the time of weevil infestation, but rather at the time that I was in the stand, although some of the seedling/sapling stands did have current attacks. Because the measurements were generally not taken at the time of attack the data should be used cautiously. Future studies are needed to examine percentage crown closure as it relates to weevil attack.

Site Index: I hypothesized that trees on sites with higher site indices would show fewer defects per tree because better growth would lead to more rapid recovery from weevil attack. I found that site index was not significantly related to the average number of defects per tree or the percentage of trees per stand with any number of defects. My results differed from Archambault et al. (1994), who found that for Norway spruce in Quebec, site index did influence the levels of attack, with those stands on the most productive sites sustaining fewer attacks from weevil than trees on poor sites. But, a study of white spruce in British Columbia found results similar to mine, that there was no relationship between site index and the amount of weevil damage (Taylor et al. 1991).

White Pine Blister Rust

Most of Michigan's Upper Peninsula and Northern Lower Peninsula is rated as moderate or high for risk from blister rust. The low number of white pine trees that had symptoms of blister rust (23) compared to the high total number of white pine trees surveyed (4,239) suggests, however, that the hazard zones may be inaccurate, too coarse, too general, or that I didn't sample enough in the areas rated high hazard. Robbins et al. (1988) found a similarly low number of trees infected with blister rust during their survey of white pine on the Ottawa and Hiawatha National Forests of Michigan's Upper Peninsula. They

surmised that the difference in the number of trees found infected, as compared to the hazard zone, was due to climate, topography, genetic resistance, and low amounts of *Ribes* resulting from both natural and artificial controls. I found no *Ribes* within any of my plots and did not observe any within the stands surveyed. This lack of *Ribes* in stands where blister rust is found was similar to observations by Dahir and Cummings-Carlson (2001) in Wisconsin. They suggested that blister rust spores are blown by wind from sites where *Ribes* is growing but white pine may not be, to sites where white pine is growing but *Ribes* is not found.

Crown closure of a stand may play an important role in limiting blister rust infections. When stands close their canopy rapidly this may cause the lower branches to be shaded out more quickly, killing any blister rust infections that may be in those branches. I was unable to make any solid conclusions on this subject, however, due to the small number of blister rust infected trees in this study.

Conclusion

When considering whether to plant white pine, it is important to consider the potential effects of white pine weevil and white pine blister rust. I selected a random sample of white pine stands on public land within three major Ecological Districts in Michigan, thus my data should be representative of the white pine resource. Based on my results I would not discourage the planting of white pine. White pine weevil damage will be completely absent in a small percentage of trees in each stand while other trees will be severely affected and it would appear from my research that to get the largest number of defect free crop trees managers should focus on planting stands of 2.0 – 4.0 ha in size and

maintaining them until sawtimber size. The final crop trees are the only trees that have to remain defect free. In every type of stand that I surveyed, there were 5 – 58% of trees in the stand that were defect free. It is also important to note that for this study any defect was considered a defect caused by white pine weevil. The probability is high that not all the defects are caused by white pine weevil and consequently these results may be slightly inflated for white pine weevil.

Land managers should evaluate each site separately for blister rust and *Ribes* and it's occurrence, or probability of occurrence. The existing hazard zones appear to be too coarse and are less accurate on the smaller scales that managers require. These current maps should be used merely as a guide for the area but should not be used to make stand level management decisions. Traditional silvicultural prescriptions should continue to be followed for limiting the susceptibility of a stand, such as planting under an overstory (Anderson 1973), and planting a high density of trees (Katovich and Mielke 1993). I encourage planting white pine in open plantations as well as exploring more options for understory establishment as the number of rust free crop trees remaining at rotation age should be satisfactory in most areas of Michigan.

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Table 1. Summary of white pine stands surveyed in 1998 and 1999 by district, tree size class, stand area, and regeneration type.

	2.04 – 4.04 h		4.05 – 20.23 ha		20.24 + ha		Total	
	Planted	Natural	Planted	Natural	Planted	Natural	Planted	Natural
Dickinson District								
seedling/sapling	0	0	0	0	0	0	0	0
poletimber	1	1	0	1	0	1	1	3
sawtimber	0	2	0	0	0	2	0	4
Luce District								
seedling/sapling	1	1	5	3	5	3	11	7
poletimber	0	4	2	7	0	4	2	15
sawtimber	0	4	0	3	0	3	0	10
Highplains District								
seedling/sapling	2	4	1	5	0	1	3	10
poletimber	0	4	2	4	2	6	4	14
sawtimber	0	3	0	7	0	2	0	12
Total	4	23	10	30	7	22	21	75

Table 2. Site index range (m) and mean $\pm$ standard error at 50 years by ecological district, regeneration type, and stand size class. Some site index data was missing from inventory data.

	Range	Mean $\pm$ SE
Highplains	7.6 – 21.3	17.3 $\pm$ 0.02
Dickinson	15.2 – 16.8	15.8 $\pm$ 0.06
Luce	12.8 – 18.9	15.4 $\pm$ 0.02
natural	13.7 – 21.3	16.5 $\pm$ 0.01
planted	12.8 – 21.3	17.3 $\pm$ 0.11
seedling/sapling	12.8 – 19.8	16.4 $\pm$ 0.04
poletimber	13.7 – 21.3	16.5 $\pm$ 0.02
sawtimber	13.7 – 21.3	16.7 $\pm$ 0.05

Table 3. Mean annual increment¹ (mm) $\pm$ standard error for white pine trees grouped by site and stand factors. Significant differences among classes for each factor are indicated by differing letters.

	Mean $\pm$ SE	significant differences
Regeneration type ²		
Natural	2.0 $\pm$ 0.06	a
Planted	2.5 $\pm$ 0.10	b
Topography		
Flat	2.0 $\pm$ 0.05	a
Rolling	2.6 $\pm$ 0.35	a
Hilly	2.1 $\pm$ 0.19	a
District		
Highplains	2.1 $\pm$ 0.08	a
Dickinson	2.0 $\pm$ 0.24	a
Luce	2.1 $\pm$ 0.06	a
Area (ha)		
2.0 – 4.0	2.1 $\pm$ 0.10	a
4.1 – 20.2	2.0 $\pm$ 0.07	a
20.2 and greater	2.1 $\pm$ 0.08	a
Site Index Class (m)		
12.2 – 15.1	2.1 $\pm$ 0.11	a
15.2 – 18.2	2.1 $\pm$ 0.07	a
18.3 – 21.2	2.3 $\pm$ 0.12	a
21.3 – 24.1	2.5 $\pm$ 0.28	a
Crown Closure Class		
60 percent	1.7 $\pm$ 0.18	a
70 percent	1.9 $\pm$ 0.08	a
80 percent	2.1 $\pm$ 0.06	ab
90 percent	2.4 $\pm$ 0.14	b
Size		
seedling/sapling	2.1 $\pm$ 0.07	a
poletimber	2.2 $\pm$ 0.06	a
sawtimber	1.5 $\pm$ 0.10	b
Dominance class		
dominant/co-dominant	2.3 $\pm$ 0.05	a
intermediate	1.6 $\pm$ 0.10	b
suppressed	1.4 $\pm$ 0.10	b
sapling	3.0 $\pm$ 0.37	a

¹ mean annual increment is equal to the total radial growth of the tree divided by the total age of the tree.

² sawtimber stands were eliminated for this analysis because there were no planted stands that were sawtimber sized.

Table 4. Overall mean number of defects $\pm$ standard error in the basal log (0 – 2.4 m), second log (2.5 – 4.9 m), and upper sections of trees. Significant differences among classes for each factor are indicated by letters in parenthesis.

average defects	overall average	basal log (0-2.4 m)	second log (2.5 – 4.9 m)	upper sections (5.0+ m)
naturally regenerated	1.0 $\pm$ 0.13 (a) ¹	0.3 $\pm$ 0.04 (a) (x) ²	0.4 $\pm$ 0.07 (a) (y)	0.3 $\pm$ 0.37 (xy)
planted stands	1.8 $\pm$ 0.25 (b)	0.6 $\pm$ 0.83 (b)	0.8 $\pm$ 0.13 (b)	0.4 $\pm$ 0.07
Highplains District	1.4 $\pm$ 0.18	0.4 $\pm$ 0.06	0.6 $\pm$ 0.09	0.4 $\pm$ 0.05
Dickinson District	1.0 $\pm$ 0.41	0.3 $\pm$ 0.14	0.3 $\pm$ 0.21	0.3 $\pm$ 0.11
Luce District	1.1 $\pm$ 0.17	0.4 $\pm$ 0.06	0.4 $\pm$ 0.09	0.3 $\pm$ 0.05
2.0 – 4.0 ha	1.4 $\pm$ 0.22	0.4 $\pm$ 0.08	0.6 $\pm$ 0.12	0.4 $\pm$ 0.06
4.1 – 20.2 ha	1.1 $\pm$ 0.18	0.3 $\pm$ 0.06	0.4 $\pm$ 0.10	0.3 $\pm$ 0.05
20.3 ha and greater	1.3 $\pm$ 0.22	0.4 $\pm$ 0.07	0.5 $\pm$ 0.11	0.4 $\pm$ 0.06
seedling/sapling size	1.4 $\pm$ 0.20	0.5 $\pm$ 0.07 (b)	0.6 $\pm$ 0.11	0.3 $\pm$ 0.06
poletimber size	1.3 $\pm$ 0.19	0.3 $\pm$ 0.06 (ab) (x)	0.6 $\pm$ 0.10 (y)	0.4 $\pm$ 0.05 (x)
sawtimber size	0.9 $\pm$ 0.23	0.2 $\pm$ 0.08 (a)	0.3 $\pm$ 0.12	0.4 $\pm$ 0.06

¹ a, b, c refer to significant differences among columns, for example the average defects in the basal log are significantly different between naturally regenerated stands and planted stands.

² x, y, z refer to significant difference among log sections within a single category, e.g. naturally regenerated stands

Table 4 (cont'd)

average defects	overall average	basal log (0-2.4 m)	second log (2.5 – 4.9 m)	upper sections (5.0+ m)
40% crown closure	1.2 ± 0.84	0.6 ± 0.29	0.6 ± 0.44	0.0 ± 0.00
50% crown closure	1.3 ± 1.19	1.0 ± 0.41	0.3 ± 0.62	0.0 ± 0.00
60% crown closure	1.2 ± 0.42	0.4 ± 0.14	0.6 ± 0.22	0.2 ± 0.11
70% crown closure	1.1 ± 0.22	0.3 ± 0.08	0.5 ± 0.12	0.3 ± 0.06
80% crown closure	1.3 ± 0.18	0.4 ± 0.07	0.5 ± 0.09	0.4 ± 0.05
90% crown closure	1.4 ± 0.34	0.4 ± 0.12	0.5 ± 0.18	0.4 ± 0.09
dominant/co-dominant	1.8 ± 0.04 (a)	0.4 ± 0.01 (x)	0.8 ± 0.02 (a) (y)	0.6 ± 0.01 (a) (z)
intermediate	1.3 ± 0.03 (b)	0.4 ± 0.01 (x)	0.6 ± 0.02 (b) (y)	0.3 ± 0.01 (b) (x)
suppressed	1.0 ± 0.02 (c)	0.4 ± 0.01 (x)	0.4 ± 0.01 (c) (x)	0.2 ± 0.01 (c) (y)
sapling	0.7 ± 0.01 (d)	0.5 ± 0.01 (x)	0.1 ± 0.01 (d) (y)	0.1 ± 0.00 (d) (z)

Table 5. Mean percentage $\pm$ standard error of trees in each stand with zero defects, one, two, three, or four or more defects when grouped by regeneration type, district, area, size, and crown closure class. Significant differences among classes for each factor are indicated by letters in parenthesis.

	no defects	one defect	two defects	three defects	four or more
naturally planted stands	44.2 $\pm$ 2.51 30.7 $\pm$ 4.73	27.9 $\pm$ 1.49 29.4 $\pm$ 2.82	14.6 $\pm$ 1.02 16.5 $\pm$ 1.93	7.8 $\pm$ 0.93 9.9 $\pm$ 1.76	5.5 $\pm$ 1.46 13.6 $\pm$ 2.75
Highplains District	38.5 $\pm$ 3.36	27.4 $\pm$ 1.97	15.4 $\pm$ 1.35	9.4 $\pm$ 1.22	9.3 $\pm$ 1.97
Dickinson District	56.4 $\pm$ 7.79	26.1 $\pm$ 4.57	12.8 $\pm$ 3.14	3.7 $\pm$ 2.83	1.0 $\pm$ 4.56
Luce District	41.2 $\pm$ 3.28	29.4 $\pm$ 1.92	15.0 $\pm$ 1.32	8.0 $\pm$ 1.19	6.4 $\pm$ 1.92
2.0 – 4.0 ha	10.4 $\pm$ 2.49	7.0 $\pm$ 1.56	16.0 $\pm$ 1.70	23.9 $\pm$ 2.44	42.8 $\pm$ 4.31
4.1 – 20.2 ha	5.2 $\pm$ 2.05	9.1 $\pm$ 1.28	13.5 $\pm$ 1.39	29.1 $\pm$ 2.00	31.2 $\pm$ 2.35
20.3 ha and greater	7.2 $\pm$ 2.41	8.2 $\pm$ 1.51	16.2 $\pm$ 1.64	31.2 $\pm$ 2.35	37.2 $\pm$ 4.16
seedling/sapling	37.3 $\pm$ 3.88	29.2 $\pm$ 2.27	15.1 $\pm$ 1.55	8.0 $\pm$ 1.40 (ab)	10.4 $\pm$ 2.25
poletimber size	39.1 $\pm$ 3.56	25.9 $\pm$ 2.08	16.6 $\pm$ 1.42	10.4 $\pm$ 1.28 (a)	8.1 $\pm$ 2.06
sawtimber size	49.3 $\pm$ 4.31	30.5 $\pm$ 2.52	12.5 $\pm$ 1.72	5.4 $\pm$ 1.55 (b)	2.2 $\pm$ 2.49
40% crown closure	58.3 $\pm$ 15.97	16.7 $\pm$ 8.69	8.3 $\pm$ 6.18	8.3 $\pm$ 5.68	8.3 $\pm$ 9.31
50% crown closure	37.5 $\pm$ 22.58	54.2 $\pm$ 12.30	4.2 $\pm$ 8.74	0.0 $\pm$ 0.00	4.2 $\pm$ 13.17
60% crown closure	38.4 $\pm$ 7.98	34.1 $\pm$ 4.35	16.3 $\pm$ 3.09	7.3 $\pm$ 2.84	3.9 $\pm$ 4.66
70% crown closure	37.2 $\pm$ 4.19	28.2 $\pm$ 22.28	17.7 $\pm$ 1.62	10.8 $\pm$ 1.49	6.2 $\pm$ 2.45
80% crown closure	43.5 $\pm$ 3.40	25.4 $\pm$ 1.85	14.1 $\pm$ 1.32	7.7 $\pm$ 1.21	9.3 $\pm$ 1.99
90% crown closure	42.2 $\pm$ 6.52	34.7 $\pm$ 3.55	13.1 $\pm$ 2.52	5.4 $\pm$ 2.32	4.6 $\pm$ 3.80

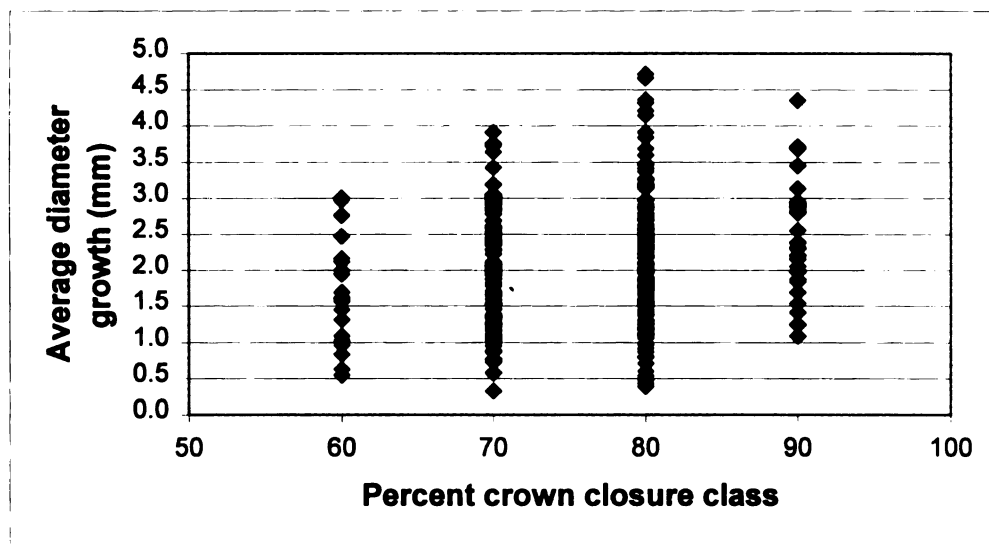


Figure 2. Scatterplot showing the range of mean annual increment of white pine trees grouped by crown closure.

Appendix 1.

Stand level data for all stands surveyed.

Unique Stand ID	Year Surveyed	Upper / Lower Natural / Planted	Area	Size classification	Percentage crown closure	Crown closure class	Number of plots	District	Average number defects 0-2.4 m	Average number defects 2.5-4.9 m	Average number defects 5.0+ m	Average number of defects	Average number of blister rust sites
1	1998	u n	2 p		97.13	9.00	7	Dickinson	0.13	0.06	0.16	0.35	0.00
2	1998	u n	3 p		85.86	8.00	7	Dickinson	0.13	0.32	0.79	1.23	0.00
3	1998	u n	1 s		74.08	7.00	3	Luce	0.07	0.20	0.60	0.87	0.00
4	1998	u n	3 ss		83.79	8.00	7	Luce	0.12	0.20	0.12	0.44	0.03
5	1998	u p	1 ss		87.25	8.00	3	Luce	1.08	1.42	0.48	2.97	0.03
6	1998	u p	3 ss		82.92	8.00	3	Luce	0.61	1.20	0.52	2.32	0.00
7	1998	u n	1 ss		64.67	6.00	3	Luce	0.23	0.63	0.23	1.10	0.00
8	1998	u n	3 s		76.80	7.00	5	Luce	0.02	0.17	0.64	0.83	0.00
9	1998	u n	2 ss		79.00	7.00	4	Luce	0.86	0.26	0.03	1.14	0.00
10	1998	u n	2 ss		69.75	6.00	3	Luce	0.20	0.43	0.09	0.73	0.00
11	1998	u n	2 p		84.17	8.00	3	Luce	0.09	0.17	0.30	0.57	0.00
12	1998	u n	2 p		77.00	7.00	3	Luce	0.27	0.49	0.51	1.27	0.00
13	1998	u n	3 ss		68.58	6.00	3	Luce	1.00	0.56	0.07	1.63	0.00
14	1998	u n	3 ss		80.50	8.00	3	Luce	1.15	0.77	0.69	2.83	0.00
15	1998	u n	1 s		78.67	7.00	3	Luce	0.13	0.03	0.13	0.30	0.00
16	1998	u n	2 p		79.92	7.00	3	Luce	0.03	0.34	0.20	0.57	0.00
17	1998	u n	3 s		82.54	8.00	7	Luce	0.04	0.25	0.24	0.53	0.00
18	1998	u n	3 p		80.79	8.00	7	Luce	0.19	0.80	0.55	1.53	0.00
19	1998	u n	2 p		83.00	8.00	3	Luce	0.00	0.00	0.14	0.14	0.00
20	1998	u n	3 p		83.08	8.00	6	Luce	0.36	0.70	0.60	1.66	0.00
21	1998	u n	3 p		78.29	7.00	7	Luce	0.47	0.84	0.48	1.80	0.00
22	1998	u n	2 s		84.33	8.00	3	Luce	0.25	0.38	0.30	0.93	0.00
23	1998	u n	2 s		64.67	6.00	3	Luce	0.26	0.68	0.39	1.34	0.03
24	1998	l p	2 p		82.75	8.00	3	Highplains	0.28	0.63	0.32	1.24	0.00
25	1998	l n	1 p		78.25	7.00	3	Highplains	0.22	0.60	0.72	1.51	0.00
26	1998	l n	1 p		83.25	8.00	3	Highplains	0.22	0.51	0.35	1.11	0.00
27	1998	l n	2 p		85.83	8.00	3	Highplains	0.23	0.75	0.85	1.81	0.00
28	1998	l n	2 p		86.33	8.00	3	Highplains	0.27	0.34	0.21	0.82	0.05
29	1998	l n	2 s		70.00	7.00	3	Highplains	0.32	1.05	0.58	1.95	0.00
30	1998	l n	1 p		75.58	7.00	3	Highplains	0.23	0.73	0.61	1.14	0.00
31	1998	l n	2 s		73.92	7.00	3	Highplains	0.13	0.35	0.55	1.03	0.00
32	1998	l n	3 ss		74.39	7.00	7	Highplains	0.59	0.77	0.18	1.55	0.06
33	1998	l n	2 ss		83.67	8.00	3	Highplains	0.73	0.23	0.01	0.97	0.00
34	1998	l n	2 s		81.33	8.00	3	Highplains	0.07	0.11	0.59	0.78	0.00
35	1998	l n	3 s		85.25	8.00	7	Highplains	0.09	0.03	0.33	0.45	0.00
36	1998	l n	2 s		87.13	8.00	4	Highplains	0.13	0.09	0.41	0.63	0.00

Unique Stand ID	Year Surveyed	Upper / Lower Natural / Planted	Area	Size classification	Percentage crown closure	Crown closure class	Number of plots	District	Average number defects 0-2.4 m	Average number defects 2.5-4.9 m	Average number defects 5.0+ m	Average number of defects	Average number of blister rust sites
37	1998	I n	3 p		85.36	8.00	7	Highplains	0.33	0.41	0.41	1.14	0.01
38	1998	I n	3 p		86.33	8.00	3	Highplains	0.06	0.00	0.09	0.15	0.00
39	1998	I n	1 p		81.17	8.00	3	Highplains	1.48	1.26	0.87	3.61	0.00
40	1998	I n	3 p		91.54	9.00	7	Highplains	0.95	1.18	0.32	2.45	0.00
41	1998	I p	3 p		74.90	7.00	5	Highplains	0.30	1.08	0.75	2.14	0.00
42	1998	I p	1 ss		75.08	7.00	3	Highplains	0.59	0.74	0.42	1.76	0.00
43	1998	I p	3 p		84.07	8.00	7	Highplains	0.32	0.92	0.62	1.87	0.00
44	1998	I p	2 p		72.50	7.00	3	Highplains	0.21	0.70	0.54	1.45	0.01
45	1998	I n	3 p		74.25	7.00		Highplains	0.17	0.40	0.19	0.76	0.00
46	1998	I n	1 s		82.58	8.00	3	Highplains	0.10	0.14	0.52	0.76	0.00
47	1998	I n	3 s		97.48	9.00	3	Highplains	0.00	0.00	0.00	0.75	0.00
48	1998	I n	1 ss		43.42	4.00	3	Highplains	0.50	1.17	0.00	1.67	0.00
49	1998	I p	1 ss		86.42	8.00	3	Highplains	2.96	5.13	2.00	10.10	0.00
50	1998	I n	2 s		95.22	9.00	3	Highplains	0.00	0.00	0.00	1.15	0.00
51	1998	I n	2 ss		93.00	9.00	3	Highplains	0.24	0.76	0.33	1.33	0.00
52	1998	I n	1 s		83.83	8.00	3	Highplains	0.17	0.07	0.01	0.24	0.00
53	1998	I n	2 s		88.50	8.00	3	Highplains	0.06	0.03	0.35	0.45	0.00
54	1998	I n	1 ss		93.92	9.00	3	Highplains	0.13	0.38	0.53	1.03	0.00
55	1998	I n	2 s		77.42	7.00	3	Highplains	0.43	1.09	0.96	2.48	0.00
56	1998	I n	1 ss		73.17	7.00	3	Highplains	0.26	0.20	0.04	0.50	0.00
57	1998	I n	2 ss		78.83	7.00	3	Highplains	0.00	0.00	0.00	1.27	0.00
58	1998	I p	2 ss		77.75	7.00	3	Highplains	0.35	0.43	0.12	0.90	0.00
60	1998	I n	2 p		73.46	7.00	3	Highplains	0.42	0.76	0.20	1.38	0.00
61	1998	I n	3 p		64.00	6.00	5	Highplains	0.34	0.86	0.24	1.44	0.00
62	1998	u n	2 ss		92.33	9.00	3	Luce	0.54	0.36	0.06	0.96	0.00
63	1998	I n	1 s		81.68	8.00	3	Highplains	0.20	0.10	0.03	0.33	0.00
64	1999	u n	1 p		90.33	9.00	3	Luce	0.31	0.78	0.33	1.42	0.00
65	1999	u n	1 p		86.08	8.00	3	Luce	0.80	0.60	0.70	2.10	0.00
66	1999	u n	3 p		82.92	8.00	6	Luce	0.26	0.39	0.29	0.93	0.02
67	1999	u n	2 p		89.27	8.00	3	Luce	0.07	0.55	0.36	0.98	0.00
68	1999	u n	1 p		85.75	8.00	3	Luce	0.36	0.40	0.37	1.13	0.00
69	1999	u n	2 p		70.20	7.00	3	Luce	0.07	0.30	0.48	0.85	0.00
69	1998	I n	3 p		84.28	8.00	5	Highplains	0.55	0.85	0.22	1.62	0.00
70	1999	u p	1 ss		86.70	8.00	3	Luce	0.09	0.00	0.00	0.09	0.00
71	1999	u p	2 ss		55.10	5.00	3	Luce	1.00	0.29	0.00	1.29	0.00
72	1999	u p	2 ss		49.27	4.00	3	Luce	0.71	0.08	0.00	0.79	0.00
73	1999	u p	3 ss		64.83	6.00	3	Luce	0.17	0.00	0.00	0.17	0.00
74	1999	u p	3 ss		70.83	7.00	3	Luce	0.80	0.00	0.00	0.80	0.00

Unique Stand ID	Year Surveyed	Upper / Lower Natural / Planted	Area	Size classification	Percentage crown closure	Crown closure class	Number of plots	District	Average number defects 0-2.4 m	Average number defects 2.5-4.9 m	Average number defects 5.0+ m	Average number of defects	Average number of blister rust sites
75	1999	u n	2	p	84.00	8.00	3	Luce	0.20	0.34	0.49	1.02	0.00
76	1999	u n	3	s	93.03	9.00	3	Luce	0.16	0.32	1.21	1.68	0.00
77	1999	u n	2	s	67.83	6.00	3	Luce	0.05	0.29	0.29	0.63	0.00
78	1999	u p	3	ss	84.80	8.00	3	Luce	0.16	0.16	0.56	0.88	0.00
79	1999	u p	2	p	75.70	7.00	3	Luce	0.68	0.73	0.39	1.80	0.00
80	1999	u p	2	p	81.53	8.00	3	Luce	0.60	0.76	0.36	1.72	0.00
81	1999	u p	2	ss	90.03	9.00	3	Luce	1.15	1.41	0.49	3.05	0.03
82	1999	u n	1	s	79.20	7.00	3	Luce	0.18	0.13	0.13	0.44	0.00
83	1999	u n	1	p	84.20	8.00	3	Dickinson	0.33	0.13	0.38	0.83	0.00
84	1999	u n	1	s	76.43	7.00	3	Luce	0.10	0.23	0.05	0.38	0.00
85	1999	l n	2	ss	88.20	8.00	3	Highplains	0.02	0.08	0.02	0.12	0.00
86	1999	l n	2	ss	78.53	7.00	3	Highplains	0.07	0.00	0.00	0.07	0.00
87	1999	u p	2	ss	96.03	9.00	3	Luce	0.26	0.83	1.04	2.13	0.00
88	1999	u p	2	ss	82.87	8.00	3	Luce	0.39	0.00	0.00	0.39	0.00
89	1999	u p	3	ss	87.10	8.00	3	Luce	0.27	0.12	0.00	0.38	0.00
90	1999	u n	3	s	86.20	8.00	3	Dickinson	0.30	0.22	0.08	0.60	0.00
91	1999	u n	1	s	74.36	7.00	3	Dickinson	0.21	0.30	0.10	0.61	0.00
92	1999	u n	1	p	86.44	8.00	3	Dickinson	0.40	0.25	0.36	1.01	0.00
93	1999	u n	1	s	91.08	9.00	3	Dickinson	0.41	0.18	0.02	0.61	0.00
94	1999	u n	3	s	69.76	6.00	3	Dickinson	0.80	1.20	0.61	2.61	0.00
95	1999	l n	1	ss	75.67	7.00	3	Highplains	0.25	0.37	0.20	0.82	0.00
96	1999	l n	2	p	83.20	8.00	3	Highplains	0.34	0.74	0.36	1.44	0.00

CHAPTER 2

THE EFFECT OF PARASITOIDS ON WHITE PINE WEEVIL SUCCESS IN EASTERN WHITE PINE IN MICHIGAN

Introduction

White pine weevil (Coleoptera: Curculionidae, *Pissodes strobi* Peck), a native insect, has historically limited interest in re-establishing white pine stands in the Great Lakes region because of the damage it can inflict on white pine trees. White pine weevil is one of the most economically important insect pests of Eastern white pine (*Pinus strobus* L.), Sitka spruce (*Picea stichensis* (Bong.) Carr.), Engelmann spruce (*P. engelmannii* Parry) and other pine and spruce species in North America (Alfaro and Borden 1980). White pine weevil adults overwinter in the duff layer, and emerge in May to mate and feed on the outside of the terminal leader (Jaynes 1958, Wallace and Sullivan 1985). Eggs are laid singly in feeding sites starting at the top of the leader and progressing down as the adult feeds along the terminal. Eggs hatch in 10 to 14 days (Peirson 1922). Larvae feed in the phloem of the terminal leader from June through August, progress through four instars, and pupate within a chip cocoon under the bark. In late September, adults emerge from the chip cocoons and feed until the weather gets cool (Wallace and Sullivan 1985). Feeding by weevil larvae effectively girdles the terminal leader of young trees, causing the terminal leader to wilt and die. Up to four years of

leader growth can be destroyed by a single attack (Marty and Mott 1964, Wallace and Sullivan 1985). Injured trees may become forked, crooked, or stag-headed (Harman and Kulman 1967), which can reduce their economic value for lumber (Waters et al. 1955, Ferguson and Kingsley 1972, Alfaro 1982, Alfaro 1995).

Silvicultural practices to limit tree damage and promote biological control of white pine weevil would benefit land managers who wish to plant white pine but are concerned about problems from weevil. There are two common silvicultural practices for re-establishing white pine, both of which are intended to limit stem crook and forking caused by weevil injury to the terminal leader. The first method requires planting trees at high densities. Competition for light resources causes a lateral shoot to assume dominance quickly when weevil feeding kills the terminal leader. This reduces the chance of crook developing in the main stem (Peirson 1922, Graham 1926). The other most common regeneration method is to establish white pine under a hardwood overstory (Marty and Mott 1964), which creates cool and shady conditions that are less suitable for the weevil.

Conserving or enhancing natural enemies of white pine weevil could be a useful tool for forest managers in controlling this pest but research has been spotty. Harman and Kulman (1967) compiled a list of reported parasites and predators of white pine weevil, but noted that many of the studies were from the late 1800's, and few were thorough or quantitative. Harman and Kulman (1967) reported 115 species of insect parasites and predators, the majority of which were in the Order Hymenoptera. MacAloney (1930), and Taylor (1929) reported that *Lonchaea corticis* Taylor (Diptera: Chloropidae), *Eurytoma pissidis* Girault (Hymenoptera: Eurytomidae), and *Bracon pini* Muesebeck

(Hymenoptera: Braconidae) were the most common parasites of white pine weevil. A study conducted in Virginia (Harman and Kulman 1968) showed that understory trees were relatively unfavorable for weevil development, and that the ability of weevils to successfully complete development to an adult was greater on edge trees than on interior trees.

The first objective of this study was to evaluate the rate of parasitism and successful development of white pine weevils on infested white pine terminals in northern Michigan. The second objective was to determine if weevil survival and percentage of parasitized larvae and pupae were significantly different between open planted and understory planted young white pine.

Methods

Study Area: Study sites were located in Michigan's Upper Peninsula in Marquette county. Two open planted white pine plantations, one established in 1993 (Appendix I, Figure 1) and the other in 1990 (Appendix I, Figure 2), and two underplanted white pine plantations with hardwood overstory, established in 1994 (Appendix I, Figure 3) and 1992 (Appendix I, Figure 4) were selected for this study. The two open planted stands had each been originally planted at a rate of about 492 TPHa (1,200 trees per acre) while the underplanted stands were planted at 164 to 246 TPHa (400 to 600 white pines per acre). Stands were visited on May 19 and June 2, 1999, and adult weevils were observed mating and laying eggs on each occasion.

Tree Selection: A one chain buffer around the edge of each stand was not sampled to eliminate edge effect. On June 2, 1999, I tagged 15 pairs of trees in each of the two open grown sites. These trees had terminal leaders that were obviously infested by white pine

weevil, as evidenced by many feeding punctures and oozing sap. For this study I assumed that feeding punctures denoted eggs laid and thus an infested leader. Two trees qualified as a pair if they were within 4.6 m (15 ft) of each other, were of similar heights, and appeared to have similar numbers of feeding punctures and oviposition sites. Estimation of feeding and oviposition was subjective, and was based upon visual examination of leaders. One infested leader of each pair of trees had a 15cm x 1m nylon net bag placed over the infested terminal leader; the other tree of each pair was left as an uncaged control. The nets were double tied, top and bottom, with two pieces of twine to exclude other insects and retain emerging adult weevils.

On June 2, 1999, I also examined the two underplanted plantations for trees with infested terminal leaders. Few trees in these two stands were infested by white pine weevil. Therefore, I tagged 15 trees with infested terminals in each stand, but did not cage any due to the small number of infested terminal leaders available. Plantations were checked on June 8, and July 14, 1999, to ensure that vandalism or other problems had not occurred.

Weevil Collection: On August 28, 1999, the infested terminals from six pairs of trees in each open-grown plantation (for a total of 24 terminals; 12 from caged trees and 12 from uncaged trees), and six terminals from each of the underplanted plantations (12 terminals total) were clipped and returned to the laboratory. The length and extent of weevil damage to the terminal leader was measured before the leader was dissected. The number of progeny weevil emergence holes was recorded prior to dissection of the leader. Nealis (1998) reported that emergence holes were a reliable estimate of the number of progeny adults emerging from leaders. Number of emergence holes and

progeny adults found within the leader were combined to determine total adults. Bark was carefully removed from the infested terminals and the leader was examined to locate larvae, pupae, and newly emerging adults that had not yet exited from the leader. When larvae or pupae were found, they were dissected and categorized as parasitized or healthy, based on color and consistency. Healthy larvae were white and evenly cylindrical, while parasitized larvae showed dark areas and/or bulges where parasitoids were located within the larvae. Healthy pupae moved in response to touch.

Remaining terminals were left in the field to be collected in December, thus allowing any parasites to complete development and pupate within the terminal leaders, as noted by VanderSar (1978a). Unfortunately, upon return in December, I found that vandals had removed cages and flagging and I was unable to locate any of the terminals that I had previously identified. Data from the August 28 collection was analyzed and is reported here.

A Kruskal-Wallace non-parametric test was used to evaluate differences in the number of weevils found in each lifestage between caged and uncaged terminals in open grown stands. A Mann-Whitney test was used to determine differences between uncaged open grown white pine and white pine located under an overstory, with a critical value of 102. Non-parametric tests were used because many observations were zero, which heavily skewed the normality of the data.

Results

A total of 36 terminal leaders were collected. From each of the two open grown plantations, six caged terminal leaders and six uncaged terminal leaders from paired trees

were collected, for a total of 24 leaders from open grown plantations. Six uncaged, infested terminal leaders were collected from each of the two understory grown plantations, for a total of 12 leaders. There was a total of 57 adult weevils and exit holes, 18 weevil pupae, and 20 weevil larvae in the 36 terminal leaders examined (Table 1). Caged terminal leaders in open plantations had an average of 2.8 adults, 0.8 pupae, and 0.6 larvae per terminal while uncaged terminal leaders in open plantations had an average of 1.8 adults, 0.8 pupae, and 1.1 larvae per terminal leader. In the terminal leaders from underplanted white pines, I recovered only two adult weevils, both from a single terminal leader, and no pupae or larvae.

A total of 21 adult weevils or exit holes were found in the open grown uncaged terminal leaders, and 34 were found in the open grown caged terminals. There were no significant differences in numbers of adult weevils found in the open grown uncaged terminal leaders compared to the open grown caged terminals ($\chi^2=2.12$, $p=0.146$). Although the understory grown white pine produced only two adult weevils, there were no significant differences between number of adults from open grown uncaged terminal leaders compared to understory planted white pine (Mann-Whitney $U=80$: critical value $U=102$).

There were seven parasitized pupae found in the terminal leaders (Table 1). Two were found in two open grown caged terminal leaders and five parasitized pupae were in three open grown uncaged terminals. There was no significant difference in numbers of parasitized pupae between the open grown caged and uncaged trees ($\chi^2=0.43$, $p=0.515$). There were greater numbers of parasitized pupae in the open grown uncaged terminal leaders compared to the uncaged terminals of the understory white pine, where none were

found, but the results were marginally insignificant (Mann-Whitney $U'=96$: critical value $U=120$). I recovered three Dipteran larvae from the open grown uncaged terminal leaders; these larvae may have been *Lonchaea corticis* Taylor but were not positively identified.

A total of 11 healthy pupae were found in six terminal leaders. Seven of these pupae were found in four open grown caged terminals and four were in two open grown uncaged terminals. There was no significant difference between the open grown caged and uncaged trees ($\chi^2=0.77$, $p=0.382$). Although there were no healthy larvae found in understory trees, the numbers of healthy pupae were not significantly different between open planted and understory planted white pine (Mann-Whitney $U'=84$: critical value $U=102$).

Seventeen parasitized larvae were found in ten leaders from open grown trees. Four parasitized larvae were found in four of the open grown caged terminal leaders and 13 were found in the six open grown uncaged terminals, but differences were not significant ($\chi^2=2.04$, $p=0.153$). Trees grown in the understory had no parasitized larvae which differed significantly from uncaged trees grown in the open (Mann-Whitney $U'=108$: critical value $U=102$).

A total of three healthy larvae were recovered from a single, open grown caged terminal leader. There was no significant difference in number of healthy larvae between open grown caged and uncaged trees ($\chi^2=1.00$, $p=0.317$), or open-grown and understory trees (Mann-Whitney $U'=72$: critical value $U=102$).

The length of terminal leader that had been damaged by white pine weevil larval feeding was not significantly different between caged and uncaged open grown terminal

leaders ($\chi^2=1.03$, $p=0.310$) (Table 1). A significantly longer section of the leader was damaged in the uncaged open grown trees compared to the understory trees (Mann-Whitney $U=126$; critical value $U=102$). Length of damage only exceeded one years worth of terminal leader growth on two of the caged, open grown terminal leaders. None of the uncaged open-grown or understory trees had damage beyond one year of terminal growth.

Discussion

The sample size in this study was relatively small, 24 leaders from open-grown trees and 12 leaders from understory trees, due to the limited number of infested terminals in the understory white pine. A similar limitation will probably be a factor in any future studies. Additionally this study was not repeated over several years whereas weevils can attack a stand for several years. Further studies should monitor parasitism rates in young stands over several years to take into account the variability of insect population numbers from one year to the next. Possible caging effects were not tested for. The cage may have had an effect on the microclimate of the caged terminals, and consequently on the weevils or their parasitoids and predators. Caging effects should be tested if future studies are conducted.

As expected, weevil density was greater in the terminal leaders of trees in the open planted stands than in terminal leaders of trees planted in the understory. This is consistent with results reported by Graham (1918), MacAloney (1930), and Alfaro and Omule (1990) who found more weevil damage in open planted sites. Sullivan (1961)

similarly found fewer weevil feeding sites and oviposition sites on terminals of trees grown in the understory compared to open planted stands.

Alfaro (1996) found that white pine weevil damage is rare in natural undisturbed spruce stands. He suggested that, although untested, the effectiveness of natural enemies is higher in natural stands because the ecosystem is more complex than a single species plantation and that a variety of vegetation could provide for other needs of predators and parasites, such as water, pollen, and alternate hosts (Alfaro 1996). Understory planted white pine more closely simulate naturally regenerating white pine than a pure open plantation.

I expected to find differences in parasitism rates between caged and uncaged terminal leaders. Nealis (1998) found a strong negative relationship between survival of weevils within a shoot and the abundance of *Lonchaea corticis* Taylor, and MacAloney (1930) noted that some areas in New Brunswick and Nova Scotia had leaders where 100% of the weevils were parasitized. A study of white pine weevil emerging from Engelmann spruce in British Columbia found that the numbers of adults emerging from infested leaders was quite low, and mortality was attributed to parasitic insects (VanderSar, 1978). Taylor (1929) noted that only 5-10% of the white pine weevil eggs laid in feeding holes emerged as adults.

It is not clear from my study that parasitoids are causing the reduced survival of white pine weevil in these understory stands, because there were few weevils for the parasites to attack. There were no significant differences between caged and uncaged terminal leaders for any weevil life stage in my study but there were consistently greater numbers of all life stages in the uncaged terminals. The cages on the open grown caged

terminal leaders apparently prevented most, but not all, of the parasitoids from reaching the developing weevils. Parasitism may have occurred before the cages were placed on the open grown terminal leaders, and may account for finding two parasitized pupae and four parasitized larvae in the caged terminals. VanderSar (1978) found that *Lonchaea corticis* was active from early May through early June in Engelmann spruce leaders in British Columbia, Canada, with the majority of *L. corticis* having emerged by May 16. Since I did not place cages over terminals until June 2 *L. corticis* could have already been present in the terminal leader.

Nealis (1998) found that when natural enemies were excluded by caging, the numbers of weevils completing development was two to five times higher than if natural enemies were not excluded, and Bellocq and Smith (1994) found similar results in jack pine plantations. Similarly, I found that the open planted caged terminal leaders had more healthy weevils (average of 2.8 adults per terminal) than the uncaged terminals (average of 1.75 adults per terminal).

For this study I attempted to choose terminal leaders that appeared to have similar amounts of feeding by the adults, and presumably similar amounts of oviposition. Low numbers of weevil life stages found when the terminal leaders were dissected could be due to feeding punctures not being a reliable estimate of oviposition, or complete destruction of larvae or pupae by natural enemies such as *L. corticis*. Bellocq and Smith (1994) found low numbers of emerging adults from jack pine terminals and suggested that weevils may have died as larvae and pupae. VanderSar (1978b), Alfaro (1988), and Trudel et al. (1994) theorized that there may also be host compounds that are required to stimulate oviposition which are different from compounds that stimulate feeding so that

there may be greater numbers of feeding holes than there are oviposition holes. This phenomenon was also observed in white spruce (Phillips and Lanier 1983a, Phillips and Lanier 1983b, Boucher 2001). My findings support this result although it does not clear up any questions associated with it.

Since I had expected lower numbers of weevils in terminals of understory trees I also expected the length of damage on the understory planted tree terminal leaders would be significantly shorter than that of open grown trees. Damaged portions of understory and most open grown trees were limited to a single year of growth. This is important because white pine weevil can damage up to four years of terminal leader growth (Marty and Mott 1964) which greatly reduces the height growth of the trees (Waters et al. 1955, Ferguson and Kingsley 1972, Alfaro 1982, Alfaro 1995). Less white pine weevil damage in understory trees, and the lower weevil densities in those trees suggests that understory trees will have less crook than open grown trees that may be damaged for many years by white pine weevil.

In conclusion, this study indicates that white pine planted under an overstory will have fewer weevils in the terminal leaders and shorter lengths of damage inflicted by the larval feeding compared to open grown pines. These data also clearly demonstrated that white pine weevil is much less likely to be found at all in understory white pine.

Parasitism rates were generally higher in the uncaged open trees than in caged trees grown in the open, indicating that parasitism can play an important role in reducing the number of weevils completing development.

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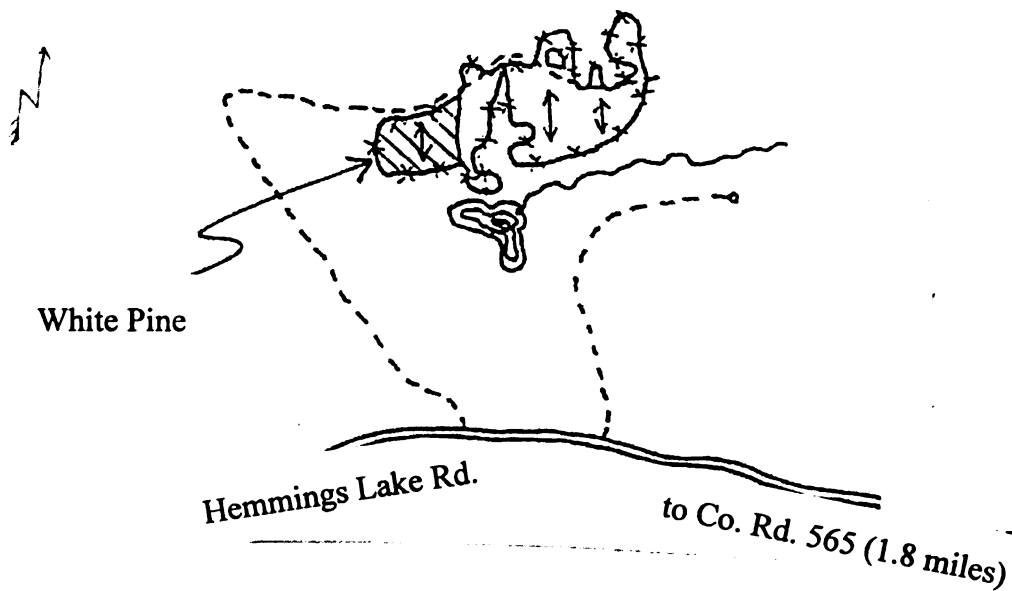
Table 1. Summary of white pine weevil life stages present in terminal leaders of open grown and understory planted white pine in northern Michigan in August 1999.

	Adults ¹	Pupae		Larvae		Length of
		Healthy	Parasitized	Healthy	Parasitized	Damage (cm)
Open grown						
Uncaged stand 1	5	3	2	0	6	114.3
Uncaged stand 2	16	1	3	0	7	137.2
Caged Stand 1	9	2	1	0	3	137.2
Caged Stand 2	25	5	1	3	1	177.8
Understory planted						
Uncaged stand 1	1	0	0	0	0	48.2
Uncaged stand 2	1	0	0	0	0	45.7
Total	57	11	7	3	17	

¹ This includes emergence holes and adult weevils.

Appendix I

Maps to study sites for parasitoid research, with directions.



M35 to County 565
Go 4.25 miles down County 565
Turn West onto Hemmings Lake Rd. (HEM is painted on a large white pine)
Go 1.8 miles down Hemmings Lake Rd.
Turn North onto trail to plantation.

Figure 1. Map and directions to parasitoid study site 1. This site consisted of open grown white pine established by planting in 1993 in Marquette County at 45N 27W Section 2 NWSE.

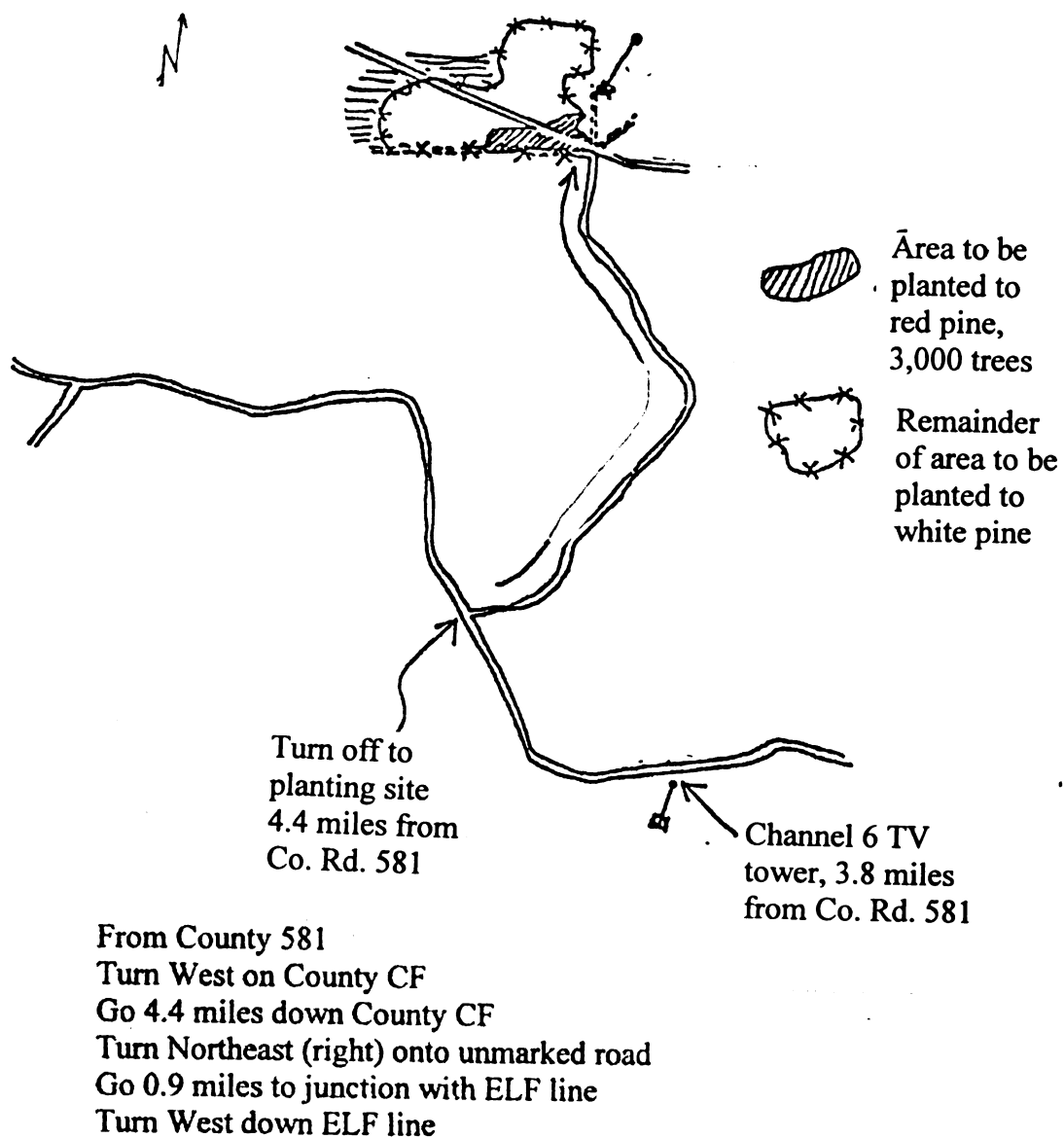


Figure 2. Map and directions to parasitoid study site 2. Site is open planted white pine established by planting in 1990 in Marquette County at 46N 28W Section 30 NWSE.

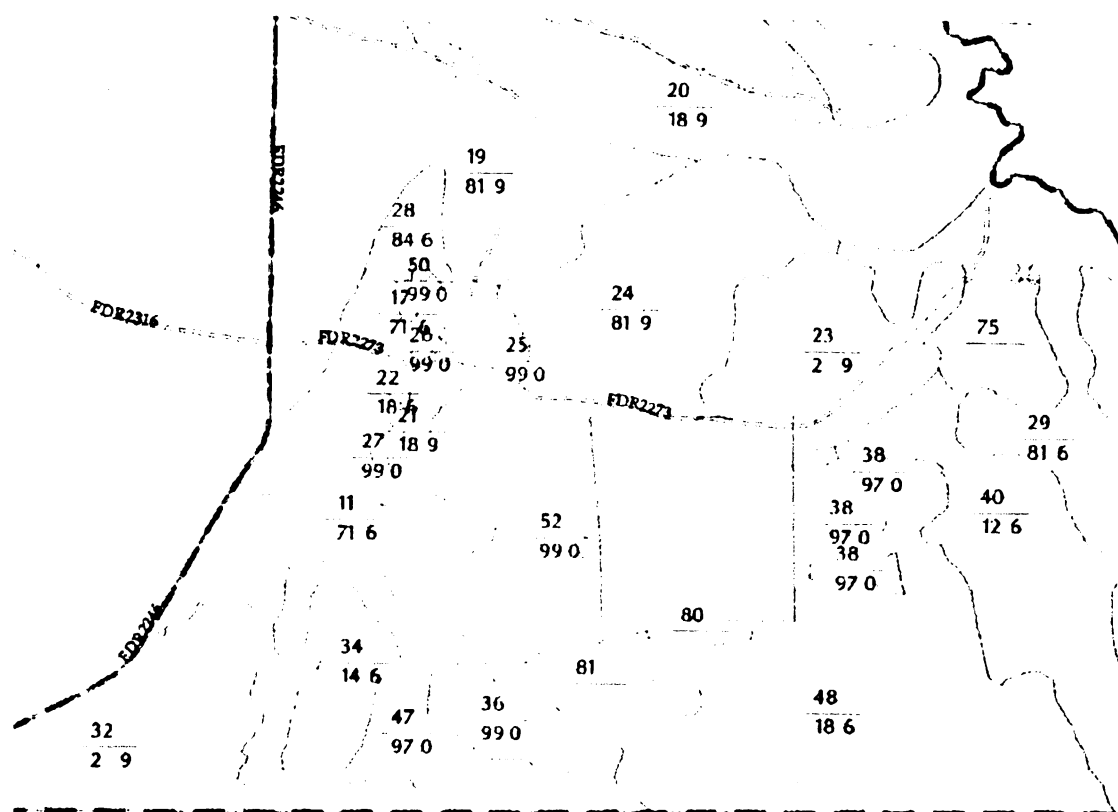
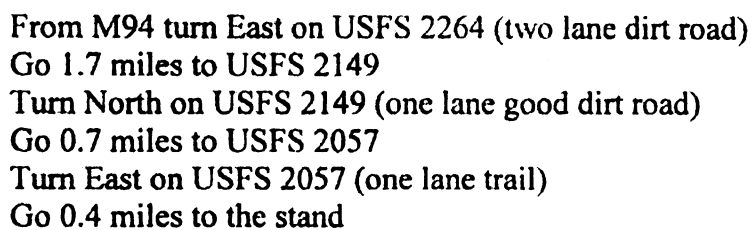


Figure 3. Map to parasitoid study site 3. Understory planted white pine established in 1994.



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CHAPTER 3

DOCUMENTATION OF PLANTING SITES SET UP TO TEST ALTERNATIVE METHODS OF WHITE PINE REGENERATION IN MICHIGAN

Introduction

Eastern white pine (*Pinus strobus* L.) once comprised a major portion of the Michigan forest land (Maybee 1976). Logging in the mid to late 1800's removed much of the timber resource and the extensive fires that followed destroyed much of the seed source (Maybee 1976). White pine weevil (*Pissodes strobi* (Peck)) and white pine blister rust (*Cronartium ribicola* (Fischer)) have largely limited the success of efforts to re-establish white pine as a major forest component. Feeding by white pine weevil larvae, a native insect, girdles and kills the terminal leader. Competition for apical dominance by lateral branches typically causes the stem to have a crook or multiple leaders upon recovery (Wilson and McQuilkin 1965, Gross 1985). This reduces overall growth of the tree, and the volume and quality of lumber (Waters et al. 1955, Ferguson and Kingsley 1972, Alfaro 1982, Alfaro 1995). White pine blister rust, an introduced fungal pathogen, is geographically localized through Michigan depending on microsite conditions and presence of secondary host plants. This pathogen can cause branch death or even mortality when present. Standardized silvicultural practices to minimize damage from these pests have not yet been established for regeneration of eastern white pine in Michigan.

Patterson and Aizen (1989) observed that although well documented, many previous silvicultural experiments were characterized by small sample size and a lack of replication, making the results applicable to a very limited area. It is important to determine which silvicultural practices effectively control damage from white pine weevil and white pine blister rust, provide acceptable white pine growth rates, and produce quality products from white pine in Michigan. Maintaining high densities of pines, maintaining partial shading of young trees with hardwood overstory, or establishing an even-aged mixed hardwood and pine stand, are the most commonly accepted silvicultural practices for limiting white pine weevil damage in white pine (Graham 1918, MacAloney 1930, Belyea and Sullivan 1956, Marty and Mott 1964, Wilson and McQuilkin 1965, Stiehl 1979, Stiehl and Berry 1985, Wallace and Sullivan 1985, Patterson and Aizen 1989, Schultz 1989, Katovich and Morse 1992, Taylor et al. 1996).

White pine stands grown in full sunlight can have twice as much weevil damage as stands in 50% light (Stiehl and Berry 1985) but planting pure stands of white pine at high densities has its benefits. The Menominee Indian tribe in northeastern Wisconsin have grown white pine to merchantable sawlog size by planting pure white pine in an open plantation at high densities on good sites. Periodic thinning, shelterwood and seed tree harvests, and pruning minimize damage from white pine weevil (Pubanz 1995). Open planted white pine growing at high densities show less deformity in the stem after an attack by white pine weevil, because lateral branches re-establish dominance quickly due to competition with neighboring trees (Graham 1918, MacAloney 1930). Open planted white pine also have higher growth rates than white pine planted under shade

(Stiell and Berry 1985, Katovich and Morse 1992). Even-aged stands, consisting of white pine and hardwoods, were shown in Ontario to have reduced rates of white pine weevil damage compared to pure white pine stands (Stiell 1979).

Partial shading is beneficial because it deters white pine weevil oviposition and feeding. Shaded trees generally have smaller diameters of the terminal leaders (Wallace and Sullivan 1985), lower bark temperatures (Sullivan 1961), and relative humidity levels are lower in stands (Sullivan 1961), reducing the suitability of trees for weevil development. Underplanting may also distort visual responses of adult weevils (VaderSar and Borden 1977, Taylor et al 1996) or alter white pine chemical properties (Harman and Kulman 1969) and is associated with increased overwintering mortality of adult weevils (Wallace and Sullivan 1985).

There are disadvantages to each of these methods though. Planting pure white pine at high densities can facilitate population explosions of some pests (Cline and Lockard 1925), and at very dense stockings can cause mortality of the trees in the lower dominance classes (Stiell 1979) although this can be a positive effect. Open-grown white pine, planted within a hardwood clearcut to produce an even-aged mixed species stand, may be overtopped or killed by the faster growing hardwoods (Patterson and Aizen 1989). A disadvantage of using partial shading to regenerate white pine is that trees grown in the understory grow more slowly than trees grown in open plantations (Stiell and Berry 1985, Katovich and Morse 1992). Overstory trees must eventually be thinned or removed which can cause damage to the white pine in the understory (MacAloney 1930, Katovich and Morse 1992).

Regeneration methods can also have an effect on the occurrence of white pine blister rust. White pine blister rust, an introduced fungal pathogen, was first found in Michigan in 1917 (Mandenberg 1933, McIntyre and Boyer 1964). White pine are susceptible to blister rust infections from the seedling stage through maturity (Wilson and McQuilkin 1965). Blister rust infections can result in dead branches, stem cankers, and tree mortality. Sporulation of the fungus occurs on white pine in the spring, infecting the secondary host *Ribes* spp., which then fruits during the summer to re-infect *Ribes* plants (Kroeber 1941). In the fall, the fungus on the *Ribes* plants releases teliospores which infect pine needles (Kroeber 1941). For spores to successfully infect pine needles, the needles must be wet, air temperatures must be between 10° and 15° C (50 - 60° F), and relative humidity must exceed 97% for at least 48 h (Anderson 1973).

Blister rust occurs in geographically localized pockets where appropriate weather conditions occur frequently (Liebhold et al. 1995) and hazard zones have been created based on those local geographic conditions (Figure 1, Literature Review) (VanArsdel 1961, Anderson 1973). Blister rust also occurs more often near the ground because moisture and temperature conditions favorable for rust inoculation occur there frequently (Charleton 1963).

Current methods for controlling white pine blister rust include pruning branches with cankers from trees, planting in low risk areas based on hazard maps, and planting blister rust resistant seedlings. White pine grown under partial shade is somewhat protected from blister rust infections because dew is not as heavy under a canopy and this limits the time when rust spores can germinate (Stearns 1992).

For the sake of documentation I will outline the planting that was done to test various regeneration methods. The overall goal of this project is to test various planting methods using a replicated design, so that tree growth, survivorship, and pest and disease incidence can be monitored over a long time period. Providing demonstration sites for forest managers and private landowners interested in planting white pine for biological diversity or sawlog production is also an important role of this study. The specific objectives of this study are to 1) quantify the effect of planting density on tree growth, survival, and insect and disease incidence, 2) compare blister rust-resistant seedlings with regular seedlings to quantify differences in growth, survival, and response to white pine blister rust in open planted white pine; and 3) evaluate tree growth, survival, and insect and disease incidence in white pine planted below varying levels of an oak overstory, in dense mixed species stands on recently harvested high-quality hardwood sites, and in mixed species stands on recently harvested low-quality hardwood sites. This chapter of this thesis is intended to be a record of four white pine plantings that were established from 1998 to 2000.

I. Open-planted White Pine Plantation with Blister Rust Resistant Seedlings

The objectives of creating a pure open-grown white pine plantation without an overstory included creating a demonstration site for future land managers, monitoring tree growth, and tracking insect and disease occurrence when white pine is planted at three densities. Additionally, this plantation is a test of the performance of blister rust resistant seedlings, compared to regular non-resistant seedlings.

Dr. Ray Miller, resident manager at the Upper Peninsula Tree Improvement Center (UPTIC) in Escanaba, Michigan, and his crew began preparing an 8.1 ha (20 ac)

planting site in June 1997 (figure 1). Herbicide (glyphosate) was applied to control alfalfa and other vegetation and the field was periodically cultivated throughout the summer and fall of 1997.

In preparation for this planting effort, Greg Kowalewski, resident manager at the W. K. Kellogg Forest, purchased 30,000 white pine seedlings in spring 1997. Seedlings came from various sources in the Lake States and were variable in quality. Seedlings were transplanted into nursery beds at MSU's Tree Research Center (TRC) where they stayed for one year. There was an 88% survival rate of the seedlings in the nursery beds at TRC. Seedlings were lifted from the TRC beds in March 1998, sorted by size, root pruned, bagged, and placed in cold storage in preparation for planting. There were 35% of the surviving trees which were less than 6 inches in height when lifted and these trees were re-planted back into the TRC beds.

About 20,000 seedlings, from the beds at the TRC, were transported to UPTIC in April 1998. Additionally, 5,000 blister rust resistant white pine seedlings were acquired from the USDA Forest Service Oconto River Nursery, in White Lake, Wisconsin. These additional seedlings were grown from seed selected from trees thought to be resistant to white pine blister rust. This resistance has not yet been thoroughly tested in field plantings.

Two planting machines, each with crews of at least three people, and two or three plot layout people, planted a total of 18,500 seedlings May 11-21, 1998. The experiment was designed as a completely randomized block design with four blocks, each with three plots (Figure 2). Each plot was 0.4 ha (1 ac) in size with an additional 9.1 m (30 ft) wide buffer strip around edges for a total plot size of 0.7 ha (1.66 ac) (Figure 3). Trees were

planted at three different spacings (one spacing per plot): 1.8 x 1.8 m (6x6 ft), 2.1 x 2.1 m (7x7 ft), and 2.4 x 2.4 m (8x8 ft) which is 1680, 2198, and 2989 trees per ha respectively (680, 890, and 1210 TPA). Each planting spacing was represented in each block, so that each block had a plot planted at 1.8 x 1.8 m (6x6 ft), 2.1 x 2.1 m (7x7 ft), and 2.4 x 2.4 m (8x8 ft) (Figure 2). Seedlings from the TRC were large, healthy, dark green in color, and had stout stems; conversely, the rust resistant seedlings obtained from the Forest Service nursery were smaller in diameter and height and light green in color. The regular seedlings in block II were on average greater than 23 cm (9+ in) in height. In blocks I, III, and IV the regular seedlings planted were 15.2-22.9cm (6-9 in) in height, refer to Figure 2 for block locations. Seedling roots were dipped in TerraSorb (Industrial Services International, Brandenton, FL) prior to planting to improve survival rates by helping to hold moisture close to the roots.

Rust resistant seedlings were planted in nine rows in the 1.8 x 1.8 m plots, in eight rows in the 2.1 x 2.1 m plots, and in seven rows in the 2.4 x 2.4 m plots. These rows were all located adjacent to each other within the plot and were located along one randomly chosen side (Figure 4). A buffer strip of regular seedlings was planted along the plot edges (Figure 3). The additional 1,500 regular seedlings that were not planted within plots were planted in irregular areas around the plots to reduce edge effects and fill in empty gaps. Remaining rust resistant seedlings were planted in Dr. Ray Miller's garden.

Herbicide (simazine) was applied over the seedlings on May 20, 1998. The entire plantation was hand-irrigated on May 21, 1998, due to drought conditions. In September 1998, herbicide (glyphosate+solfometuraon) was applied over dormant seedlings.

Mortality was surveyed in November 1998, and May 1999, and showed that overall 17% of the rust resistant seedlings, and 3% of the regular seedlings had died.

In May 1999, some of the TRC seedlings that had been planted in odd areas to fill in around the edges of blocks were lifted and used to replace regular seedlings within the blocks which had succumbed to mortality. The extra rust resistant stock was also lifted at that time and used to replace rust resistant seedlings which had died.

II. Mixed Species – Underplanting Below an Oak Overstory

This planting was established to evaluate relationships among varying levels of overstory shade, tree growth, and white pine weevil damage. By planting under varying levels of crown closure, we will be able to monitor how white pine weevil responds to a variety of crown cover densities, as well as how the growth of white pine is affected by differing amounts of shade.

Michigan DNR personnel located a 16.2 ha (40 ac) stand dominated by red oak (*Quercus rubra* (L.)) in Kalkaska County in 1998 (Figure 5). A selection cut, where individual trees were marked, stand resulted in levels of oak crown closure ranging from 0 to 100% within the remaining stand. Some natural regeneration of white pine was present; these saplings were roughly 6 to 8 cm DBH and patchily distributed throughout the stand. Slash from the harvests was collected from most of the area by the Michigan DNR. White pine seedlings were purchased from commercial suppliers in April 1999, root pruned, packed in sphagnum moss, and transported to Roscommon on April 30, 1999 where they were placed in cold storage until planting. On May 2, 1999, a 13 person crew hand planted approximately 29,000 seedlings in this area at a 2.1 x 2.1 m (7 x 7 ft)

spacing. Herbicide (Garlon) was applied on June 22, 1999, to control aspen and maple sprouts.

III. Mixed Species – Even Aged High-quality Hardwood Clearcut – Russ Forest

The objective of this planting was to establish white pine in recently harvested high-quality hardwood sites. This method will presumably allow white pine to grow in an even-aged cohort with hardwoods, thus reducing the ability of white pine weevil to locate terminal leaders of young white pine. This method may also protect the pine from deer browse if deer feed preferentially on hardwood sprouts or find it difficult to locate pines due to the low density of stems per acre. Twenty acres of hardwoods scheduled for harvest at the Michigan State University Fred Russ Forest, in Cass County, were inspected and approved for white pine plantings in July 1997. This area was divided into three stands.

From November 1997 to March 1998, 2.8 ha (7 ac) of black locust (*Robinia pseudoacacia* L.), tulip poplar (*Liriodendron tulipifera* L.), and mixed hardwoods were clearcut in Russ Forest (T6S R13W Section 16). A total of 1,500 white pine were hand-planted on 2.0 ha (5 ac) of that clearcut from April 7-10 and from April 13-14. One thousand of those seedlings were planted at a 3.0 x 3.0 m (10 x 10 ft) spacing (1074 trees per ha, 435 TPA) and 500 seedlings were planted at a 4.6 x 4.6 m (15 x 15 ft) spacing (479 trees per ha, 194 TPA).

Harvest of a 4.5 ha (11 ac) area occurred in April 1998 in Russ Forest (T5S R14W Section 20 NESWSE). Before harvest, this area was a plantation of red oak (*Quercus rubra* L.), tulip poplar, black walnut (*Juglans nigra* L.), black cherry (*Prunus serotina* Ehrh.), and white ash (*Fraxinus americana* L.), that was established in 1945.

Survival of the hardwoods was variable, trees had poor form, and red maple had filled in the plantation. Only 4.0 ha (10 ac) of this clearcut were planted with white pine following the harvest. On May 8-14, 1998, 2,500 white pine seedlings were planted, and an additional 500 white pine seedlings were planted May 26, 1998 (total of 3,000 seedlings). Two thousand of the seedlings planted were machine planted at a spacing of approximately 2.4 x 3.7 m (8 x 12 ft) (1028 trees per ha, 416 TPA), and 1,000 seedlings were machine planted at an approximate spacing of 4.9 x 3.7 m (16 x 12 ft) (526 trees per ha, 213 TPA).

A 2.4 ha (6 ac) area in Russ Forest (T5S R14W Section 29 SENESE) was also clearcut in April 1998 and 2.0 ha (5 acres) were planted to white pine following the harvest. This site was originally a tulip poplar planting established in 1939. This stand was thinned in 1982 and clearcut in 1998. White pine seedlings were planted from May 27-29, 1998. A total of 1,500 white pine seedlings were planted; 1,000 were machine planted at a spacing of approximately 2.4 x 3.7 m (8 x 12 ft) (1124 trees per ha, 455 TPA), and 500 were machine planted at an approximate spacing of 4.9 x 3.7 m (16 x 12 ft) (561 trees per ha, 227 TPA).

IV. Mixed Species - Low Quality Hardwood Clearcut

Three recently harvested poor quality hardwood sites were identified in 1999; one site in the Lower Peninsula and two sites in the Upper Peninsula. The goal of these plantings was to establish even-aged mixed species stands with white pine as a component. Seedlings for this objective were grown from seed in containers at MSU's TRC. White pine seedlings were planted in spring 2000 at a rate that would bring the

total number of saplings (hardwood and planted white pine) to 2223 – 2470 stems per ha (900-1000 stems per ac).

The site in the lower peninsula is located in Kalkaska County (T28N, R6W, Section 8). The original stand, which includes aspen, sapling sized maple, and other hardwoods, was harvested in 1999 and the slash was left on the site. Some overstory maples and a few large white pine were left. Ten acres were hand planted with 2-0 white pine by a DNR crew in spring 2000 at a 2.1 x 2.1 m (7 x 7 ft) spacing. Two pairs of three acre plots were identified within this area. One randomly chosen plot from each of the two pairs of plots was herbicided in 2002 or 2003 to control aspen and other hardwood regeneration.

The two sites in Michigan's Upper Peninsula are located just off Hog Island Road (T43N, R8W, Section 25), and near Cranberry Lake Road (T44N, R9W, Sections 23, 26, and 35). The Hog Island site consists of two 2.6 ha (6.5 acre) blocks, each block consisting of two three acre plots with a one chain planted buffer area around each block. These two blocks are split by a road. The westernmost block had an original stand composition of low quality red maple and black cherry which was clearcut, then burned in spring 1999. Dead overstory cherry and aspen trees remain standing on the western block. White pine seedlings were planted in spring 2000 at 1.8 x 2.7 m (6 x 9 ft) and 1.8 x 3.0 m (6 x 10 ft) spacings. The easternmost Hog Island block is located across the road and was similar in stand composition. It was also harvested in spring 1999 but was not burned. One plot from each block was randomly chosen for herbicide treatment in 2002 or 2003 to control cherry and aspen regeneration. The Cranberry Lake Road site, had a heavy selection harvest performed during winter 1999/2000. The original stand was low

quality sugar maple and birch, with some white pine and hemlock. White pine seedlings were planted in spring 2000 at a 1.8 x 1.8 m (6 x 6 ft) spacing in some of the openings which were created by the selection harvest. In other openings the DNR planted a mixture of white pine and red oak seedlings.

The study sites which were detailed in this chapter represent a unique opportunity for long term studies related to white pine growth, insect pests, and incidence of white pine blister rust, in varied planting sites. These plantings will provide study sites for many years to come and should be monitored for survival, growth, and insect and disease presence at three or five year intervals for the life of the stand, which could be more than 100 years.

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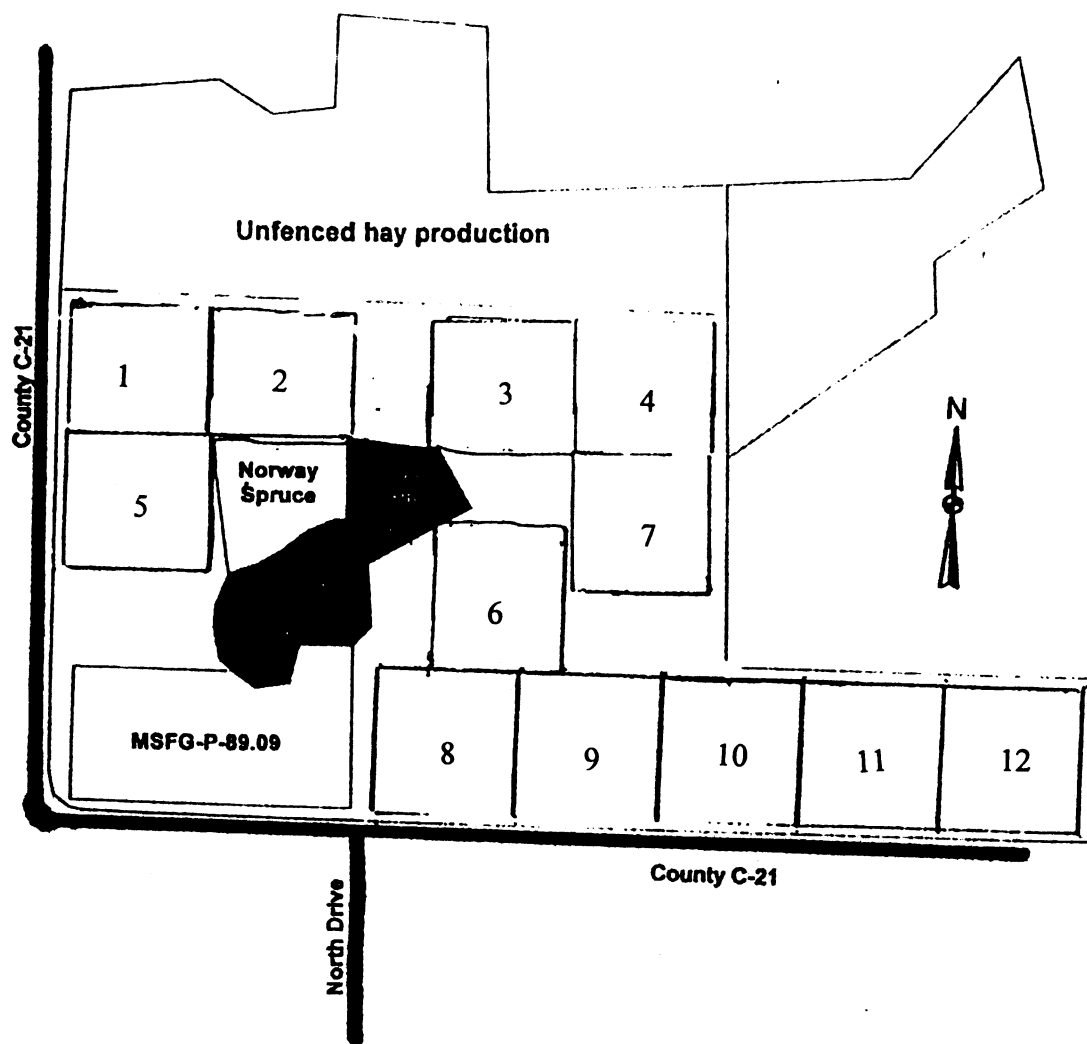


Figure 1. Upper Peninsula Tree Improvement Center site for white pine plantation. Located in Delta County at 39N 23W Section 18 SESE. Numbered areas represent areas where white pine is planted.

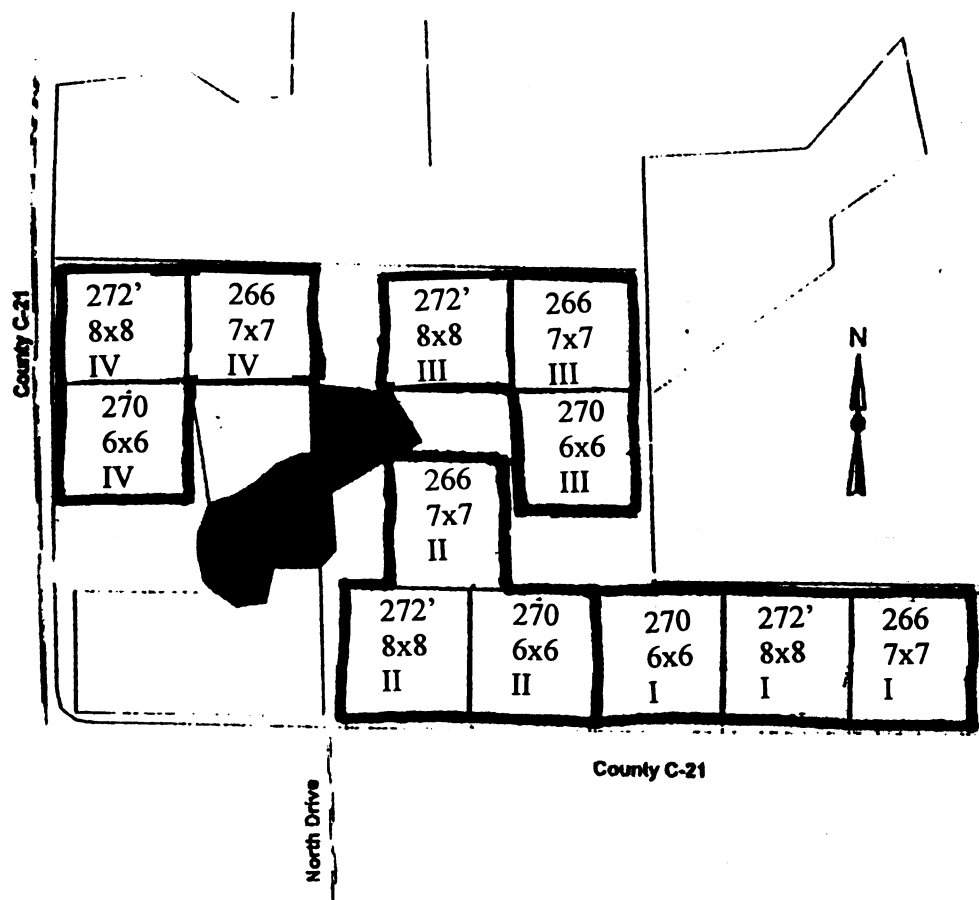


Figure 2. White pine planting at Upper Peninsula Tree Improvement Center. Spacings by plot. Roman numerals denote block number.

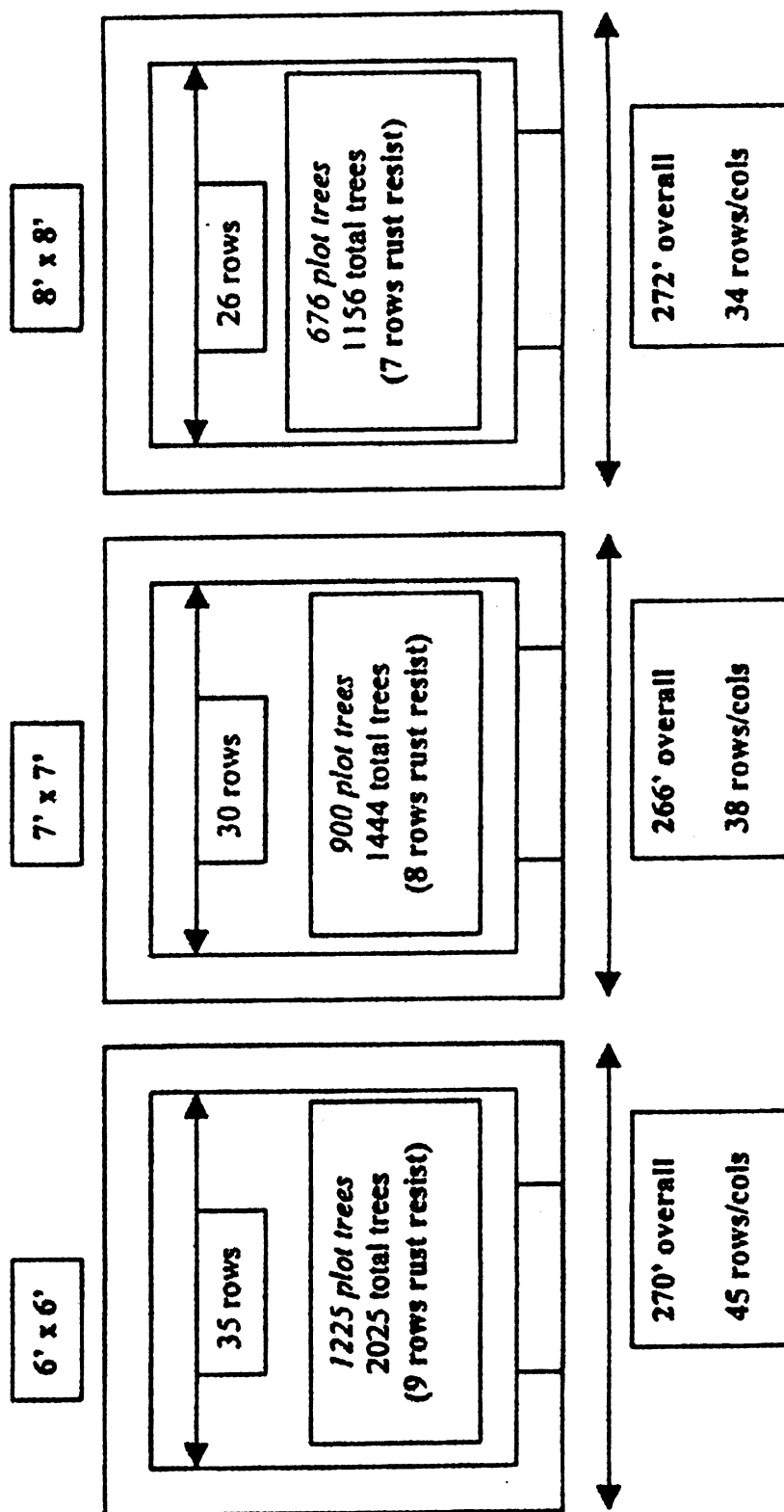


Figure 3. Diagram of plots including number or border rows in each spacing.

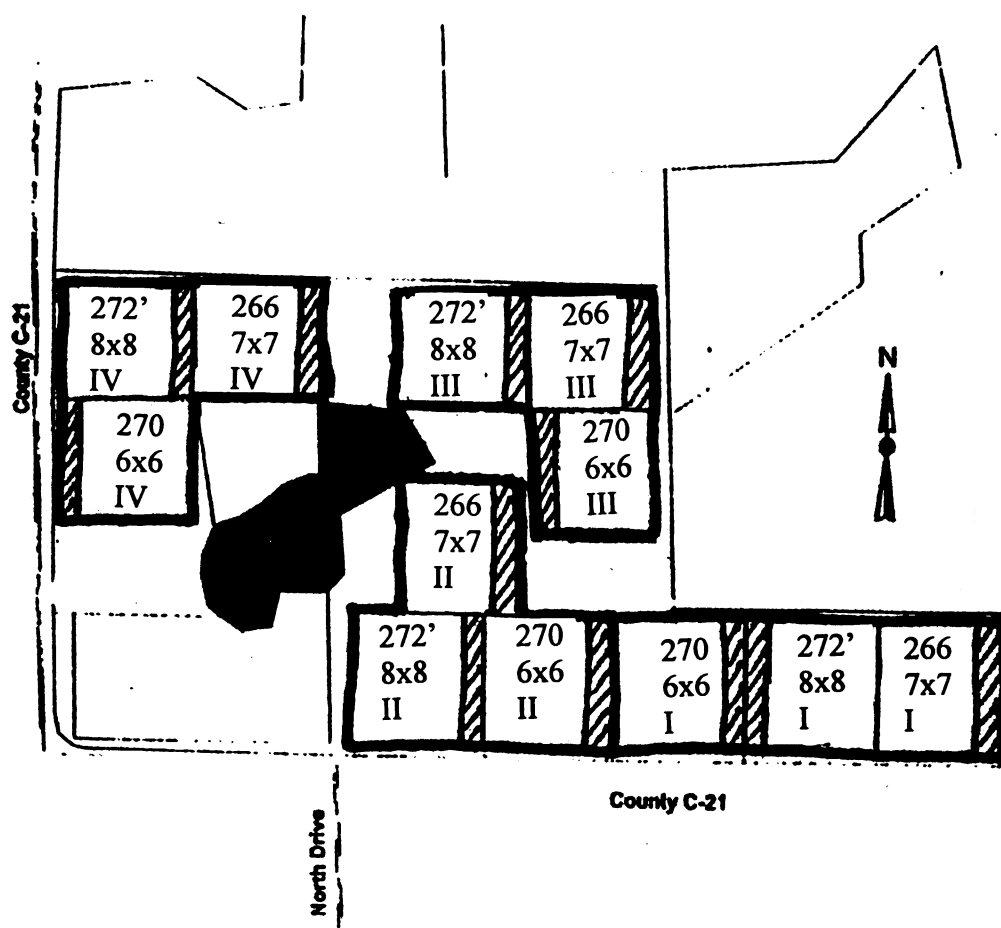
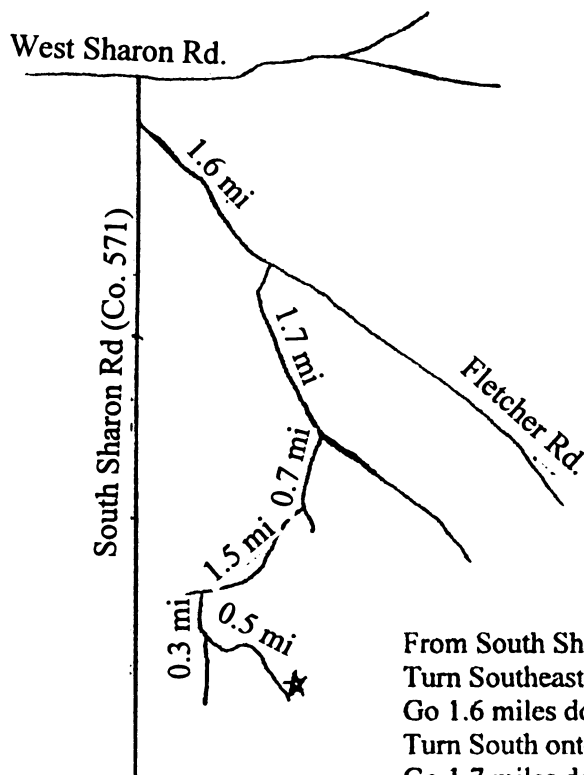


Figure 4. Hash marks in each plot note the location of white pine blister rust resistant seedlings in each plot. Border rows are not shown but are the same as in Figure 10, blister rust resistant rows started after border rows were planted.



From South Sharon Rd (County 571)
 Turn Southeast onto Fletcher
 Go 1.6 miles down Fletcher to Naples Rd.
 Turn South onto Naples Rd.
 Go 1.7 miles down Naples Rd.
 Turn Southwest onto unmarked dirt road
 (a "keep it clean" sign is on the North side of the road
 about 10 ft up in a tree, the road is just past the tree
 with the sign)
 Go 0.7 miles down the unmarked trail
 Turn right onto another unmarked trail
 Go 1.5 miles on this unmarked trail
 Turn left onto another unmarked trail
 Go 0.3 miles to a fork in the road
 Take the left fork (the right fork goes to a steep hill)
 Go 0.5 miles past the fork
 The road ends in the stand

Figure 5. Directions to get to the oak overstory white pine planting site.

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Appendix 1

Record of Deposition of Voucher Specimens*

The specimens listed on the following sheet(s) have been deposited in the named museum(s) as samples of those species or other taxa, which were used in this research. Voucher recognition labels bearing the Voucher No. have been attached or included in fluid-preserved specimens.

Voucher No.: 2002-09

Title of thesis or dissertation (or other research projects):

Evaluation of white pine regeneration in Michigan.

Museum(s) where deposited and abbreviations for table on following sheets:

Entomology Museum, Michigan State University (MSU)

Other Museums:

Investigator's Name(s) (typed)

Linda Williams

Date: 31 July 2002

*Reference: Yoshimoto, C. M. 1978. Voucher Specimens for Entomology in North America.
Bull. Entomol. Soc. Amer. 24: 141-42.

Deposit as follows:

Original: Include as Appendix 1 in ribbon copy of thesis or dissertation.

Copies: Include as Appendix 1 in copies of thesis or dissertation.

Museum(s) files.

Research project files.

This form is available from and the Voucher No. is assigned by the Curator, Michigan State University Entomology Museum.

Appendix 1.1

Voucher Specimen Data

Page 1 of 1 Pages

Species or other taxon	Label data for specimens collected or used and deposited	Number of:							Museum where deposited
		Eggs	Larvae	Nymphs	Pupae	Adults ♀	Adults ♂	Other	
<i>Pissodes strobi</i> (Peck)	MI., Marquette Co., 12 mi. S of Ishpeming T45N,R27W,S2 NWSE 19 May 1999					8			MSU
<i>Pissodes strobi</i> (Peck)	MI., Marquette Co., 14 mi. SW of Ishpeming T46N,R28W,S30 NWSE 2 June 1999					12			MSU

(Use additional sheets if necessary)

Investigator's Name(s) (typed)

Linda Williams

Date 31 July 2002

Voucher No. 2002-09

Received the above listed specimens for deposit in the Michigan State University Entomology Museum.

[Signature] 31 July 2002
Curator Date



3 1293 02372 0372