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AN HISTORICAL AND DENDROECOLOGICAL ANALYSIS OF A LONG-TERM REFORESTATION EXPERIMENT IN GRAYLING, MICHIGAN.

By

Jason Scott Kilgore

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ABSTRACT

AN HISTORICAL AND DENDROECOLOGICAL ANALYSIS OF A LONG-TERM REFORESTATION EXPERIMENT IN GRAYLING, MICHIGAN.

By

Jason Scott Kilgore

The long-term survival, growth, and reproduction of planted trees yield insights on physiological responses to local conditions and potential for colonization. The Grayling Beal Plantation was established in 1888 to test 41 native and nonnative species of trees in the pine barrens of northern Michigan. After 112 years, survival of original stems was greatest for the nonnative *Picea abies* (L.) Karst. and the native *Pinus resinosa* Ait. and *P. strobus* L.; no hardwood stems survived. Regeneration was dominated by *P. strobus*, *P. resinosa*, *Picea abies*, and the nonnative *Pinus sylvestris* L., while *P. strobus* and *P. sylvestris* were successfully regenerating in the old agricultural field adjacent to the plantation. Low site index values (28-45) reflect low productivity associated with the infertile soil. Although the high-frequency variation in radial growth for all four conifers was positively correlated to April temperatures, the native conifers were more complacent to variations in precipitation and temperature. *P. sylvestris* was sensitive to variations in January, April, and September precipitation, while *Picea abies* was sensitive to variations in precipitation of the previous December. These results suggest that the nonnative conifers, *P. abies* in closed-canopy and *Pinus sylvestris* in open-canopy conditions, have the potential to colonize the pine barrens ecosystem.

ACKNOWLEDGEMENTS

I would like to thank my major advisor, Dr. Frank Telewski, for introducing me to the Beal Plantation and entitling the completion of Professor Beal's historic experiment to me. His relentless enthusiasm and support of my pedagogical pursuits were greatly appreciated. Dr. Peter Murphy has long been a mentor and friend who continues to look out for my best interest. Dr. Donald Dickmann presented pointed discussions on pine barrens ecology and, like the aforementioned committee members, advocates consideration of the important role humans have played in the forest landscape. Dr. Rich Kobe has forced me to think out of the conventional statistical box when considering trees in the landscape. I appreciate the resources all of these men have provided to this project and my professional development.

This research was funded in part by a grant from Sigma Xi (The Scientific Research Society) and with logistical support from the Division of Campus Park and Planning (CPP). Grants to present this work at three conferences (Disturbance Dynamics in Boreal Forests, Kuhmo, Finland; Michigan Academy of Science, Arts, and Letters, Mt. Pleasant, MI; and Ecological Society of America Annual Meeting, Tucson, AZ) were obtained from CPP, Paul Taylor Fund (Dept. of Botany and Plant Pathology / Plant Biology), The Graduate School, International Studies and Programs, and the Ecology, Evolution, and Behavioral Biology Program.

Locating and tying together historical data presents many challenges. Fred Honhart (Michigan State University Archives & Historical Collections) assisted me in locating assorted files on Professor Beal's many activities associated with the early Michigan Agricultural College. Bill Botti directed me to a wealth of information on the State's interest in the Plantation in the 20th century, while Roger Rasmussen related the activities of the Beal Plantation Committee. Besides being a friendly face at the end of a long field day, Kevin Gardiner (Camp WaWaSum) provided his detailed account of the 1977 windstorm and its local effects.

I could not have completed the collection of increment cores, tree metrics, and countless data points from oak seedlings without field assistance. My loving wife, Pam Kilgore, spent more time than any other person with me at the Beal Plantation; not only does she write legibly, but the time together was invaluable. Robyn Ast, Steve Nimcheski, Steve Lettero, Denise Kemp, Frank Telewski, and Alex Zörnig also helped me in the field, usually in suboptimal conditions.

I received outside assistance in the interpretation of the modern ecological data. At the Laboratory of Tree-Ring Research (University of Arizona), Chris Baisan, Rex Adams, Tom Harlan, and Dr. Harold Fritts allocated time and their expertise to reviewing some of the dendrochronological data presented in this thesis. Marty Kroell (Natural Resource and Conservation Service) provided interpretation of soil-related data at the Beal Plantation. Finally, colleagues in the Departments of Plant Biology and Forestry critiqued several presentations of this project as it unfolded through the last few years.

The Beal Plantation would no longer exist if Roger Rasmussen and Dan Sikarskie (both from Huron Pines Resource Conservation and Development Council), had not taken the initiative to protect this important piece of forest history. I also interacted with Ann Stephens and Susan Thiel (both from Michigan Department of Natural Resources). Denise Kemp (Kirtland Community College) took the lead on sponsoring the Beal Plantation to foster local academic interest. These folks, along with the rest of the Beal Plantation Committee and others before them, must be acknowledged for persevering in the face of industrial expansion.

Finally, I would like to recognize the support that my family has provided. In particular, Pam forms my foundation in recognizing the value of life beyond the University. The rest of my close family, especially Bob and Kathy Reynolds, Lucy Dueck, Kim Reynolds, Justin and Jackie Kilgore, and Jason Tallant, provide the encouragement and diversions necessary to enjoy my work and life. I appreciate all of their unbiased support as I continue toward my goal of teaching at the collegiate level.

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EARLY EXPERIMENTAL RESEARCH IN THE PINE BARRENS OF NORTHERN MICHIGAN: HISTORY OF THE GRAYLING AGRICULTURAL EXPERIMENT STATION

ABSTRACT

The need for experimental research in agriculture and forestry was recognized coincidentally with the 19th century logging of Michigan's northern forests. Supported by the Federal Morrill Act of 1862 and Hatch Act of 1887, Michigan Agricultural College established five Experiment Stations across the sandy pine barrens of northern lower Michigan to determine how to improve the soil for agriculture and to reforest the land. Forage crops were planted at the Walton (Grand Traverse County) and Baldwin (Lake County) substations, which have not been located, and forage crops and trees were planted at the Harrison (Clare County) and Oscoda (Iosco County) substations where red pines remain. Forage crops, vegetables, fruit trees, and a variety of forest trees were planted at the main Grayling (Crawford County) substation. The agricultural research lasted less than 5 years, and the mixed-species plantation in Grayling has been irregularly surveyed for over 110 years. Recognized for its importance as the birthplace for reforestation in Michigan, the Beal Plantation in Grayling is now listed on the State Register of Historic Sites and supports an interpretive facility as part of the Hartwick Pines and North Higgins Lake State Parks, Michigan.

OBJECTIVES

The objective of this chapter is to compile all information relevant to the establishment and operation of the first Agricultural Experiment Stations (AES) in northern lower Michigan. This chapter will serve as a base from which historical research on these AES can be conducted in the future. Sources have included files from the Forest Management Division (Michigan Department of Natural Resources) and the Michigan State University (MSU) Archives & Historical Collections, newspaper articles from The Avalanche in Grayling, Annual Reports of the Michigan Board of Agriculture, and published literature. Additional materials not investigated in this study may exist at the Michigan Historical Museum in Lansing.

INTRODUCTION

By the end of the 19^{th} century, loggers had harvested most of the native pine forests in the Lower Peninsula of Michigan and had begun cutting hardwoods (Whitney 1987). After traveling through the State, A.A. Crozier, a professor from Michigan Agricultural College (MAC), said that he "cannot now recall having seen in any one place as much as a single standing acre of white pine in good condition" (Dempsey 2001). Imperfect logs and timber slash left on the land and recurrent droughts created conditions suitable for chronic wildfires set by land-clearing operations, locomotive sparks, careless settlers, and berry pickers. When Chicago (IL) and Peshtigo (WI) were burning in October 1871, a series of devastating wildfires stretched across the northern

Lower Peninsula from Lake Michigan to Lake Huron (Sodders 1997). As Professor Liberty Hyde Bailey, also from MAC, wrote in a Detroit Free Press article and later cited by Beal (1888b), "What little herbage the plains afford is burned off, instead of passing into the ground to enrich it. In this manner a continual impoverishment of the soil is progressing."

Consequently, much of the northern Lower Peninsula was rendered infertile, acidic, dry, and covered with windblown sand. Because the logging companies did not pay taxes on their staked and now deforested land, the property reverted to the State of Michigan, who in turn encouraged agricultural settlement by selling the property at low prices (Dempsey 2001). However, most settlers were unsuccessful at farming the sandy soils in the 15-county region known as the Pine Barrens (Figure 1-1). The farmsteads were abandoned, and the property again reverted to State ownership (Willits 1888).

Reforestation efforts had already begun in the East, but governmental support for reducing the rate of logging and reforestation efforts was minimal in Michigan. Representative Robert C. Kedzie, later an MAC professor, led an early effort to preserve the remaining forests of Michigan and to begin replanting trees at the same rate as removal by logging (Dickmann and Leefers in press). Kedzie appealed to landowners that forests have practical value by controlling extreme fluctuations in rainfall, protecting crops from harsh winds, and preventing sand and snow from blowing over agricultural land (Dempsey 2001). In 1867, Michigan passed legislation to sanction shade tree planting along roads and to penalize removal or destruction of these trees. A decade later, another early conservationist, Representative Charles Garfield, introduced legislation to credit roadside property owners for a portion of their highway tax if they planted trees. Still, in the early 1880s, legislative efforts to limit logging of the northern forests were minimal because a majority of legislators had financial ties to the logging or mining industries, which considered the forest resource limitless (Dempsey 2001).

With concern over the cutting of Michigan's forests, Professor William James Beal of MAC began growing trees in 1873 for the purpose of reforestation (Telewski 1998). Specifically, Beal wanted to determine the growth requirements for a variety of tree species so that second-growth forests could provide income in the future (Beal 1878). For 17 years, Beal planted trees and shrubs from 215 taxa in The Arboretum on the campus of MAC with the purpose of educating visitors on the value of growing trees as a crop (Telewski 1998). As a result of his efforts, the public began to pressure the State government to take legislative action against the wanton forest destruction (Garfield 1905).

In 1887, Hon. N.A. Beecher introduced a bill in the Michigan legislature to create an Independent Forestry Commission to investigate "the extent to which the forests of Michigan are being destroyed by fires, used by wasteful cutting for consumption or for the purpose of clearing lands for tillage or pasturage" (Reynolds 1888a,b). The Commission was also charged with reporting the effects of logging on the water bodies and climate of the State and to consider "the protection of denuded regions, stump, and swamp lands." Within two years, the Commission, directed by Beal and Garfield, was to report back to the Governor with the results of their inquiries and proposed legislation in an effort "to preserve and restore the forest wealth of the State."

The Commission began its inquiries by asking every township supervisor a series of questions relating to the conditions of the forests and wastelands in their domain. Any fires occurring and the extent of their damage were also to be reported back to the Commission. Of the 1185 sets of questions mailed, 722 were returned, and most were incompletely written. Over half, or 488, of the supervisors saw no need for forestry legislation (Reynolds 1888b).

In January 1888, the Commission organized a Forestry Convention in Grand Rapids to "awaken a general interest in forestry matters and to aid in gathering and disseminating information on this subject" (Reynolds 1888d). Prominent landholders, academics, politicians, and lumbermen were invited to participate in this "first public step" toward addressing Michigan's dwindling forests. Hon. Beecher opened the Convention by telling of the facts relating to Michigan's forests that inspired him to introduce the bill calling for an Independent Forestry Commission. Adding to his own experiences, Beecher consulted with others concerned about the forests, including "Dr. Beal, Prof. Bailey, President Willits, Senator Holbrook, Senator Monroe, Governor Luce, Chas. W. Garfield, Representative Watson, Representative Cross, Hon. Geo. M. Dewey, Dr. Palmer, of Grayling, an ex-member of the Legislature, and many others" (Reynolds 1888d). The rest of the Convention was given to professors, land owners, and politicians such as Bernard E. Fernow, Chief of the United Stated Division of Forestry, presenting papers on topics that included fruit tree growing, statistics on the remaining forests, use of timber products, wildfires, tree and wheat culture in "waste places," woodlot management, proposed legislation, water use, maple syrup production, forestry reserves, and civic pride in tree-planting (i.e., Arbor Day). The Convention was closed with "A Convention of Michigan Trees," a humorous and educational narrative on forest use played out by members of the Convention acting as different species of trees.

In June 1888, Beal organized a 2-week expedition to survey the condition of northern Michigan's forests firsthand from Harrisville on Lake Huron's shore to Frankfort on Lake Michigan's shore (Beal 1888, Voss and Crow 1976). Accompanying Beal on this expedition were two recent graduates of MAC (L.A. Dewey and D.A. Pelton) and two prominent botanists, Professor Liberty Hyde Bailey (MAC) and Charles Wheeler. Two reporters from Detroit newspapers, Mr. Fisher from the Free Press and Mr. H. Parish from the Tribune, were invited along to present their readers with an impression of the devastated northern woods. Their teamster and guide was W.W. Metcalf from Grayling (Beal 1888b). In the Pine Barrens, the explorers found vast stretches of logging slash and open sand fields dominated by scrubby oaks, which resprout after fire (Beal 1888, Voss and Crow 1976).

After considering the current status of Michigan's forests and actions taken in other states and Canada, the Forestry Commission made several immediate recommendations to the State (Reynolds 1888c). First, data on forest conditions should be collected from sources considered most reliable by the Commission rather than from township supervisors. Second, to minimize the number of and damage from wildfires, the use of fire when clearing land should be prohibited from April 1 to November 1, unless the township supervisor provided written permission. Third, the Commission should be authorized to purchase "cheap lands … to be set aside and maintained as a preserve." Finally, the Commission recommended additional funds to continue their work for two more years.

The need for experimentation was recognized several decades before the organization of the Independent Forestry Commission. Supported by the Federal Morrill Act of 1862, the Agricultural Colleges had been promoting "agricultural and mechanic experimentation" through the State Farmers' Institutes and published circulars (Beal 1915). By the mid-1880s, representatives of Agricultural Colleges were politicking for Federal funds to support stations devoted exclusively to experimentation. In 1885, the Michigan legislature authorized experiment station work, and, in 1887, the Federal government provided funds for these stations through the Hatch Act. Given the $15000 allotment, MAC organized its first experiment station network in 1888 under the directorship of then MAC President Edwin Willits (Beal 1915). In February 1888, among other appointees, Professor Beal was appointed Botanist, and Professor Kedzie was appointed Chemist of the newly formed experiment station network (Willits 1888). According to Willits' (1888) opening report, he believed that "a special and thorough knowledge of the laws of nature as allied to agriculture will reduce the reducible uncertainties to a minimum and raise the productivity to a maximum."

The main experiment station was located on the campus of MAC, while substations were established throughout the lower peninsula of Michigan. The South Haven substation was launched to identify hardy varieties of fruit trees, while a series of substations were instituted across the Pine Barrens to investigate their "restoration to agricultural possibilities" (Willits 1888). These substations were located at Walton (Grand Traverse County), Baldwin (Lake County), Oscoda (Iosco County), Harrison (Clare County), and Grayling (Crawford County) (Willits 1888). In the hope of making the Pine Barrens agriculturally productive, Professor Kedzie wanted to test the effects of inexpensive fertilizers on the production of forage and food crops. Since animal manures were not available due to lack of forage for raising livestock and the use of superphosphates was cost prohibitive, Kedzie used readily accessible fertilizers: lake marl, salts, and plaster (Kedzie 1888d). Professor Beal had two clear objectives for these substations (Beal 1888b): "To find one or more grasses or other forage plants that shall be better adapted to the soil and climate than any heretofore in general use in such places; and to test many kinds of forest trees to learn which are best fitted to plant for timber on the sandy plains."

GRAYLING AGRICULTURAL EXPERIMENT STATION

In early 1888[1], the Michigan Central Railroad Company[2] donated "eighty acres of wild land" to MAC for the Grayling Agricultural Experiment Station (GAES, W½ of

[1] The last year Michigan Central Railroad is named as payer of taxes on this parcel was 1887, thus the State Board of Agriculture assumed ownership by 1888 (Crawford County Equalization Department 1887).

NE¼ of Section 17, Crawford County, T.26N., R.3W., Figure 1-1) (Willits 1888). This property, located approximately 1½ miles southeast of the existing village of Grayling, had been cut (Figure 1-2) and exposed to recurrent fire, especially on the north and south ends (Kedzie 1888b), which left scattered jack pines and oak root sprouts (Figure 1-3). The GAES was considered the base substation because the area's climate and conditions would "best represent the average, - neither the best nor the poorest of the sterile land" (Willits 1888). Two problems were identified with the Grayling location (Willits 1888). First, because of Grayling's relatively higher elevation (347 m above sea level) on the High Plains and other climatic factors, "frosts come late in the spring and early in the fall." Frosts occur later than May 30 and earlier than September 17 in half of the years in the period 1951-1980 (Weirlein 1998). Second, recurrent fires following logging reduced the humus content of the soils: "there is but little vegetable matter in the soil."

In the Spring of 1888, Professors Beal and Kedzie supervised the clearing, fencing, and preparation of ground at GAES (Figure 1-4). The barbed wire and board fencing was intended to exclude cattle from the experiments, while a 5-foot strip of plowed ground along both sides of the fence was to prevent fire from entering the property (Kedzie 1888a,b). Kedzie (1888a) opened bid for materials and labor in the local newspaper to remove roots and stems ("grub") from the south 20 acres by May 1, plow the south 20 acres by May 12, deliver 50 cubic yards of marl by May 23, and construct a board and barbed wire fence around the south 40 acres by May 23. Contracts

[2] The tax rolls indicate that Jackson, Lansing and Saginaw Railroad Company (J.L.&S.R.R. Co.) paid the taxes on the property known as the "State Farm" prior to 1887; an assumption is made that this railroad company was later known as the Michigan Central Railroad Company.

were let by the end of April to Alpheus Slaght (Grayling Township) for grubbing, James Gallamore (Ball Township) for plowing, and A.J. Rose (Grayling) for fencing and marl (Avalanche 1888a). An additional contract was let in May to clear and plow another 20 acres on the north side of the GAES (Avalanche 1888b, Kedzie 1888b). All but the middle 40 forested acres were cleared and either plowed or grubbed. Except for a "tool barn" constructed on the northwest corner of the property in 1888, little infrastructure was developed at this and the other substations.

AGRICULTURAL RESEARCH AT GAES

The north and south 20 acres of the GAES were dedicated to agricultural experiments (Figure 1-5). The goal of this research was to determine how to increase the soil fertility with affordable fertilizers and green manures. Consequently, Professors Beal and Kedzie tested the survival and growth of different grasses, clovers, and legumes under the influence of marl, plaster (gypsum), salt, and no fertilizer. The marl was dug from the bottom of the nearby School Section Lake, while plaster and salt were shipped to Grayling by rail. Both fields were plowed 7 inches deep and harrowed to remove small woody plants, which were raked into windrows for burning (Figure 1-4). The fields were then rolled to "compact the soil," and the harrow-rake-roll sequence was repeated (Kedzie 1889b, Kedzie 1889a).

Without knowing which plants would survive, the researchers sowed seed from about two dozen species in carefully measured plats in the south 20 acres at the end of

May 1888 and in the north 20 acres on July 5 of that year. The south field was divided into one-acre plats for each of 20 species (Figure 1-6), while the north field held plats of varying sizes (Figure 1-7). Few of the sown plants were able to tolerate the frosts and droughty conditions at the GAES. In addition, insects destroyed many of the crops; for example, red clover was devastated year after year by cut worms (Kedzie 1890). Marl was an effective fertilizer, as was plaster "in most cases," but salt was of little value (Kedzie 1890). Spurry, winter vetch, clovers, and field pea showed the greatest potential for forage and green crops (Kedzie 1890). Tall fescue, perennial rye, and tall meadow oat grass were the best performing individual grasses, but combinations of timothy and redtop with other crops like clover produced a better "sward" (Kedzie 1890). The only vegetables tested at GAES were spinach (Kedzie 1889b, 1890) and sugar beets (Kedzie 1890) in the northwest plat of the north field (Figure 1-7). Overall, the results suggested to Beal (1889b) that no crop can be grown "profitably...without the aid of some fertilizer."

A shift in the management of the experiments at GAES may have led to a discontinuation of the agricultural research. In August 1890, Professor Kedzie (1891) was relieved of his duties at GAES by the Board of Agriculture, while Professor Beal was completely relieved of Experiment Station work the next year (Beal 1910, 1915). In 1892, Dr. O. Palmer, a local agent and GAES agriculturist, was directing the agricultural research in Grayling (Harwood 1892). The last Experiment Station report mentioning this work summarized the continuation of activities begun by their predecessors. Tall meadow oat grass, orchard grass, fescue, and spurry showed the most promise as forage and green manures (Harwood 1892). No subsequent reports of these experiments at GAES were located.

FRUIT TREE RESEARCH AT GAES

The north 20 acres of the GAES were unforested but were included in the fenced 80 acres (Figure 1-5). For the first two years, "recuperative crops" were planted to increase the organic matter in the sandy soils (Avalanche 1888d, Taft 1890). After plowing under a crop of spurry in the Fall of 1889, the land was harrowed in the Spring and then planted to test hardy varieties of fruit trees. Taft (1890) reported "four trees" each of "45 varieties of apples, 5 of pears, 12 of plums, and 5 of cherries were planted." The only fertilizer used was "one half pint of ground bone and potash to a tree" (Taft 1890). A 4-5 foot diameter circle around each tree was raked every 10 days. All of these trees survived their first winter but put on little growth in their second summer, which was particularly dry (Taft 1891). Another hundred trees, "mostly Russian varieties of apples," were planted the following year (Taft 1891). After two years, the orchard had not lost any trees due to the climate, as reported by Dr. O. Palmer, who was directing this research for MAC's Horticulturist, L.R. Taft (1892).

The orchard was not mentioned again in the annual Experiment Station reports but was noted by others. Professor Crozier wrote in 1895 that the "orchard has made but little growth" (Anonymous 1913). Most of the trees had died, except some of the uncultivated trees. By 1900, the orchard of mostly Russian apple trees had been abandoned (Anonymous 1913).

SILVICULTURAL RESEARCH AT GAES

Within the middle 40 acres that were not cleared, Professor Beal began his silvicultural experiments. To test the effects of common site preparation on tree growth (Figure 1-5), he prepared three plots of land and planted trees from 40 species: 3 native to the jack-pine plains, 21 native to North America but not the plains, and 16 exotic to North America (Appendix I). All of the stock for the GAES silvicultural experiment was obtained from W.W. Johnson of Snowflake, Antrim County, Michigan (Beal 1888b).

The first "newly broken" 1-acre plot just north of the grass plots was 4 rods[3] wide from south to north and 40 rods long from west to east, and was "well broken up" (Beal 1888, Anonymous 1913). Fourteen rows were plowed approximately 4 feet apart, thus the author calls this the Plow Treatment. On May 21, 1888[4], a total of 2145 seedlings and cuttings from 39 species[5] of native and exotic trees were planted on 4-foot centers in this plot (Anonymous 1913).

[3] Rods are antiquated surveyor units of length with 1 rod equaling 16.5 feet, or 5.0292 meters; a chain is composed of 4 rods and is equal to 66 feet, or 20.1168 meters.
[4] The actual day of May 21, 1888, is assumed to be the planting date for the Plow Treatment based on the referenced planting date for the Harrow Treatment (Anonymous 1913). The actual date is likely within a couple of days prior to May 22, 1888.
[5] European/Scotch elm (*Ulmus montana/glabra*) was not planted in this Treatment.

The second "unbroken" 2-acre plot lay just north of the Plow Treatment and was 5 rods wide at the east end, 11 rods wide at the west end, and 40 rods long (Beal 1888, Anonymous 1913). The orientation of the north and south boundaries for this treatment is unknown but is assumed to be oriented as shown in Figure 1-5. Since the plot was "passed over once with a spring-toothed harrow, which seemed to tear up the soil considerably, though most of the wild shrubs and other perennials were still left in the ground ready to grow" (Beal 1888b), the author calls this the Harrow Treatment. Before planting, the plot contained some jack pine, scrub oak, "blueberries, one bear berry, trailing arbutus, wintergreen, eagle fern, sweet fern, some dwarf service berry, choke cherry and a few grasses and other perennials" (Beal 1888b). Although Beal did not replicate his plantings, "an assortment of the trees obtained of Mr. Johnson" (Beal 1888b) "are placed here as in plowed land" (Anonymous 1913). Based on the 4-foot center planting rate observed in the Plow Treatment plot, approximately 4290 seedlings and cuttings could have been planted in the Harrow Treatment; however, this number is too large when considering that a total of 5260 seedlings and cuttings were planted in the entire plantation in 1888. Unfortunately, the trees in the Harrow Treatment were "mostly plowed up" the year after planting (Beal 1889a), thus unknown numbers of unknown species remained in the Harrow Treatment plot.

The third 0.4-acre plot lay north of the Harrow Treatment, was "six rows 40 rods long," and was not cultivated (Anonymous 1913), thus the author calls this the Control. The record (Beal 1888b) provides an ambiguous account of species planted here: "another lot of the same kinds was planted on a piece where there had been no cultivation." If Beal planted at the 4-foot center planting rate as in the Plow Treatment, 900 seedlings and cuttings could have been planted in the Control plot. However, as for the Harrow Treatment, which species and how many of each were planted in the Control plot could not be ascertained.

The records for the plantation in the few years after planting are found largely from notes transcribed on January 21, 1913, from Beal's handwritten notes by an unknown person (Anonymous 1913). Beal's September 21, 1888, report states that the Summer had been very dry, cultivation occurred two or three times, and hoeing occurred once. Trees doing well included locust, Russian mulberry, green ash, black cherry, box elder, catalpa, coffee-tree, beech, Norway spruce, and honey locust; trees in fair condition included weeping willow, red cedar, red pine, and white poplar; and trees doing poorly included white pine, Scotch pine[6], basswood, hackwood, black ash, and European larch. A "good many" of the trees died during the first Summer and Winter (Beal 1889a). The unusually warm and dry Summer (Kedzie 1889b) was faulted, especially for the mortality of nearly all of the cuttings (Beal 1889a).

The following Spring, Beal (1889a) plowed and planted a one-acre plot with "small trees," including white pine, red pine, Norway spruce, box-elder, and locust. The location of this small stand is unknown and was not again reported. He also planted seeds of pitch pine in "two or three places" and chestnuts; two 19th century pitch pine trees have survived in the plantation. Another inventory (Anonymous 1913) on July 4,

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[6] Scotch pine is both an historical and silvicultural name for Scots pine (*Pinus sylvestris*). The former name will be used when referring to historical texts.

1889, reported that the cultivation with horse and hoe the previous Fall had removed "some trees," that the trees in the Harrow Treatment were "mostly plowed up," and that additional pines and Norway spruce were planted in the "south rows" to replace trees that had not survived. By this second Summer, trees reported to be doing well included white pine, red pine, red cedar, box elder, and Scotch pine; trees in fair condition included green ash, red cedar, beech, elms, sugar maple, and black cherry; and trees doing poorly included locust, Russian mulberry, willows, European larch, and catalpa. Subsequent inventories appear to refer only to those trees planted in the Plow Treatment.

In his report to the Director of the Experiment Station, Beal (1890) only noted that "some of the best so far are Norway pine[7], White pine, Jack pine, Red Cedar, and box elder." On November 13-14, 1895, A. A. Crozier reported the number, and sometimes condition, of trees within each of the 14 rows of the Plow Treatment (Anonymous 1913). While he considered Scotch pine to be doing the best, many other species were also surviving in good numbers: white pine, red pine, green ash, American elm, white spruce, and Norway spruce. Silver poplar was noted to be "thrifty" and sprouting up to "12 ft away from the parent tree." In a report by an unknown author from November 3, 1900 (Anonymous 1913), red pine was said to hold the most promise followed by white pine, red cedar, and Scotch pine, on the "planted acre." Norway and white spruce and white cedar were also growing well. Professor E.E. Bogue (1903) "studied" the plantation and concluded that the "native White and Norway Pine give the

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[7] Norway pine is an historical name for red pine.

best promise of success" and "are now 14 to 16 feet high and thrifty" (Figure 1-8).

On a 1918 visit with then State Forester Marcus Schaaf, Professor Filibert Roth (1919, University of Michigan) noted that Scotch and red pine were the proven winners. Scotch pine was "the only one which produced a promising young growth or natural reproduction from seed, some of which are now 8 ft, in height," while "Norway [red] pine made the best and most shapely trees, some of them over 25 ft. tall." White pine, Norway spruce, and larch grew fairly well but were less impressive than the two aforementioned pines. Black locust rootsuckers and seedlings were present but appeared to die back regularly, while ash, elm, and poplar made a "precarious and useless existence." No other planted hardwoods or conifers were mentioned. Roth declared the experiment to be a success in showing that the land could be restocked to a forest, even with minimal care. An unauthored report of "all planted trees on the 4x40 rod area," presumably the Plow Treatment, confirms Roth's report in that Scotch and red pine showed the largest diameter and height growth followed by white pine and Norway spruce. Given the temporal coincidence, this report may be Roth's field report.

Shortly thereafter, Professor A. K. Chittenden (1921) wrote in a State Board of Agriculture Special Bulletin that he was to begin an inventory of MAC's forest plantations. In that Summer, he inventoried and calculated the mean and maximum diameter and height for all surviving trees in the Plow Treatment. Chittenden (1922) wrote the following summary for the trees originally planted here:

> "Of all the hardwood species which have survived none have shown any possibilities. They have largely failed even to develop to tree form and are

mostly merely a scrubby growth, being either unable to withstand the severity of the climate or the infertility of the soil."

"Of the 9 species of conifers planted, specimens of all still exist but only a few have apparently demonstrated their ability to succeed under these conditions, the red pine, white pine and Norway spruce. Two others show possibilities, the Scotch and pitch pines. The others have either made such slow growth or grow under such disadvantages that their use for forest planting on a large scale in similar localities should not be attempted.

The conifers arranged in order of their success are red pine, Norway spruce, pitch pine, white pine, Scotch pine, European larch, red cedar, white spruce, and white cedar."

After the passage of four more decades, interest in the plantation was renewed. A "reappraisal by the Forest Division of the Conservation Department in 1961 confirmed the validity of the 1918 report" (Daw 1968); the "1918 report" probably refers to Roth's (1919) report, which was contained within the 1918 Report of the State Forester. The 1961 report, which has not been located, noted the slow growth of species that had survived since the original planting.

On 24-25 September 1968, Weldon J. Montgomery (Area Forester, Forest Division) surveyed the 1-acre Plow Treatment, apparently unaware that trees were also planted adjacent to this stand. By this forester's estimation, at least 95% of the merchantable volume was composed of red pine, white pine, and Norway spruce, in that order (Table 1-1). Only two Scotch pine stems had survived, but this species was seeding in adjacent to the Plantation. Four other conifers, pitch pine, European larch, eastern red cedar, and northern white cedar, survived in low numbers, as well. Several hardwood species, such as elm, ash, red and Norway maple, cherry, and black locust, survived in shrubby form but were gradually dying out. Although State employees visited the Plantation again in the next decade (Kreger 1978), the trees were not tallied or surveyed.

No other inventory was made until 1997 when Dr. Frank Telewski, in his capacity as Curator for the W.J. Beal Botanical Garden and Campus Arboretum at MSU, visited the site (Figure 1-9). With assistance from Denise Kemp (Kirtland Community College), he located, flagged, and measured the diameter of all trees that were most likely to have been planted in the Plow Treatment. From 1998-2000, I relocated and measured all surviving trees in all three treatments (Table 1-1) and surveyed the plant community within the plantation and old agricultural field just south of the plantation. The 4-foot center rows of trees and cut stumps from windthrow removal in 1974 (TMR 1994) and after the 1977 windstorm (K. Gardiner, personal communication) in the Plow Treatment and Control are plainly visible.

Of the 41 tree species planted as seedlings, cuttings, or seeds in 1888-1889, no original hardwood stems survived, but original stems from seven of nine conifer species survived to 2000 (Table 1-1, Appendix I). Of these seven species, only red pine (34.5% survival) and white pine (8.4% survival) are considered to be native to the jack pine barrens, Norway spruce (26% survival) is exotic to North America, pitch pine (2 stems from an unknown number of seeds) is native to eastern North America, and white spruce

(4% survival), eastern red cedar (3% survival), and northern white cedar (1% survival) are native to this region but not to this forest type (Voss 1972, 1985, 1996). The two conifers with stems that did not survive were European larch and Scots pine; however, Scots pine regeneration is very common under open canopy in the plantation and old agricultural field. Several stump sprouts of red maple, white ash, eastern red cedar, and northern white cedar can be found within the plantation. Wild black cherry seedlings and bushes in the plantation and old field could be derived from outside seed sources or original root sprouts, while white poplar and black locust, which could only have been derived from the plantation, are common root sprouts in the old field.

Table 1-1. Number and mean diameter and height of surviving trees from Weldon Montgomery's survey of the Plow Treatment in 1968 and from the whole Plantation survey in 2000. Diameter was measured at 1.37 m, while height was estimated in 1968 and measured with a Vertex Forestor hypsometer in 2000. A "-" indicates no data available.

	1968 – Plow Treatment only			2000 – Whole Plantation survey		
Species	No. stems	Diameter (cm)	Height (m)	No. stems	Diameter (cm)	Height (m)
Ash	9	6.9	6.1	0	-	-
Cedar, eastern red	10	10.4	6.1	3	17.7	12.2
Cedar, northern white	15	7.4	4.6	1	16.3	6.9
Cherry, black	3	10.4	-	0	-	-
Elm	8	6.9	6.1	0	-	-
Larch, European	1	25.4	12.2	0	-	-
Maple, Norway	1	-	1.2	0	-	-
Maple, red	1	-	-	0	-	-
Pine, pitch	2	29.5	15.2	2	21.0	14.6
Pine, red	62	33.8	17.7	69	40.9	21.8
Pine, Scots	2	32.3	16.8	0	-	-
Pine, white	99	27.9	17.7	37	42.0	23.8
Spruce, Norway	51	25.7	15.8	24	35.9	19.5
Spruce, white	2-3	-	-	2	26.6	18.3

AGRICULTURAL AND SILVICULTURAL RESEARCH AT BRINKS' FARM

In addition to the GAES, MAC rented 8 acres of cultivated land (Brinks' Farm, S½ of SW¼ of Section 8, Crawford County, T.26N., R.3W.) from William Brinks (Crawford County Equalization Department 1884, 1886, 1888) within a mile of the GAES for additional experiments (Avalanche 1888a, 1888c, Kedzie 1888b). While the GAES had never before been plowed, the Brinks' Farm had been cultivated for 3-4 years (Kedzie 1888b). On May 15, 1888, Professor Beal planted 2-10 cuttings or seedlings each of 35 species of central Russian trees and shrubs from Iowa Agricultural College in close rows on two acres in the southwest corner (Beal 1888, 1889a, Anonymous 1913). Two days later, the north five acres were plowed and seeded in 1-rod^2 (272.25 ft^2) plots of 19 species of potential forage, such as lupine, clovers, timothy, vetch, Kentucky blue grass, and rye (Avalanche 1888c, Kedzie 1888b). The last acre in the southeast corner was fertilized with plaster and sown in spurry and vetch (Avalanche 1888c). Most of the grasses did not germinate or survive the Summer, so Beal sowed more seed from 7 forbs and 92 grasses in September (Beal 1889a). He also planted a Niagara grape vine from E.M. Roffee (Clyde, NY) in 1888, but the vine could not withstand the Winter and late frosts of Grayling (Beal 1889a). Beal (1890) reported the successful growth of several species of grasses and alsike clover at the Brinks' Farm and contemplated plowing, fertilizing, and seeding with the "most promising clovers and grasses" the following Spring. He also reported that some of the Russian trees and shrubs seemed "to promise more for this soil and climate than most of our natives," while others died or grew little

(Beal 1889a). However, no mention was made of the experiments at Brinks' Farm after 1890. A restaurant now operates on this site.

RESEARCH AT OTHER SUBSTATIONS IN THE PINE BARRENS

Given the demand by settlers of northern Michigan, Professor Beal was directed to locate, rent, and conduct experiments at four more substations to improve the agricultural condition of the Pine Barrens (Beal 1888b). These substations were to be 5-10 acres each and "subordinate to Grayling" (Willits 1888). Although more travel would be required to manage all five substations, Beal agreed that better results could be obtained by using multiple locations representing the breadth of Pine Barrens productivity (Beal 1888b). In fact, the eventual substation at Oscoda represented the poorest of the "jack-pine plains," followed by Grayling, then Walton and Baldwin, and finally Harrison with the best land (Beal 1889b). While the condition of the soil indicated its potential productivity, Beal also noted that the number of native plant species was smallest at Oscoda and largest at Harrison (Beal 1889b). At each of the four substations, Beal established similar experiments with plots containing the same species of seed, either as individual species or mixtures within each plat, including mammoth clover, red clover, alsike clover, sweet clover, tall oat grass, orchard grass, perennial rye grass, June grass, meadow foxtail, millet, Hungarian grass, meadow fescue, spurry, timothy, alfalfa (lucerne), and field peas. Although Beal conducted agricultural experiments at all of the substations, he intended to plant trees only at Harrison and Oscoda (Willits 1888).

The poorest of jack-pine plains was located in northeast lower Michigan. Beal approached Mr. James Barlow, a farmer producing grains and vegetables on drained swampland on the south side of the AuSable River and ½-mile northwest of Oscoda's railway station (Beal 1888b). Barlow was so convinced that the "Jack-pine land" was unproductive that he deeded 10 acres of such property upon which Beal could conduct his experiments. After fencing the deeded property, 5 acres were cleared, plowed, harrowed, and sown with seed on May 15, 1888 (Beal 1888b) (Figure 1-10). In April 1889, Beal topdressed a portion of each plat with fine barnyard manure, which improved growth in every species by July, and another portion near the center of each plat with superphosphate (Beal 1889a). In that same Spring, Beal plowed and harrowed another acre of the deeded property, taking care to leave standing jack pines alone, and he planted small (6 in tall) seedlings of white pine, red pine, Norway spruce, box elder, and locust and sowed seeds of pitch pine (Beal 1889a). The source for the stock and seeds is unknown. The trees, too small by Beal's account, were planted in hoed rows spaced 4 ft apart and running east to west. No other records were located that describe the specific activities at the Oscoda substation. At some point during the 20th century, the land containing the substation was incorporated into the Huron-Manistee National Forest as part of the River Road National Forest Scenic Byway (Telewski 1998). Although the plantation was harvested in the early 1980s, several mature red pine trees, probably left as seed sources, remain within 4-ft rows of stumps (Figure 1-11), and black locust and pitch pine grow within the sapling layer. The plantation is easily located near the trailhead to the Eagle Run Trail System.

The 10-acre Walton substation of fenced jack-pine plains was rented from Abram F. Philips and was located about ½-mile northwest of Walton and adjacent to the north side of the Grand Rapids & Indiana Railroad (Beal 1888, 1889a). Five acres of this "new land" in the southeast corner were rented for agricultural experiments. Similar to Oscoda, this rented land was platted, plowed, harrowed, sown with seeds, and rolled on the eleventh and at the end of May 1888 (Beal 1888, 1889a) (Figure 1-12). In October, Beal visited this substation with Hon. C.W. Garfield, a member of the State Board of Agriculture; Garfield agreed that the Pine Barrens "rank as poor" and that farmers would be most interested in the best land while it remains "cheap and abundant" (Beal 1889a). In the following April, Beal spread barnyard manure over 20 ft^2 on the east end of each plat and covered a similar area near the middle of each plat with "Homestead superphosphate" (Beal 1889b). As at other substations, Beal reported that manure helped all species but especially the grasses, while superphosphate helped the clovers most (Beal 1889a). To test when plowing and seeding were most effective, Beal shallowly (5 in deep) plowed about 1/3-acre of the "new land" in July 1889, fertilized with superphosphate (300 lbs/acre) and slaked lime, harrowed, and seeded the area with a mix of three clovers, tall oat grass, orchard grass, and timothy (Beal 1890). This mixture of clovers and grasses had proven to be the most productive to date for improving the constitution of the soil. Although no details were reported about this experiment, Beal did note that Summer plowing followed by Spring backsetting and seeding seemed to work better than Spring plowing and seeding because woody species did not have sufficient stored "protoplasm" to recover from disruption during the Summer (Beal

1890). No other records were found that describe the specific activities at the Walton substation, which has not been relocated.

The Baldwin substation was located on 8 acres of jack-pine plains rented from T.V. Childs and located "some 40 rods" (660 ft) south of the "village school-house" and adjacent to the Chicago & West Michigan Railway (Beal 1888b). The land, which had been first plowed in Spring 1888, was platted in an experimental design similar to Oscoda, harrowed, rolled, and sown with seeds on May 9, 1888. A brief visit on July 30 showed growth "a little better than those at Oscoda." On June 29, 1889, Beal noted that the plants in the plats with harrowing only (Plat 1) did not survive (Beal 1889a). In that visit, he applied plaster and a little manure from the village stables on portions of each plat. In July, Beal shallowly (5") plowed 1/3-acre and, in the following Spring, backset, fertilized, sowed seed, and harrowed similar to what he did at Walton. This substation was not mentioned after 1890 and also has not been relocated.

Supposedly representing the best of the jack-pine plains, the Harrison substation was originally located on 5 acres of rented land from B.B. Pixley (Beal 1888b). This land had been cropped for 6 years without manure in rutabagas, muskmelons and watermelons, oats, beans, corn or beans, buckwheat or millet, and light oats, respectively. On the seventh and end of May 1888, the property was plowed, harrowed, sown with seeds, and rolled in a fashion similar to that at Oscoda. An August visit showed less promise in the plants than at other stations where the "newly broken land" contained fewer weeds, such as lamb's quarter, pigeon grass, sorrel, and wild morning glory (Beal

1888b). Beal also seeded some "new land" in that Spring that "all caught first rate" (Beal 1889b). However, Beal was not satisfied with Pixley's fence maintenance practices, so he abandoned his experiments here but concluded that fertilizers would be necessary to grow crops (Beal 1889a). Instead, Beal accepted the deed for 10 acres of jack-pine land from W.H. and F.A. Wilson (Beal 1888b). This property was located ½-mile north of Harrison near the fairground and railroad. After fencing the property, from which some sizable red pine had been formerly cut, Beal plowed the south 5 acres but not before grubbing the most southern 2 acres in Fall 1888 (Beal 1888, 1889a). In the following Spring, the plowed area was rolled, harrowed, and seeded in plats with clovers, grasses, and alfalfa. A "liberal dressing ... of fairly well rotted barn-yard manure" was spread over 20 ft^2 of each plat. These seeds reportedly did well but did not receive superphosphate according to Beal's plan. Although Beal stated that trees would be planted on the Wilson property in Spring 1889 (Beal 1888b), he did not mention any trees again in the record. However, a 1-acre plantation of 18 mature red pines dating back to at least the 1890s (F. Telewski, unpublished data) grow in 4-foot center rows on the site, located on private property just north of Budd Lake and adjacent to the abandoned railroad right-of-way (Telewski 1998) (Figure 1-13). Beal apparently planted at least red pine at this substation.

The record of activity for all four substations ends before the 20th century, thus the substations can be assumed to have been abandoned by that time. Beal (1890) last reported that he planned to plow under the crops in June 1891 and to seed in a mixture of the seeds that showed the most promise: mammoth clover, red clover, alsike clover, tall oatgrass, orchard grass, timothy, and a "few other promising sorts not in the market." He concluded that a mixture rather than single species produced the best crop. Beal was also interested in developing methods to kill regenerating woody species in the agricultural field. Cutting "oak grubs" and other sprouts at the very base in July and August prevented their return, and mowing sweet fern and bracken fern close to the ground would kill these "very common and persistent" plants (Beal 1890).

GRAYLING BEAL PLANTATION, HARTWICK PINES STATE PARK

The silvicultural work at the GAES was the first designed experiment to test the effects of soil preparation on the growth of a variety of native and exotic trees in North America. However, trees had been planted for the express purpose of reforestation since the early 1800s on the East Coast and for experimental purposes since the 1860s in the Midwest. In 1820, Zachariah Allen planted chestnut, oaks, hickories, and locust on 40 acres of a previously pastured hillside near Smithfield, Rhode Island (Sargent 1876). The seeds were planted in furrows 10 feet apart and carefully followed for at least 57 years. Around 1840, white pine seedlings dug from nearby woods were planted in furrows to reforest sand barrens in Massachusetts (Sargent 1886). In 1846, Richard S. Fay planted at least 400,000 imported and native trees over 200 acres of stony hillside near Lynn, Massachusetts, and, seven years later, J.S. Fay planted 35,000 imported trees, many native trees, and tree seed on 125 acres near Woods Hole, Massachusetts (Sargent 1876). After two decades, the brothers found Scots pine, European larch, and Corsican pine to be most successful. In 1871, Burnet Landreth began planting his 7,000 privately-owned acres in Virginia with white pine, chestnut, catalpa, and other species (Rodgers 1991). While these previous efforts were made by private individuals with land and wealth, academic institutions did not become active in forest planting experiments until around 1867 when Thomas Jonathan Burrill investigated the "proper treatment of soils" for forest plantings at the Illinois Industrial University (now University of Illinois) (Rodgers 1991). In 1872, the Arnold Arboretum of Harvard College was established with Charles Sprague Sargent its first director to grow native and exotic trees (Rodgers 1991). In 1874, the Massachusetts Agricultural (State) College planted larches, Scots pine, and Austrian pine on a barren hillside (Rodgers 1991). In the early 1880s, Joseph Lancaster Budd was experimenting with introduced tree species at the Iowa Agricultural College, and Kansas Agricultural College had two experiment stations that tested different trees to that State's climate and soil (Rodgers 1991). Similar to its neighbors, University of Nebraska was interested in shelterbelt plantings and experimented with tree plantings well before the Montreal Congress of 1882 (Rodgers 1991). Finally, William Brown of Ontario Agricultural College at Guelph experimented with introduced species at its Experimental Farm in the early 1880s (Rodgers 1991). Although the plantings at GAES were certainly not the earliest experiments with native and exotic trees, they did occur earlier than the more famous Biltmore (1895, Schenck 1955), Harvard Forest (1907, Spurr 1907), and Fort Valley (Coconino) Experiment Station (1908, Gaines and Shaw 1959) experimental plantings. Furthermore, Beal did appear to be the first to explicitly design an experiment to test the effects of soil preparation on the survival and growth of native and exotic trees in North America.

The value of the early silvicultural and agricultural efforts at the GAES was not recognized until later in the 20th century. The Public Domain Commission purchased the original 80 acres from the State Board of Agriculture in 1917 (Daw 1968). The following year, Filibert Roth (1919) visited the Plantation and recommended that the entire property be left undisturbed and used as an "object lesson" of a "forest and park" for visitors. However, the north 30 acres of orchards and woods were obtained by the Northeastern Michigan Development Bureau in an exchange in 1920 (Daw 1968) and now support a restaurant and wood products company. The south 20 acres of former agricultural test plots were obtained by the H.A. Young Lumber Company in another exchange in 1964 (Daw 1968); this property was sold in August 1983 to Georgia-Pacific Corporation, who transferred ownership to Alro Steel Corporation in May 1998 (S. Seifert, Crawford County Equalization Department, personal communication). By 1968, the Michigan Department of Conservation (MDC) was interested in the value of the remaining 30 acres of the former GAES, now a part of the AuSable State Forest. Ted E. Daw (1968, Chief, Forestry Division, MDC) concluded that the plantation should be designated as an historical attraction and used in the Conservation Training School because the research provided the basis for the land use and reforestation policies for the State. The Plantation gained public recognition through a Michigan Forest Association (MFA) booklet showcasing Michigan's prominent trees (Moore and Botti 1976).

However, the Plantation's existence became threatened when Grayling's City Manager, Jerry Morford, wanted to expand the City's Industrial Park into the 30 acres still owned by the MDNR and containing the 5-acre Plantation. In a letter to Theodore

Tucker (Chief, Lands Division, MDNR) Morford (1977a) expressed interest in purchasing the 30 acres stating that the land offers "little current recreational or other value to the State of Michigan." After consulting the Forestry Division (Tucker 1977a), Tucker replied that the City would need to demonstrate an "urgent need" to convert "the oldest (1888) recorded forest plantation in Michigan" to industrial park use (Tucker 1977b). Meanwhile, a devastating wind storm on 4 September 1977 blew down a number of the larger conifers in the Plantation (K. Gardiner, personal communication) resulting in a salvage cut approved by Weldon Montgomery (1977, Forest Management Division (FMD), MDNR) that Fall. Some of the logs were offered to MSU's Forestry Club for the construction of a cabin but were not accepted (Morford 1978c). Many of the tipped stumps showing the salvage cut remain in the Plantation to this day.

Citing the wind storm damage, lack of site identification, and lack of scientific value of the Plantation, Morford (1978a) lobbied Commissioner Harry Whiteley to convince the Natural Resources Commission to accept a 6-acre City-owned property located on the AuSable River in exchange for the 30 acres containing the Plantation. The State was initially interested in this offer of river frontage (Tucker 1978a) and began the process to consummate the even-trade exchange (Tucker 1978b, Schafer 1978). Support for the exchange grew within the Department as field staff were able to investigate the site. Noting that the 6-acre property where the East Branch and Main Stream of the AuSable River join is considered a "kids only" trout fishing location, Gary Schnicke (1978, District Fisheries Biologist, MDNR) recommended that the State acquire the property, especially considering the City's lack of "protection or enhancement of natural resources." Raymond Perez (1978, Wildlife Habitat Biologist, MDNR) agreed that the protection of riparian wetland, which constitutes most of the 6 acres, for wildlife production should be considered and thus the land exchange approved; Perez did not assess the Plantation property. Although noting that the river property has no easement or legal description and is not contiguous with the existing Fish Hatchery, William Tarr (1978) recommended the land exchange with the City making up the difference in the far greater value of the State-owned 30 acres. He also pointed out that the City did not appear to have a great need for expanding into the Plantation property since only 6 of the Industrial Park's 18 parcels had been sold to date. Representing the District, A.J. Coates (1978, District Forest Supervisor, MDNR) communicated to Robert Borak (Regional Forest Supervisor, MDNR) that the Plantation's value is "negligible" but the river property should be protected against development. C. Troy Yoder (1978a, Regional Director, MDNR), on the other hand, agreed to the exchange if the City would include additional property and an easement to the river property but was opposed to the offer as submitted since the property was already protected from development by existing regulations. Fortunately, a City well is located on this additional property, so Morford was not interested in losing the easement (Yoder 1978b).

However, some in the MDNR were concerned over the potential loss of the Beal Plantation. Weldon Montgomery contacted and requested Janet Kreger (1978, Regional Preservation Coordinator, Michigan History Division (MHD), Michigan Department of State) to assess the historical importance of the Plantation. In late March 1978, Kreger investigated the Plantation with Mac Collins (Architectural Coordinator, MHD) and

William Tarr (Area Forester, MDNR). She concluded that the Plantation should be protected and listed on the State Register of Historical Sites and that a State-owned buffer should be maintained around the Plantation (Kreger 1978). The President of the Michigan Forest Association (MFA), Wesley Manley (1978a), also caught wind of the proposed land exchange and expressed to Howard Tanner (Director, Natural Resources Commission) that the Beal Plantation represents significant research related to forestry in Michigan and should be preserved. Henry Webster (1978, Chief, FMD, MDNR) invited MFA to contribute "specific suggestions and active help" as well as bring MSU into the process of commemorating the research at the Plantation. Manley (1978b) promised to produce such a report as soon as an MFA committee had investigated the site.

Conflict among different interests within the Department was brewing. C.D. Harris (1978, Chief, Bureau of Renewable Resource Management) complained to Wayne Tody (Deputy Director) that the FMD was dragging its feet on the proposed land exchange and brought to light that a FMD employee had notified the MHD and MFA about the proposal. He felt the "trees on the tract are not of any special value" and sought Tody's approval to proceed with the land exchange. C.D. Harris had apparently not attended the November meeting where a one-acre reserve was proposed to be maintained for the Plantation, as only one acre was recognized to have survived to this time, and the other 29 acres would be considered in a land exchange (Morford 1978b); furthermore, this consideration was not recorded in the joint status report (Tucker and Webster 1978) as a result of the meeting attended by Jerry Morford, Walter Nowak (Manager, Grayling Chamber of Commerce), C.D. Harris, Theodore Tucker, Henry Webster, C. Troy Yoder, and Weldon Montgomery. However, right before the MFA tour of the Plantation in December 1978, Weldon Montgomery phoned Jerry Morford to inform him that he was supporting retention of 5 acres for the Plantation and wanted to get MFA to support his proposal (Morford 1978b). While Morford (1978b) was certainly not satisfied with this proposal, MFA passed a resolution urging the FMD to retain the 5 acres (Clark 1979). Meanwhile, due to understaffing problems, the MHD postponed the processing of the application for the Plantation in the State Register of Historic Sites (Eckert 1979), and the Upper Great Lakes Regional Commission supported Grayling's proposal to convert the 30 acres to industrial park (Rehberg 1979). However, Grayling Township, in which the 30-acre parcel is located, stated that the parcel is zoned Commercial as a buffer between Industrial and Residential property and should be placed on the market in an open bid process if the State chose to dispose of the property (Fowler 1979).

By May 1979, the State was prepared to exchange all but 5 acres containing the Plantation with properties purchased by the City of Grayling based on the State's selection (Schafer 1979). Concerned that the State's offer did not include the 6-acre river property as the even exchange, Walt Nowak (1979) again lobbied Commissioner Harry Whitely to apply pressure to the MDNR. Even more brazen and close to the deadline for the land exchange agreement, Jerry Morford (1979) insisted on a meeting with the Natural Resources Commission to discuss the MDNR's denial of the river property and full 30 acres as an exchange and inflation of assessed value for the 30 acres. In a stalwart yet refined response to Morford, Tucker (1980) reiterated the MDNR's case: the river property was not deemed acceptable for exchange consideration; the Beal Plantation is of historic significance but can be contained within a 5-acre reserve; lands purchased by the City for exchange must have the same appraised value as the 25 acres; the key decision has been on Grayling's desk for over 7 months; and the only other alternative would be to dispose of the 25 acres by public sale procedure, as Grayling Township had suggested. Nine days later, Jerry Morford (1980) signed the proposed Land Exchange Agreement but still contended that the additional 5 acres were needed for industrial expansion. By February 1981, the State had selected private land[8] to be purchased by the City (Harmes 1981), and the exchange was consummated on 4 May 1981 (Laylin 1981).

However, Jerry Morford would not relent in his pursuit of the remaining 5 acres. In early July 1982, he requested the Department of Forestry (FOR) at MSU to evaluate the Beal Plantation with regard to its scientific values and to make suggestions as to alternative uses of the property. On 16 July, Dr. Victor Rudolph (Associate Chairman, FOR) and Jan Hacker (Graduate Assistant, FOR) made an on-site review of the Plantation with regard to its surrounding land use and prepared a report (Rudolph and Hacker 1982), which was submitted to Morford and the MDNR (Rudolph 1982). In the report, the authors concluded that the Plantation "no longer contains any scientific value to MSU, the DNR or the residents of the area" but does have some historical value. They suggested alternatives ranging from retention with no management to development and maintenance as a park to total conversion to industrial use.

[8] That part of the NW ¼ NE ¼ lying E'ly of the AuSable River, T26N, R1W, Section 32, South Branch Township, Crawford County (Harmes 1981).

In the meantime, Janet Kreger (1983) restarted the process to nominate the Plantation to the State Register of Historic Sites, and Dean Sandell (1983, MDNR) prepared a development plan for the Plantation complete with parking, walking trail, and interpretive signs. A property survey ordered by Michael Moore (1983a) revealed that approximately one chain (66 ft) width of the Plantation was located on property owned by Georgia-Pacific Company (formerly owned by H.A. Young Lumber Company) to the south (Borak 1983). Taking advantage of Morford's interest in gaining more land for the Industrial Park, Moore (1983b) requested Grayling to acquire this strip from Georgia-Pacific for another three-way exchange of land at the north end of the 5-acre parcel containing the Plantation. Meanwhile, the City of Grayling had overcome the Commercial zoning by the Township by annexing the property sometime before 1983 (Morford 1983). Although Morford (1984a) was more interested in gaining all 5 acres, he agreed to acquire a 60-ft strip from Georgia-Pacific in exchange for a 190-ft, or 2.9-acre, strip on the north side of the remaining 5-acre Plantation parcel (Morford 1984b), which Moore (1984) supported. Four years later, the MDNR was still waiting to acquire the acre owned by Georgia-Pacific and to develop Sandell's vision of an interpretive facility at the Plantation (Botti 1988).

Jerry Morford (1993) applied another surge of pressure to the MDNR for the entire 5 acres, probably as a result of an expansion planned by Monarch Millwork, Inc., north of the Plantation property (Hees 1993). Support for retaining ownership (McMillan 1993) and incorporating the Plantation into the Hartwick Pines State Park interpretive program (McMillan 1993, Dilts 1994) was high within the Department, but a compromise was sought between the City, MDNR, and Monarch Millwork (Reuschel 1994a). As a result of an on-site meeting in late March 1994, Reuschel (1994b) agreed to a three-way exchange of an 80-ft swath of land on the north side of the 5-acre Plantation property for an 80-ft swath on the north side of Georgia-Pacific's property to be acquired by Grayling. Four months later, the deal was negated as Georgia-Pacific expressed no interest in negotiating over their one-acre parcel due to financial stress at this plant and Monarch Millwork had begun expanding on their own property (Reuschel 1994c).

The final push for protection of the Beal Plantation came in 1996 when Roger Rasmussen and Daniel Sikarskie, both from the Huron Pines Resource Conservation & Development Council (Huron Pines RC&D), were given the go-ahead from Gerald Thiede (State Forester, FMD, MDNR) to organize a Beal Plantation Committee (R. Rasmussen, personal communication). Persons and agencies who might be interested in preserving and interpreting this portion of Michigan's early forest history were invited to an on-site meeting on 15 October 1996 (McMillan and Rasmussen 1996). Eleven persons, including Dr. Frank Telewski (MSU), attended this first planning meeting and determined that a property survey was needed, administrative authority between FMD or Parks and Recreation Division (PRD) should be decided, Ron Nagel (PRD) would develop an interpretive plan, Frank Telewski would complete an inventory of the Plantation, funding would be needed to implement the interpretive plan, and publicity was needed. The MDNR approved of the Committee's direction and left the decision of which Division to administer the site up to the local Division managers (Reuschel 1996). The survey showed that "at least two rows of the largest trees are on Georgia-Pacific property" (Rasmussen 1997), so the Committee requested the donation of the 190-ft wide swath of Georgia-Pacific property to the State (Rasmussen 1998). By June 1998, Georgia-Pacific had donated the 2.7-acre parcel (Thiel and Sikarskie 1999). The Beal Plantation Committee gained the needed momentum with the land donation to begin planning the interpretive facilities. In August 1998, I joined the project and began an historical and ecological survey of the Plantation as well as participated in the planning process for the facility. This rustic yet moderately accessible site would feature a walking trail with interpretive signs and be linked to Hartwick Pines and North Higgins Lake State Parks by an auto tour.

While persons from a number of organizations contributed to the Beal Plantation project (Table 1-2), Huron Pines RC&D provided the key coordination and leadership to keep the project moving. An over 1100-ft handicap-accessible crushed gravel trail and crushed gravel parking lot was designed by Frank Telewski, Ann Stephens (PRD, MDNR), and me and installed by youths from the Shawono Center (Grayling, MI). As the trail winds through the Plantation, four interpretive nodes with wheelchair pullouts describe the site history (Figure 1-14) and role of the FMD in multiple use management of forest resources. The interpretive signs were written and designed by Earl Wolf (Office of Information Services, MDNR), Frank Telewski, Ann Stephens, and me. Construction materials were obtained by Huron Pines RC&D through grants from the Michigan Department of Agriculture and The Weyerhauser Company Foundation. A.J.D. Forest Products Company donated and installed three sturdy wooden benches along the trail. The interpretive facility is administered by the FMD and sponsored by

Kirtland Community College under the Michigan Adopt-A-Forest Program. On 7 October 1999, the Beal Plantation was formally dedicated as the birthplace of reforestation in Michigan.

The Beal Plantation is an important historical and auto tour stop for forest visitors between the Hartwick Pines Logging Museum and Interpretive Center and the old Forest Nursery Site at North Higgins Lake State Park (Thiel and Sikarskie 1999). Visitors to the Plantation are impressed by the low impact on the site integrity, diversity and size of trees, and excellent interpretation of Michigan's early forest history.

Table 1-2. List of participants in the Beal Plantation Committee, which was formed in Fall 1996 to protect and recognize the historical importance of the Grayling Beal Plantation. Coordination was provided by Huron Pines Resource Conservation and Development Council.

Representative(s)	Organization
Roger Rasmussen Daniel Sikarskie	Huron Pines Resource Conservation and Development Council
Dr. Frank Telewski Jason Kilgore	W.J. Beal Botanical Garden and Campus Arboretum, Department of Botany and Plant Pathology, Michigan State University
Ron Nagel Ann Stephens	Parks and Recreation Division, Michigan Department of Natural Resources
Jim McMillan Susan Thiel	Forest Management Division, Michigan Department of Natural Resources
Denise Kemp	Natural Science Department, Kirtland Community College
Jerry Meyer Lynn Porritt-McConnell	Grayling Regional Chamber of Commerce
Dave Stephenson	A.J.D. Forest Products Company
Paul Call	Weyerhaeuser Company
Herb Burkett	Michigan Department of Agriculture
Charlie Guenther	Private citizen

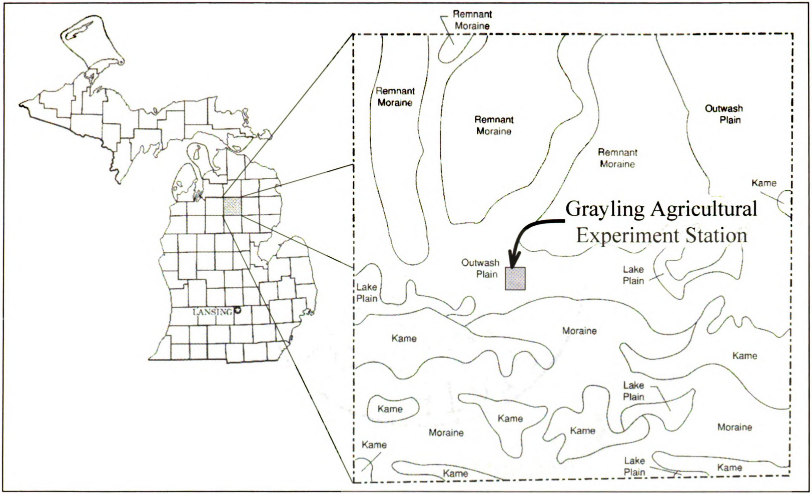

Figure 1-1. Location of the former Grayling Agricultural Experiment Station in Crawford County, Michigan. The geophysiographic map for Crawford County shows the distribution of major glacial deposits; in particular, note the outwash plain upon which the GAES was located. Glacial map taken from Werlein (1998).

Figure 1-2. When Professor Beal arrived at the location for the Grayling Agricultural Experiment Station in early 1888, little more than stump fields remained. Photograph courtesy of Michigan State University Archives & Historical Collections.

Figure 1-3. The land prior to clearing for the Experiment Station in Crawford County, Michigan, was covered with scattered jack pine and scrubby oak resprouts from frequent fires. The photograph was taken from just east of the plantation looking into the southwest corner; the plantation will be established to the right of this view. Photograph courtesy of Michigan State University Archives & Historical Collections.

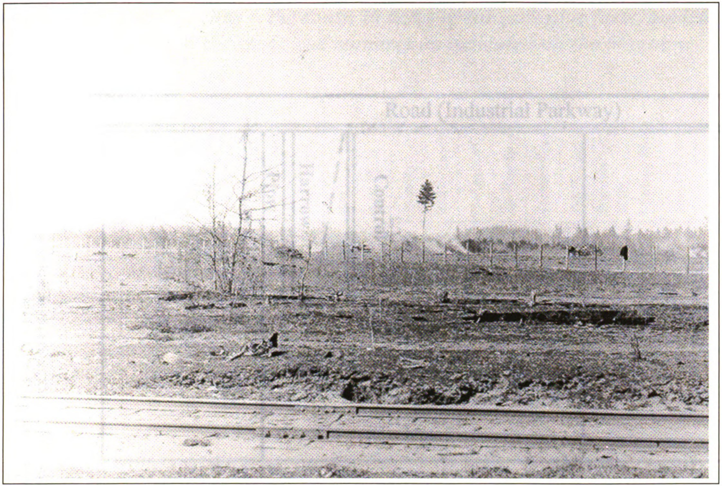

Figure 1-4. The southern 40 acres of the donated land were fenced, and the southern 20 acres were cleared, grubbed, and prepared for agricultural experiments. This photograph was taken from the railroad tracks south of the Experiment Station looking north to the land clearing and windrow burning. Note the unfinished fence and sole red pine tree, which can also be seen in Figure 1-3. Photograph courtesy of Michigan State University Archives & Historical Collections.

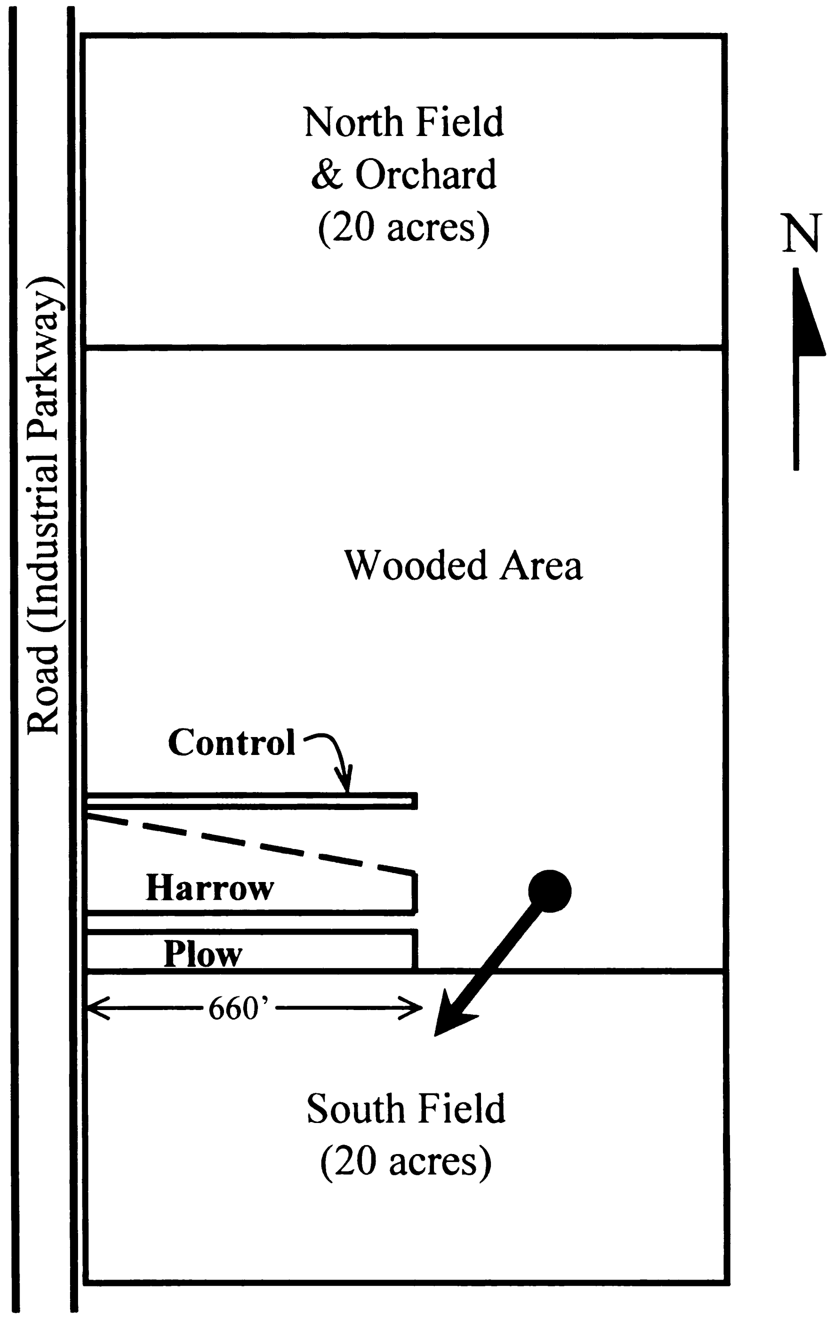

Figure 1-5. Layout for the 80-acre Grayling Agricultural Experiment Station as reconstructed from various sources. The silvicultural experiment contained the 1-acre Plow Treatment, 2-acre Harrow Treatment, and 0.4-acre Control. The end widths and length of the Harrow Treatment are known, but the actual orientation of the north and south boundaries is unknown; since several surviving trees border the Plow Treatment in a line, the location of the north boundary (dashed) is less known. The large arrow represents the approximate location and direction for the photograph shown in Figure 1-3.

Experimental field at Grayling – the south 20 acres of the jack pine farm, seeded 31 and June 1, 1888 – the seeds and manures as indicated on the diagram.

N.

W. — E.

Spurry.	Alfalfa	Mammoth Clover.	Red Clover.	Alsike Clover	Hungarian Grass.	Vetch.	White Mustard.	Field Peas.	Rye.	Buckwheat.	Timothy.	Yellow Lupins.	Hungarian Grass.	Ky. Blue Grass.	Orchard Grass.	Tall Fescue.	Perennial rye grass	Meadow Fescue.	Meadow Foxtail.
								No	ma	nur	e.								
						Sal	t	200	lbs.	to	th	e a	cre.						
			Pl	ast	er	200	lbs.	an	d s	alt	200	lbs.	to	th	e a	cre.			
						Pl	ast	er	200	lbs.	to	th	e a	cre.					
					La	ke	Ma	rl 6	to	ns	to	the	ac	re.					

Figure 1-6. Experimental design for the south 20 acres of the Grayling Agricultural Experiment Station. Each species was sown on a one-acre plat, which was then divided into five fertilizer treatments. Salt and plaster were brought in by the railroad at the southwest corner of the Station, while the marl was dug from the nearby School Section Lake. Figure redrawn from Beal (1888a).

North Field of Twenty Acres, Seeding for Three Years.

Size.	1888.	1889.	1890.
8X20 rods.	Spurry.	New Zealand Spinach	Sugar Beet

Size of Plat.	**1888.**	**1889.**	**1890.**
3X58 rods.	Spring Vetch.	Peas.	Timothy and Red Top.
1X58 rods.	Timothy.	Peas.	Timothy and Red Top.
1X58 rods.	Rye.	Peas.	Timothy and Red Top.
2X20X5X58 rods.	Buckwheat	Spurry.	Timothy and Red Top.
7X78 rods.	Spurry.	Spring Vetch.	Orchard Grass and Red Top.
7X78 rods.	Red Clover and White Turnip.	Mammoth Clover.	Rye Grass and Clover.
2X78 rods.	Bokhara Clover.	Bokhara Clover.	Bokhara Clover.
3X78 rods.	Millet.	Spurry.	Sheeps' Fescue.
2X78 rods.	Hungarian Grass.	Spurry.	Sheeps' Fescue.
5X78 rods.	Spurry.	Spurry.	Meadow Fescue.
5X78 rods.	Spurry.	Spurry.	Red Fescue.
2X78 rods.	Alfalfa.	Alfalfa.	Alfalfa.

Woods.

Figure 1-7. Experimental design for the north 20 acres of the Grayling Agricultural Experiment Station for the years 1888-1890. Sources for the fertilizer were the same as for the south field. Figure redrawn from Kedzie (1890).

Figure 1-8. View into the west end of the Plow Treatment of the Plantation from the old agricultural field, August 1902. Note the "thrifty" white pine and Norway spruce, as noted by Bogue (1903). Photograph courtesy of Michigan State University Archives & Historical Collections.

Figure 1-9. The Grayling Beal Plantation, as seen in 1998. The successful white and red pines and Norway spruce can be easily detected in the background, while the old agricultural field in the foreground in dominated by Scots and jack pine, white poplar, and red oak regeneration. Black locust rootsprouts are common in the old agricultural field east of this point. Photograph courtesy of F. Telewski, Michigan State University.

THE EXPERIMENTAL PLATS.

Where a plat is marked as containing nine sorts there are the following: Orchard grass, Perennial rye grass, June grass, Meadow foxtail, Red clover, Mammoth clover, Alsike clover, Timothy, Meadow fescue.

N. ———— S.

	No plowing, no harrowing; nine sorts, mixed. Sown May 15.
	This plat only harrowed, not plowed; nine mixed sorts. Sown May 15.
Blank.	Field Peas. Sown May 15.
Spring rye. Sown May 15.	Nine sorts, mixed. Sown May 15.
Perennial Rye Grass. Mammoth Clover, mixed,	Perennial Rye Grass. Sown May 15.
Perennial Rye Grass, Orchard Grass,	Italian Rye Grass. Sown May 15.
Mammoth Clover, Orchard Grass, mixed,	Orchard Grass. Sown May 15.
Mammoth Clover. Sown May 15.	June Grass. Sown May 15.
Alsike Clover. Sown May 15.	Meadown Foxtail. Sown May 15.
Alfalfa, or Lucerne, with a little Mammoth Clover on one side. Sown May 15.	Hungarian Grass. Sown May 15.
Timothy. Sown May 15.	Millet. Sown May 15.
Meadow Fescue. Sown May 15.	Sweet Clover. Sown May 15.
Spurry. Sown May 15.	Red Clover. Sown May 15.

Figure 1-10. Experimental design for the agricultural plots at the Oscoda (Iosco County) substation, which contained 10 acres deeded by Mr. James Barlow. Each plat was 3 rods wide by 10 rods long (8167.5 ft^2 or 0.1875 acre). Figure redrawn from Beal (1888b).

Figure 1-11. Red pines remaining from the Oscoda Substation, now located at the trailhead to the Eagle Run Trail System, Huron-Manistee National Forest. Photograph courtesy of F. Telewski, Michigan State University.

<table>
<tr><td>27.—Blank. Plowed not sown.</td><td>26.—Hungarian. Sown about May 20. Sown to red clover late in Aug.</td><td>25.—Rye. Sown about May 20. Sown to red clover late in August.</td><td rowspan="6">9.—Left wild.</td></tr>
<tr><td>24.—Meadow fescue. Sown about May 20.</td><td>23.—Millet. Sown about May 20. Sown to red clover late in August.</td><td>22.--Alfalfa. Sown about May 20.</td></tr>
<tr><td>21.—Alsike clover. Sown about May 20.</td><td>20.--June grass. Sown May 11.</td><td>19.—Eight sorts. Sown May 11.</td></tr>
<tr><td>18.—Timothy. Sown May 11.</td><td>17.—Italian rye grass. Sown May 11.</td><td>16.--Spurry. Sown May 11.</td></tr>
<tr><td>15.—Perennial rye grass. Sown May 11.</td><td>14.—Meadow foxtail. Sown May 11.</td><td>13.—Field peas. Sown May 11. Sown to orchard grass late in August.</td></tr>
<tr><td>12.—Mammoth clover. Sown May 11.</td><td>11.—Red clover. Sown May 11.</td><td>10.—Sweet clover. Sown May 11.</td></tr>
<tr><td>8.—Orchard grass. Sown May 11.</td><td>7.—Tall oat grass. Sown May 11.</td><td>6.—Orchard grass. Sown May 11.</td><td>5.—Unplowed, not harrowed. Seven sorts. Sown May 11.</td></tr>
<tr><td>4.—Orchard grass. Sown May 11.</td><td>3.—Tall oat grass and orchard grass. Sown May 11.</td><td>2.—Mammoth clover and orchard grass. Sown May 11.</td><td>1.—Unplowed, but harrowed. Seven sorts. Sown May 11.</td></tr>
</table>

Figure 1-12. Experimental design for the agricultural plots at the Walton (Grand Traverse County) substation on 5 acres rented from Abram F. Philips. Each plat was 3 rods wide by 10 rods long (8167.5 ft^2 or 0.1875 acre). Figure redrawn from Beal (1889b).

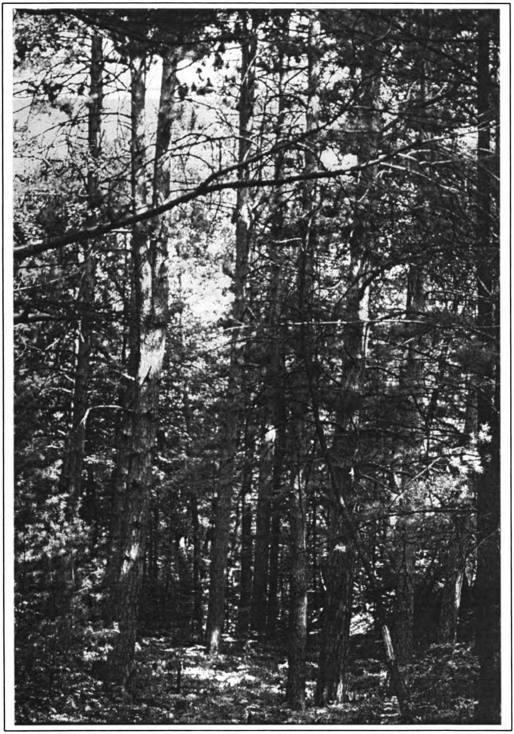

Figure 1-13. Red pines remaining from the Harrison Substation, now located on private property just north of Budd Lake. Photograph courtesy of F. Telewski, Michigan State University.

Figure 1-14. Entrance kiosk to the ¼-mile interpretive trail at the Grayling Beal Plantation, now an annex of the Hartwick Pines State Park. Photograph taken by J. Kilgore, Michigan State University.

CHAPTER 2

RESULTS FROM A LONG-TERM REFORESTATION EXPERIMENT IN THE PINE BARRENS OF NORTHERN MICHIGAN

ABSTRACT

The establishment, growth, and regeneration of 3 locally native, 22 regionally native, and 16 nonnative (exotic to North America) tree species were measured in a common garden experiment established in 1888 on the pine barrens of northern Lower Michigan. Species with the greatest survival of original stems were *Pinus resinosa* Ait. (35%), *Picea abies* (L.) Karst. (24%), and *Pinus strobus* L. (7%); several stems of *Juniperus virginiana* L., *Picea glauca* (Moench) A. Voss, *Pinus rigida* Miller, and *Thuja occidentalis* L. also survived. Regeneration was dominated by *Pinus strobus*, *Pinus resinosa*, *Picea abies*, and *Pinus sylvestris* L. in the plantation and by *Pinus strobus*, unplanted *P. banksiana* Lamb., *P. sylvestris*, and unplanted *Quercus* spp. in the old field next to the plantation. No originally planted hardwoods survived, but regeneration from *Prunus serotina* Ehrh., *Populus alba* L., *Robinia pseudoacacia* L., *Fraxinus americana* L., *Acer rubrum* L., and *A. platanoides* L. was present in the plantation and/or old field next to the plantation. Site index values reflect the low productivity of the site: *Picea abies*, 28; *P. glauca*, 29; *Pinus resinosa*, 44; and *P. strobus*, 45.

The nonnative *Pinus sylvestris* and *Picea abies* performed as well as or better than species native to the pine barrens. *Pinus sylvestris* is successfully spreading out from the original plantation and competing with the native early successional species *P. banksiana* and *P. strobus*. Within the plantation, *Picea abies* survived and produced as much regeneration as the native dominant *Pinus strobus*. The successful colonization by nonnative *Pinus sylvestris* and *Picea abies* indicates that both have the potential to become invasive in the pine barren ecosystem.

OBJECTIVES

The objective of this chapter is to report the current community composition and structure of the Grayling Beal Plantation, which was established as an experiment in 1888 by Professor Beal to determine which trees species would survive and regenerate in the Pine Barrens of northern Michigan. This chapter can provide ecological data useful to investigators interested in the survival and growth of a variety of native and exotic trees species in this pine barren ecosystem.

INTRODUCTION

Reforestation of anthropogenically affected landscapes is recognized as important for sustainable land management by government (United Nations 1995, United Nations Division for Sustainable Development 2000), academia (Keddy and Drummond 1996), and industry alike (American Forest and Paper Association 2001). The question of which native or nonnative species to use for reforestation was addressed early in Europe (Pontey 1828) as well as in the United States (Sargent 1876) and continues to be an issue for land managers. The ability of a species to survive and successfully regenerate determines the species assemblage of a reforested area. Furthermore, tree species not native to the reforested area could affect the ultimate composition, structure, disturbance regime, and functional attributes of the community (Richardson and Higgins 1998).

The pine barren ecosystem is an often overlooked system that has been drastically affected by human disturbance. Traditionally, a barren was described as an unproductive community lacking canopy trees and dominated by grasses, forbs, shrubs, and scattered stands of trees (Curtis 1959, Anderson and Bowles 1999). Barrens are generally regulated by edaphic conditions and natural disturbances, especially fire, resulting in a particular flora, often containing a number of endemic species. For example, the shale barrens of the Appalachian region form on highly weathered shale outcrops that experience active erosion and extremely warm midday temperatures (up to 60° C) and support an open canopy forest of *Pinus virginiana*, *Quercus prinus*, *Q. rubra*, *Q. ilicifolia*, and *Juniperus virginiana*; at least 18 vascular plant species are shale barren endemics (Braunschweig *et al.* 1999). Eastern serpentine outcrops also produce barrens dominated by xerophytic graminoids and herbs and fire-tolerant *P. virginiana*, *P. rigida*, and *J. virginiana*, species that can tolerate the low calcium to magnesium ratio, low water availability, and high heavy metal (e.g., nickel and chromium) concentrations (Tyndall and Hull 1999). Perhaps the most studied pine barren ecosystem in North America is the barrens of the New Jersey Pine Plains (Forman 1998). Dominated by stunted *P. rigida* and *Q. marilandica*, these barrens are underlain by deep, acidic, and highly leached sand and are structured by short (<20 yr) fire return intervals (Gibson *et al.* 1999).

The pine barren ecosystem of the northern Great Lakes region of North America occurs on post-glacial outwash plains, sand lake plains, and sandy riverine terraces. The development and composition of forests on these glacial features prior to European settlement have been summarized by Curtis (1971), Whitney (1986, 1987), Mokma and Vance (1989), Graumlich and Davis (1993), Barrett *et al.* (1995), Schaetzl and Brown (1996), Radeloff *et al.* (1999), and Zhang *et al.* (2000). In Michigan, the pine barren forests were dominated by *Pinus banksiana* (Roth 1905) with elements of *P. resinosa*, *P. strobus*, *Quercus ellipsoidalis*, *Prunus serotina*, and *Populus* spp. (Whitney 1986, 1987, Comer 1996). After the merchantable timber was logged in the second half of the 19th century and numerous wildfires spread across northern Michigan, the pine barrens regenerated to forests of *Pinus*, remained stump prairies (Barrett and Schaetzl 1998), or were planted to *Pinus resinosa*, *P. strobus*, *P. banskiana*, or *P. sylvestris* during the 1930s (Curtis 1971, Whitney 1987). Historical and experimental research has shown that edaphic factors and disturbance, especially fire, are important for maintenance and restoration of the pine barren ecosystem (Simard and Blank 1982, Abrams and Dickmann 1984, Whitney 1986, Host *et al.* 1988, Host and Pregitzer 1992, Vora 1993, Little 1998, Pregitzer and Saunders 1999). However, forest management practices such as fire suppression and monotype plantations have resulted in the destruction or conversion of all but 7% of presettlement barrens in the Great Lakes region (Whitney 1987, Temple 1995).

The effects of management and natural regeneration on the pine barrens are thus well documented, but no studies exist on the survival and successional outcome of a mixture of planted tree species in this ecosystem. The former Grayling Agricultural Experiment Station (GAES) in northern lower Michigan provides a unique opportunity to address this issue. In 1887, Michigan's legislature directed the Independent Forestry Commission to survey the condition of the State's remaining forests following extensive logging, rampant wildfires, settlement, and agriculture (Reynolds 1888a, Telewski 1998). In the following year, the U.S. Congress passed the Hatch Act, which provided $15000 to every land grant institution to conduct experiments in agriculture and cognate sciences (Beal 1915). Using the Hatch funds, Michigan Agricultural College (now Michigan State University) established the GAES to determine how to reforest and increase agricultural productivity in the pine barrens of northern lower Michigan. As part of this effort, Professor William J. Beal established a test planting of 41 native and nonnative tree species to determine which would survive and reproduce in this ecosystem (Beal 1888, 1889a). The results of this test plantation from 1888 have not been thoroughly evaluated until now.

The purpose of this study was to complete an historic silvicultural experiment, *viz.* determine which tree species became established and their success at regenerating at the former GAES in northern lower Michigan. Given the environmental limitations (e.g., low pH, nutrients, and water holding capacity) to successful tree establishment in this ecosystem, I predicted that species native to the pine barrens would be better adapted to survive and regenerate than nonnative species.

METHODS

Study site

The investigation took place between August 1998 and October 2000 at the Grayling Beal Plantation (Hartwick Pines State Park annex) in Crawford County, Michigan (44°39'N, 84°42'W, elev. 348 m; Figure 2-1). This area became deglaciated about 12500 years ago (Weirlein 1998) and is located geomorphologically within the Grayling Outwash Plain (Albert 1994) and floristically within the Great Lakes Pine Forest (Küchler 1964). The soils at the plantation are a coarse, loose, strongly acidic, and excessively drained sand of the Grayling series (Typic, frigid Udipsamment) (Mokma and Vance 1989, Werlein 1998). Government Land Office Survey records show that presettlement forests on this soil type were largely composed of *Pinus banksiana* (Whitney 1986). Prior to planting in 1888, the site had experienced frequent fires leaving mostly *P. banksiana*, scattered *P. resinosa*, and scrubby *Quercus* spp. and *Prunus* spp. (Kedzie 1888b), but no record or evidence of fire exists at this site since planting.

The climate of Crawford County is characterized as humid continental (Whitney 1986). The mean annual precipitation (1951-1980) is 811 mm with 62% of the precipitation falling during April-September (Figure 2-2). The mean annual temperature is 6.3° C with a mean summer temperature of 18.6° C and a frostfree growing season of 110 days (Weirlein 1998). The growing season is generally cool and short with only 2068 growing degree days (Weirlein 1998).

Beal's experiment at the plantation was designed to test the effects of site preparation (plowing or harrowing) on survivorship, growth, and reproduction of 40 native and nonnative tree species (Beal 1888, Anonymous 1913) (Appendix I). In May 1888, Beal planted an arbitrary mix of 5260 hardwood and conifer seedlings and cuttings on 4-foot (1.2 m) centers in rows running west-east. The plowed treatment was 1 acre (0.40 ha), the harrowed treatment was 2 acres (0.81 ha), and the control (no site preparation) was 0.4 acre (0.16 ha) in size. In the following year, the harrowed treatment was plowed under, and an unknown number of *Pinus strobus* and *Picea abies* seedlings were planted in the plowed treatment (Anonymous 1913). Beal (1889a) also planted seeds of *Pinus rigida* in a couple locations in early 1889. Unfortunately, Beal's original notes (Anonymous 1913) are not sufficiently detailed to determine the original number of trees planted in each treatment, thus the site preparation treatments were not compared. Subsequent management, alteration, and monitoring (see Chapter 1) of the plantation have been minimal prior to the present.

Survivorship and growth

Using historical notes, I located, flagged, and measured all surviving planted trees. Survivorship was resolved simply by the presence or absence of stems purportedly planted in 1888-89 as determined by a stem's relative size and location within an apparent row. Each surviving stem was given a unique alphanumeric aluminum tag, and height and diameter at breast height (dbh; breast height = 1.37 m) were measured using an electronic hypsometer (Vertex Forestor) and diameter tape, respectively.

The allometric aboveground biomass and site index were estimated for selected surviving *Pinaceae* only, including *Picea abies*, *Picea glauca*, *Pinus resinosa*, and *Pinus strobus*. Standard allometric biomass equations available for forest stands in the geographically nearest region were used to calculate biomass (Table 2-1) for each tree and site index (Table 2-2) for each species.

Table 2-1. Allometric biomass equations used to estimate total aboveground biomass (AB), including foliage and branches, of individual surviving *Pinaceae* at Grayling Agricultural Experiment Station (Ter-Mikaelian and Korzukhin 1997).

Species	Biomass Equation (Kg)	Diameter Range (cm)	Region	Source
Picea abies	AB = 0.2722*dbh^2.1040	12-44	New York	Jokela *et al.* 1986
Picea glauca	AB = 0.0777*dbh^2.4720	1-33	Minnesota	Harding and Grigal 1985
Pinus resinosa	AB = 0.0778*dbh^2.4171	3-46	Upper Great Lakes	Perala and Alban 1994
Pinus strobus	AB = 0.0755*dbh^2.3833	5-26	Upper Great Lakes	Perala and Alban 1994

Table 2-2. Equations used to estimate site index for surviving *Pinaceae* based on mean height at Grayling Agricultural Experiment Station (Carmean *et al.* 1989).

Species	Site Index (SI) Equation	Year Range	Region	Source
Picea abies	SI = (0.0259)(ht)^(1.2496)(1-exp^ (-0.0021)(112 yr))^(1.7841)(ht^(-0.1088))	Planting–60 yr	Wisconsin	Wilde *et al.* 1965
Picea glauca	SI = (0.0380)(ht)^(1.5142)(1-exp^ (-0.0124)(114 yr))^(-6.484)(ht^(-0.355))	20–130 yr	Minnesota	Carmean and Hahn 1981
Pinus resinosa	SI = (0.52919)(ht)(1-exp^ (-0.0198)(114 yr))^(-1.3892)	20–120 yr	Minnesota	Gevorkiantz 1957a
Pinus strobus	SI = (0.5086)(ht)(1-exp^ (-0.024)(114 yr))^(-1.8942)	20–120 yr	Northern Wisconsin	Gevorkiantz 1957b

To measure average radial growth, trees of the four selected *Pinaceae* and regenerating *Pinus sylvestris* were cored perpendicular to the stem lean to avoid reaction wood with 5.15 mm diameter increment borers. Cores were obtained at approximately 0.3 m from the ground to obtain as many growth-rings as possible. Increment cores were prepared, cross-dated, and measured using standard dendrochronological techniques

(Stokes and Smiley 1967). Ring-width measurements were analyzed to detect anomalies within each time series and to obtain descriptive statistics for each species with the program COFECHA Version 6.06P (Holmes 2000).

Demography

The current stand structure reflects the survival and regeneration of the originally planted trees. Since the trees were planted non-randomly in rows parallel to the treatments, I divided the plantation into four equal widths perpendicular to the planting rows and randomly selected two 2 m wide belt transects within each quadrant (Figure 2-1). The remaining portion of the old agricultural field associated with the original GAES and abandoned by 1900 was also sampled to determine which woody species were migrating into open areas as opposed to establishing under the plantation cover. Each of the eight belt transects was approximately 143 m long and covered 0.02 ha, thus approximately 8.4% of the 5-acre (2.02 ha) area encompassing the plantation was sampled.

The position of all woody plants (except *Vaccinium* spp. and *Comptonia peregrina*) with stems within the belt transects was recorded relative to the transect tape. The height, linear crown cover within the belt transect, and dbh for each stem were measured. The number of stems for each species within a belt transect was grouped by diameter size class and by location (plantation versus old field), standardized to a hectare basis, and grouped across all belt transects. Frequency was calculated as the number of 2 m long plots in which a species was present within the 2 m wide belt transects. To capture the relative contribution of each species in the plantation community, an Importance Value (IV) was calculated based on the sum of relative frequency, relative density, and relative [height*cover] by transect. The index [height*cover] was used instead of other units of coverage (e.g., basal area) to include stems less than 1.37 m tall and to incorporate the effect of light interception; [height*cover] creates an appropriate dimensional occupation of space for each stem. However, since understory trees are more likely to have relatively horizontal rather than vertical canopies to optimize light capture (Oliver and Larson 1996), this index may disproportionately weight cover from understory stems. A Success Index was calculated as the IV for a species divided by the number of seedlings originally planted to compare relative success of each species based on original presence.

Statistical Analyses

Means and standard deviations for the height, dbh, and biomass of each species were calculated in Systat Version 9.01 (SPSS Science Inc. 1998), while the mean ring-width and standard deviation were calculated in the program RESPO Version 6.06P (Holmes 2000). Differences in growth among originally planted species of select *Pinaceae* were tested using species as the fixed effect in a one-way analysis of variance for each growth category (height, DBH, biomass, and ring-width) in Systat Version 9.01 (SPSS Science Inc. 1998).

RESULTS

Survivorship and growth

Of 41 tree species originally planted as seedlings, cuttings, or seeds in 1888-1889, none of the original stems from the 32 hardwood species survived, but seven of nine conifer species had stems surviving to 2000 (Appendix I). Of these seven species, only *Pinus resinosa* (34.5% survival) and *P. strobus* (8.4% survival) are considered to be native to the Great Lakes pine barrens, *Picea abies* (26% survival) is exotic to North America, *Pinus rigida* (2 stems from an unknown number of seeds) is native to eastern North America, and *Picea glauca* (4% survival), *Juniperus virginiana* (3% survival), and *Thuja occidentalis* (1% survival) are native to this region but not to this forest type (Appendix I). Two of the conifer species that did not survive were *Larix decidua* and *Pinus sylvestris*; the latter is present as regeneration in the plantation and old field. Several stems of *Acer rubrum*, *Fraxinus* spp., *Juniperus virginiana*, and *Thuja occidentalis* are present as stump sprouts within the plantation, and *Populus alba*, *Prunus serotina*, and *Robinia pseudoacacia* are present as root sprouts in the plantation and old field. Survivorship among species was not statistically compared because trees were not planted randomly within each treatment and because postplanting activities selectively removed trees from particular species, as described in Methods.

Of the surviving *Pinaceae*, those species native to these pine barrens demonstrated greater mean growth than all other *Pinaceae* examined in this study (Table

2-3). *Pinus strobus* attained the greatest mean height and dbh and had a mean ring-width similar to that of *Pinus resinosa*, but its aboveground biomass was similar to that of the exotic *Picea abies*. Based on its small surviving population, *Picea glauca*, which is native to the region but not to the pine barrens, expressed stunted growth relative to the native *Pinaceae* in this study. Growth of the two native species was more similar to each other and greater than the nonnative species (Table 2-3).

Table 2-3. Mean size and growth statistics [±1 SD] for originally planted and surviving *Pinaceae* at the former Grayling Agricultural Experiment Station, Crawford County, MI. Species with the same letter do not differ significantly (Tukey HSD, $p<0.05$).

Species	Trees (n)	Height (m)	DBH (cm)	Aboveground Biomass (Kg)	Site Index	Trees/ Cores (n)	Series Length (yr)	Ring-Width (mm)
Picea abies	24	19.5 ± 3.7a	35.9 ± 9.2a	545 ± 292a	28	11/25	92.3 ± 8	1.79 ± 0.5ab
Picea glauca	2	18.3 ± 2.5abc	26.6 ± 4.7a	266 ± 112a	29	2 / 4	74.5 ± 28	1.35 ± 0.1a
Pinus resinosa	69	21.8 ± 3.3b	40.9 ± 6.2b	636 ± 217a	44	48 / 97	82.6 ± 14	2.18 ± 0.5c
Pinus strobus	37	23.8 ± 3.7c	42.0 ± 6.7b	580 ± 219a	45	10 / 21	89.7 ± 13	2.17 ± 0.7bc

Demography

A total of 2301 stems from 20 woody species (except *Vaccinium* spp. and *Comptonia peregrina*) were documented within the belt transects. Approximately 72% and 92% of all woody stems in the plantation and old field, respectively, were seedlings (less than 1.37 m tall). Species originally planted at the GAES accounted for 38% of all woody stems and 24% of stems greater than 5 cm dbh in the plantation (Appendix II), and accounted for 13% of all woody stems and 53% of stems greater than 5cm dbh in the old field (Appendix III).

Only *Pinus strobus* (plantation and old field), *P. sylvestris* (old field), and *Quercus rubra*-group (plantation) (Figure 2-3) exhibited the reverse-J shape diameter distribution characteristic of old growth stands (Oliver and Larson 1996). The other species showed no presence in the plantation or old field (e.g., *P. rigida*), presence as juvenile trees only (e.g., *Populus alba* in old field), presence as large trees only (e.g., *Q. ellipsoidalis* in old field), or presence as a relatively uniform size class (e.g., Acer rubrum in plantation). Of the originally planted *Pinaceae*, only *Pinus strobus* had increasing numbers of trees in the smaller size classes for the plantation and old field. *Picea abies* experienced a reduction in the smallest size class (0-4.9 cm dbh) in both communities, while *Pinus resinosa* increased in density in the same size class in the plantation. *Pinus sylvestris* had a relatively flat distribution in the plantation but increased in abundance in the smaller classes in the old field.

The majority of the non-seedling component of both the plantation and old field was of species native to these pine barrens (Figure 2-4). *Pinus strobus* clearly had the highest number of saplings (<20 cm dbh) and large trees (>20 cm dbh) in the plantation, followed by the subdominants *P. resinosa*, *P. sylvestris*, *Q. rubra*-group[1], *P. banksiana*, and *Picea abies*, in order of stem prevalence. The relative density of large trees in the old field was partitioned among the native species *Pinus banksiana* and *Q. ellipsoidalis* and the exotic *P. sylvestris*. The advanced regeneration stratum in the old field was

[1] Due to the presence of adult *Quercus rubra*, *Q. ellipsoidalis*, and possible hybrids between the two related species (Overlease 1964, Tomlinson *et al.* 2000), seedlings of the *Quercus* section of Lobatae were lumped as *Q. rubra*-group.

dominated by *P. banksiana*, *P. strobus*, and *P. sylvestris*.

Species native to these pine barrens accounted for the majority of the total Importance Values (Tables 2-4,5, Figure 2-5). In the plantation, 78% of the total IV was from species native to the jack pine barrens, and the top four species accounted for 64% of the total IV. The exotics *Picea abies* and *Pinus sylvestris* accounted for 9% of the total IV, while the remaining 14 species contributed less than 5% each to the total IV. In the old field, 68% of the total IV was from species native to the pine barrens (Table 2-5). The large number (672, or 82% of all old field stems) of *Quercus rubra*-group seedlings from a recent mast year (personal observation) contributed heavily to the extraordinarily high IV for this species. The exotics *Picea abies*, *Pinus sylvestris*, and *Populus alba* accounted for 21% of the total IV in the old field.

The Success Index (SI) indicates the relative success of each species as a function of the known number of stems originally planted in the plantation and its IV as measured in 2000. In the plantation, planted species native to the pine barrens (Table 2-4; SI=35% of summed SI for all species) were less successful than the other species (SI=65%). *Picea abies*, *Pinus strobus*, and *Prunus serotina* were most successful, followed closely by *Pinus resinosa*. In the old field, species exotic to North America (Table 2-5; SI=71% of summed SI for all species) were more successful than planted species native to the region (SI=13%) and pine barrens (SI=16%). The exotic *P. sylvestris* had an SI over five times higher than the next species, the exotic *Picea abies*.

Table 2-4. Rank in dominance by Importance Value of woody species and their Success Index in the plantation at the Grayling Agricultural Experiment Station, Crawford County, MI. Status indicates whether the species is considered to be Native (N) to these pine barrens, native to the Region (R) but not the forest type, or Exotic (E) to North America. Number planted based on Beal's notes for 1888 (Anonymous 1913). Despite the strong presence of *Pinus strobus*, note the similar relative success of *Picea abies* and *Prunus serotina*.

Rank	Status	Number Planted	Species	Importance Value	Success Index
1	N	500	*Pinus strobus*	80.99	0.162
2	N	0	*Quercus rubra*-group	64.24	*
3	N	200	*Pinus resinosa*	29.33	0.147
4	N	0	*Quercus alba*	17.36	*
5	E	100	*Picea abies*	16.42	0.164
6	R	100	*Prunus serotina*	16.20	0.162
7	N	0	*Amelanchier* sp.	15.42	*
8	N	0	*Pinus banksiana*	10.24	*
9	R	100	*Acer rubrum*	10.22	0.102
10	E	100	*Pinus sylvestris*	9.96	0.100
11	N	0	*Quercus ellipsoidalis*	4.74	*
12	N	0	*Populus tremuloides*	4.62	*
13	N	0	*Prunus virginiana*	3.61	*
14	R	1000	*Robinia pseudoacacia*	3.49	0.003
15	R	200	*Fraxinus* sp.	3.09	0.015
16	R	0	*Prunus* sp.	2.80	0.000
17	R	100	*Fraxinus americana*	2.78	0.028
18	R	0	*Prunus pensylvanica*	1.98	*
19	R	seeds	*Pinus rigida*	1.40	*
20	R	100	*Juniperus virginiana*	1.13	0.011

*These species were not planted or, in the case of *Pinus rigida*, planted by seed.

Table 2-5. Rank in dominance by Importance Value of woody species and their Success Index in the old agricultural field south of the plantation at the Grayling Agricultural Experiment Station, Crawford County, MI. Status indicates whether the species is considered to be Native (N) to these pine barrens, native to the Region (R) but not the forest type, or Exotic (E) to North America. Number planted in plantation based on Beal's notes from 1888 (Anonymous 1913). Although the recent *Quercus* mast year (personal observation) gives much weight to the group's importance value, the exotic *Pinus sylvestris* is as prevalent as its native analog *P. banksiana*.

Rank	Status	Number Planted	Species	Importance Value	Success Index
1	N	0	*Quercus rubra*-group	104.00	*
2	N	0	*Pinus banksiana*	49.03	*
3	E	100	*Pinus sylvestris*	45.11	0.451
4	N	500	*Pinus strobus*	24.57	0.049
5	N	200	*Pinus resinosa*	15.66	0.078
6	R	1000	*Robinia pseudoacacia*	13.73	0.014
7	R	0	*Quercus alba*	11.28	*
8	E	400	*Populus alba*	9.30	0.023
9	E	100	*Picea abies*	8.83	0.088
10	R	100	*Prunus serotina*	6.77	0.068
11	N	0	*Quercus ellipsoidalis*	5.17	*
12	N	0	*Amelanchier* sp.	4.54	*
13	R	100	*Acer rubrum*	2.01	0.020

*These species were not planted.

DISCUSSION

Within the original plantation, the species native to these pine barrens had greater survival rates, radial growth, height, and regeneration rates than all other species. Of 41 hardwood and conifer species originally planted, stems from only seven conifer species survived, with *Pinus resinosa*, *Picea abies*, and *P. strobus* showing the highest survival rates (Appendix I). Site index was 44-45 for the native *Pinus resinosa* and *P. strobus*, 29 for the regionally native *Picea glauca*, and 28 for the nonnative *P. abies*. Relative to the number of individuals originally planted, *P. abies*, *Pinus strobus*, and *Prunus serotina* showed the greatest overall success based on total number of stems (including regeneration), ground coverage, and frequency. However, *P. strobus* had the highest relative density of both saplings and large trees in the plantation.

The old field community adjacent to and south of the plantation was composed of a different set of species than the plantation community. *Pinus sylvestris* and the unplanted natives *P. banksiana* and *Quercus ellipsoidalis* dominated the overstory, while *P. strobus*, *P. banksiana*, and *P. sylvestris* composed most of the advanced regeneration. However, the seedling stratum was composed almost entirely of *Q. rubra*-group. Relative to the number of individuals originally planted in the plantation, *P. sylvestris* was the dominant in the old field based on total number of stems (including regeneration), ground coverage, and frequency.

Survivorship and Growth

Survival, establishment, and growth of the planted seedlings, cuttings, and seeds depended upon a number of factors at the GAES. Most of the largest site preparation treatment (harrowing) was plowed under the year after planting, resulting in the loss of an unknown number of individuals (Anonymous 1913). This area may have been replanted, but no records exist to this effect. Assuming "the same lot" (Beal 1888b) were truly planted in each treatment, then the removal of these individuals should have had no effect on relative survival but would have an effect on the eventual plantation composition by providing preexisting trees (i.e., *Pinus banksiana*, *Quercus* spp.) an opportunity to mature in this area of the plantation. An additional unknown number of seedlings of *Pinus* sp. (presumably *P. strobus*) and *Picea abies* were planted in the south side of the plantation to replace individuals accidentally removed while cultivating (Anonymous 1913), which could have given these species an advantage in numbers. Other human-related factors affecting the plantation include removal of holiday trees by local people and loss of large-diameter *Pinus resinosa* and *P. strobus* due to windthrow in 1977 (Montgomery 1977, K. Gardiner, personal communication).

Site index (SI) is an indicator of the potential productivity for a particular species on that site (Barnes *et al.* 1998). Besides the general problems association with older anamorphic SI curves reviewed by Carmean *et al.* (1989), some curves are not long enough to include stands over 100 years old. Extrapolation, such as for *Picea abies* in this study, is required to derive the SI, but errors are magnified in the process. SI values estimated for *Picea* spp. at GAES were lower than those derived for *P. glauca* (SI 40-47, Alban 1985) on similar soils southwest of Grayling. Higher SI were calculated for *Pinus resinosa* (SI 62-70, Alban 1985) at the same site southwest of Grayling and on sandy soils (SI 62-69, Alban *et al.* 1987) in Minnesota and Wisconsin. In stands on well-drained sands and closer in age to that at GAES, SI values for *P. resinosa* and *P. strobus* were similar (Shetron 1975). Overall, the GAES site is on the low end for potential productivity for these four *Pinaceae*, especially for the species not native to the pine barrens.

Environmental factors play an obvious role in determining the survival, establishment, and growth of trees at the GAES. Of the 41 planted species, many are not adapted to the droughty, infertile, cold conditions. Some individuals probably never established due to high susceptibility to transplant shock, such as *Picea glauca*, which grows better in boreal environments with higher relative soil moisture (Burns and Honkala 1990a). Other species have not naturalized because of the short growing season in northern Michigan, such as *Catalpa speciosa*, *Celtis occidentalis*, *Gleditsia triacanthos*, *Gymnocladus dioica*, and *Juniperus virginiana* (Burns and Honkala 1990b, Voss 1972, 1985, 1996). On the other hand, species such as *Salix* spp., *Fraxinus nigra*, *F. pennsylvanica*, and *Thuja occidentalis* are not drought resistant and thus cannot survive in the excessively drained pine barrens (Barnes and Wagner 1981, Burns and Honkala 1990a, Voss 1996). Some species may not be able to extract nutrients from the low-fertility soils, while others, such as *Pinus sylvestris*, have evolved efficient mechanisms for cation uptake in such soils (Burns and Honkala 1990a). Although allelochemical interactions with these tree species are not recognized in the literature, lichens and plants common at the plantation, such as bracken fern, blueberry, and Cladina lichens, repress growth and reproduction of some *Pinaceae* (Burns and Honkala 1990a, Dolling 1996, Jäderlund *et al.* 1997, Dolling 1999). Once the planted individuals established, herbivores and pathogens could have had deleterious effects on growth and possibly survival of both conifers (e.g., blister rusts, insects) and hardwoods (e.g., white-tailed deer). A multitude of factors, probably involving edaphic and climatic controls, prevented the successful establishment of 37 of the 41 species originally planted at the GAES.

Growth and eventual reproduction of established individuals planted at the GAES were limited by edaphic and climatic conditions. The excessively drained sands are very strongly acid (pH 3.7-4.7) and contain very little (1%) organic matter in the B Horizon (Mokma and Vance 1989). Organic matter had only 110 years to accumulate since the last series of fires ran through the area prior to planting (Kedzie 1888b). Since organic acids are important for chelating aqueous cations like iron and calcium, cation exchange capacity (2.2-4.2 meq/100g) and water holding capacity are very low (Mokma and Vance 1989). In addition, the growing season is short with good chances for frost as late as early June and as early as early September, and most of the precipitation falls outside of the growing season (Werlein 1998). Consequently, growth at the GAES is limited by droughty, infertile sand in a short frostfree growing season.

Biotic controls could have limited the growth of the less competitive individuals planted at the GAES. All individuals were originally planted on four-foot centers (Beal 1888b), thus all had less than one meter of aboveground space to branch horizontally. Those species that invest in height growth (e.g., *Pinus resinosa* or *P. strobus*) or produce dense shade (e.g., *Picea abies*) would have the greatest opportunity to sequester growing space (*sensu* Oliver and Larson 1996). Belowground resource competition could also have limited the growth of some species. *Pinus sylvestris*, for example, when planted with other native pines, is a better belowground resource competitor due to its development of a taproot and ability to sequester nutrients at low concentrations (Burns and Honkala 1990a).

Conversely, facilitation through direct and indirect interactions rather than direct competition for resources could have promoted the establishment and growth of some species (Callaway and Walker 1997). The conceptual model of Holmgren *et al.* (1997) predicts that in xeric habitats, such as the pine barrens, moisture limitation is more important than light limitation. Consequently, as the intensity of abiotic stresses, such as soil moisture limitation, increases, competition should decrease and the importance of facilitatory interactions should increase (Callaway and Walker 1997). Reanalyzing the data of Bertness and Callaway (1994), Callaway and Walker (1997) detected an increase in the nurse plant effect, or sheltering of one species by another, as the abiotic stresses in the environment increased. Furthermore, in a sandy habitat, Kellman and Kading (1992) found increased seedling and sapling densities of *Pinus resinosa* and *P. strobus* under canopies of mature *Quercus rubra* than in open areas. Before the practice was widely used, Beal insightfully planted deciduous species as nurse trees for the conifers at GAES, as he did at other experimental plantations and arboreta (Telewski 1998). While Beal might have expected the nurse trees to provide shade, limit evapotranspirative water loss, and add organic matter to the soil, most of the hardwood seedlings did not survive their first year (Anonymous 1913) and thus did not provide this expected nurse effect. Additionally, fast-growing conifers (e.g., *P. resinosa*, *P. strobus*, and *Picea abies*) could have eliminated shade-intolerant species (e.g., *Pinus sylvestris*) within the plantation, thus opening up areas for less competitive species (e.g., *Picea glauca*, *Juniperus virginiana*, and *Thuja occidentalis*) (*sensu* Connell 1990).

Demography

The composition and structure of the plantation and old field are a function of residual species at time of planting, the tree species and number planted in 1888-1889, stand dynamics, and establishment, growth, and reproduction of all tree species present. However, the initial establishment, or mortality, of Beal's seedlings played the greatest role in determining which species would subsequently mature and reproduce within the plantation. Following seedling establishment, though, moisture limitation can be a selective force in community succession (Livingston 1905, Holmgren *et al.* 1997), but shade tolerance appears to be more influential in shaping this community (*sensu* Kobe *et al.* 1995).

The intermediate shade-tolerant *Pinus strobus* contributes more to the plantation community in terms of mature trees, advanced regeneration, and seedlings, which can tolerate up to 80% shade (Burns and Honkala 1990a), than any other species planted here. Although seedlings of the shade-intolerant *Quercus rubra*-group are now very common, saplings and adults are not common. While most of the *Q. rubra*-group seedlings are probably a result of a recent mast year, some may be sprouts from older root stock that had previously produced unsuccessful shoots (Beal 1888a, Burns and Honkala 1990b). Although *Pinus resinosa*, another native shade-intolerant species, has slow-growing seedlings (Burns and Honkala 1990a), successful advanced regeneration was present in the plantation. *Picea abies*, an exotic shade-tolerant conifer, produced abundant seedlings and advanced regeneration within the plantation (Appendix II).

Although *Pinus banksiana* was initially present and *P. sylvestris* was planted, these conifers contributed less to the plantation community than the aforementioned conifers. The seeds for both of these species require bare mineral soil for germination and both species are very shade intolerant (Burns and Honkala 1990a). By the time these trees were sexually mature, the previously bare mineral soil likely was covered by deciduous and conifer leaf litter, and the canopy was beginning to close due to the other taller, more shade-tolerant conifers. Consequently, any regeneration by *P. sylvestris* and *P. banksiana* within the plantation was excluded due to lack of germination sites, except in areas of unsuccessful *P. strobus*, *P. resinosa*, or *Picea abies* establishment (e.g., harrow treatment).

The shaded understory of the plantation provided an opportunity for regeneration of shade-tolerant *Pinus strobus* and deciduous trees. A few individuals of *Amelanchier* sp., a slow-growing, shade-tolerant shrub native to the pine barrens (Barnes and Wagner 1981), established and now contributes an abundant number of seedlings to the plantation floor. *Prunus* spp. seedlings are very common in the understory, as is the intermediately shade-tolerant *Quercus alba* (Barnes and Wagner 1981). These species are characteristic of hardwood forests that have evolved from fire-suppressed pine forests (Whitney 1986).

The old agricultural field presents an artifact of the species originally present at the site combined with the invasive nature of two conifer species. *Pinus banksiana*, the namesake for the jack pine barrens, was predominant in this physiographic landtype, with

Quercus rubra-group also common (Whitaker 1986, 1987). Both species are adapted to relatively short crown fire return times (80 yr, Whitney 1986)[2] through mechanisms such as cone serotiny in *P. banksiana* and stump sprouting in *Quercus* spp. Although no severe fires have occurred since 1888, this area had been used for growing cereal grains and pasture crops (Kedzie 1888b). The fallow land was colonized by those shade-intolerant species best adapted to growing in soil after a land-clearing disturbance: *P. banksiana*, *Q. rubra*-group, and *P. sylvestris*. *Q. rubra*-group seedlings were the most common (91%) seedling in the old field, but this was probably due to a recent mast year. Under the plantation's heterogeneous canopy cover, *P. banksiana* and *P. sylvestris* were able to survive and regenerate in the gaps and thus producing a noncontiguous seed source, while *P. strobus* produced a steady supply of seed throughout the plantation edge that could germinate in the old field. The relatively flat size class distribution for *P. banksiana* and *P. resinosa* and strongly sloped distribution for *P. strobus* in the old field suggest that suitable sites for regeneration of the shade intolerant pines are limiting and that the shade tolerant *P. strobus* will increase in abundance in the old field.

Oliver and Larson's (1996) stand development model for single-cohort mixed-species stands best explains some of the dynamics observed in both the plantation and old agricultural field. In this four-step model, a relatively even-aged cohort of trees is established (i.e., planted) following a large disturbance. Following establishment, growing space decreases such that competition for space resources increases. Those species with a competitive size advantage (e.g., *Pinus strobus*) or growth pattern (e.g.,

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[2] Less severe ground fires in presettlement had a shorter return time (20-40 yr, Heinselman 1981; 25 yr, Whitney 1986) in the jack pine forests of the Great Lakes region.

Picea abies) can usurp growing space and reduce the growth rate sufficiently to stunt or kill less competitive species (e.g., *Picea glauca*). In addition, other species not present at the stand initiation stage are also excluded from successfully establishing in the stand. As the overstory grows and begins producing its own regeneration, new shade-tolerant species (e.g., *Amelanchier* spp. and *Acer rubrum*) are able to colonize and establish in the understory. Only those species adapted to low light levels are able to survive in the understory of the densely planted stand, until gaps form in the overstory due to localized disturbances, such as windthrow or damage, insect defoliation and mortality, and senescence. Gap formation sets back the stages of stand development and may allow less shade-tolerant but faster growing species (e.g., *P. sylvestris*) to attain canopy (Kobe *et al.* 1995). The old growth stage is reached once the overstory trees begin dying in an irregular spatial pattern. Although neither area appears to have reached the old growth stage, a diverse understory of new shade-tolerant species and overstory regeneration has developed in the plantation. The old field, however, contains an overstory and understory of predominately shade-intolerant species (e.g., *P. banksiana, P. sylvestris*, *Q. rubra*-group), suggesting that the old field is still in the stem exclusion stage. Although the shade-tolerant *Pinus strobus* is dispersing from the plantation into the old field, this species is also quite light-tolerant and often acts as both a pioneer and long-lived successional species (Burns and Honkala 1990a).

In essence, the dynamics of this planted forest community, as a function of survival, growth, and reproduction of different species in an initially uniform environment, are largely regulated by interspecific physiological differences.

Traditionally shade-tolerant species maximize survival and net growth by maintaining a slow rate of growth, lower rates of whole-plant respiration, lower tissue turnover, and increased whole-plant carbohydrate storage (Walters and Reich 1999). As a consequence, these species are able to survive for long periods of time in the shaded understory to eventually attain canopy status. Conversely, shade-intolerant species possess a high rate of growth at low and high light levels but have short leaf lifespans, high respiration rates, and high nutrient turnover rates (Gower *et al.* 1993, Walters and Reich 1999), especially since nutrients can be difficult to sequester in this low fertility soil. Similarly, regeneration is affected by this interaction of light and moisture availability. These interspecific morphological and functional trade-offs provide the interplay for community succession.

Invasive Potential of Nonnative Species

Nonnative species that perform as well or better than the locally adapted native species could become invasive in a particular ecosystem (Sax and Brown 2000). Based on the measures used in this study, two exotic *Pinaceae* may be classified as invasive species in this pine barrens ecosystem. Although rigorous criteria to designate species as invasive are not available, the accepted criterion for an invasive *Pinus* is that the species regenerates naturally and recruits seedlings in natural or semi-natural vegetation at least 100 m from the parent plants (Richardson *et al.* 1994). Beyond the 40 m width of the old agricultural field at GAES, the area surrounding the plantation has been impacted by industrial development and unknown land use practices, thus the 100 m criterion cannot be used here. However, the potential for spread of nonnative species can be assessed within the limits of this study.

Within the forest cover of the plantation, the exotic *Picea abies* may be considered an invasive species commensurate in performance with the native *Pinus strobus*. While planted *Picea abies* did not exhibit growth as great as *Pinus strobus*, the exotic species occupied an equitable amount of space relative to the native pine (Table 2-4). Regeneration within the plantation was not particularly high (Figure 2-4), but *Picea abies* effectively blocks light needed by other species for regeneration and can regenerate asexually by layering (Burns and Honkala 1990a) as observed at GAES. *Picea abies* was the second most successful planted species in the old agricultural field (Table 2-5), indicating that it has the ability to spread into unoccupied habitat. *Picea abies* could compete effectively with the native *Pinaceae*, especially *Pinus strobus* and *P. resinosa*, in this ecosystem.

The exotic *Pinus sylvestris* was highly successful in spreading from the main plantation to the old agricultural field. This species was over five times as successful compared to any other planted species in the old field; only *Pinus banksiana* and *Quercus rubra*-group, preexisting non-planted species, had greater importance values (Table 2-5). Within the plantation, *Pinus sylvestris* was not common under closed canopy conditions but was common in areas with canopy gaps (personal observation). Thirty years after planting, *P. sylvestris* was considered to have surpassed all of the other species in growth and was the only species with regeneration by seed (Roth 1919). *P. sylvestris* is able to germinate in low nutrient conditions, acquire nutrients at low concentrations, grow in high light conditions, and produce copious seed at an early age (Burns and Honkala 1990a), making it a potentially successful invader of jack pine barrens.

The interest in potentially invasive pines increases as the structure and functioning of native ecosystems, especially shrublands and grasslands, are altered (Richardson and Higgins 1998). Although no phylogenetic relationship between invasive pines is known (Price 1998), the strongest correlates to invasiveness include small seed mass, short juvenile period, and a short interval between large seed crops (Rejmánek and Richardson 1996). However, the interaction of these life history traits and the environment in which invasive species colonize determines the eventual community composition. If growth to the seedling stage as a function of the environment were guaranteed, then survivorship and regeneration should be a better measure of the potential for a species to colonize a site. There is a need for predictive models for which pine species are invasive in different locations (Richardson and Higgins 1998). Given the results of this study, potentially invasive species should not be used for reforestation, and existing populations should be controlled to prevent their spread.

Future Composition of the Plantation and Old Field

Barring major disturbances, such as fire, logging, and windthrow, the plantation and old field at the GAES are expected to evolve similar to other fire-suppressed forests in the pine barren system (Radeloff *et al.* 1999). As the less shade-tolerant species are excluded by the more shade-tolerant species, *Pinus strobus* and *Picea abies*, which are already dominant species in the overstory and understory, are likely to become more important in the plantation, but, through gap dynamics and senescence, a hardwood-dominated community characterized by *Quercus* spp. and *Acer rubrum* may develop (Curtis 1971, Radeloff *et al.* 1999). Although delayed, the old agricultural field will likely undergo a similar succession, especially since overstory disturbance is absent there as well. Since the GAES is enclosed by development on three sides and is now annexed to the Hartwick Pines State Park, return to a natural disturbance regime that would maintain the species typical of this pine barren ecosystem is not expected.

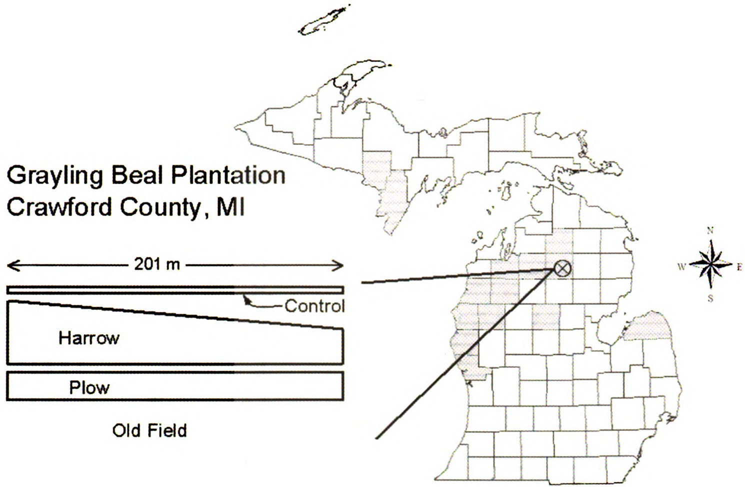


Figure 2-1. Location and detail of the former Grayling Agricultural Experiment Station in Crawford County, Michigan. Seedlings and cuttings were planted in west-east rows within each soil preparation treatment (plow, harrow, control). Counties in Michigan predominated by sandy pine barrens are shaded (Cohen 1996, Comer 1996). Base map courtesy of L. Zheng.

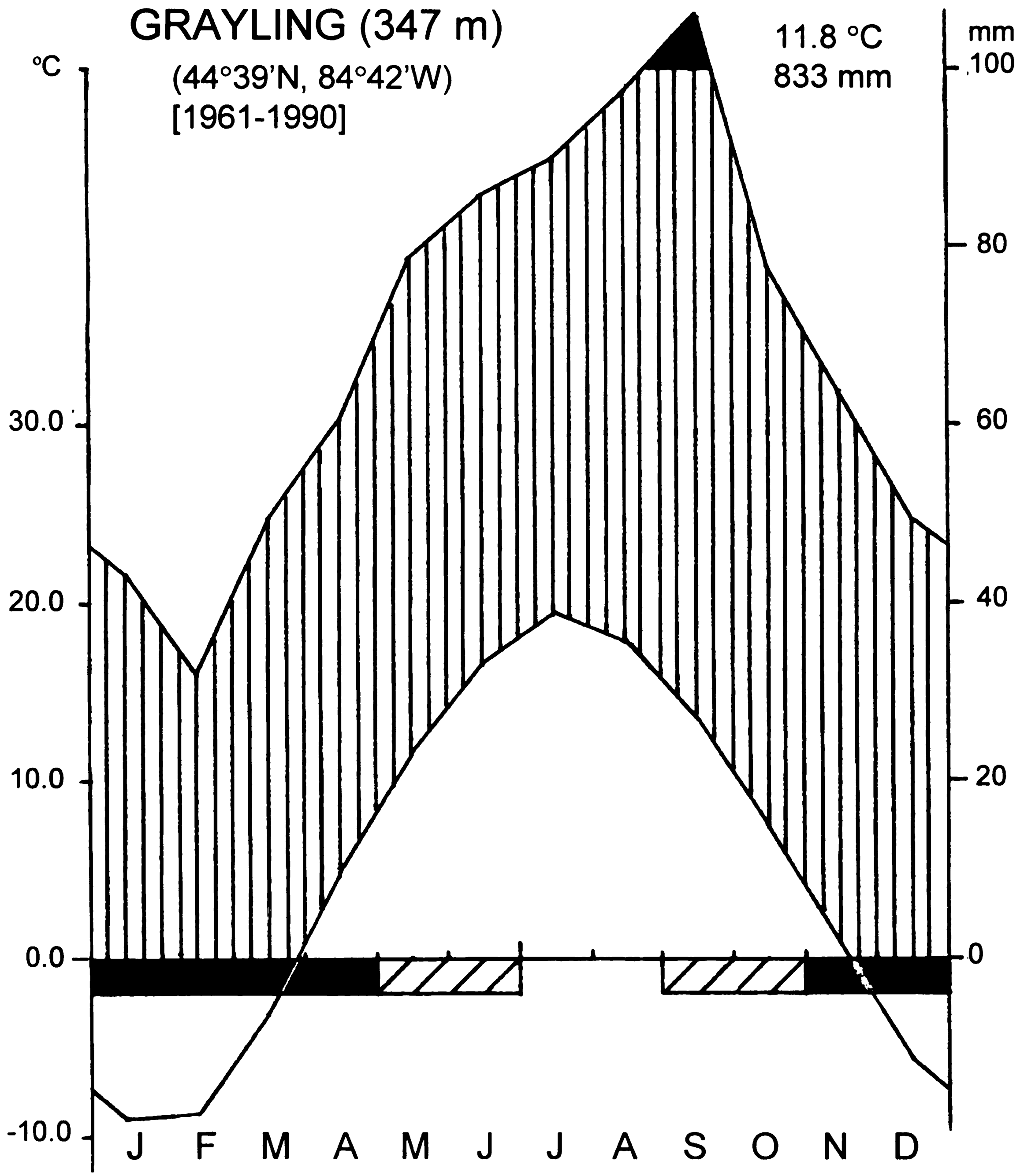
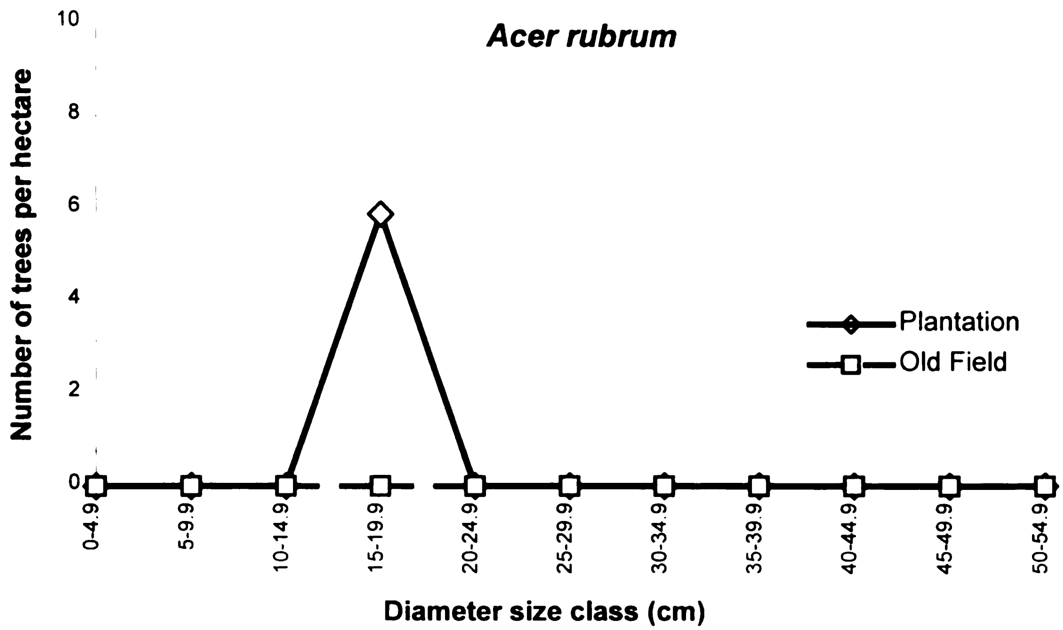


Figure 2-2. Climate diagram (*sensu* Walter and Leith 1967) based on 1961-1990 data from the Grayling, Michigan, Station (COOP ID 203391), National Climatic Data Center. Mean annual temperature is 11.8C, and mean annual precipitation is 833 mm. The top line refers to average monthly precipitation (mm), and the bottom line refers to average monthly temperatures (°C), The solid bars along the horizontal axis refer to months with freezing conditions, and hatched bars refer to months with chance of frost (Weirlein 1998).



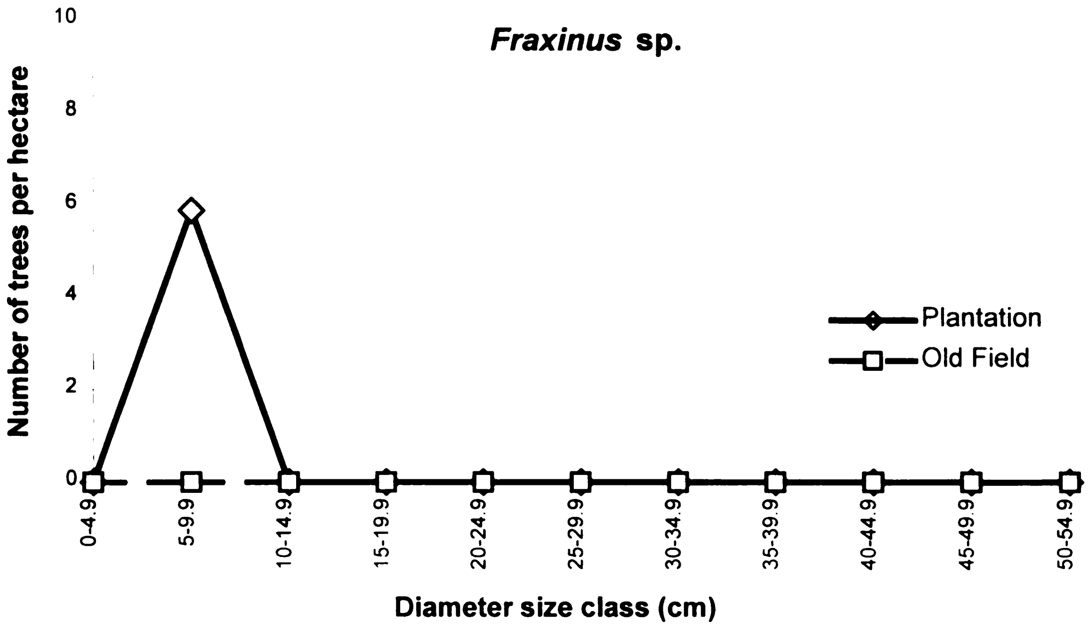
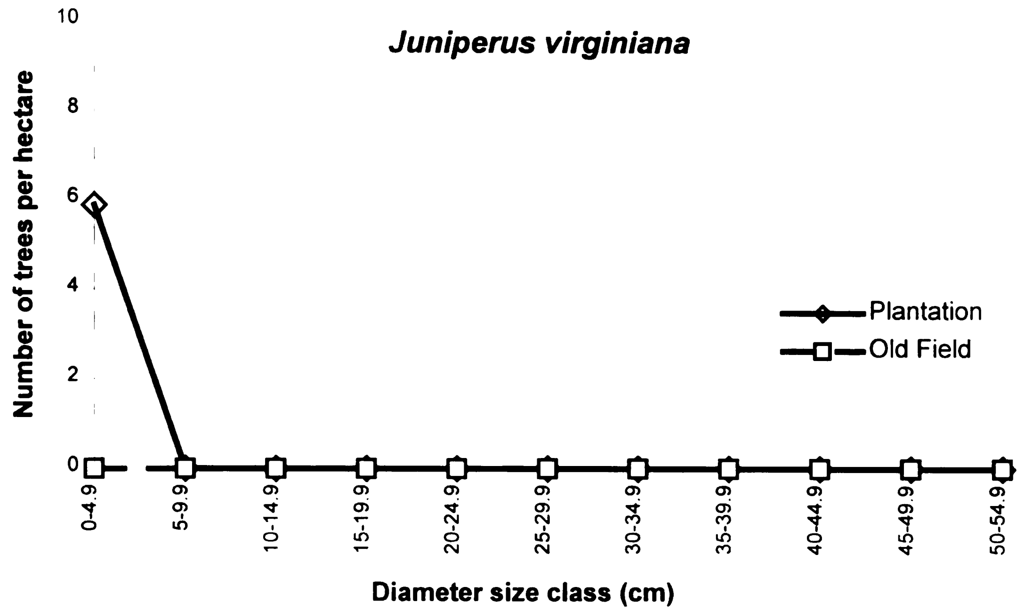


Figure 2-3. Number of stems (>1.37 m tall, per hectare) for each shrub and tree species surveyed in the plantation (solid line) and old field (dashed line) at the Grayling Agricultural Experiment Station, Crawford County, MI. Numbers were converted to per hectare to standardize for the different area sampled in the plantation and old field. The values on the *y*-axis differ by species.



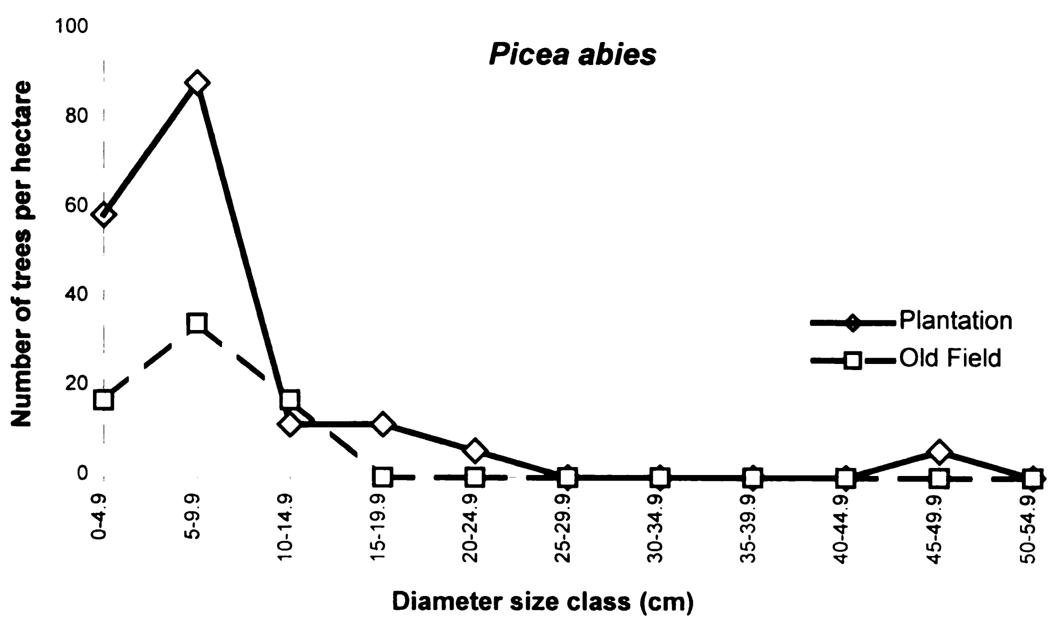
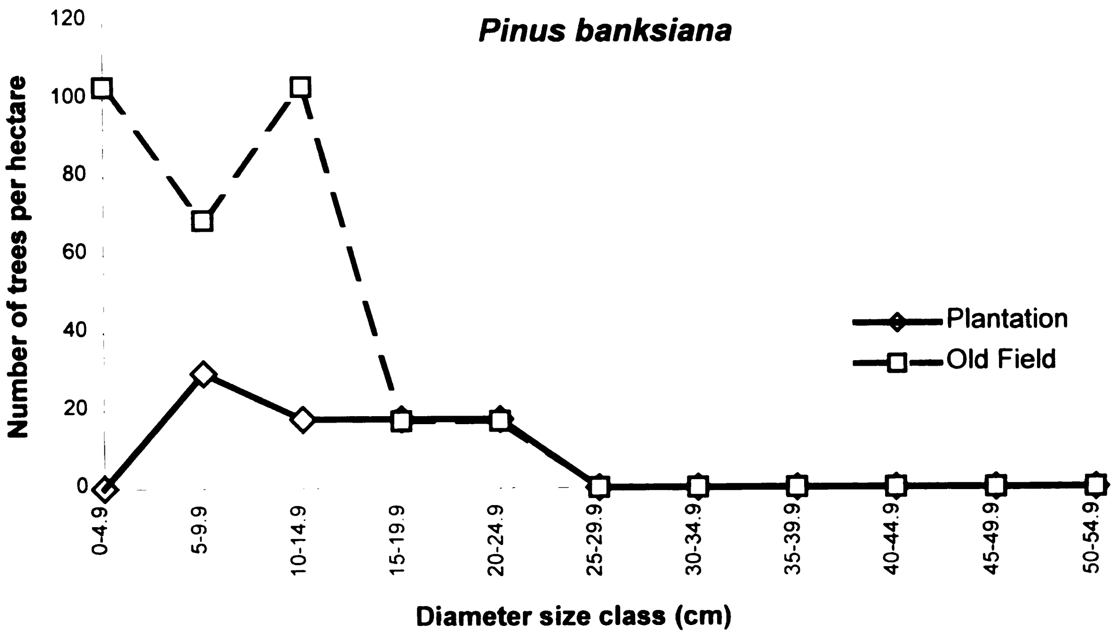
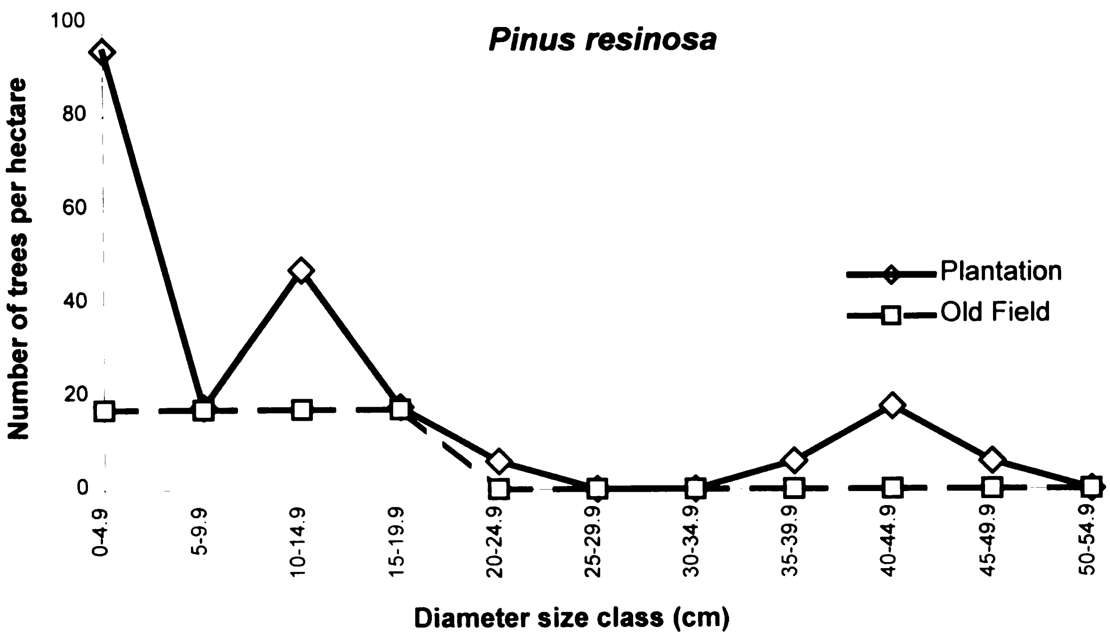


Figure 2-3 (cont'd).





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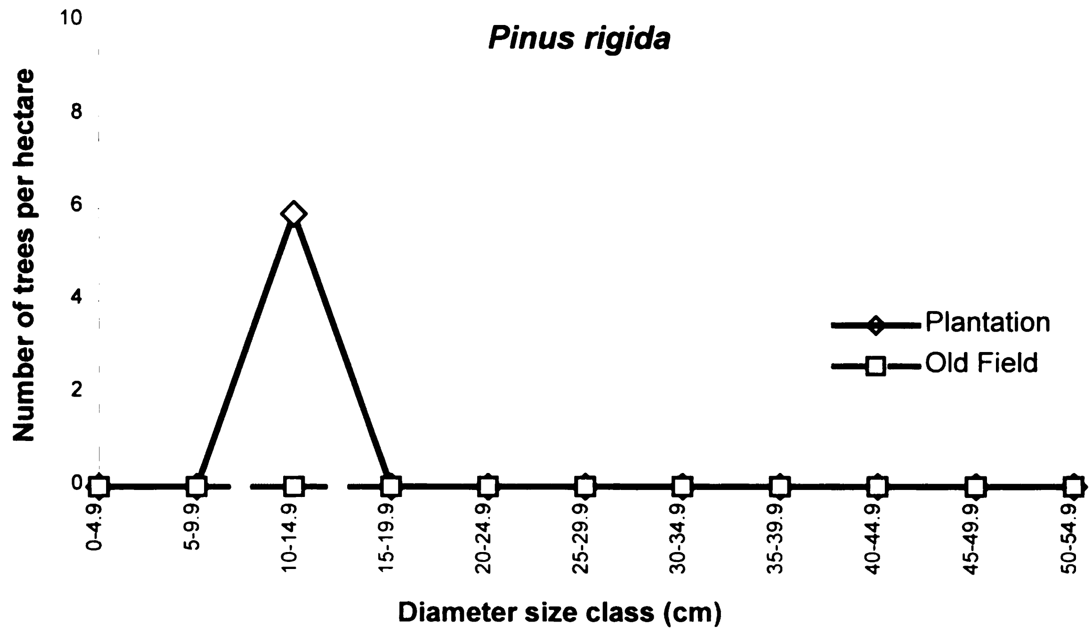


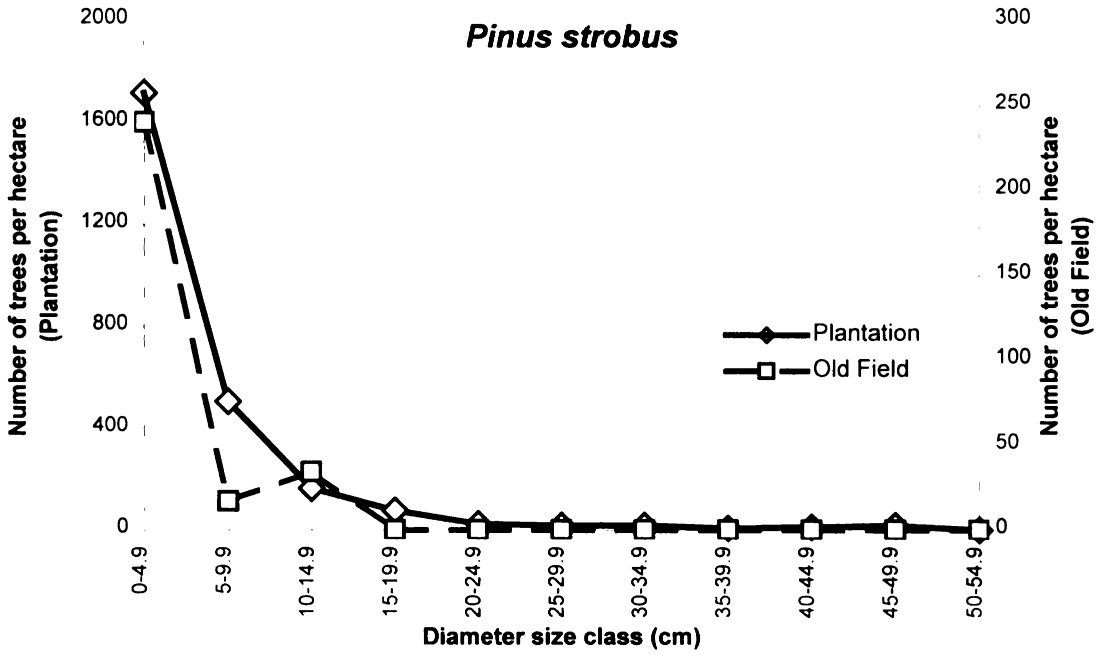
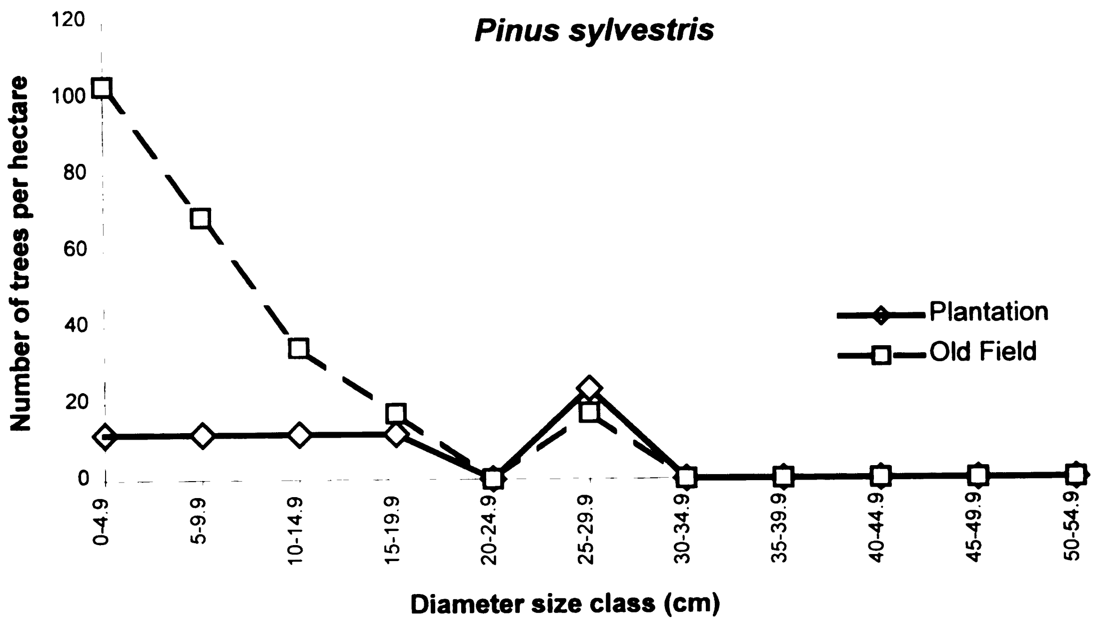
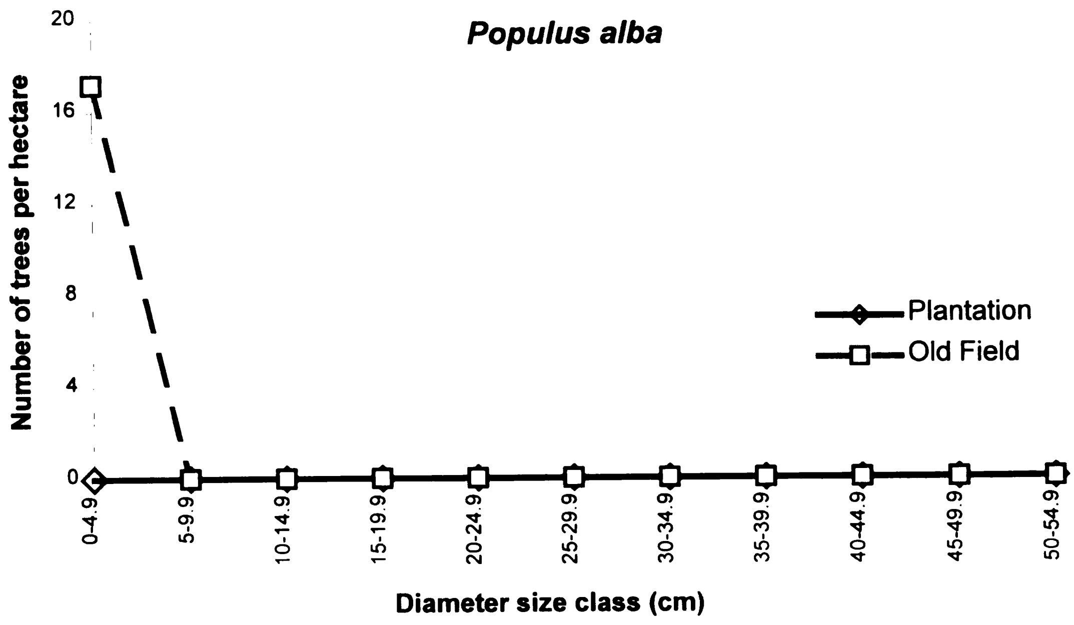


Figure 2-3 (cont'd). Note the second *y*-axis for *Pinus strobus* in the old field.





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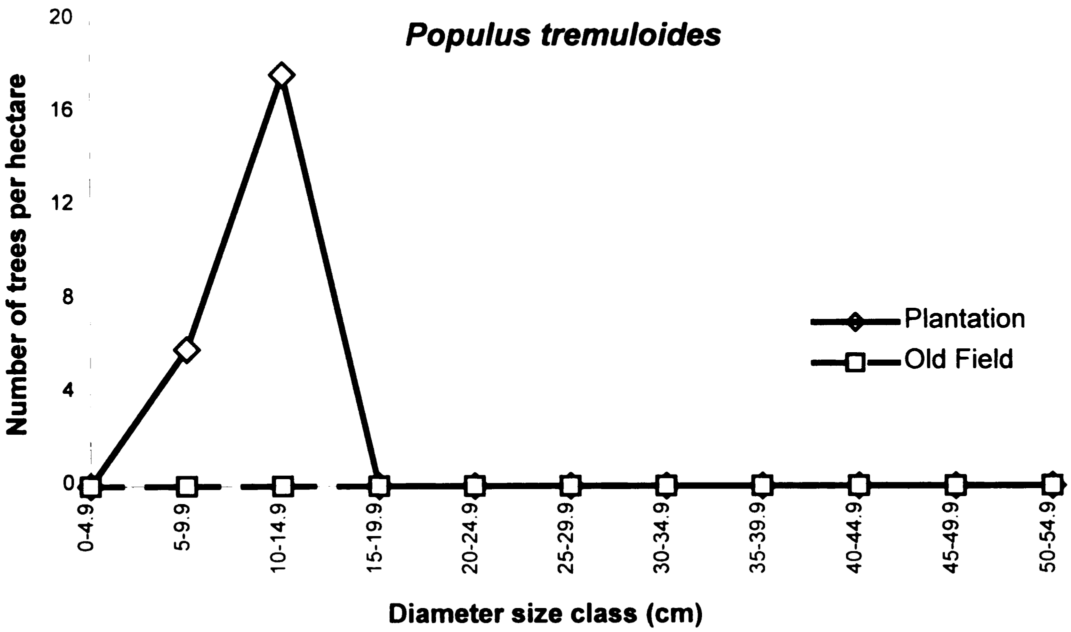

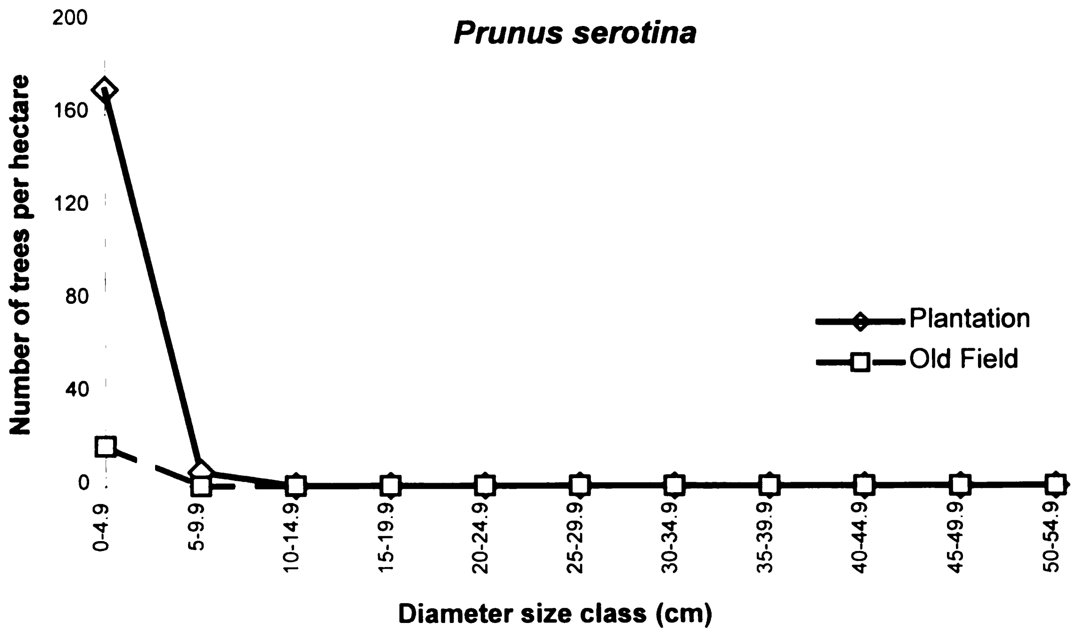

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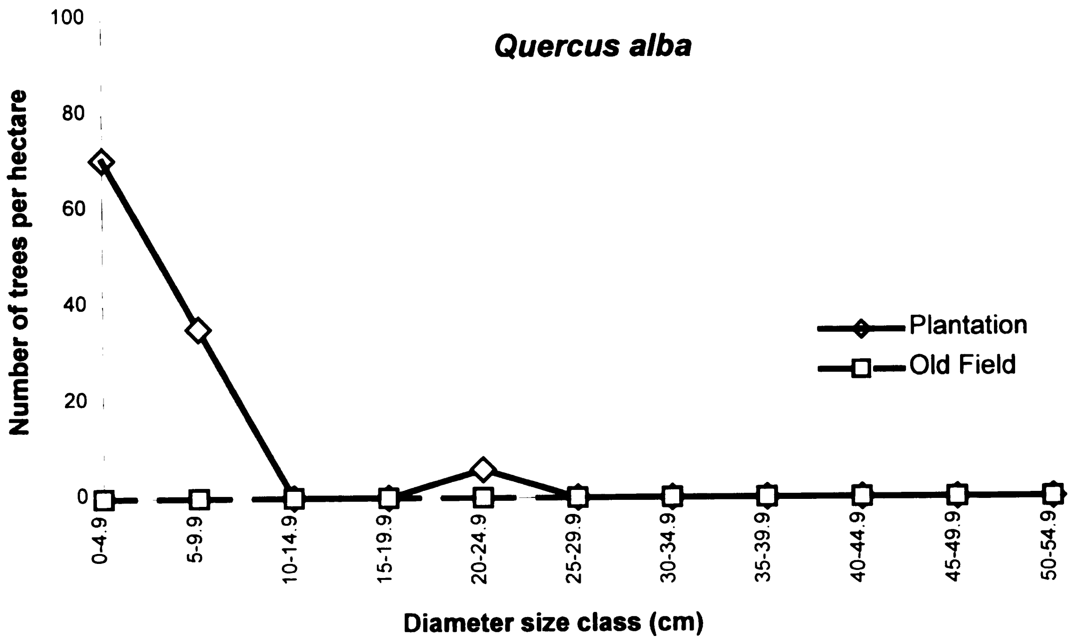


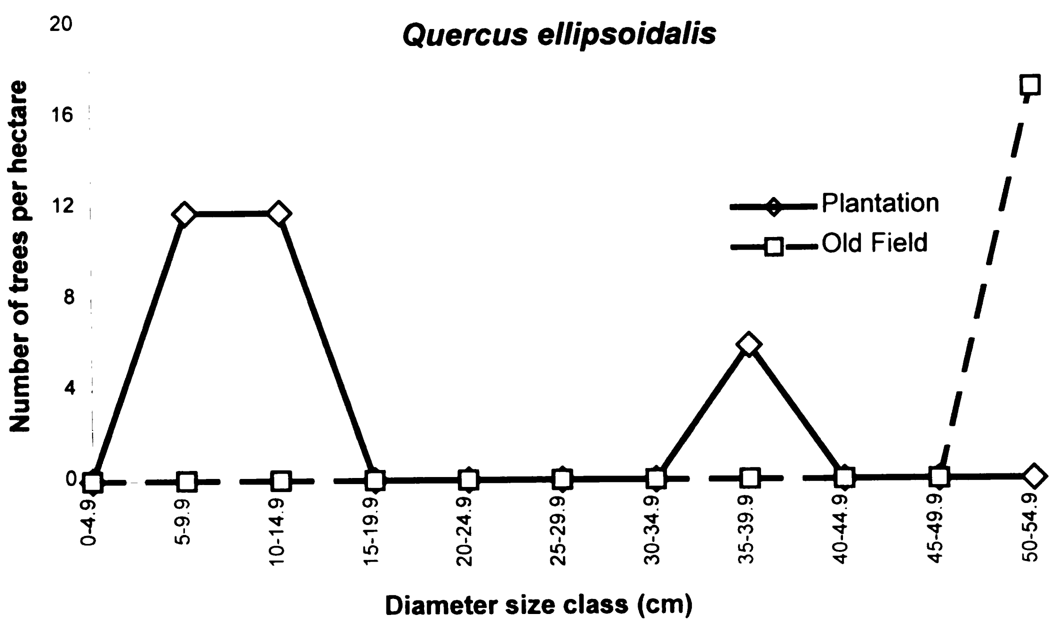
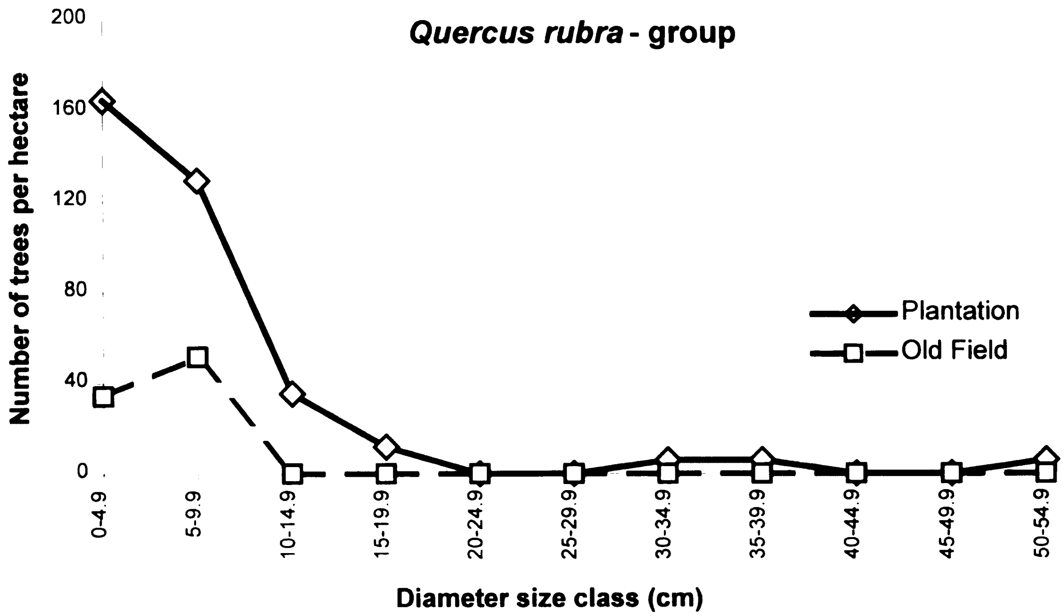


Figure 2-3 (cont'd).



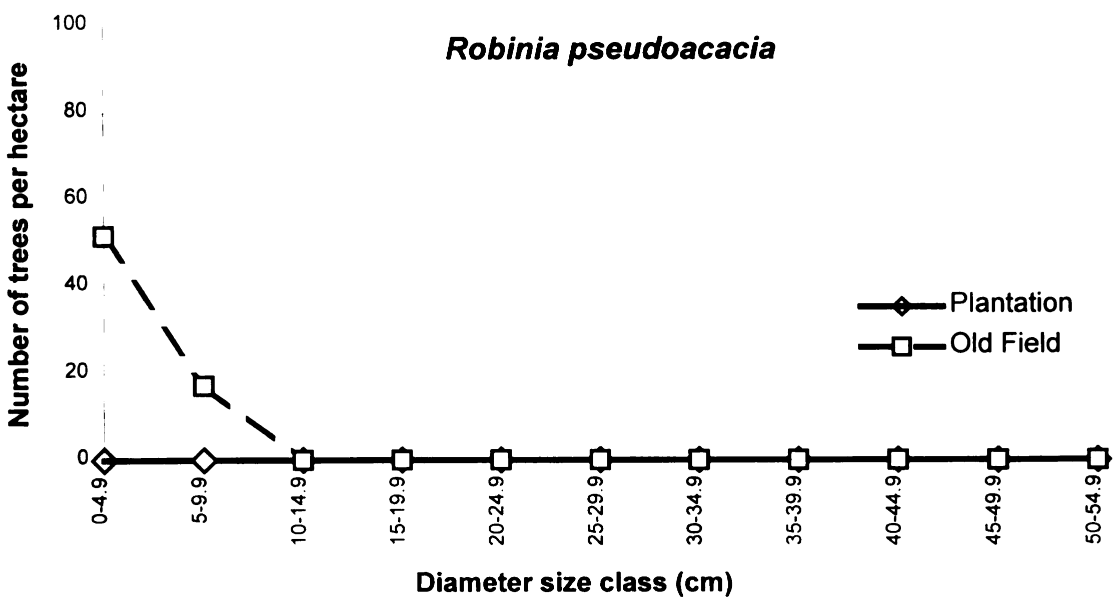


Figure 2-3 (cont'd).

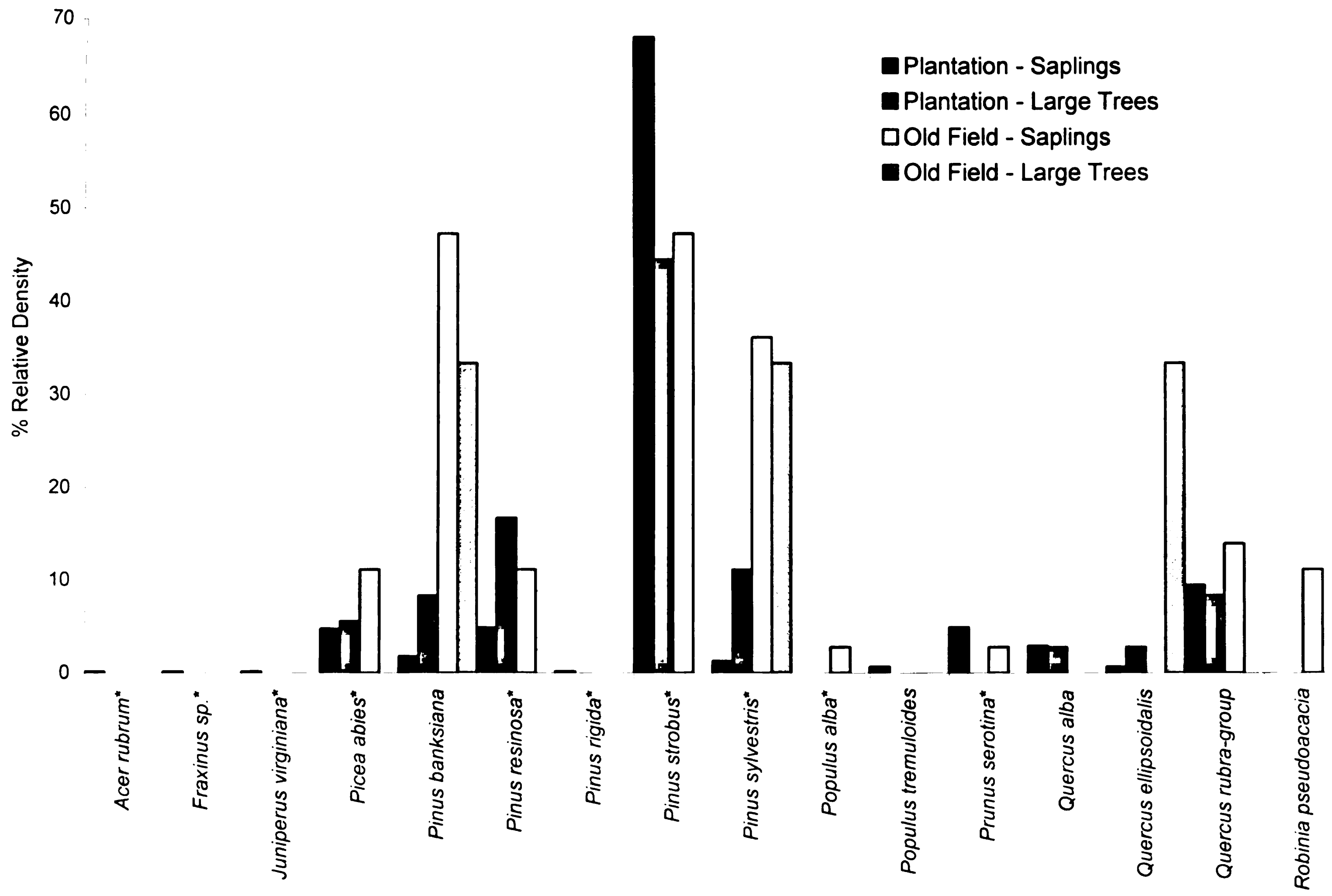


Figure 2-4. Relative density of saplings (0-20 cm dbh) and large trees (>20 cm dbh) by species in the original Grayling Agricultural Experiment Station plantation and old agricultural field south of the plantation, Crawford County, MI. The asterisk indicates that the species was originally planted in the plantation in 1888.

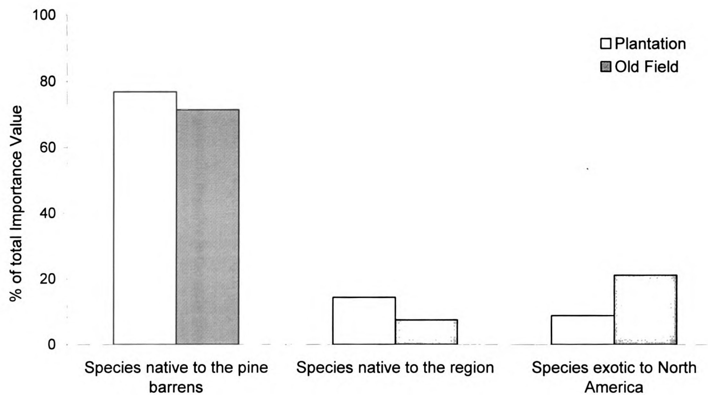


Figure 2-5. Distribution of Importance Values (IV) among woody species in the plantation and old agricultural field at the former Grayling Agricultural Experiment Station, Crawford County, MI. Determination of species status (i.e., native versus exotic) made from Voss (1972, 1985, 1996).

CHAPTER 3

COMPARISON OF CLIMATE-GROWTH RELATIONSHIPS FOR *PINACEAE* IN THE PINE BARRENS OF NORTHERN MICHIGAN

ABSTRACT

Mean chronologies were constructed for living *Picea abies* (L.) Karst., *Pinus resinosa* Ait., *P. strobus* L., and *P. sylvestris* L. at an historical mixed-species plantation and from an existing raw ring-width data set for old-growth *P. resinosa* in the pine barrens of northern lower Michigan. All ring-width series were standardized by fitting a negative exponential or negative linear regression, and mean chronologies were constructed as biweight robust means of the autoregressively modeled indices. Chronologies ranged from 85 to 202 years in length. Correlation function analysis of the ARSTAN chronologies to 15-month precipitation and temperature data showed all species exhibiting positive responses to April temperatures. Responses to variations in precipitation were generally negative in the early growing season but varied strongly by species and location. The native pines were more complacent to variations in precipitation but exhibited similar responses to variations in temperature as compared to the responses of the nonnative *P. sylvestris*. The nonnative *Picea abies* responded more to variations in temperature from the previous growing season and in a different pattern to precipitation than all other species. Continuing work with *Pinus sylvestris* and the

native pines may elucidate physiological mechanisms that explain patterns of successful colonization of this nonnative species in the pine barrens.

OBJECTIVES

The objective of this chapter is to determine the climatic limiting factors to secondary growth in surviving trees at the Grayling Beal Plantation in order to elucidate causes for differences in relative survival and growth in this pine barren ecosystem. The raw and standardized tree-ring data from this chapter will be contributed to the International Tree-Ring Data Bank for use by investigators interested in dendroecological relationships in the Great Lakes region.

INTRODUCTION

Climate is an important factor defining the geographic range for a plant species (reviewed by Woodward 1987). While many species can survive within the normal range of climatic variation in a region, extreme events (Cook *et al.* 1987), such as early and late season frosts, extreme winter temperatures, and droughts, affect growth and success in regeneration and therefore restrict the long-term species pool (Woodward 1987). Dendrochronology is a useful procedure for identifying the climatic limiting factors to growth for a tree species (Fritts 1966, 1976, La Marche 1978, Fritts and Swetnam 1989) and in turn provides a measure for assessing the suitability of that species to its particular environment. I propose the use of dendrochronological techniques to assess the suitability of native and nonnative *Pinaceae* to growth in the pine barrens of northern Michigan.

The pine barrens of the Midwest were formed upon the thick deposits of glacial outwash, largely composed of coarse soils, laid down about 12000 years ago during the Pleistocene glaciation (Whitney 1986, Weirlein 1998). This region is now covered by at least second-growth upland pine forests and barrens growing on sandy soils interspersed with bogs and poor conifer swamps bordering former meltwater channels. The pine forests are dominated by *Pinus strobus* and *P. resinosa*, while the barrens are dominated by *P. banksiana* with scattered *P. resinosa* (Curtis 1971, Whitney 1986, 1987, Comer 1996). In addition to these native pines, the nonnative *P. sylvestris* has been planted in the pine barrens for timber and Christmas tree production (Wright *et al.* 1976, Burns and Honkala 1990a), while the nonnative *Picea abies* was historically planted in this region but is no longer planted in the pine barrens. The sandy soils of the barrens contain low nutrients, organic matter, and water holding capacity (Mokma and Vance 1989). Due to the droughty, infertile soil and cold continental climate in the region (Whitney 1986), trees growing in the pine barrens may be particularly sensitive to variations in climate and may express climatic limitations to their geographic spread. The only dendroclimatic study on the pine barrens of the Midwest reported that *P. resinosa* was sensitive to April and June-July temperatures and June precipitation (Koop 1985).

The purpose of this study is to develop correlation functions from the climatic signal in the high-frequency variation of radial growth in native and nonnative *Pinaceae* in pine barrens. In general, I predicted that radial growth for all species would be limited by cool early and late growing season temperatures and dry summers. However, the native species should be more adapted to their local environment and thus would be more complacent to variations in climate as compared to the nonnative species, assuming their native range has a more favorable climate than here. Two stands of *Pinaceae* located in the pine barrens of northern lower Michigan were studied to address these predictions.

METHODS

Study site

This study took place on the Grayling Outwash Plain (Albert 1994), Crawford County, Michigan (44°N, 84°W; Figure 3-1). Two study sites were selected based on the availability of tree species and existing tree-ring data. The Grayling Beal Plantation (GBP) site is located southeast of the town of Grayling and contains a 5-acre (2.0 ha) plantation of native and nonnative tree species. Seedlings, cuttings, and seed (*Pinus rigida* Mill. only) from 41 species were planted in 4-foot-centered rows in 1888-1889. Prior to planting, the site had experienced frequent fires leaving mostly *P. banksiana* and scattered *P. resinosa*, scrubby *Quercus* spp., and dwarf *Prunus* spp. (Kedzie 1888), but no record or evidence of fire exists at this site since planting. The mapped soil is a coarse, loose, strongly acidic, and excessively drained sand of the Grayling series (Typic, Frigid Udipsamment) (Mokma and Vance 1989, Werlein 1998). Although the depth to the water table was not measured in this study, Weirlein (1998) notes the water table to be > 6 ft (1.83 m) in this soil type, while a soil scientist at the Natural Resources Conservation Service stated the water table to be 2-3 m from the surface (M. Kroell, personal communication). Government Land Office Survey records show that pre-European settlement forests on this soil type were largely composed of *Pinus banksiana* (Whitney 1986).

The Hartwick Pines State Park (HRP) site is located just north of Grayling and contains a 40-acre (16.2 ha) remnant stand of old-growth *P. resinosa* and *P. strobus* (Koop 1985). This stand was bypassed during Michigan's logging era of the late 19th century due to the depressed logging markets and the relatively small size of the stand (Koop 1985). Consequently, trees several hundred years old remain on this site. The stand is located along a ridge with 10-15 m relief (Koop 1985) and on soils mapped as a strongly acidic, excessively well-drained sand to loamy sand of the Kalkaska-Blue Lake Association (Typic Frigid Lamellic Haplorthod) (Koop 1985, Werlein 1998). Although Koop (1985) did not measure the depth to the water table, Weirlein (1998) notes the water table to be > 6 ft (1.83 m) in this soil type. Pre-European settlement forests on this soil type and topography were dominated by *P. resinosa* (Whitney 1986).

The local climate is characterized as humid continental (Whitney 1986). The mean annual precipitation (1951-1980) is 811 mm with 62% of the precipitation falling during April-September (Figure 3-2). The mean annual temperature is 6.3° C with a mean summer temperature of 18.6° C and a frostfree growing season of 110 days

(Weirlein 1998). The growing season is generally cool and short with only 2068 growing degree days (Weirlein 1998).

Sample Collection and Data Analysis

Large diameter *Picea abies*, *Pinus resinosa*, *P. strobus*, and *P. sylvestris* at the GBP site were cored perpendicular to the stem lean to avoid reaction wood with 5.15 mm diameter increment borers (Haglof and Suunto) in 1998-2000. One full diameter core or two cores were obtained at approximately 0.3 m from the ground to obtain as many growth-rings as possible. Increment cores were prepared, cross-dated, and measured to 0.01 mm using standard dendrochronological techniques (Stokes and Smiley 1967). Ring-width measurements within each time series were computer analyzed to detect anomalies (COFECHA Version 6.06P, Holmes 2000). Tree-ring data for *P. resinosa* from the HRP site were obtained from the International Tree-Ring Data Bank (ITRDB, Koop and Grissino-Mayer 1988). Methods used to obtain cores, measure ring-widths, and check for quality control followed Stokes and Smiley (1967) and are fully described in Koop (1985). Mean raw ring-width was compared across species using the conservative Tukey HSD Multiple Comparison procedure (Systat Version 9.01, SPSS Science Inc. 1998).

All series of raw data were converted to mean chronologies for climate response analysis using the same program settings to ensure consistent comparisons among species and sites. Each series was detrended with a single pass high-frequency filter, i.e., a negative exponential or negative linear regression was fit to the series (ARSTAN Version 6.04P, Holmes 2000). This conservative technique removes exogenous variation and the age-related growth trend but retains the climatically induced high-frequency variation (Fritts 1976, Cook et al. 1990a). Three types of mean chronologies can be constructed from the detrended series: STANDARD, RESID, and ARSTAN (ARSTAN Version 6.04P, Holmes 2000). The STANDARD chronology is the biweight robust mean of the detrended series. While the use of a biweight robust mean enhances the common signal and minimizes the influence of outlier index values, which could be a result of endogenous disturbance events that are random in space and time (Cook *et al.* 1990b), the STANDARD chronology retains some autocorrelation in successive index values (i.e., autoregression) (Cook and Holmes 1997). The RESID chronology contains the biweight robust mean of the normalized residuals (>3 standard deviations) from univariate autoregressive modeling and results in a strong common signal without persistence (Cook and Holmes 1997). The ARSTAN chronology combines the pooled autoregression model from multivariate regression modeling with the residual chronology to produce a chronology expressing the greatest sensitivity to climatic variations (Cook and Holmes 1997). Since the objective of this study was to determine climatic responses, the ARSTAN chronology was developed (Appendix IV). Similar temporal response patterns among the ARSTAN chronologies constructed for each species were compared by simple correlation analysis (Pearson correlation, Bonferroni probability, Systat Version 9.01, SPSS Science Inc. 1998).

The relative importance of monthly precipitation and monthly mean temperature in influencing tree-ring growth for each species and site was determined by correlation and response function analysis (RESPO Version 6.06P, Holmes 2000). Correlation functions are the correlation coefficients between the predictors and predictands, while the response function is a result of a multivariate regression analysis on a set of principal components (PCs) calculated from climatic variables (Fritts 1976). PCs enter the stepwise regression if the cumulative multiple of eigenvalue is greater than one, thus the number of PCs retained varies by chronology (RESPO Version 6.06P, Holmes 2000). Although response function analysis has been shown to be highly effective at showing relationships between climate and growth (Fritts and Wu 1986), the response function can be more difficult to replicate and interpret (Blasing *et al.* 1984). However, providing the statistical constraints used in the analysis and making the tree-ring data available (e.g., ITRDB) allows other researchers to make comparative studies. In this study, the predictand was each ARSTAN chronology, and the predictors were15 sequential months (previous July through current September) of total precipitation and mean temperature variables for the period 1931-1988 for HRP and for the period 1931-1998 for GBP (National Climatic Data Center 2001, Appendix V).

RESULTS

Site master chronologies (Figure 3-3) were constructed for four species based on the standardized ring-width data summarized in Table 3-1. The GBP site yielded four master chronologies ranging from 85-105 years in length, and the HRP site yielded a single 202-year master chronology. Based on a signal strength threshold of 0.85 (Briffa and Jones 1990), *Pinus sylvestris* was the only species that would have required additional samples to fully replicate the chronologies from a subsample. The mean ring-widths for the native pines at GBP were larger than for the nonnative *Pinaceae*, while the old-growth *P. resinosa* at HRP had a significantly smaller mean ring-width. The signal-to-noise ratio (SNR), a measure of variance common within detrended series (Graumlich 1993), varied by species but was more a reflection of sample size (Briffa and Jones 1990). The mean sensitivity was highest for *Picea abies* followed by *Pinus strobus*, while *P. resinosa* and *P. sylvestris* expressed less but similar amount of high-frequency variance. Graumlich (1993) found similar mean sensitivity in *P. strobus* and slightly higher mean sensitivity in *P. resinosa*. The amount of low-frequency variance as expressed by the standard deviation of the chronology was highest for *P. resinosa* at GBP. This chronology also retained the largest first-order autocorrelation coefficient, suggesting that some low-frequency variance remains in the standardized chronology. Since these conifers retain needles, a higher first-order autocorrelation is expected (Graumlich 1993). However, the chronology for *Picea abies* retained little low-frequency variance even at the first-order for autocorrelation. Although the correlations between ARSTAN chronologies were generally more significant within the genus *Pinus* than to *Picea abies*, the *Pinus strobus* chronology was significantly ($p<0.001$) correlated to the *Picea abies* chronology (Table 3-2).

The response functions of mean monthly temperature and monthly precipitation explained 28-52% of the variation in the ARSTAN chronologies examined in this study (Figures 3-4 through 8). A greater number of significant responses to variations in temperature and precipitation were indicated by the correlation functions than by response functions, consistent with Fritts (1976). However, caution must be given regarding the interpretation of the direction of correlation coefficients or weights, in the case of response functions, since either a wider or narrower ring could be associated with an abnormally high or low climate parameter. In addition, the more conservative and interpretable correlation functions, rather than response functions, are considered in this study (Blasing *et al.* 1984).

Table 3-1. Dendrochronological characteristics for the raw ring-width data and ARSTAN (ARS) mean chronology for each of the *Pinaceae* at Grayling Beal Plantation (GBP) and Hartwick Pines State Park (HRP). Mean ring-width values with different letters across species are significantly different (Tukey HSD, $p<0.01$). Signal-to-noise ratio (SNR) based on detrended series. Minimum sample size based on a signal strength (SS) threshold of 0.85 (Briffa and Jones 1990). All values calculated by ARSTAN (Holmes 2000).

Characteristics	GBP *Picea abies*	GBP *Pinus resinosa*	GBP *Pinus strobus*	GBP *Pinus sylvestris*	HRP *Pinus resinosa*
No. trees	11	22	10	10	28
No. cores	25	82	21	20	52
Total years	105	101	105	85	202
Mean ring-width (mm)	1.788b	2.177a	2.167ab	1.896ab	1.136c
SNR (detrended)	3.697	9.818	5.949	1.131	8.452
Mean index (ARS)	1.0063	1.0446	0.9863	0.9603	0.9845
Mean sensitivity (ARS)	0.2569	0.1330	0.1810	0.1349	0.1462
Std. deviation (ARS)	0.2511	0.3646	0.2232	0.2389	0.2045
Skewness (ARS)	-0.3041	2.1610	-0.2052	0.4611	0.1966
Kurtosis (ARS)	0.7971	6.8889	0.2696	0.9911	0.1009
Partial Autocorrelation (ARS)					
1st order	0.1318	0.8021	0.5049	0.7399	0.6307
2nd order	-0.0623	-0.0304	-0.0121	-0.1707	-0.0300
3rd order	-0.1197	-0.0765	-0.1053	0.0443	0.0142
Min sample size (no. trees)	10	13	6	38	10

Table 3-2. Pearson correlation coefficients (r) and significance (Bonferroni probability) between the ARSTAN master chronologies developed for each species at Grayling Beal Plantation (GBP) and Hartwick Pines State Park (HRP). All values calculated by Systat Version 9.01 (SPSS Science Inc. 1998).

	GBP *Picea abies*	GBP *Pinus resinosa*	GBP *Pinus strobus*	GBP *Pinus sylvestris*	HRP *Pinus resinosa*
GBP - *Picea abies*	1.000				
GBP - *Pinus resinosa*	0.234	1.000			
GBP - *Pinus strobus*	0.408***	0.594****	1.000		
GBP - *Pinus sylvestris*	0.313	0.583****	0.429***	1.000	
HRP - *Pinus resinosa*	0.162	0.447****	0.335*	0.458****	1.000

*$p<0.05$, **$p<0.01$, ***$p<0.001$, ****$p<0.0001$

Significant responses by the nonnative *Picea abies* were limited to a positive correlation (r=0.28) to December temperatures of the previous growing season (Figure 3-4). The other nonnative, *Pinus sylvestris*, responded positively to April temperatures (r=0.31) and September precipitation (r=0.25) and negatively to April (r=-0.30) and previous January precipitation (r=-0.34) (Figure 3-7). Similarly, the native *P. strobus* (Figure 3-6) and *P. resinosa* (Figure 3-5) at GBP exhibited positive associations with April temperatures (r=0.26, 0.24, respectively) but expressed no other significant response to variations in temperature or precipitation. *P. resinosa* at HRP responded negatively to July temperatures (r=-0.30) and precipitation in August (r=-0.29) and the previous September (r=-0.32) (Figure 3-8). Since the HRP chronology ended at 1988, the *P. resinosa* chronology at GBP was reanalyzed for the common period (1931-1987); I observed no difference in significant correlations from the full period (1931-1998). A *post-hoc* correlation analysis of March-April mean monthly snowfall and maximum snow depth (National Climatic Data Center 2001) to the STANDARD chronologies yielded no significant ($p<0.05$) correlations.

DISCUSSION

This study examined the high frequency radial growth response of four species of *Pinaceae* to monthly variations in mean temperature and total precipitation on the pine barrens of northern lower Michigan. All of the species demonstrated sensitivity to climatic variations but to somewhat different signals and extents. The response functions from monthly temperature and precipitation explained 28-52% of the total variation in annual radial growth. The most common growth response was to abnormally high April temperatures, a correlation also observed by Koop (1985) and Graumlich (1993), who worked with *Pinus resinosa* and *P. strobus* in the upper Great Lakes region, suggesting that warmer early growing season temperatures may increase radial growth. No species showed significant correlations to variations in late growing season temperatures. In general, abnormally high precipitation during the growing season correlated to greater radial growth in all chronologies but *P. resinosa* at HRP.

The *Pinaceae* native to less xeric environments appear to be less adapted to short-term fluctuations in the climate regime of the region, which is not expected to influence the responses as much as the species-to-species variation (Graumlich 1993). Mean sensitivity, an indication of the degree to which radial growth varies from year to year (Fritts 1976), was largest for *Picea abies* and *Pinus strobus* (Table 3-1), species that prefer more mesic soil conditions than the other *Pinaceae* growing at GBP (Whitney 1986, Schweingruber 1993, MacDonald *et al.* 1998). Allocation to secondary radial growth appears to be more sensitive to available resources, or photosynthates, in the short-term for these two species. Since radial growth is affected by climate (Fritts 1976), greater mean sensitivity gives an indication of the strength of dependence on a limiting factor(s) having high-frequency variance, presumably climate. In addition, the chronologies for *Picea abies* and *Pinus strobus* exhibit lower first-order autocorrelation coefficients than the other species (Table 3-1), indicating lower persistence in growth in subsequent years (Graumlich 1993).

While the chronologies for *Pinus strobus* (Figure 3-6) and *P. resinosa* (Figure 3-5) responded similarly to climatic variables, the *Picea abies* chronology (Figure 3-4) expressed more significantly negative responses to temperature in the previous growing season than any other chronology. Physiologically, an abnormally warm, dry Fall could result in an excess of root and stem respiration over gross photosynthesis, thereby reducing carbohydrate stores available for Spring growth (Fritts 1976). Alternatively, a abnormally cool, wet Fall could reduce water stress and thus allow for continued cambial growth later in the season than during normal years. In either case, radial growth in *P. abies* is more sensitive to variations in climate, especially in the previous growing season (Mäkinen *et al.* 2001), than the native *Pinaceae* considered here. Although species living at the edge of their range express the greatest sensitivity to limiting factors like climate (Fritts 1976), the geographic range for *P. abies* includes much colder to more mesic environments (Schweingruber 1993) than Grayling. However, the physical features (e.g., short needles and fastigiate shape) of the *P. abies* at GBP resemble the more northern races of the species (F. Telewski, personal communication).

Despite a low mean sensitivity, the nonnative *Pinus sylvestris* responded more to variations in precipitation (Figure 3-7) than any other species considered here. Increased radial growth was associated with higher late season precipitation, suggesting that *P. sylvestris* has a longer phenology of cambial activity than the other *Pinaceae* thereby increasing production of photosynthates at the end of the growing season in these years more efficiently than the other species. Furthermore, although all species at GBP expressed a negative association of radial growth with January and March/April precipitation, these correlations are significant only for *P. sylvestris*. Abnormally high snowfall in January may maintain low soil temperatures through early Spring (Thomsen 2001), thus delaying bud break, leaf expansion, and cambial induction and reducing radial growth for the year. The negative April relationship may be better explained by less influx of solar radiation due to clouded skies than by water availability (Fritts 1976); unfortunately, these climate data are not available. Although the small sample size and low SNR for this species necessitates concern over the interpretation of these results, the broad ecological distribution (Burns and Honkala 1990a) of *P. sylvestris* and its potential ability to take advantage of local climate conditions supports the notion that *P. sylvestris* is a successful pioneer species (Gutierrez 1989).

The ARSTAN master chronologies for *Pinus resinosa* at GBP and HRP were significantly ($p<0.0001$) correlated (Table 3-2), but their growth responses to variations in monthly precipitation and mean temperature were different. Both chronologies had similar mean sensitivities (Table 3-1) and indicated positive correlations to April temperatures, but the trees at HRP expressed negative correlations to July temperatures and precipitation in August and the previous September (Figure 3-5,8). Using a different version of the HRP chronology (RESID versus ARSTAN) with only the current year's climatic parameters, Koop (1985) also found significant correlations to June-July ($p<0.005$) and April ($p<0.05$) temperature but found a slightly positive correlation to June precipitation ($p>0.05$). The difference in Summer precipitation responses could be most attributable to the use of a different number of climatic parameters in the analysis. Furthermore, while GBP is a relatively even-aged closed canopy forest on level ground, the crowns of the uneven-aged trees at HRP are more exposed to solar radiation and wind, and the roots are presumably further from the soil water since they grow along a ridge (Koop 1985). Consequently, these trees may suffer greater water stress through evaporative water loss and have less access to soil water than those trees at GBP. In addition, the pines at HRP are larger, thus have a greater overall respiratory demand, and older, thus are less physiologically robust (Kozlowski 1971). A differential response to variation in temperature and precipitation would thus be expected across the two sites.

In general, the correlation and response function models showed that radial growth appears to be more limited by climate before and at the beginning of the growing season. The models explained 28-52% of the variation observed in the standardized radial growth data. Some of the unexplained variation could be due to the low waterholding capacity of the excessively drained soil. If all rain and melted snow drains through the soil before roots are able to absorb the water, then the trees could be contantly drought stresssed and may show greater sensitivity to fluctuations at a higher amount of precipitation. Since the plantation was planted within a small, homogeneous plot, some of the unexplained variation should be attributed to genetic differences between individuals and within-stand (endogenous) disturbances rather than climate alone. Given the mixed-species planting, the branching architecture and foliage density of neighboring trees could increase the variation in radial growth observed between trees of the same species in the plantation. Wind stress is an endogenous disturbance that removes photosynthate sources and sinks of individual and neighboring trees, dehydrates foliage, and induces differential cambial development (Telewski 1995). Trees at the edge of the plantation suffer greater acute and chronic wind stress. Furthermore, gaps in the canopy created by windfall, such as after the windstorm of 1977 (Montgomery 1977, K. Gardiner, personal communication), released some trees from competition for light, soil moisture, and nutrients, thus increasing overall variation in photosynthetic activity and cambial growth within a species. However, these trees also endured greater wind sway as a result of the disruption of the canopy boundary layer (Telewski 1995). Subsequent establishment of regeneration in the gaps would eventually moderate any initial release from competition for subcanopy resources. Finally, although evidence was not observed here, acute defoliation (Fritts and Swetnam 1989) and chronic pathogenesis could affect photosynthate production and subsequent radial growth leading to intraspecific variation. Nevertheless, the linear models derived in this study explain a substantial percentage of the high-frequency variation in radial growth for trees in the Midwestern United States (Fritts 1976).

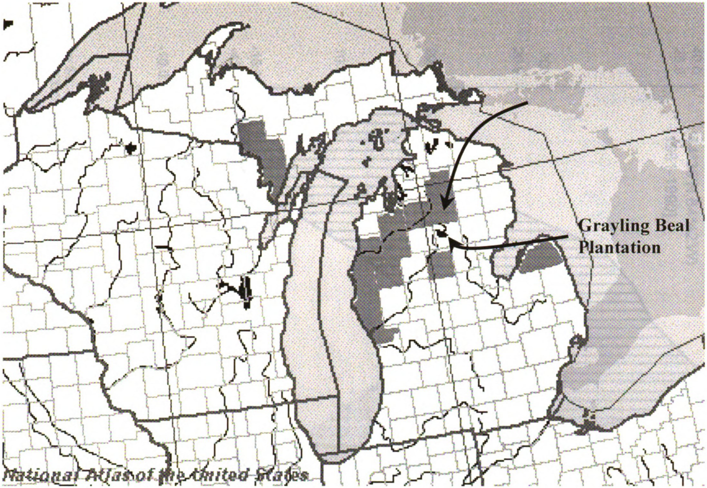


Figure 3-1. Great Lakes regional map showing the location of the Grayling Beal Plantation and Hartwick Pines State Park in Crawford County, Michigan. Counties in Michigan predominated by sandy pine barrens prior to European settlement are shaded (Cohen 1996, Comer 1996). Base map source: United States Department of the Interior, National Atlas of the United States, http://nationalatlas.gov/natlas/natlasstart.asp.

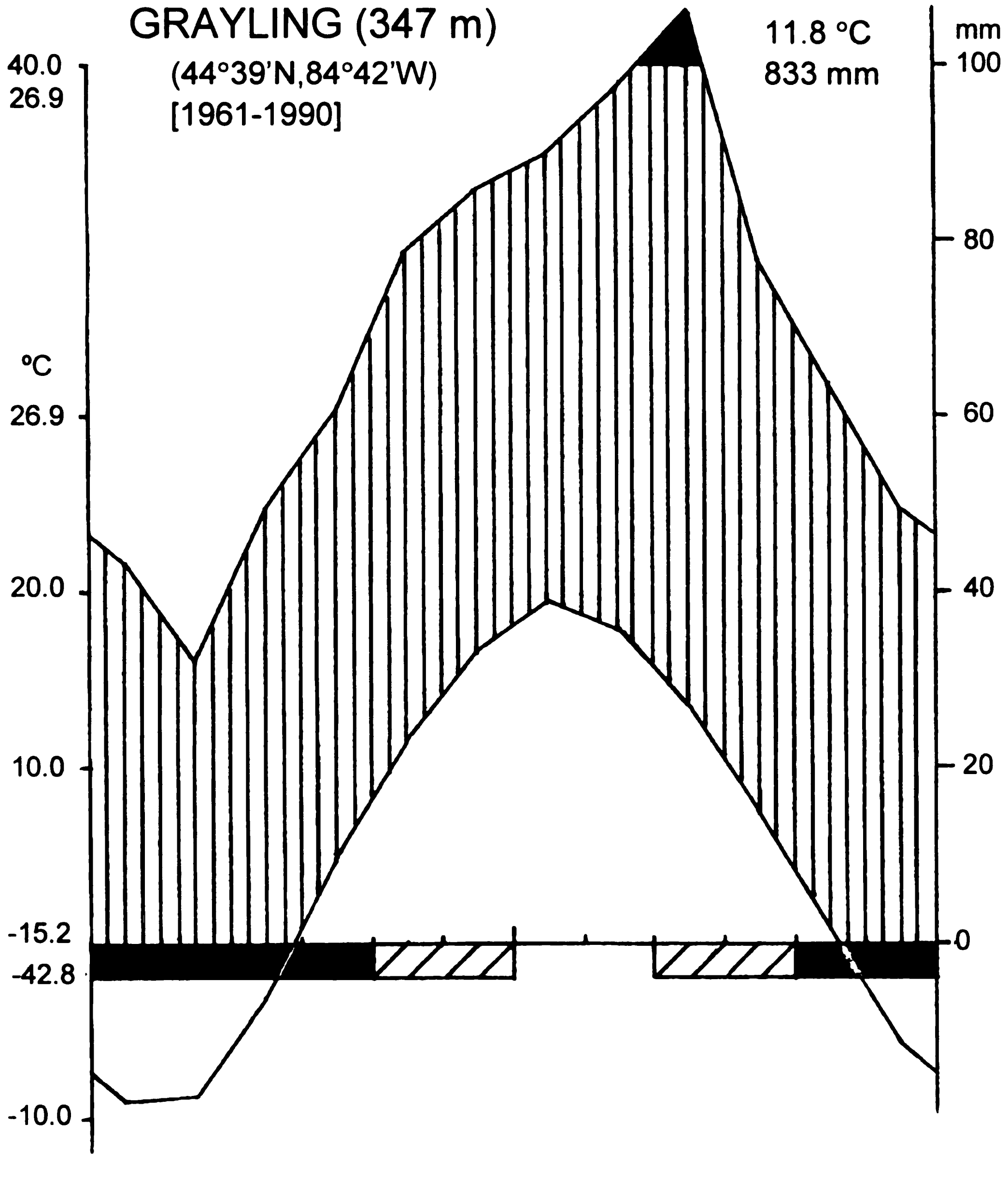


Figure 3-2. Climate diagram (*sensu* Walter and Leith 1967) based on data from the Grayling, Michigan, Station (COOP ID 203391), National Climatic Data Center. The top line refers to average monthly precipitation (mm), the bottom line refers to average monthly temperatures (°C), solid bars refer to months with freezing conditions, and hatched bars refer to months with chance of frost for the period 1961-1990.

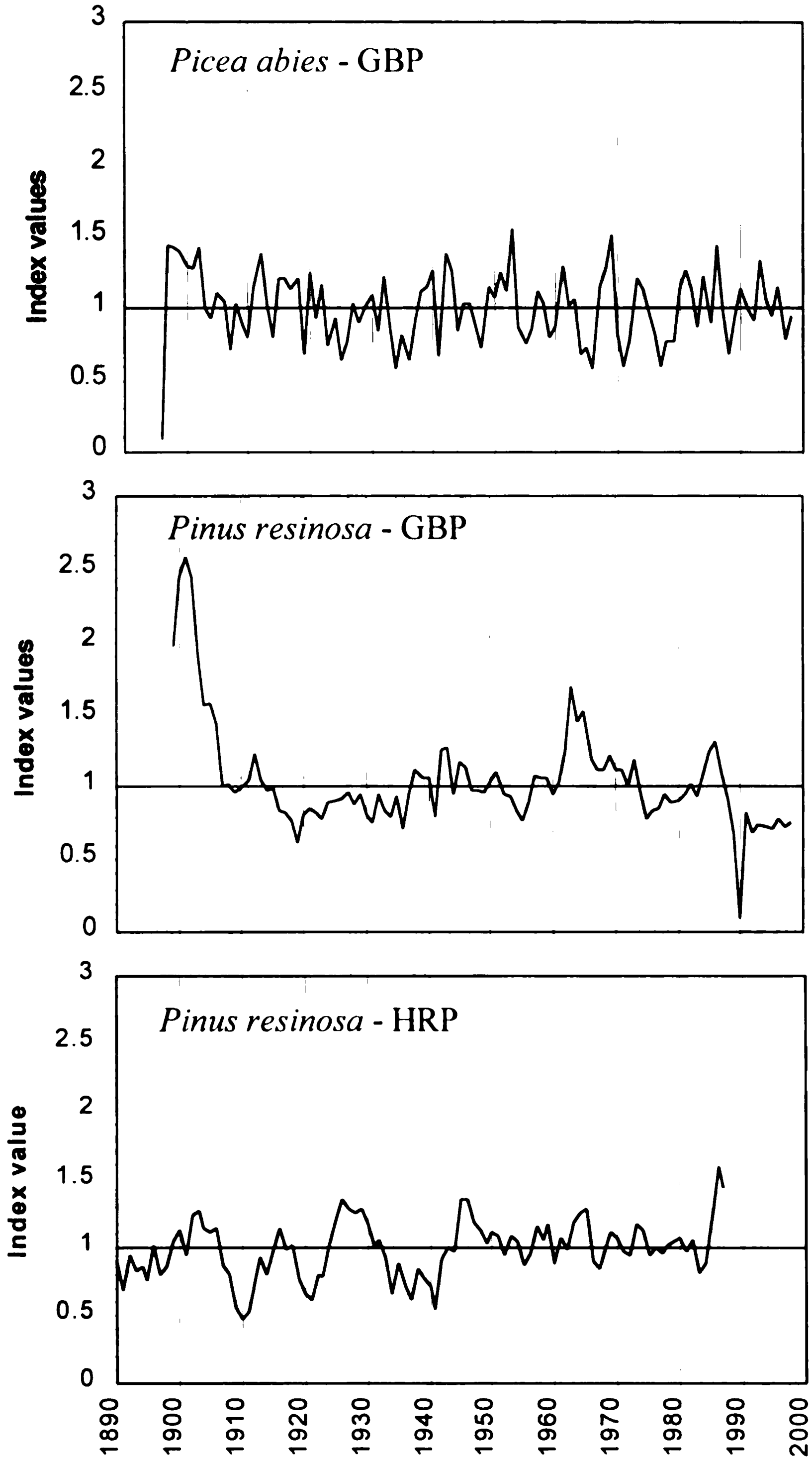


Figure 3-3. ARSTAN ring-width chronologies constructed for conifers at the Grayling Beal Plantation (GBP) and Hartwick Pines State Park (HRP).

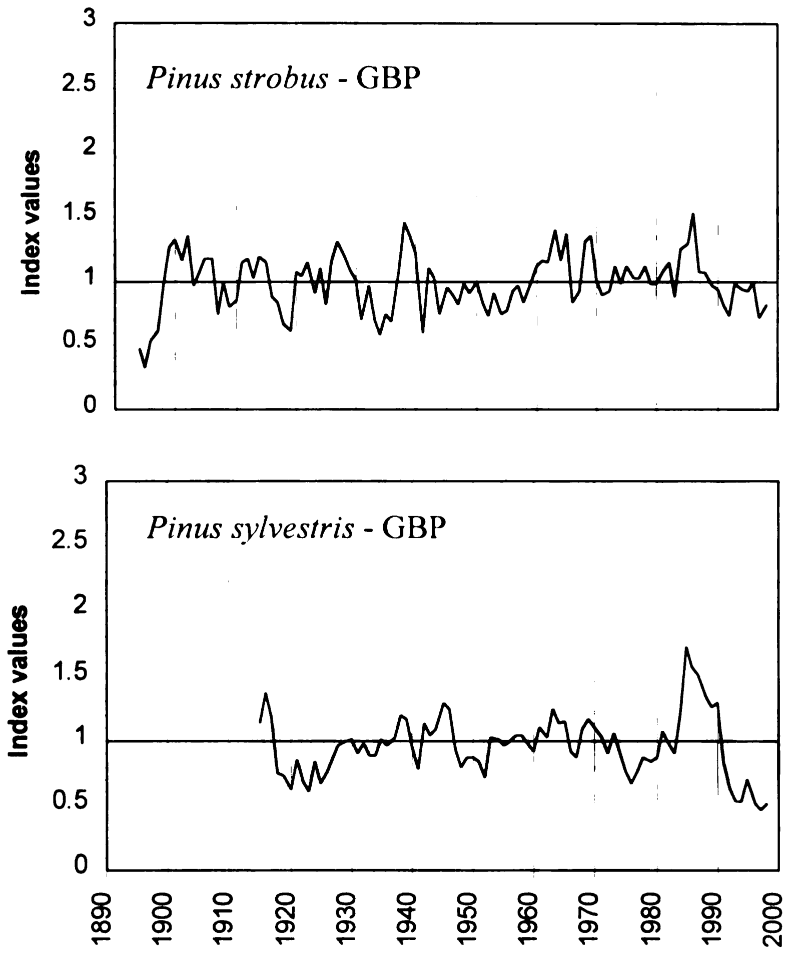
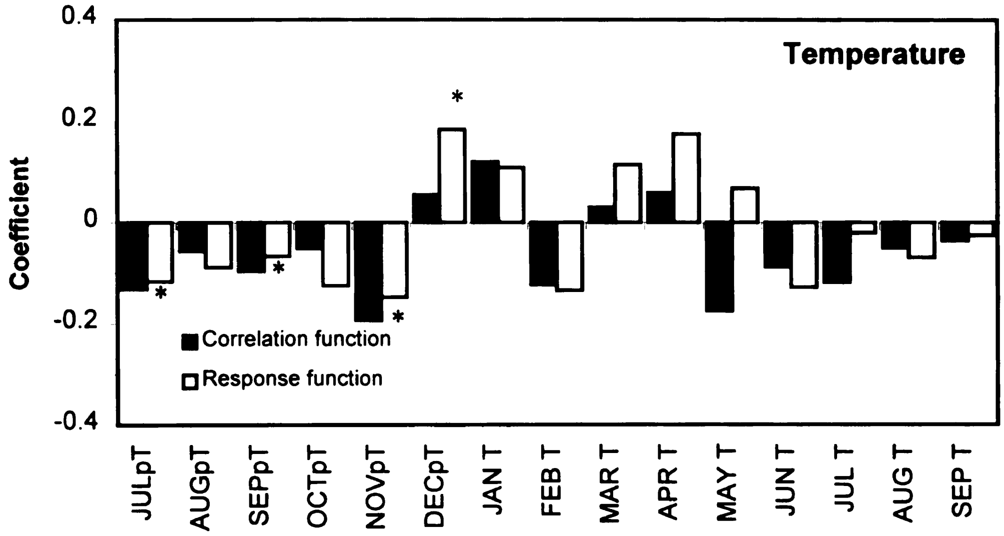


Figure 3-3 (cont'd).



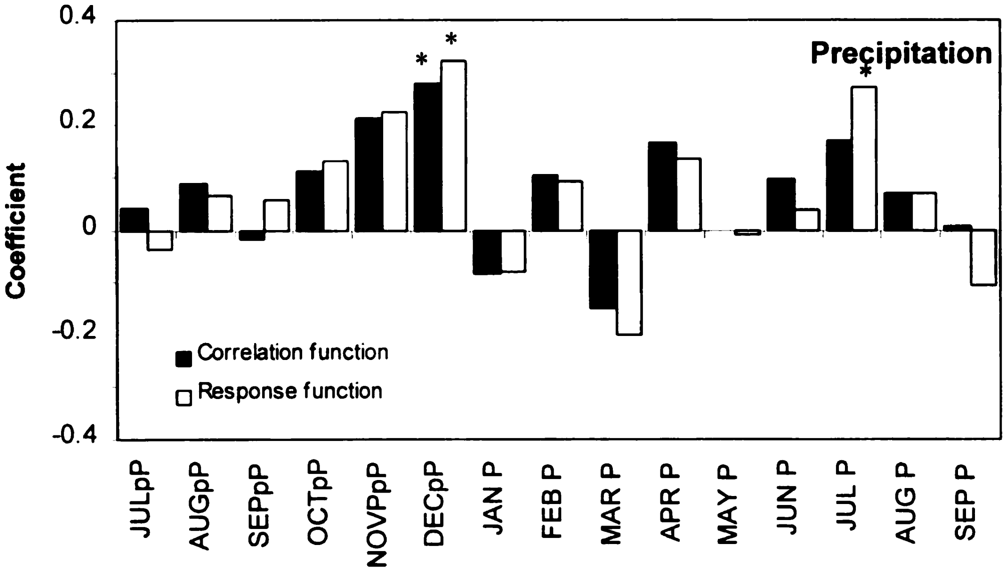


Figure 3-4. Correlation and response functions (22 PCs retained, R^2=0.4021) for the ARSTAN chronology (6 trees, 25 series) for *Picea abies* against the mean monthly temperature (T) and monthly precipitation (P) for the previous (p) and current growing seasons at the Grayling Beal Plantation. Significant (p<0.05) responses to a climatic variable are denoted by a *.

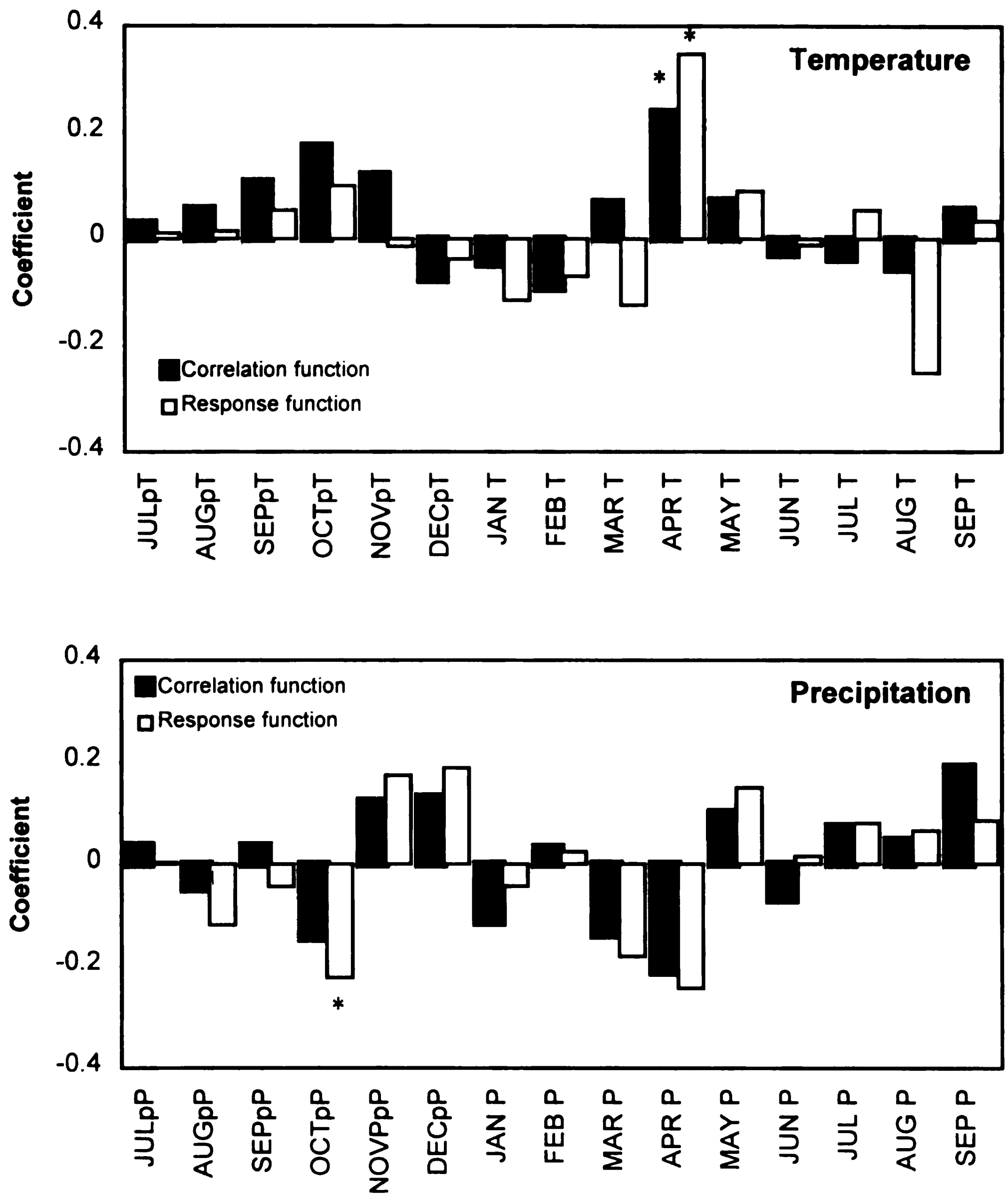


Figure 3-5. Correlation and response functions (22 PCs retained, R^2=0.3380) for the ARSTAN chronology for *Pinus resinosa* (23 trees, 82 series) against the mean monthly temperature (T) and monthly precipitation (P) for the previous (p) and current growing seasons at the Grayling Beal Plantation. Significant (p<0.05) responses to a climatic variable are denoted by a *.

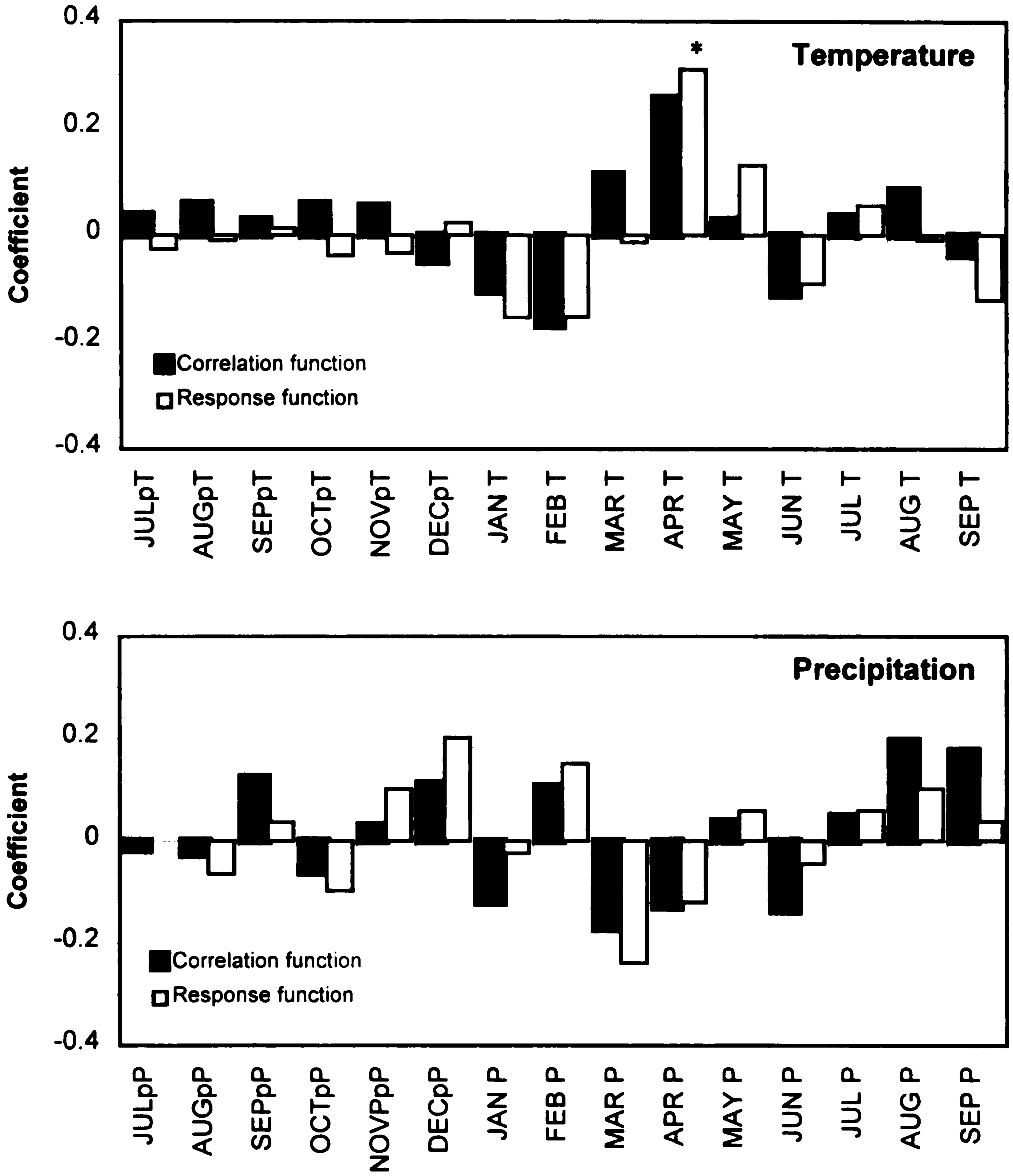


Figure 3-6. Correlation and response functions (22 PC retained, R^2=0.2835) for the ARSTAN chronology for *Pinus strobus* (10 trees, 21 series) against the mean monthly temperature (T) and monthly precipitation (P) for the previous (p) and current growing seasons at the Grayling Beal Plantation. Significant (p<0.05) responses to a climatic variable are denoted by a *.

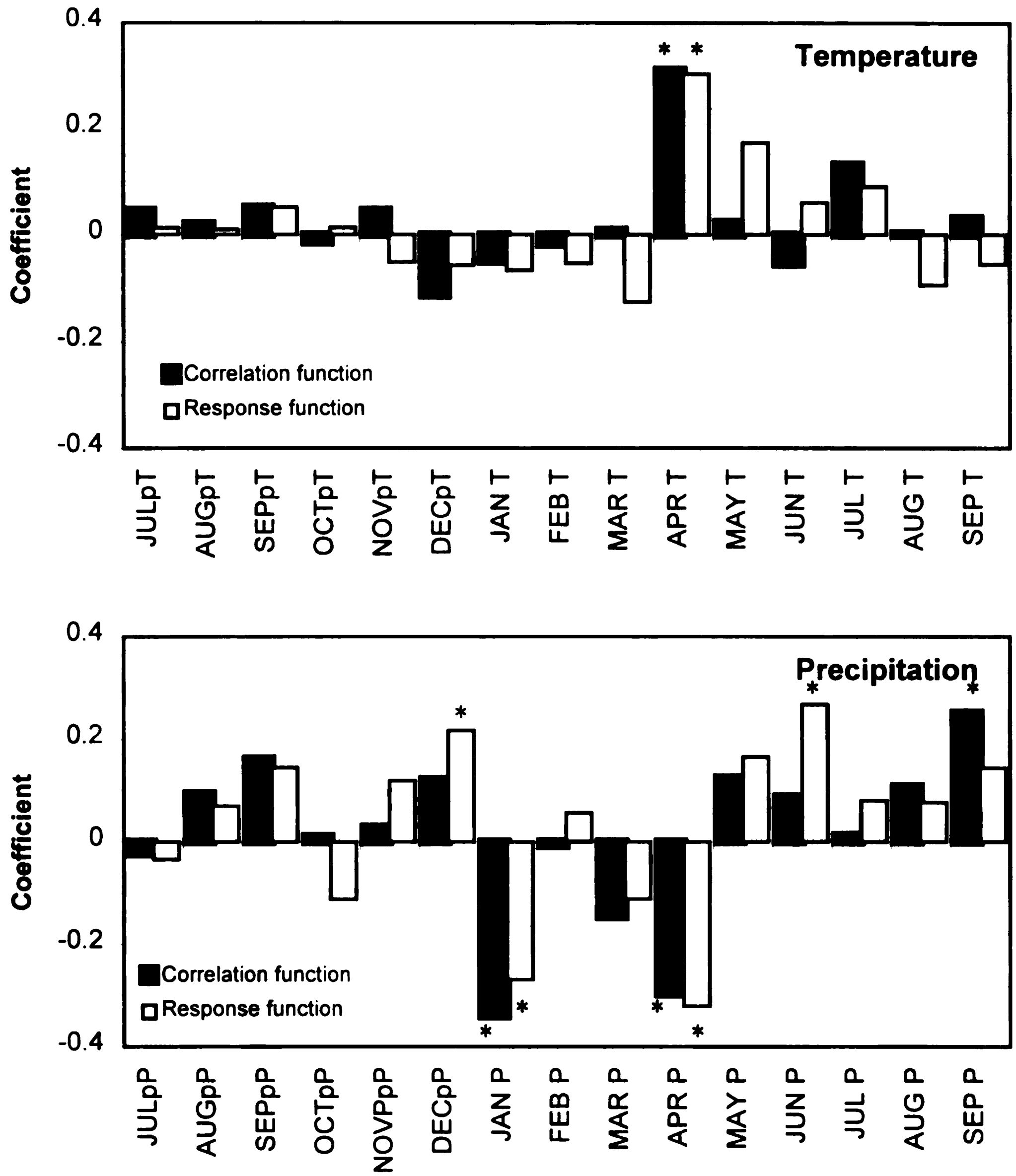


Figure 3-7. Correlation and response functions (22 PCs retained, R^2=0.4680) for the ARSTAN chronology for *Pinus sylvestris* (5 trees, 20 series) against the mean monthly temperature (T) and monthly precipitation (P) for the previous (p) and current growing seasons at the Grayling Beal Plantation. Significant (p<0.05) responses to a climatic variable are denoted by a *.

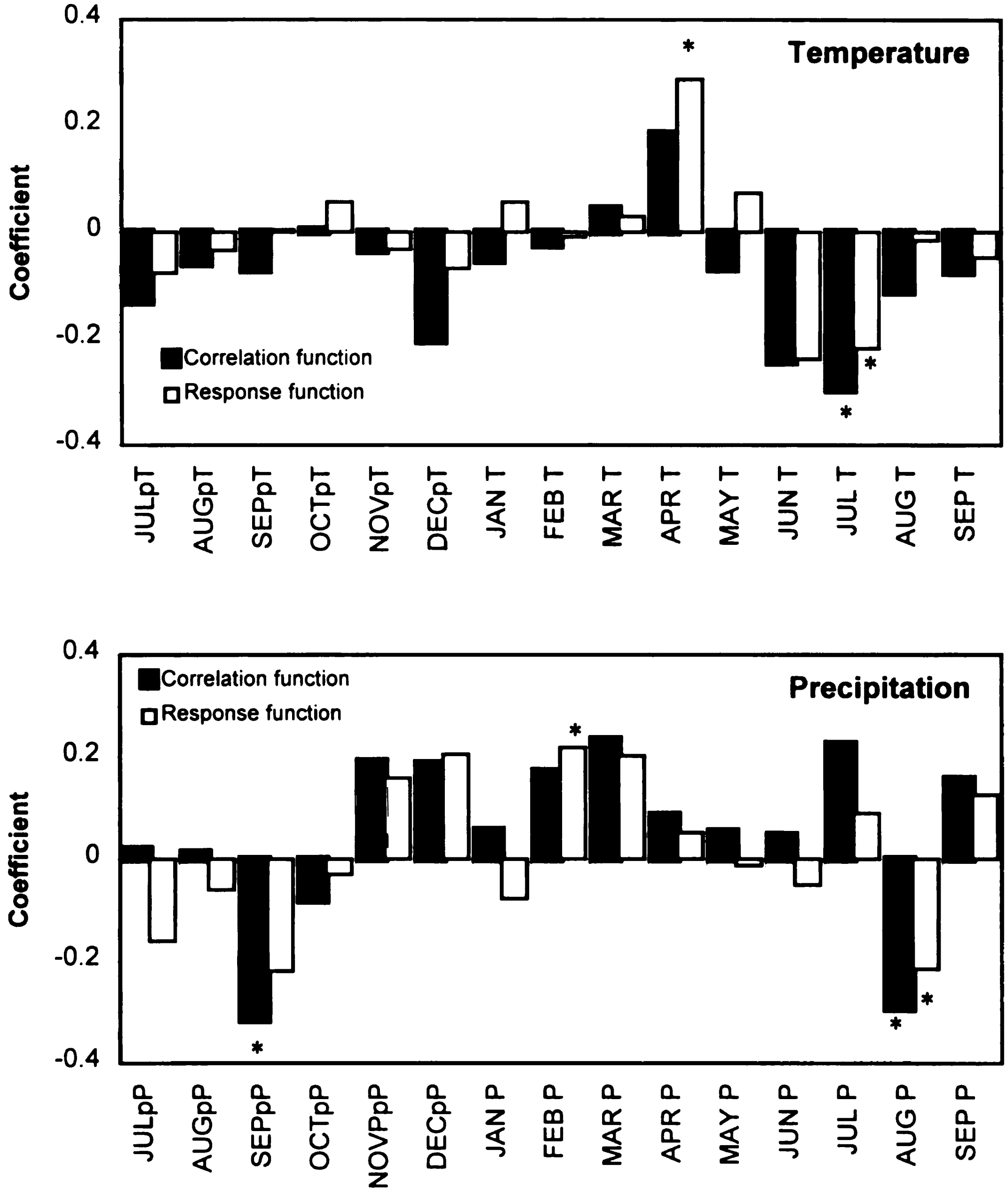


Figure 3-8. Correlation and response functions (21 PCs retained, R^2=0.5238) for the ARSTAN chronology for *Pinus resinosa* (28 trees, 52 series) against the mean monthly temperature (T) and monthly precipitation (P) for the previous (p) and current growing seasons at Hartwick Pines State Park. Significant (p<0.05) responses to a climatic variable are denoted by a *.

APPENDIX I

APPENDIX I

SPECIES LIST OF TREES ORIGINALLY PLANTED AT THE GRAYLING AGRICULTURAL EXPERIMENT STATION

This list is a composite of modern synonymy (Otis 1931, Gleason and Cronquist 1991, Griffiths 1994, Voss 1972, 1985, 1996) of the old scientific and common names (Beal 1888, Chittenden 1922) for species originally planted in the plantation at the Grayling Agricultural Experiment Station on May 22, 1888. The number and size planted, survival, presence(+) or absence(-) of regeneration, and status for each species is also listed. Status indicates whether the species is considered to be Native (N) to the jack pine barrens, native to the Region (R) but not the forest type, or Exotic (E) to North America (Voss 1972, 1985, 1996). Biological data was collected in 1998-2000.

Modern Synonymy	Listed Scientific Name	Listed Common Name	Planted (n)	Size	Surv. (n)	Regen.	Status
Acer negundo L.	*Negundo aceroides* Mœnch.	Box Elder	50	24in.	0	-	R
Acer platanoides L.	*Acer platanoides*	Norway Maple	100	12in.	0	+†	E
Acer pseudoplatanus L.	*Acer pseudo-platanus*	Sycamore Maple	20	unknown	0	-	E
Acer rubrum L.	*Acer rubrum* L.	Red Maple	100	6in.	0	+	R
Acer saccharinum L.	*Acer dasycarpum* Ehrhart.	Silver Maple	100	24in.	0	-	R
Acer saccharum Marsh.	*Acer saccharinum* Wang.	Sugar Maple	100	6in.	0	-	R
Betula alleghaniensis Britton	*Betula lutea* Michx.	Yellow Birch	100	6in.	0	-	R
Betula papyrifera Marsh.	*Betula papyracea* Ait.	Paper Birch	100	10in.	0	-	R
Catalpa speciosa (Warder) Engelm.	*Catalpa speciosa* Warder.	Hardy Catalpa	100	18in.	0	-	R
Celtis occidentalis L.	*Celtis occidentalis* L.	Hackberry	20	12in.	0	-	R
Fagus grandifolia Ehrh.	*Fagus ferruginea* Ait.	Beech	100	18in.	0	-	R
Fraxinus americana L.	*Fraxinus americana* L.	White Ash	100	12in.	0	+	R
Fraxinus nigra Marsh.	*Fraxinus sambucifolia* Lam.	Black Ash	100	6in.	0	-	R
Fraxinus pennsylvanica Marsh.	*Fraxinus viridis* Michx.	Green Ash	100	12in.	0	-	R
Gleditsia triacanthos L.	*Gleditsia triacanthos* L.	Honey Locust	100	12in.	0	-	R
Gymnocladus dioica (L.) K. Koch	*Gymnocladus canadensis* Lam.	Kentucky Coffee-tree	20	6in.	0	-	R
Juniperus virginiana L.	*Juniperus virginiana* L.	Red Cedar	100	9-12in.	3	+	R
Larix decidua Mill.	*Larix europæa* L.	European Larch	200	9-12in.	0	-	E
Morus alba v. *tatarica* Loud.	*Morus*	Russian Mulberry	200	6in.	0	-	E
Picea abies (L.) Karst.	*Picea excelsa*	Norway Spruce	100	9-12in.	24	+	E
Picea glauca (Moench) A. Voss	*Picea alba* Link.	White Spruce	50	9-12in.	2	+	R

APPENDIX I – Continued

Modern Synonymy	Listed Scientific Name	Listed Common Name	Planted (n)	Size	Surv. (n)	Regen.	Status
Pinus resinosa Aiton	*Pinus resinosa* Ait.	Red Pine	200	4-6in.	69	+	N
Pinus rigida Mill.	*Pinus rigida*	Pitch Pine	unknown	seeds	2	+	R
Pinus strobus L.	*Pinus strobus* L.	White Pine	500	10in.	37	+	N
Pinus sylvestris L.	*Pinus sylvestris* L.	Scotch Pine	100	9-12in.	0	+	E
P. x *jackii* Sarg.	*Populus balsamifera* Vas. *Candicans* Gray.	Balm of Gilead	100	cuttings	0	-	E
Populus alba L.	*Populus argentea* L.	Silver Poplar	200	cuttings	0	+	E
Populus alba L.	*Populus argentea* Vas.	Large Silver Poplar	200	cuttings	0	-	E
Populus balsamifera L.	*Populus balsamifera* L.	Balsam Poplar	100	cuttings	0	-	E
Prunus serotina Ehrh.	*Prunus serotina* Ehrh.	Black Cherry	100	12in.	0	+	N
Robinia pseudoacacia L.	*Robinia pseudoacacia* L.	Common Locust	1000	16in.	0	+	R
Salix alba L.	*Salix alba* L.	White Willow	100	cuttings	0	-	E
Salix alba var. *vitellina* L. (Stokes)	*Salix alba* var. *vitellina*	Yellow Willow	100	cuttings	0	-	E
Salix x pendulina Wender.	*Salix*	Wisconsin Weeping Willow	100	cuttings	0	-	R
Salix purpurea L.	*Salix purpurea*	Purple Willow	100	cuttings	0	-	E
Thuja occidentalis L.	*Thuya occidentalis* L.	Arbor Vitæ	100	6in.	1	+	R
Tilia americana L.	*Tilia americana* L.	Basswood	50	4in.	0	-	R
Ulmus americana L.	*Ulmus americana* L.	American Elm	100	12in.	0	-	R
Ulmus glabra Hudson	*Ulmus montana* Sm.	Scotch/European Elm	50	unknown	0	-	E
Ulmus procera Salisb.	*Ulmus campestris* Sm.	English/Camperdown Elm	50	unknown	0	-	E
Ulmus rubra Muhl.	*Ulmus fulva* Michx.	Red Elm	50	6in.	0	-	E
Ulmus thomasii Sarg.	*Ulmus racemosa* Thomas.	Rock Elm	*	*	0	-	R

†Unconfirmed information from Telewski and Kemp, unpublished data.

*Beal (1888) lists *Ulmus racemosa* Thomas. as one of the species planted at the Grayling Agricultural Experiment Station, but no other record (Beal 1889, Anonymous 1913, Chittenden 1922) includes this species. Consequently, *U. racemosa* is not included as one of the planted species.

APPENDIX II

APPENDIX II

DISTRIBUTION OF WOODY STEMS BY SPECIES AND SIZE IN THE PLANTATION AT THE FORMER GRAYLING AGRICULTURAL EXPERIMENT STATION

This table shows the species, number, and percent by size class of woody stems surveyed in eight 2-m wide belt transects running south to north through the former plantation. Status indicates whether the species is considered to be Native (N) to the jack pine barrens, native to the Region (R) but not the forest type, or Exotic (E) to North America (Voss 1972, 1985, 1996). Shaded species were not originally planted, while unshaded species were originally planted (see Appendix I). Data were collected in 2000.

Status	Species	Seedlings		Trees in dbh (cm)											Total
		<0.5m	>0.5m	0-5	5-10	10-15	15-20	20-25	25-30	30-35	35-40	40-45	45-50	50-55	
R	*Acer rubrum*	21	0	0	0	0	1	0	0	0	0	0	0	0	22
N	*Amelanchier* sp.	179	0	0	0	0	0	0	0	0	0	0	0	0	179
R	*Fraxinus americana*	14	0	0	0	0	0	0	0	0	0	0	0	0	14
R	*Fraxinus* sp.	13	0	0	1	0	0	0	0	0	0	0	0	0	14
R	*Juniperus virginiana*	0	0	1	0	0	0	0	0	0	0	0	0	0	1
E	*Picea abies*	12	9	10	15	2	2	1	0	0	0	0	1	0	52
N	*Pinus banksiana*	0	0	0	5	3	3	3	0	0	0	0	0	0	14
N	*Pinus resinosa*	3	3	16	3	8	3	1	0	0	1	3	1	0	42
R	*Pinus rigida*	0	0	0	0	1	0	0	0	0	0	0	0	0	1
N	*Pinus strobus*	84	102	292	86	28	13	4	3	3	1	2	3	0	621
E	*Pinus sylvestris*	0	0	2	2	2	2	0	4	0	0	0	0	0	12
N	*Populus tremuloides*	0	0	0	1	3	0	0	0	0	0	0	0	0	4
N	*Prunus pennsylvanica*	0	1	0	0	0	0	0	0	0	0	0	0	0	1
N	*Prunus serotina*	86	24	29	1	0	0	0	0	0	0	0	0	0	140
N	*Prunus* sp.	13	0	0	0	0	0	0	0	0	0	0	0	0	13
N	*Prunus virginiana*	8	0	0	0	0	0	0	0	0	0	0	0	0	8
N	*Quercus alba*	152	0	12	6	0	0	1	0	0	0	0	0	0	171
N	*Quercus ellipsoidalis*	0	0	0	2	2	0	0	0	0	1	0	0	0	5
N	*Quercus rubra*	916	5	28	22	6	2	0	0	1	1	0	0	1	982
R	*Robinia pseudoacacia*	3	2	0	0	0	0	0	0	0	0	0	0	0	5
	Total	**1504**	**146**	**390**	**144**	**55**	**26**	**10**	**7**	**4**	**4**	**5**	**5**	**1**	**2301**
	% of Total	**65.36**	**6.35**	**16.95**	**6.26**	**2.39**	**1.13**	**0.43**	**0.30**	**0.17**	**0.17**	**0.22**	**0.22**	**0.04**	

APPENDIX III

APPENDIX III

DISTRIBUTION OF WOODY STEMS BY SPECIES AND SIZE IN THE OLD FIELD ADJACENT TO THE FORMER GRAYLING AGRICULTURAL EXPERIMENT STATION

This table shows the species, number, and percent by size class of woody stems surveyed in eight 2-m wide belt transects running south to north through the old field just south of the former plantation. Status indicates whether the species is considered to be Native (N) to the jack pine barrens, native to the Region (R) but not the forest type, or Exotic (E) to North America (Voss 1972, 1985, 1996). Shaded species were not originally planted, while unshaded species were originally planted (see Appendix I). Data were collected in 2000.

		Seedlings		Trees in dbh (cm)											
Status	Species	<0.5m	>0.5m	0-5	5-10	10-15	15-20	20-25	25-30	30-35	35-40	40-45	45-50	50-55	Total
R	*Acer rubrum*	1													1
N	*Amelanchier sp.*	5	1												6
E	*Picea abies*			1	2	1									4
N	*Pinus banksiana*			6	4	6	1	1							18
N	*Pinus resinosa*	3	1	1	1	1	1								8
N	*Pinus strobus*	8	6	14	1	2									31
E	*Pinus sylvestris*	11	1	6	4	2	1		1						26
E	*Populus alba*	8	7	1											16
N	*Prunus serotina*	6		1											7
N	*Quercus alba*	15													15
N	*Quercus ellipsoidalis*													1	1
N	*Quercus rubra*	672		2	3										677
R	*Robinia pseudoacacia*	8	1	3	1										13
	Total	**737**	**17**	**35**	**16**	**12**	**3**	**1**	**1**	**0**	**0**	**0**	**0**	**1**	**823**
	% of Total	**89.55**	**2.07**	**4.25**	**1.94**	**1.46**	**0.36**	**0.12**	**0.12**	**0.00**	**0.00**	**0.00**	**0.00**	**0.12**	

APPENDIX IV

APPENDIX IV

TREE-RING CHRONOLOGIES DEVELOPED FOR *PINACEAE* AT THE FORMER GRAYLING AGRICULTURAL EXPERIMENT STATION AND HARTWICK PINES STATE PARK

Raw ring-width data from the Grayling Beal Plantation will be made available via the International Tree-Ring Data Bank (ITRDB), a searchable database maintained by the National Oceanic and Atmospheric Administration; the raw ring-width data from Hartwick Pines State Park (Koop and Grissino-Mayer 1988) were obtained from the ITRDB. The ARSTAN chronologies (ARSTAN Version 6.04P, Holmes 2000) developed from the raw ring-width data and used to detect climate sensitivity are provided in this Appendix.

Picea abies **– Grayling Beal Plantation**

	0	1	2	3	4	5	6	7	8	9
1890							0.08404	1.43938	1.43107	1.39603
1900	1.29877	1.28073	1.43303	1.00533	0.92791	1.10313	1.04524	0.71119	1.04120	0.90107
1910	0.80832	1.14398	1.38590	1.02490	0.80075	1.21506	1.20357	1.14232	1.20835	0.69123
1920	1.25518	0.92842	1.16880	0.74388	0.92843	0.63992	0.77119	1.03799	0.89567	1.00723
1930	1.09741	0.84808	1.22751	0.87582	0.58508	0.81295	0.64786	0.91579	1.12318	1.15133
1940	1.27393	0.66483	1.37923	1.27051	0.83875	1.04109	1.03225	0.88432	0.72814	1.15563
1950	1.07731	1.25330	1.12759	1.56357	0.86753	0.76434	0.85231	1.12626	1.03124	0.79377
1960	0.86967	1.29974	1.01783	1.06073	0.67823	0.73008	0.58899	1.14891	1.28564	1.51652
1970	0.81062	0.59837	0.77447	1.12427	1.13591	0.98211	0.82367	0.58984	0.76845	0.76826
1980	1.13584	1.27332	1.14047	0.87961	1.21942	0.89828	1.44441	0.99455	0.68883	0.93927
1990	1.12904	0.98944	0.91218	1.34690	1.06058	0.94806	1.15200	0.78393	0.94272	

Pinus resinosa **– Grayling Beal Plantation**

	0	1	2	3	4	5	6	7	8	9
1890										1.96439
1900	2.43952	2.57670	2.43775	1.89389	1.55836	1.57289	1.43844	1.00529	1.01229	0.96009
1910	0.99742	1.04755	1.22553	1.04833	0.97902	0.98792	0.84050	0.82522	0.77350	0.60782
1920	0.81195	0.84526	0.82151	0.77827	0.89237	0.90320	0.91594	0.95588	0.88049	0.95065
1930	0.80872	0.75125	0.95039	0.83940	0.79672	0.93428	0.70720	0.94590	1.11061	1.06583
1940	1.05481	0.79679	1.26030	1.26534	0.94859	1.17426	1.13688	0.97908	0.98163	0.95767
1950	1.02908	1.09990	0.94288	0.92992	0.84436	0.77385	0.89658	1.07589	1.05571	1.05853
1960	0.95119	1.03539	1.24394	1.69134	1.44797	1.52466	1.18901	1.11260	1.16094	1.21263
1970	1.17458	1.12511	1.00029	1.18271	0.97776	0.78475	0.84087	0.84479	0.94355	0.89828
1980	0.90556	0.95539	1.02122	0.93341	1.09181	1.24832	1.30859	1.10902	0.91935	0.68146
1990	0.90618	0.82812	0.68463	0.74560	0.73092	0.70646	0.78510	0.72450	0.75551	

***Pinus resinosa* – Hartwick Pines State Park**

	0	1	2	3	4	5	6	7	8	9
1770			0.80135	0.89023	1.00532	1.04032	1.35573	1.58100	1.27730	1.18320
1780	1.16413	1.09316	1.29851	1.33232	1.01233	0.81699	1.03759	1.31608	0.80931	0.68997
1790	0.69684	0.81209	0.73329	0.82969	0.71525	0.74720	0.74387	0.78854	0.85826	0.82905
1800	0.85337	0.87837	1.04492	0.77197	0.63461	1.00464	1.02451	0.93756	0.78565	0.76367
1810	0.96875	1.14908	1.02523	1.11763	0.95427	1.19014	1.15041	1.2033	0.81285	0.91384
1820	0.67091	0.60759	0.83712	0.96692	1.16522	1.28095	0.93528	1.27780	1.39378	1.19596
1830	1.49255	1.36366	1.18197	1.07623	1.14760	1.04115	1.14344	0.89482	0.92820	1.03678
1840	1.03419	1.10308	1.33710	1.27777	1.37157	1.00855	0.87622	0.60100	0.94065	0.81816
1850	0.79852	1.04724	0.88066	0.93931	0.99149	1.04379	0.92962	1.12163	1.03779	0.96854
1860	0.85338	0.99392	1.02879	1.06259	0.74959	0.87158	0.83095	0.85431	0.83106	0.99297
1870	1.19791	1.10292	1.06336	1.05123	0.65261	0.76531	0.78546	0.70955	1.03705	0.88028
1880	0.98525	0.83336	0.97855	1.05804	1.12951	1.08771	1.07586	0.88413	0.64360	1.07407
1890	0.89244	0.68602	0.94217	0.83039	0.85930	0.75908	1.00656	0.79071	0.84681	1.03289
1900	1.12470	0.93173	1.24011	1.26588	1.13410	1.10846	1.13465	0.87449	0.79024	0.55811
1910	0.47048	0.51999	0.77439	0.92303	0.79313	0.96687	1.13320	0.97752	1.00834	0.76867
1920	0.65983	0.60754	0.80274	0.78019	1.00425	1.19301	1.35123	1.28426	1.25195	1.27641
1930	1.15990	0.99674	1.05718	0.92099	0.64686	0.87552	0.71880	0.60635	0.83287	0.77387
1940	0.71043	0.53352	0.91388	1.00130	0.96624	1.35644	1.34883	1.18691	1.11838	1.02977
1950	1.10741	1.08628	0.93235	1.08706	1.04000	0.86840	0.94688	1.14601	1.05523	1.17225
1960	0.88602	1.06097	0.98605	1.17927	1.25628	1.27471	0.89417	0.83301	0.94660	1.10216
1970	1.07232	0.96337	0.93710	1.16352	1.12190	0.93828	1.00023	0.95172	1.01443	1.03363
1980	1.06145	0.96071	1.04805	0.80848	0.88639	1.22218	1.59275	1.43102		

***Pinus strobus* – Grayling Beal Plantation**

	0	1	2	3	4	5	6	7	8	9
1890					0.47006	0.32449	0.52785	0.60930	0.96219	1.26140
1900	1.32293	1.15539	1.35371	0.97023	1.06657	1.16925	1.17300	0.74131	0.99688	0.79845
1910	0.84897	1.15021	1.18017	1.02561	1.19055	1.14883	0.87997	0.83806	0.66262	0.60612
1920	1.06357	1.03448	1.14753	0.90311	1.10337	0.81206	1.16091	1.31000	1.18902	1.09005
1930	1.00445	0.69963	0.97187	0.70046	0.58167	0.74338	0.68655	1.07645	1.45702	1.35518
1940	1.21660	0.59431	1.09276	1.02300	0.74446	0.94740	0.89269	0.81860	0.98543	0.90796
1950	0.99231	0.83313	0.72812	0.90514	0.74097	0.77739	0.92651	0.97177	0.83811	1.00235
1960	1.11997	1.16372	1.15007	1.39816	1.15937	1.36622	0.83201	0.91373	1.30193	1.35612
1970	1.00831	0.89316	0.91929	1.11885	0.98097	1.11458	1.02006	1.01925	1.19056	0.97797
1980	0.98136	1.07952	1.14706	0.87322	1.24585	1.29811	1.52531	1.06311	1.07203	0.97115
1990	0.94348	0.81095	0.72952	0.97358	0.93017	0.92581	0.98763	0.71287	0.81873	

***Pinus sylvestris* – Grayling Beal Plantation**

	0	1	2	3	4	5	6	7	8	9
1910						1.13048	1.36331	1.18722	0.75155	0.72833
1920	0.62211	0.85759	0.68146	0.60505	0.84234	0.66153	0.74587	0.84901	0.96573	1.00229
1930	1.01666	0.89568	0.97998	0.88687	0.89105	1.00854	0.96404	1.02466	1.19018	1.17288
1940	0.94599	0.77089	1.13511	1.04000	1.08709	1.29646	1.24909	0.92583	0.79617	0.87743
1950	0.87640	0.83678	0.71670	1.03068	1.01100	0.96956	0.98926	1.04042	1.04326	0.97541
1960	0.91611	1.10839	1.02196	1.24645	1.14150	1.15210	0.92155	0.87404	1.08965	1.16931
1970	1.09661	1.02875	0.90765	1.05287	0.92014	0.76730	0.66988	0.76814	0.86879	0.84018
1980	0.87727	1.07882	0.97755	0.89806	1.21369	1.72646	1.57623	1.51191	1.33216	1.26254
1990	1.28343	0.83652	0.64047	0.52277	0.52954	0.69643	0.51017	0.47294	0.51847	

APPENDIX V

APPENDIX V

CLIMATE DATA

Monthly precipitation and mean monthly temperature data used in the correlation analysis were obtained for the Grayling Station (COOP ID 203391) from the National Climatic Data Center (2001), a website maintained by the U.S. Department of Commerce, National Oceanic and Atmospheric Administration, and National Environmental Satellite, Data, and Information Service.

Monthly precipitation (hundredths of inches)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
1931	63	32	116	228	524	400	112	220	685	565	457	163
1932	147	144	48	146	506	377	573	492	79	581	134	227
1933	117	94	114	287	391	224	140	80	244	733	177	110
1934	58	20	84	139	126	311	192	206	822	348	258	92
1935	81	85	115	95	91	284	104	393	292	227	186	78
1936	115	75	61	219	397	106	209	343	414	458	161	87
1937	123	94	26	109	96	266	460	260	602	268	206	84
1938	193	206	174	48	348	228	451	525	477	128	201	180
1939	141	128	99	249	490	363	160	706	304	223	133	196
1940	105	58	84	172	441	329	302	685	427	247	441	127
1941	121	130	63	271	275	68	227	282	478	626	323	149
1942	150	25	383	113	527	354	588	128	540	216	227	293
1943	139	185	305	257	462	829	587	352	243	237	470	82
1944	89	104	239	264	315	743	331	194	413	141	317	115
1945	70	111	65	337	779	378	389	397	694	359	346	99
1946	206	139	136	129	327	493	235	222	363	89	296	168
1947	176	119	104	411	689	165	327	236	625	32	213	174
1948	60	80	261	481	201	731	591	72	121	181	537	166
1949	277	142	149	256	203	503	535	339	242	174	241	296
1950	377	220	243	355	182	444	639	429	325	306	201	193
1951	176	160	213	423	306	297	461	374	475	507	291	194
1952	227	86	241	225	148	418	744	398	209	50	538	233
1953	193	358	192	284	434	300	782	359	307	82	187	247
1954	179	144	156	592	357	866	115	120	457	442	142	114
1955	130	104	254	161	262	154	110	159	41	334	277	161
1956	51	96	42	403	223	371	563	746	250	131	287	166
1957	124	61	106	345	357	550	398	164	295	274	348	127
1958	79	57	48	62	89	219	168	296	397	275	313	91
1959	141	206	216	391	402	63	579	717	388	537	275	230
1960	163	167	176	271	589	235	388	216	282	216	425	52
1961	80	164	175	204	185	296	548	496	744	167	328	147
1962	195	204	112	79	297	274	279	359	306	257	80	114
1963	235	72	308	168	446	350	451	301	212	68	342	167
1964	105	36	221	271	417	55	483	217	465	153	260	136
1965	271	123	153	364	251	261	97	901	555	247	227	302
1966	137	92	239	294	69	161	451	183	300	300	589	268
1967	228	94	117	478	220	708	73	301	251	285	344	215
1968	109	199	57	152	332	512	352	264	389	325	205	254
1969	240	24	97	246	317	584	354	67	170	605	228	101
1970	143	79	187	160	342	250	383	178	672	250	397	172
1971	217	361	189	208	253	72	314	296	257	89	304	404
1972	90	136	254	163	202	149	365	536	310	282	139	446
1973	182	167	142	206	429	475	236	191	420	317	249	252
1974	307	147	140	422	328	492	254	270	308	214	130	170
1975	279	200	348	186	425	459	495	676	445	172	216	171
1976	221	250	453	145	399	274	207	136	201	194	127	137
1977	132	95	181	197	130	156	525	430	607	322	178	99

APPENDIX V – Continued

Monthly precipitation (hundredths of inches)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
1978	132	39	87	107	318	263	282	390	724	298	157	182
1979	178	105	359	507	307	260	273	486	28	374	268	135
1980	142	52	96	406	242	624	222	218	456	269	165	187
1981	64	175	74	477	193	249	434	395	218	355	143	61
1982	308	43	259	254	147	288	849	268	415	380	342	387
1983	80	81	175	162	819	100	202	590	493	532	144	198
1984	119	78	212	154	317	505	567	441	491	358	132	243
1985	144	255	245	199	353	187	334	592	595	379	345	166
1986	98	140	191	204	360	496	487	184	1251	316	85	96
1987	108	60	72	122	219	453	160	903	389	368	196	234
1988	122	120	206	252	162	221	526	536	318	567	621	157
1989	125	82	284	130	343	469	133	419	214	234	284	83
1990	327	113	247	181	420	472	293	323	416	442	282	154
1991	125	61	228	484	624	152	399	264	503	1048	202	182
1992	129	168	179	459	59	223	390	233	499	323	541	155
1993	165	71	43	484	344	676	243	601	466	255	226	84
1994	163	111	168	512	324	394	992	437	347	242	373	45
1995	243	37	189	454	199	274	408	458	212	527	476	231
1996	183	184	59	245	193	453	508	177	506	340	181	209
1997	209	212	197	63	367	102	345	444	204	227	149	38
1998	209	71	417	214	202	326	143	114	202	382	268	167

Mean monthly temperature (tenths of degree Fahrenheit)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
1931	212	240	254	412	517	650	706	652	628	502	420	275
1932	288	222	220	364	536	644	666	674	585	473	315	246
1933	272	182	273	410	572	694	706	646	632	457	283	203
1934	214	80	210	384	584	670	700	636	588	478	387	204
1935	178	176	297	410	484	606	728	676	552	474	337	192
1936	158	86	301	358	584	618	714	670	606	450	302	270
1937	206	229	244	410	564	634	690	708	586	445	340	202
1938	174	226	346	444	545	641	694	706	560	512	376	254
1939	208	171	248	384	570	652	688	672	588	456	328	275
1940	145	196	208	356	507	626	670	636	573	454	310	245
1941	174	176	200	452	556	640	672	626	596	456	352	272
1942	172	154	285	460	522	620	636	626	534	436	306	168
1943	102	166	178	332	476	620	629	612	492	404	259	158
1944	202	159	182	318	526	604	618	618	574	440	378	198
1945	134	218	418	462	488	604	662	671	575	460	358	190
1946	204	176	398	433	507	621	670	631	597	518	377	230
1947	199	163	224	368	476	598	678	732	602	572	309	234
1948	136	174	257	410	510	624	679	673	621	465	398	253
1949	239	228	281	434	553	685	703	676	561	526	324	257
1950	228	192	229	339	543	645	657	626	573	520	326	207
1951	192	207	279	422	579	616	663	640	557	496	278	233
1952	227	223	259	457	543	668	705	660	605	433	376	285
1953	233	232	306	395	546	657	685	680	590	532	405	278
1954	174	284	257	440	505	670	669	658	583	492	380	227
1955	195	202	267	502	591	655	748	731	586	510	317	209
1956	188	214	243	395	522	658	642	661	551	536	368	266
1957	150	237	296	450	536	656	691	648	574	468	364	266
1958	213	166	310	448	537	591	674	669	583	508	371	159
1959	140	150	266	419	600	658	687	720	619	458	293	284

APPENDIX V – Continued

Mean monthly temperature (tenths of degree Fahrenheit)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
1960	217	197	195	451	556	608	658	666	611	485	393	196
1961	163	243	329	402	522	629	678	658	637	506	361	238
1962	165	151	291	430	600	635	650	661	557	495	351	227
1963	113	108	294	458	521	662	688	628	574	573	404	186
1964	235	222	282	449	593	640	694	633	574	460	398	218
1965	170	192	236	394	590	622	647	649	580	473	361	290
1966	148	223	338	401	490	665	719	665	578	472	355	237
1967	233	154	288	438	491	669	656	629	576	462	309	253
1968	175	135	333	464	508	627	674	672	613	497	354	218
1969	199	201	253	438	537	584	675	681	587	445	328	209
1970	122	157	239	432	557	644	706	673	574	468	358	242
1971	152	183	243	389	521	678	654	645	618	557	350	266
1972	189	162	206	349	566	591	664	645	558	414	327	219
1973	220	161	372	414	498	645	668	686	558	504	350	222
1974	194	124	271	417	490	598	666	641	532	437	363	261
1975	194	206	235	346	583	622	662	649	532	478	402	224
1976	146	229	276	438	493	652	669	631	541	416	277	136
1977	99	158	335	450	601	612	692	609	579	435	336	200
1978	136	98	207	384	558	609	651	645	571	425	349	189
1979	106	72	289	385	497	614	656	604	583	450	349	252
1980	188	121	210	407	550	585	669	673	555	412	320	168
1981	118	220	305	440	514	627	666	652	542	414	338	234
1982	89	143	228	361	594	576	672	609	561	489	348	308
1983	199	235	303	380	463	617	716	680	582	446	344	156
1984	112	262	209	438	492	646	655	677	535	473	335	260
1985	146	165	286	445	552	584	651	627	580	451	316	174
1986	160	171	284	458	559	588	683	603	557	429	308	257
1987	189	201	310	439	558	656	699	637	574	413	356	267
1988	149	153	242	405	552	652	695	676	558	412	355	216
1989	216	130	213	386	520	608	679	626	546	453	290	101
1990	246	196	293	426	499	615	660	641	560	429	369	245
1991	136	219	295	447	590	663	670	667	544	460	313	238
1992	200	200	248	3737	522	591	609	602	541	426	308	241
1993	176	123	260	372	520	591	679	665	517	421	323	229
1994	59	80	268	399	512	644	660	621	583	477	361	282
1995	211	151	301	364	508	673	675	696	530	474	263	166
1996	118	148	215	348	487	626	635	654	582	450	280	239
1997	149	196	242	374	447	636	660	609	559	446	308	276
1998	214	294	291	427	596	622	663	669	602	480	366	279

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