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DEVELOPMENT AND GROWTH OF SIX CONIFEROUS TREE SPECIES ON ABANDONED AGRICULTURAL SOILS IN SOUTHERN MICHIGAN

By

Ji Hong Kim

A DISSERTATION

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ABSTRACT

DEVELOPMENT AND GROWTH OF SIX CONIFEROUS
TREE SPECIES ON ABANDONED AGRICULTURAL
SOILS IN SOUTHERN MICHIGAN

By

Ji Hong Kim

The W. K. Kellogg Experimental Forest of Michigan State University is an excellent demonstration of reforestation on land previously farmed and then abandoned in the early 1930s. This study was conducted to evaluate the performance of six coniferous species in plantings established more than 40 years ago. Included species are red pine, eastern white pine, Scotch pine, European larch, white spruce, and Norway spruce.

Tree measurements, together with site characteristics, were obtained from 35 field plots in unthinned and thinned stands. Understory plants were also identified in selected plots within plantations.

The species varied in overall performance. All the selected plantations have been developing normally and have grown far above average, exceeding 7 cubic meters per hectare (100 cubic feet per acre) per year of merchantable volume in all unthinned stands.

Thinning practices decreased the residual growing

stock, but increased diameter growth rate for all species. Total volume production has been identical between unthinned and thinned stands. Thinning is essential in overstocked stands to reduce mortality, to yield high quality crop trees, and to obtain intermediate income.

The development of understory vegetation was outstanding in Scotch pine and European larch plantations. Competition could not be avoided with well-grown hardwoods in these stands.

White pine in mixture with red pine, and European larch were damaged by insects and disease. A high rate of juvenile mortality also was recorded for white pine. The stagnated growth rate of European larch may be attributed in part to larch sawfly attack.

Growth and yield performance between species must be drawn guardedly since the original experiments were not set up for inter-species comparisons. More research is needed to determine the comparative performance of different species on different sites for highly successful reforestation. However, the study does suggest that red pine is the most generally reliable native timber species for plantations in southern Michigan, but it also suggests that with careful seed selection Norway spruce and Scotch pine will outgrow native species.

Achieved with

Soon Sung and Soerynn,

dedicated to

my father and mother,

Mr. Y. K. Kim and Mrs. H. S. Choi.

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INTRODUCTION

The establishment of vegetation is of great importance in the control and prevention of erosion on abandoned agricultural land by reducing the exposure of bare soils and slowing down runoff. Not only for conservation of the soil, but also for forest production, planting trees plays an essential role in land use programs that are associated with natural resources. More beneficial and desirable outputs can be obtained from the resources with the same amount of inputs through creditable manipulation of the forest. It is necessary to develop appropriate establishment and maintenance criteria for the forest, corresponding with basic ecological principles, including the selection of tree species to be planted.

Trees in a stand differ from each other because of interaction between genetic and environmental factors, but individual genotypic differences are less apparent and more difficult to discern among a group of the same species. However, different species have distinctive growth potentials and characteristics when grown on the same site where growing conditions may be presumed to be uniform. The site consists of physical (atmospheric, edaphic, and physiographic) and biotic factors surrounding the forest community. Site factors and the forest community are closely interrelated with one another in terms of environmental interaction. Likewise, species selected for forest planting need to be compatible with these ecological factors of the site, but as these species become mature, the forest has positive influences through changing microenvironmental factors on the area where the trees are growing. It is quite difficult to understand and evaluate the sum total of the interaction among these environmental factors that make up the complex, but the growth rate of the forest stand is a good indication as to which factors determine site quality.

On bare land once cleared for cultivation, the establishment of forest stands by planting trees is an example of the development of plant successional stages by human intervention. From an economic point of view, climax vegetation is not always the most beneficial for us, but seral stages, such as a pine stand on a northern hardwood forest site, may grow faster than the hardwood forest and produce a higher yield of forest products.

The present study of maturing coniferous plantations was made at the W. K. Kellogg Experimental Forest near Augusta, Michigan. Managed by the Department of Forestry, Michigan State University, the forest is an excellent demonstration of reforestation on eroded old fields. Twelve coniferous plantations, all more than 40 years of age, were selected for this study. They included red pine (*Pinus resinosa* Ait.), eastern white pine (*Pinus strobus* L.), Scotch pine (*Pinus sylvestris* L.), European larch (*Larix decidua* Mill.), white spruce (*Picea glauca* (Moench) Voss), and Norway spruce (*Picea abies* (L.) Karst).

The specific objectives of this study were as follows:

1. To evaluate the growth and yield of the six coniferous species used for reforestation in the W. K. Kellogg Experimental Forest.
2. To observe local site conditions in each plantation and their effects on stand productivity.
3. To examine the development of understory vegetation in each plantation and to determine differences in species composition among the plantations.

LITERATURE REVIEW

Red Pine

Red pine (Pinus resinosa Ait.) is a species native to northeastern and northcentral United States and adjacent Canada. Red pine stands made up about a third of the 8.9 million hectares (22 million acres) of the pine forests that were in Michigan, Wisconsin, and Minnesota a century ago. Today, the species occupies a little more than 0.4 million hectares (1 million acres)--mostly in stands planted since 1930 (Benzie, 1977). It is increasing in popularity for planting because of ease of nursery culture and plantation establishment, relative freedom from insects and diseases in most areas, and high productivity on suitable sites (Buckman, 1962; Fowler and Lester, 1970).

Red pine plantations are usually made only within its natural range (Fowler and Lester, 1970). However, moderate growth rates have been reported for the species planted in eastern Nebraska (Sprackling and Read, 1975), Washington (Silen and Woike, 1959), and New Zealand (Sweet, 1965). But high rates of failure characterize most red pine provenance experiments in Europe (Fowler and Lester, 1970). No varieties of red pine have been described, and the species is morphologically very uniform with little genetic variation having been reported in the species (Mirov, 1967; Wright, et al., 1972). The narrow range of variation, including growth rates, survival, and wood quality suggests that an interpretation of traits may be more subject to uncertainties associated with non-genetic local environmental factors than with genetic factors. The genetic pattern is not usually apparent and it is difficult to relate to environmental data.

As a consequence of its increasing popularity, red pine is now planted on many soils on which it was not native, or on soils formerly cultivated. Even though such plantations have generally been successful, some of them have failed or grown poorly, mainly because of inappropriate edaphic factors (Stone et al., 1954). Variation in reproduction capacity and growth rate of red pine have frequently been attributed to soil differences (Hannah, 1969).

The high proportion of sandy particles is a characteristic of the soil most often occupied by this species. Plantation development is usually best in coarse, well-drained, deep loamy sand or sandy loam soils (Horton and Brown, 1960; Fisher and Stone, 1968; Stone, 1976; Stiell, 1978). Wilde and his co-workers (1965) reported that, on coarse sandy soils in Wisconsin, unless they had been depleted in fertility by previous agricultural activity or repeated fires, a red pine stand could annually produce more than 9 cubic meters per hectare (1 cord per acre) even on short rotations. Stone (1976) suggests that merchantable volume production on some well-drained and sandy northern hardwood sites could be doubled by conversion and intensive management of red pine plantation.

The species is not suited to poorly drained soils which cause poor development of the root system and growth inhibition. Appropriate drainage classes, ranging from moderately well-drained to well-drained, are essential for its best development (DeMont and Stone, 1968). But it is evident that summer droughtiness reduces the growth of red pine, especially on upper slopes (Braekke and Kozlowski, 1975). However, red pine planted on sandy and relatively infertile soils grows well with minimum attention, simply because there is very little vegetative competition with other plants on such sites (Fowells, 1965; Stone, 1976).

Once plantations are established, red pine stands need to be thinned periodically. Periodic thinning is essential to obtain optimum volume production, larger tree sizes, and better stand quality (Day and Rudolph, 1962; 1966; 1971; 1972; Dissemeyer, 1962; Morrow, 1974; Coffman, 1976; Wilson, 1979; Lundgren, 1981). Most thinning studies have emphasized the necessity of periodic thinning, but there is still no general agreement as to the stand density which will show the optimum growth results, especially for the first thinning.

Three basic thinning methods in red pine plantations have been examined by a number of researchers; residual basal area, row thinning, and percent of height. In the residual basal area method (Lemmien and Rudolph, 1964; Day and Rudolph, 1972) removes every other row, every third row, or every fourth row. The percent of height method (Day and Rudolph, 1962; 1972; Dissmeyer, 1962) maintains average spacing between residual trees which is a specified percent of average dominant tree height.

Thinning prescriptions for red pine plantations should be based on a guide that considers future stand development as well as rapid volume growth. A careful evaluation of alternatives is needed to determine the best course of action to meet management objectives. Day and Rudolph (1972) studied various thinning methods in a 32-year-old red pine plantation in the Hiawatha National Forest and reported that residual stand densities of 20.7 to 23.0 square meters per hectare (90 to 100 square feet per acre) of basal area showed highest growth rate, while lower and higher densities showed less growth. Coffman (1976) noted similar results with the 20.7 square meters per hectqare (90 square feet per acre) residual basal area treatment showing the highest productivity on a good site. Lundgren (1981) recommends 27.5 square meters (120 square feet) of basal area to maximize volume growth in Lake States. Row thinning, removing every third row, has been recommended by Lemmien and Rudolph (1964) for the initial thinning, to be followed by periodic individual tree selection thinnings on suitable sites for red pine.

White Pine

White pine (*Pinus strobus* L.) was one of the major timber species in Michigan during the early lumbering history of the State. Although the original growth has largely disappeared, white pine is still in high demand and is commonly used in plantation establishment. Barret and his students (1976) recommended the growing of white pine because of its high-level and sustained growth. Goldsmith and Barret (1973) have also reported favorably on white pine in New Hampshire, comparing it with lobolly pine (*Pinus taeda* L.) in southeastern United States.

The natural range of white pine is broader than that of red pine which is confined to the area of the last Pleistocene glaciation (Cook, Smith, and Stone, 1952). White pine grows from Manitoba to Newfoundland in Canada, and throughout northern and eastern United States from Minnesota to the Atlantic Coast and deep into the South along the Appalachians (Wilson and McQuilkin, 1963; Fowells, 1965). White pine has also shown successful growth as an exotic species in Europe, Asia, and New Zealand (Wright, 1970).

White pine grows on practically all soils within its natural range. Like red pine, it is closely related with well-drained sandy soils (Horton and Bedell, 1960; Horton and Brown, 1960; Wilson and McQuilkin, 1963; Fowells, 1965; Stiell, 1978). The species occurs also on loamy and silty soils either with good drainage class or without hardwood competition during the establishment period (Wilson and McQuilkin, 1963; Fowells, 1965). Horton and Brown (1960) have indicated that the growth rate of white pine is not directly associated with soil texture, but finer-textured soils are generally superior to coarser-textured soils in water-holding capacity and available nutrients. In the latter point of view, the appropriate level of soil texture is essential for the optimum performance of white pine stands.

White pine is not commonly found on soils with clayey-textured or poorly drained soils (Wilson and McQuilkin, 1963; Fowells, 1965). It is assumed that the high fertility of these soils has played a negative role in white pine plantations by encouraging the development of undesirable vegetation. On the heavier soils white pine meets severe competition from many hardwoods, since several of these species outgrow and are more shade-tolerant than the white pine. On the lighter, sandier soils fewer hardwoods compete with white pine (Hawley, 1936). Likewise, in the soils with highly productive potential, rapid growth cannot be expected without intensive management of the plantation (Wilde et al., 1965). This includes the elimination of external parasitic factors. Otherwise, the growth of white pine plantations is likely to be inversely related to soil fertility.

White pine has been commonly planted in mixture with other species. It has been pointed out that mixed plantings have several advantages over pure plantings. Mixed stands provide greater use of the productive capacity of the site, can result in the production of higher quality products, are less susceptible to serious insect and disease attack, have less risk of loss by fire, and have greater effectiveness in building up soil fertility (Hawley, 1936; Rudolf, 1950).

Growth and development of white pine in mixtures with red pine have been examined by a number of researchers in the Lake States and northeastern United States (Stevenson and Bartoo, 1940; Hicock, 1942; Skog, 1951; Graiser and Merz, 1953; Rudolph and Lemmien, 1955; Rudolph et al., 1956; Grisez, 1968). Except for Grasier and Merz (1953), all experiments showed that white pine does not perform as well as red pine in survival rate and height, diameter, and volume growth. Graiser and Merz (1953) concluded differently, stating that white pine outgrew red pine. However, they based their experiment on only five dominant and five co-dominant trees on each of the 100 plots in Ohio and Indiana. Consideration of all trees of each species might have led to different conclusions. Rudolph and Lemmien (1955) had similar results in a 20-year-old mixed white and red pine plantation at the Kellogg Forest. However, they concluded that even though white pine was taller and had greater diameter in the dominant crown class, there were fewer white pine trees in this class due to poor survival rate. Consequently, white pine may not be an important component in the total stand structure. Grisez (1968) pointed out that soil drainage class is the major factor of growth between the two species in mixed plantations. On somewhat poorly drained soils, white pine showed better height growth than red pine, but on well drained soils white pine fell behind red pine.

It is evident that suppression by red pine or other species is continuing to reduce the white pine component in such mixed plantations. The value of mixed plantings with red pine may be expected to show up more definitely under particular site conditions and later on in the life of the stand. More studies are needed to bring out more clearly the advantages or disadvantages of mixing white pine with other species in plantations.

Scotch Pine

Scotch pine (Pinus sylvestris L.) occupies a natural range larger than that of any other pine species. It grows from Scotland to the Pacific Coast of Siberia, and from Norway to Spain (Wright and Bull, 1963; Mirov, 1967). It is natural to expect that Scotch pine is more variable genetically than any other species to be commonly planted (Wright et al., 1976), mainly because it grows over such a large area and under such different environmental conditions.

Scotch pine has been planted fairly widely in the Lake States and elsewhere in the United States since early colonial times when the species was introduced to this country from Europe. It is well known that Scotch pine has its reputation for Christmas tree plantings because of ease of plantation establishment, desirable tree form, unexacting site requirements, and excellent market condition (Wright et al., 1976). Scotch pine may also prove to have potential as a pulpwood or lumber species in North America as it does in its native range. Some studies have reported that, if Scotch pine is properly managed, its growth rate is comparable to or may even exceed the growth of red pine or other native species (Grisez, 1968; Lemmien and Botti, 1974; DeHayes et al., 1980). Hundreds of hectares of Scotch pine stands intended for Christmas trees have developed beyond the Christmas tree stage in Michigan. Some, depending on seed source, may have potential for timber resources (Lemmien and Botti, 1974). Such stands can be managed to produce high quality pulpwood or sawlogs through cultural treatments. Rudolph and Lemmien (1959) obtained good response to thinning treatment in a 22-year-old Scotch pine plantation in southern Michigan. They reported that thinning had significantly increased the diameter growth of crop trees.

Even though Scotch pine has been found in extremely variable environmental conditions (Echols, 1958; Mirov, 1967), the species demands similar site conditions to red pine and white pine for successful plantations in North America. Optimum growth may be expected on well-drained loamy sand or sandy loam soils (Wright et al., 1976; Homerich, 1980). The species shows slow growth rate or stunted form on poorly drained, heavy-textured soils or deep sandy soils with poor water-holding capacity. Mirov (1967) pointed out that the species grows well on infertile sandy soils without competition from other trees, but on more fertile and moist soils, Scotch pine growth may be suppressed by competition with hardwoods.

In addition to selecting appropriate planting sites, the selection of appropriate seed sources is an important factor in successful plantations. Wright and his co-workers (1976) noted that, if the best seed sources are used, 10-20 percent more volume production can be obtained from Scotch pine than from native pine species. Provenance trials definitely indicate that hereditary characteristics are important in the growth of Scotch pine. Pest resistance and external tree form are also influenced by heredity. This is evidenced by a number of experiments in various regions of the United States. The studies provide good provenance information on which to base the selection of seed sources and varieties when Scotch pine is planted outside of its natural range (Wright and Baldwin, 1957; Wright and Bull, 1963; Ruby, 1964; Wright et al., 1976; Homerich, 1980). Wright and his collaborators (1976) have suggested, based on a Michigan provenance study, the varieties from eastern Czechoslovakia (*var. carpatica*) and from the region stretching over Belgium, northeastern France and western Germany (*var. haguenensis*) grow fast and have good stem form. According to them, an average of 76 cm (2.5 feet) of annual height growth can be expected on good sites with these varieties in Michigan.

European Larch

European larch (*Larix decidua* Mill.) is a deciduous conifer, native to central Europe. Even though the range of the species has been extended by planting as far north as Scotland and Sweden, its natural distribution is confined from southeastern France to central Rumania, and north to central Poland (Hunt, 1932; McComb, 1955). It was first introduced into the New England region in the middle of the nineteenth century, and has been planted over considerable areas in northeastern United States and eastern Canada (Hunt, 1932; Cook, 1939; Littlefield and Eliason, 1956; Lemmien and Rudolph, 1968; Barnes, 1977). A number of studies have suggested that European larch has greater potential for reforestation than native coniferous species or tamarack (*Larix laricina*) in the northeastern and Lake States regions of the United States and eastern Canada (Bushman, 1952; Cook, 1969; MacGillvrary, 1969; Sartz and Harris, 1972; Hall, 1977; DeHayes et al., 1980).

In addition to studies in Europe, the relation of European larch survival and growth to soil properties has been investigated in the United States. McComb

(1955) noted that fertility and reaction of the soil were not significant to the species' site quality; however, the soil physical properties relating to water-holding capacity and aeration were important to the growth of the species. European larch grows best on deep, well-drained soils with texture ranging from sandy loam through silt loam (Hunt, 1932; Aird and Stone, 1955; McComb, 1955). The species does not perform well on moisture-deficient soils or clayey textured and poorly drained soils (Aird and Stone, 1955). It is not suitable for planting on wet sites where native tamarack often grows (Hunt, 1932). Nevertheless, Lemmien and his co-workers (1968) established a fairly successful plantation by planting on furrow slices on a wet site in southwestern Michigan. McComb (1955) noted that the species is also capable of growing on the alkaline, naturally calcareous soils as well as on quite strongly acid soils.

Plantations established on cutover sites or bushy old-fields required weed control during the early developing stage for about 10 years (Hunt, 1932; Cook, 1955) due to the extreme intolerance of the species (McComb, 1955). Spacing for plantations must also be wide enough to obtain adequate survival and growth for this intolerant species (Morrow, 1978).

Since red pine has been planted more than any other species in the Lake States and northeastern United States, the performance of European larch is often compared with that of red pine (Grisez, 1968; Lemmien and Rudolph, 1968; Sartz and Harris, 1972). Even though red pine usually outgrows European larch on drier sandy sites (Grisez, 1968; Lemmien and Rudolph, 1968), European larch frequently shows better diameter and height growth on well-drained silt loam soils (Sartz and Harris, 1972). Cook (1969) also reported that on a suitable well-drained soil of loam texture in New York European larch was twice the height of red pine and Norway spruce only five years after planting.

Both diameter and height growth tend to have a much wider range in European larch than in red pine (Lemmien and Rudolph, 1968). With this tendency, Sartz and Harris (1972) noted that the growth of red pine may not differ significantly with site quality, but that European larch growth varies significantly with site.

European larch is a deciduous species which produces a large amount of litter cover with its annual needle fall. Sartz and Harris (1972) found that the amount of litter in a larch plantation was twice as much as that in a pine plantation. The thick layer of litter helps to insulate the soil against freezing and to aid the percolation of rainfall and melting snow.

Because of this hydrologic effect, European larch has a great potential for use in watershed management.

Intensive site preparation, weed control, and insect and disease control should be carried out for successful establishment of European larch plantations (Cook, 1969; DeHayes et al., 1980). Besides cultural practices, the importance of using suitable seed source has been recognized for the species (Cook, 1955, 1974, 1975; McComb, 1955; Barnes, 1977). The variability of seed sources is closely related to the macroclimate of their origin, especially latitudial and elevational factors (Barnes, 1977). A desirable provenance is essential as recommended seed sources must be based on extensive testing over a wide range of environments (Teich and Holst, 1973; Barnes, 1977).

White Spruce

White spruce (Picea glauca (Moench) Voss) is medium-sized and one of the most widely distributed native coniferous species in North America. The species ranges from Alaska to Newfoundland, in most of the boreal forest region of Canada, the northern Lake States, and New England (Fowells, 1965; Nienstaedt, 1957). Since the wood of white spruce has long fibers, the species produces pulp and paper products of high quality (Fowells, 1965; Nienstaedt and Teich, 1971). But it has not been planted as widely as the pines in the Lake States, mainly because of slower growth rate and more exacting site requirements than pine species (King and Rudolf, 1969).

White spruce grows naturally on a variety of soils ranging from heavy clays to alluvial plains where it reaches its best development (Fowells, 1965). However, the most successful plantations of the species occur on loamy soils which have optimum moisture and nutrient levels. If water relationships are not a limiting factor, the species will show moderate growth on sandy or clayey soils. It tends to tolerate a wide range of moisture conditions, but its growth will be stunted and scrubby on both very wet and very dry soils (Nienstaedt, 1957). Wilde and his co-workers (1965) have agreed with these findings, and have noted that excessively well-drained, coarse sandy soils are generally unsuitable for white spruce. Most plantations in Wisconsin supported by these soils have shown annual height growth of less than 23 cm (9 inches). These authors also pointed out that extremely slow growth can occur on fertile soils where competition from hardwood species is severe.

In addition to a suitable site, the combination of a desirable seed source and adequate care after planting will result in high survival and growth (Wright et al., 1977; Nienstaedt, 1981). Variations in height and diameter development are often dependent on the seed origin. In a Michigan study, Wright and his collaborators (1977) have suggested that local seed sources are not always the best. Seed sources from Ontario, Quebec, and Maine have shown better growth, both in diameter and height, compared with Michigan seed sources. King and Rudolf (1969) have derived similar results from a study in northeastern Wisconsin.

When established in an even-aged plantation, white spruce stands need thinning to increase growth rates, to reduce mortality, and to produce desirable crop trees. A number of studies have strongly suggested the necessity of thinning in plantations (Stiell, 1965; Frank, 1973; Stiell, 1980). Frank and Bjorkbom (1973) have recommended initial thinning at 25 to 35 years of age, followed by periodic thinning at 10-to 20-year intervals for best results. Day (1972) also agreed that, in order to be biologically effective, thinning treatment should be done at an early stage in stand development and continued on a relatively frequent basis.

In general, white spruce stands of various ages and in various locations have responded positively to thinning. Cleve and Zasada (1976) reported a significant increase in basal area increment over the unthinned control in a 70-year-old thinned stand in Alaska. By the end of the first growing season after thinning, the diameter increment in thinned plots was 2.6 greater than that in unthinned control plots. Rapid response to thinning has been also reported.in a 70-year-old stand in Maine by Frank (1973). He found evidence of response to thinning in the first year. Significantly different annual growth was noted in the third year after treatment, and growth differences peaked in the ninth year after thinning. It is evident that heavy thinning intensities result in greatly increased diameter increment, especially in young stands. Berry (1968) attained maximum diameter increment with a residual basal area of approximately 19.1 square meters per hectare (83 square feet per acre) in a 30-to 35-year-old stand. Day and Rudolph (1974) used three different thinning methods for planted white spruce. Although all thinning treatments accelerated growth, removing every other row resulted in the greatest increase in growth rate. It was also a more convenient thinning method than residual basal area methods.

Norway Spruce

Norway spruce (*Picea abies* (L.) Karst), a native of Europe, has a narrower natural range than Scotch pine, but the distribution has been extended by planting.

Norway spruce has been one of the first introduced and most widely planted non-native coniferous species in northeastern United States since the 1860s. Many of the first plantings were made with stock from Germany (Hosley, 1936). The species is characterized by a straight and seldom-forked stem and high wood quality, especially for pulp and paper. This suitability along with its good growth rate makes the species highly desirable for pulpwood plantations.

The growth rate of Norway spruce has been compared with some native coniferous species in many field experiments in the United States and Canada (Hosely, 1936; Hawley and Lutz, 1943; Hughes and Loucks, 1962; King and Rudolf, 1969; Hughes, 1970; DeHayes et al., 1980). The species is superior to native spruces and firs such as white spruce, red spruce, black spruce, and balsam fir. Compared with other conifers, Norway spruce has retained its reputation as a useful species for a planting in northeastern and northcentral United States, but not in the West (Fowler and Coles, 1980). One limitation in growing Norway spruce is its greater susceptibility to damage by the white pine weevil and the spruce budworm than native spruces. Winter injury and windthrow are also serious problems for plantations in some regions (Hosley, 1936; Grisez, 1968; Hughes, 1970; DeHayes et al., 1980; Fowler and Coles, 1980).

Norway spruce is capable of maintaining good survival and growth on appropriate sites in the Lake States and the northeast. The species requires loamy soils with an abundant supply of moisture and nutrients but with adequate aeration and preferably an acid soil for the best growth (Hosley, 1936; Wilde et al., 1965). The species is less suited to sandy, heavy-textured or poorly drained soils where slower growth will result. Moisture extremes should be avoided (DeHayes et al., 1980; Day, 1980; Fowler and Coles, 1980). Grisez (1968) reported an outstanding plantation (site index-70) at the bottom of a slope on deep, moderately well to somewhat poorly drained silt loam soils.

In addition to a suitable site, successful plantations depends on careful control of competing vegetation in the early development stage (Wilde et al., 1965) and the use of nursery stock grown from seed of a desirable provenance (King and Rudolf, 1969; Fowler and Coles, 1980). In the selection of a seed source, both high growth rate and resistance to adverse climatic and edaphic influences should be given consideration. Higher production than with many other species is possible when the provenance of Norway spruce planting stock is adapted to the climate and soils. King and Rudolf (1969) have suggested that Polish provenances are best for plantations in the Lake States region.

Since Norway spruce is a fairly tolerant species, the mortality is very low even in dense stands. To avoid stagnated growth because of overstocking, thinning is essential for increasing diameter growth and for producing high quality crop trees as well as intermediate yields (Hosely, 1936; Hughes and Loucks, 1962; Hughes, 1970). Hosley (1936) has recommended that even though a stand originally spaced 3 by 3 meters (10 by 10 feet) or wider may not need to be thinned before 50 years, a closely spaced stand should be thinned when dead lower branches constitute 50 to 60 percent of total tree height. Pruning also should be done to produce high quality crop trees because very little natural pruning takes place in this species.

THE W. K. KELLOGG EXPERIMENTAL FOREST

The W. K. Kellogg Experimental Forest, owned by Michigan State University, is located in Ross Township of northeast Kalamazoo County, Michigan (Township 1 South, Range 9 West, Michigan Principal Meridian) (Figure 1). The forest consists of approximately 234.6 ha (602 acres) of rolling land. The forest has been managed by the Department of Forestry since 1932. First efforts by the department were to establish tree cover on the eroded hills that had been abandoned for agricultural use. The Kellogg Forest was selected for this study because it is a good example of land resource management with plantations of useful tree species on once abandoned agricultural land (Figure 2).

Climate

The climate at the Kellogg Forest is cool and humid, which is the general climate in the southern Great Lakes Region of North America. However, extremes of temperature are relatively uncommon. The climate is modified locally because of proximity to the Great Lakes. Prevailing westerly winds from Lake Michigan

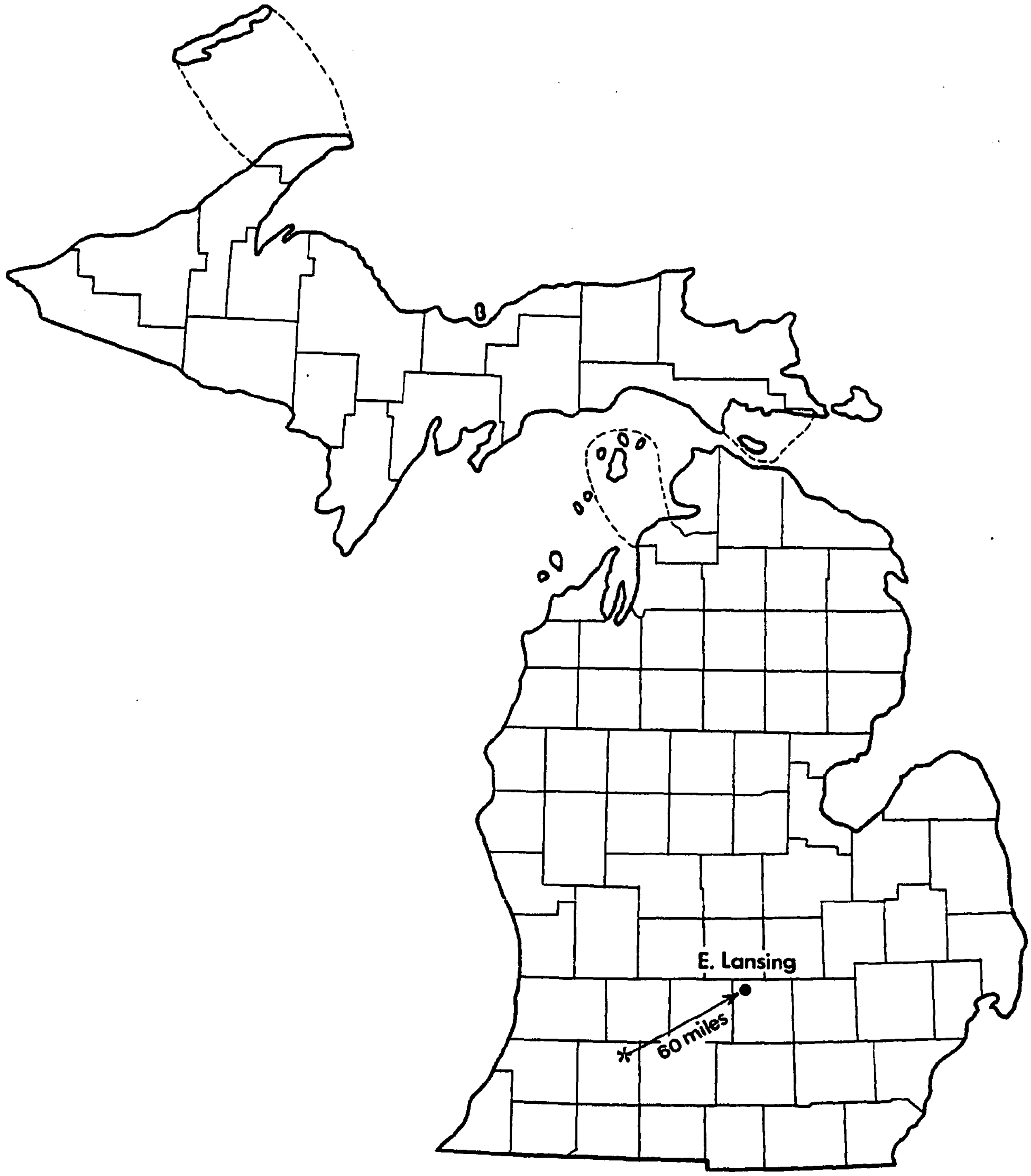


Figure 1. Location of the W. K. Kellogg Experimental Forest in Michigan.

* The W. K. Kellogg Experimental Forest

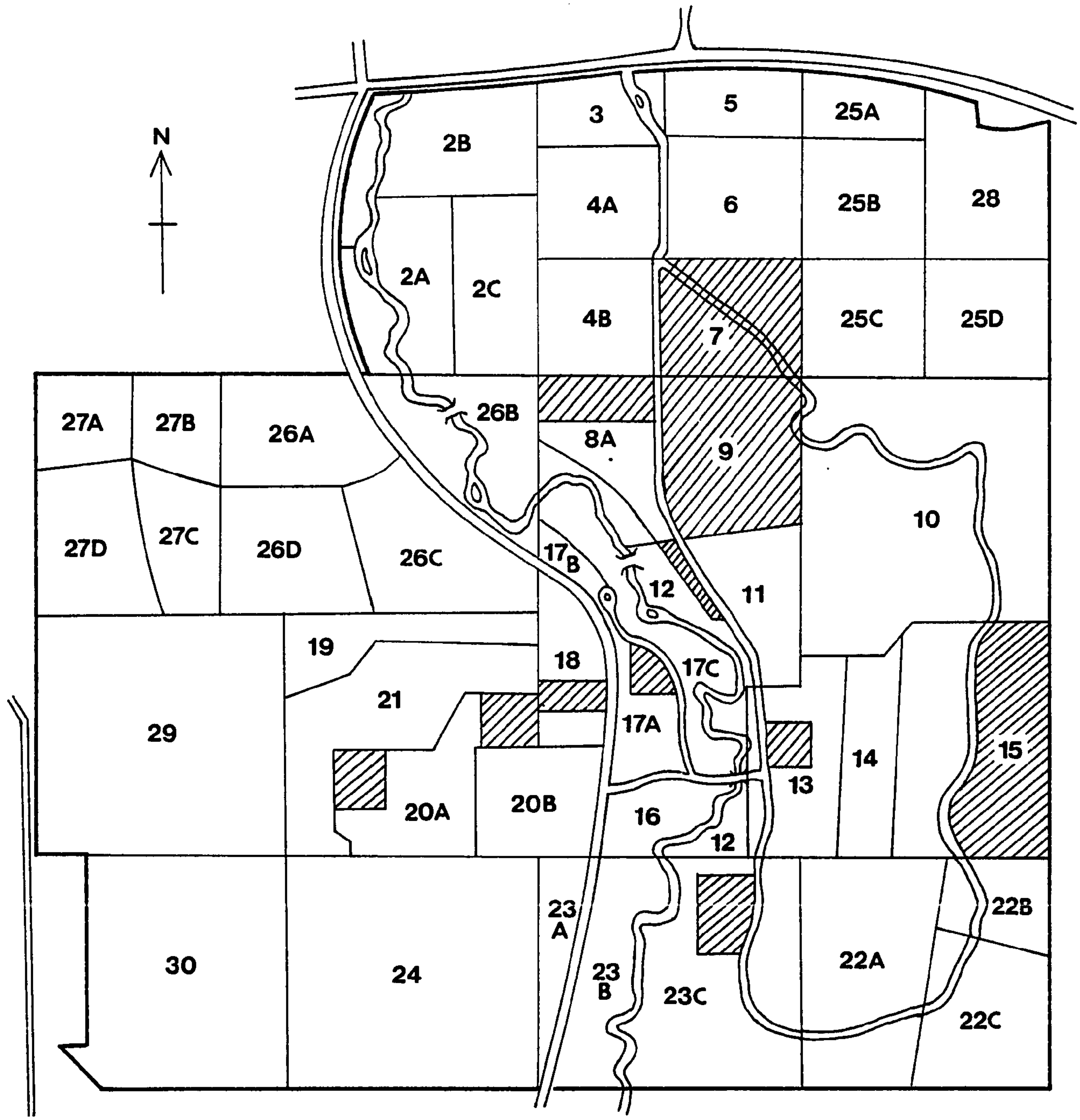


Figure 2. Map of the W. K. Kellogg Experimetal Forest. Shaded areas indicate selected plantations.

are warmed in the winter and cooled in the summer while crossing the lake, moderating the climate considerably (Eichmeier, 1963).

According to the meteorological survey record for a 20-year period at Kalamazoo, the summer average temperature is 21.9 degrees C (71.4 degrees F), and the average daily maximum temperature is 28.5 degrees C (83.3 degrees F). In winter the average temperature is -2.8 degrees C (27.0 degrees F), and the average daily minimum temperature is -6.9 degrees C (19.6 degrees F). The average annual precipitation is 87.4 cm (34.4 inches). Of this total, an average 50.8 cm (20.0 inches), or 58 percent, usually occurs during the warm season, from April through September. Snowfall averages about 181.4 cm (71.4 inches) (USDA, 1979).

Soil

The soils of the Kellogg Forest are the ultimate product of climatic conditions in this area. The soils in the forest differ from those formed in a moist and hot climate or in a dry and warm climate. The features of weathering, leaching, and organic matter decomposition, which are primarily regulated by climate, determine most of the soils' chemical and physical properties.

The parent material of the soils on the area was deposited by glacial drift of the Wisconsin age, formed in glacial outwash and morainic phases. Some of these materials have been shifted by subsequent action of water and wind. The soil properties vary greatly, depending on how the material was deposited. Irregular morainic relief is typical, composed of mostly sandy to gravelly, somewhat calcareous materials. The land is generally undulating to steep. Soils are mostly well drained or somewhat excessively drained; subsoils are sandy or loamy and sandy.

The soils of the Kellogg Forest are primarily Kalamazoo and Oshtemo series of the Hapludalf great groups. The Kalamazoo series (a fine-loamy, mixed, mesic, Typic Hapludalf) consists of well drained soils that are moderately permeable in the upper portion and rapidly permeable in the lower portion of the profile. They were formed from loamy material over sandy material. The surface layer is dark grayish-brown loam about 28 cm thick. The subsoil is dark yellowish-brown and dark brown sandy loam to clay loam about 110 cm thick. The available water-holding capacity is moderate, and fertility is correspondingly fair. Reaction ranges from medium acid (pH 5.6-6.0) to neutral (pH 6.6-7.3) to a depth of 140 cm. The characteristics of the Oshtemo series (a coarse-loamy, mixed, mesic Typic Hapludalf) are very similar and adjacent to the Kalamazoo soils, but Oshtemo soils have less clayey material in the profile than the Kalamazoo soils and are more droughty. They were formed from sandy materials. The surface layer is dark-brown sandy loam 22 cm thick. The subsurface layer is yellowish-brown sandy loam about 25 cm thick. The subsoil consists of dark-brown sandy loam to yellowish loamy sand. Average moisture availability is moderate. The soil acidity varies from slightly acid (pH 6.1-6.5) to neutral (pH 6.6-7.3) to a depth of 170 cm or more.

Topography

The topography of the Kellogg Forest is mostly rolling and typical of the unstratified morianic hill forms, much like most of southern Michigan. Slope gradients vary, ranging from gently rolling to steep, occasionally as steep as fifty percent. Natural drainage of soil ranges from excessively drained on the ridgetops to very poorly drained in small depressions near Augusta Creek. The glacial deposits are so thick that no bedrock is exposed or occurs near the surface of the soil. In some cases the original topography has been modified by accelerated soil erosion caused by improper use of the land until the early twentieth century.

History of Land Use

The area in which the Kellogg Forest is located was settled about 1835-1840. The land had been cleared for farming or pasturing, except for 24.3 ha (60 acres) of hardwoods which were kept as farm woodlots. Agricultural activity continued for many years prior to 1929, typical of land use history in much of southern Michigan. The original hardwood forests, mainly oak-hickory type in this area, were cleared for agriculture by the end of the nineteenth century. Declining yields and income from cultivation led to abandonment of eroded farm land by the early 1930's.

The abandonment of fields for farming was primarily due to misuse of the land which was too steep for agricultural purposes. Serious degradation of the land and its productivity by erosion occurred when much of the fertile soil surface was lost.

Mr. W. K. Kellogg and the Kellogg Foundation of Battle Creek purchased and donated the original property to Michigan State University in 1932. In succeeding years, Michigan State University has added to the forest, primarily by purchases from adjacent landowners. Mr. Kellogg expressed the desire that the property would be used to illustrate the rehabilitation and use of such eroded land by appropriate land management practices. He thought that the land's productivity could be restored by forest establishment and management.

Under the management of the Department of Forestry, forest plantations of many species have been established throughout the property. Most plantings have been established with research as well as demonstration objectives in mind.

DESCRIPTION OF STUDY PLANTATIONS

A total of twelve plantations of six coniferous species was included in this study: one mixed red and white pine stand, three red pine stands, two Scotch pine stands, three European larch stands, one white spruce stand, and two Norway spruce stands. These plantations were established between 1932 and 1940. All early established plantations in the forest are fairly successful and productive at this time. Detailed planting, replanting, and site preparation information for each plantation are listed in Table 1.

Red and White Pine--Compartment 7

A red and white pine mixed plantation was established with 2,990 red pine and an equal number of white pine seedlings on 3.6 ha (8.8 acres) in May, 1932. The area is characterized by gently sloping to very steep topography with gradients ranging from 5 to 30 percent. The general aspect is west. Before the planting was made, soil erosion had been so severe that several deep gullies had formed on the central portion of the area. The soil is composed of Oshtemo sandy loam on the steeper upper east portion and

Table 1. Data for planting, replanting, and silvicultural treatment by compartment in each plantation.

Plantation	Compart-ment	Initial Planting: Area (ha)	No. of seedlings per ha.	Stock used	Spacing (mxm)	Date planted	Replanting: No. of seedlings	Stock used	Spacing (mxm)	Date planted	Site preparation	Pruning	Initial thinning
Red & white pine	7 Red	1.8	1,680	3-0	2.4x2.4	May '32	595	2-2	replace	Apr. '35	furrowing	1948 & 1952	1968
	White	1.8	1,680	3-0	2.4x2.4	May '32							
Red pine	8A	1.5	2,471	2-0	1.8x2.4	Apr. '37					furrowing		1960
	9	2.4	2,306	2-0	1.8x2.4	May '36	3,000	2-0	1.8x1.8	Oct. '36	furrowing		1960
	15	2.5	2,511	2-0	1.8x1.8	Oct. '36 May '37					furrowing scalping		1960
Scotch pine	18			2-0		Apr. '38							1955
	20A	0.4	2,471	2-0	1.8x2.1	Apr. '38							1955
European larch	8A	0.8	2,471	2-0	1.8x2.4	Apr. '37					furrowing		1965
	13	0.2	2,471	2-0	1.8x2.4	Apr. '37					furrowing		1965
	20A	0.2	2,471	2-1	1.8x2.4	Oct. '37					furrowing		1965
White spruce	17A	0.3	2,318	2-0	1.8x2.4	May '38							
Norway spruce	11	0.4	2,347	3-0	1.8x1.8	Apr. '38						1950	
	23C					Apr. '40							

Hillsdale sandy loam on the less steep lower west portion.

The planting stock of both species consisted of 3-year-old seedlings, 13 to 25 cm (5 to 10 inches) tall, grown at the Michigan State College nursery, East Lansing. The red pine seedlings were of fair quality with well developed tops and moderately well developed root systems, but the white pine seedlings were rather poor, with only fairly well developed root systems and somewhat spindly tops which had a pale green color. Vegetation at the time of planting was somewhat sparse, consisting mostly of June grass, goldenrod, sorrel and some annual herbs. This cover varied in density from 40 to 75 percent. The soil was moderately moist throughout the period of planting. The west half of the planting site was furrowed in a north-south direction where the sod cover was relatively heavy, resulting in general cross-slope furrows. The trees were hole-planted in the bottom of the furrow, using a shovel to open the holes. The remainder of the area was not furrowed; the trees were spot-planted in holes. The spacing was 2.4 by 2.4 m (8 by 8 feet).

Even though initial survival was good, in April of 1935, 393 red pine trees, approximately 124 trees per hectare (50 trees per acre) were replanted where the trees of the original planting had died. The planting stock was 2-2 transplants grown at the same place as the original planting stock. After an additional growing season, survival was 88 percent for red pine, based on the initial planting and replanting, and 57 percent for white pine.

Silvicultural practices other than protection were confined to crop-tree pruning until the stand was 20 years old. In 1948, an average of 297 crop trees per hectare (120 trees per acre) were selected and pruned to a height of 2.3 m (7.5 feet). In 1952, these trees were pruned again, clearing an additional 1.5 m (5 feet) to a height of 3.8 m (12.5 feet).

A thinning study was begun in 1968 to determine the optimum residual basal area for an older red pine and white pine mixed plantation. The planting was 36 years old at that time. The experiment was a randomized block design with six replicates and five treatments per block on 0.0405 hectare (0.1 acre) plots. Except for the unthinned control, thinning was done to residual basal areas of 20.7, 25.3, 29.8, and 34.4 square meters per hectare (90, 110, 130, and 150 square feet per acre). Remeasurements and further thinning were done in 1973 and 1978.

Red Pine--Compartment 8A

A red pine plantation was established with 3,800 seedlings on the west side of the main road in April, 1937. The area consists of 1.5 ha (3.8 acries) characterized by gently to moderately sloping topography, ranging from 3 to 15 percent slopes. Representative soils are Oshtemo sandy loam and Ockley loam, both in the well-drained class.

The seedlings were planted in furrows plowed on the contour in the spring. The planting stock was 2-year-old seedlings grown at the College nursery in East Lansing. The spacing was 1.8 by 2.4 meters (6 by 8 feet). Since the initial survival rate was fairly good, it was not necessary to replant.

A thinning study was begun in 1960 to evaluate the growth and yield of the stand. The plantation was 23 years old at that time. The thinning study included other red pine plantations in Compartments 9 and 15. A randomized block design was used with four replicates and nine treatments per block on 0.0405 ha (0.1 acre) plots. The treatments were residual basal areas of 16.1, 207., 25.3, and 29.8 square meters per hectare (70, 90, 110, and 130 square feet per acre); row thinnings removing every other row, every third row and every fourth row with later selection thinnings;

row thinnings removing every fourth row followed by removal of the center row in each group of three rows remaining; and unthinned controls. Residual basal area plots of 20.7, 25.3, 29.8 square meters per hectare (90, 110, 130 square feet per acre) and row thinnings removing third and every fourth row were remeasured and rethinned in 1967, 1974, and 1980. Residual basal plots of 16.1 square meters per hectare (70 square feet per acre) and alternate row thinning plots were remeasured and rethinned in 1970 and 1980.

Red Pine--Compartment 9

Fifty-six hundred red pine seedlings were planted on 2.4 hectares (6 acres) of eroded steep slopes in May, 1936. The area is composed of a hill top and very steep slopes, ranging up to 45 percent gradients with the general aspect being southwest. The soil is a very gravelly and coarse-textured Oshtemo sandy loam in the well drained class. Since the area was severely eroded and sod had formed a heavy cover over most of the area, the planting site was furrowed on contour at about 1.8-meter (6-foot) intervals. The planting stock was 2-years-old seedlings in good condition with well developed tops and roots, grown at the College nursery in East Lansing. The spacing was 1.8 by 2.4 meters (6 by 8 feet). Trees were hand-planted in the furrows with spades, planting bars, mattocks, and shovels.

Records show that, in the fall of 1936, the mortality rate was 53 percent, and in the spring of 1937, the mortality rate reached 87 percent. For this reason, replanting was tried in October, 1936, where the trees of the initial planting had died. Three thousand red pine seedlings, mostly in good condition, were used for the purpose. The spacing was 1.8 by 1.8 meters (6 by 6 feet). The soil condition was very moist at the time of planting from frequent September and October rains.

At age 23, this plantation was included in a thinning study with other red pine plantations in compartments 8A and 15.

Red Pine--Compartment 15

A red pine plantation was established on the eastern portion of this compartment with 1,000 seedlings planted in October 1936, and 5,300 seedlings planted in April and May of 1937 on a total area of 2.5 hectares (6.2 acres). The area has varied topography. Slope on the area ranges from nearly level to steep, up to 35 percent gradients. Most slopes face to the east and south. The soil is well-drained Oshtemo sandy loam with some gravel in a portion of the area.

At the time of planting, the site appeared rather sterile with little plant cover. The soil surface was severely eroded in some places. The planting stock was 2-year-old seedlings in good condition with adequate root and top ratios. The spacing was 1.8 by 1.8 meters (6 by 6 feet). Furrowing and scalping were employed for site preparation at the time of planting. Unlike other pine plantations of this compartment, the red pine planting was fairly successful so that it was not necessary to make replantings.

A thinning study begun in 1960 when this plantation was 23 years old combined this plantation with other red pine plantations in Compartments 8A and 9.

Scotch Pine--Compartment 18

Approximately 600 Scotch pine seedlings were planted in a part of this compartment in April, 1938. The site is characterized by moderately sloping terrain, ranging from 8 to 15 percent slopes. The soil is well-drained Oshtemo sandy loam. The planting stock was 2-year-old seedlings grown at East Lansing. The seed source is not known, but it was probably Germany or Belguim.

A thinning study, begun in 1955 when the plantation was 17 years old, combined this plantation with other Scotch pine stands in Compartment 20A. Their total area is slightly more than 0.8 hectare (2 acres). The study was planned to determine an appropriate thinning regime for pulpwood and sawtimber. The thinning has been done every 5 years, by cutting back to 14.9 square meters per hectare (65 square feet per acre) and 19.5 square meters per hectare (85 square feet per acre). An unthinned control was included in the study. The experiment was a randomized block with three replicates and three treatments per replicate on 0.0405-hectare (0.1-acre) plots. Crown thinning was done in 1955, 1960, 1965, and 1970. Although a severe ice storm damaged most of the plots in 1974, the study has been continued, and remeasurement and rethinning were carried out in 1975 and 1980.

Scotch Pine--Compartment 20A

A Scotch pine plantation was established in a part of Compartment 20A in April, 1938 on a gently sloping area, ranging from 0 to 6 percent gradients. The soil is Oshtemo sandy loam and it is well-drained. The planting stock was 2-year-old seedlings, but seed source is unknown. The spacing was 1.8 by 2.1 meters (6 by 7 feet), equivalent to approximately 2,570 trees per hectare (1,040 trees per acre).

Mortality during the next 18 years after planting averaged about 30 percent, leaving around 1,730 trees per hectare (700 trees per acre). A thinning study in this and other Scotch pine stands in Compartment 18 was begun in 1955 when this plantation was 17 years old.

European Larch--Compartment 8A

This European larch plantation, directly east of the main road, was established with 2,000 seedlings on approximately 0.8 hectare (2 acres) in April, 1937. The area is moderately sloping with 5 to 12 percent gradients, with the general aspect being west. The soils are Oshtemo sandy loam and Ockley loam, both in the well-drained class.

The planting stock was 2-year-old seedlings, but the origin of the seed is unknown. The spacing was 1.8 by 2.4 meters (6 by 8 feet). The planting site was furrowed in a north-south direction to prepare for hole-planting in the furrows. The stand had shown good survival and growth for the first 20 years after planting. Average DBH of the stand was 15.0 cm (5.9 inches) and height was 11.6 m (38 feet) in December, 1956.

With the objective of determining an appropriate thinning regime, a thinning study was begun in 1965 when the plantation was 28 years old. Other European larch stands in Compartments 13 and 20A were included in the study. The study utilized a randomized block design with three replicates and three treatments, including residual basal areas of 18.4 and 25.3 square meters per hectare (80 and 110 square feet per acre), and an unthinned control on each 0.0405 hectare(0.1 acre) plot.

The plots have been remeasured and rethinned every 5 years. For the past 15 years, the trees have been attacked by larch sawfly to some degree, but control measures do not appear to be practical at this time.

European Larch--Compartment 13

A European larch plantation was made with other hardwood and coniferous plantings in this compartment in April, 1937. Five hundred larch seedlings were planted on 0.2 hectare (0.5 acre) of moderately sloping area with the general aspect being west. The soils are composed of Oshtemo sandy loam and Ockley loam of the well-drained class. The planting site was furrowed in a north-south direction. The planting stock was 2-year-old seedlings, and the spacing was 1.8 by 2.4 meters (6 by 8 feet). The seed source is unknown.
A thinning experiment was started in this compartment in 1965 when the stand was 28 years old, along with other European larch plantations in Compartments 8A and 20A. This stand has also been defoliated to some extent for the past 15 years by the larch sawfly. Some efforts were made to control the insect in this plantation with a chemical spray with moderate success.

European Larch--Compartment 20A

About 500 European larch seedlings were planted on 0.2 hectare (0.5 acre) in November, 1937 on an area with moderate slopes. The slopes range from 6 to 15 percent gradients with the general aspect being northwest. The soil is well drained Oshtemo sandy loam. The site was furrowed in an east-west direction for hole-planting. The planting stock was 2-1 transplants, and the spacing was 1.8 by 2.4 meters (6 by 8 feet). The seed source is unknown. A thinning study begun in 1965 when the plantation was 28 years old, included other European larch stands in Compartments 8A and 13. This stand has also been damaged by larch sawfly for the last 15 years.

Norway Spruce--Compartment 11

A Norway spurce stand was established in April, 1938, with 1,150 3-year-old seedlings. They were hand-planted on 0.5 hectare (1.2 acres). The seed source is unknown. The terrain is characterized as gently sloping to the west. The soil is well-drained Ockley loam. The trees were pruned to increase their quality in February 1950, when the planting was 12 years old. Long handled pruners were used and limbs were removed to an average height of 1.5 meters (5 feet). Except for the pruning, the plantation has not received any other silvicultural practics.

Norway Spruce--Compartment 23C

A plantation of Norway spruce was made on a nearly level to gently sloping area of well-drained Oshtemo sandy loam soil. The seed source is not known. The stand has grown without any silvicultural treatments. Additional information is not available for this plantation.

White Spruce--Compartment 17

Seven hundred and fifty white spruce seedlings were planted on 0.3 hectare (0.8 acres) in May 1937, on a gently sloping area, ranging from 2 to 5 percent gradient. The soil is Ockley loam, well drained. The planting stock was 2-year-old seedlings. The spacing was 1.8 by 2.4 meters (6 by 8 feet). The seed source is unknown.

For the first 20 years, many of the trees in this planting were stunted in growth and had very poor foliage color, especially the trees adjacent to a hardwood stand along the picnic area road. In the fall of 1958, 0-20-20 (N-P-K) fertilizer was applied to the four rows on the east side bordering the hardwood stand. In the fall of 1959, evenly mixtured 12-12-12 fertilizer was applied again to the trees in these same four rows and ammonium nitrate (NH_4NO_3) was also applied to all trees in these rows. A home mixture of 15-20-20-fertilizer was applied to the remainder of the poorer trees in the plantation. Most of the sicklier-looking trees were in the eastern half of the stand. Except for fertilization, the stand has not had any silvicultural treatment.

STUDY METHOD

Field data were collected during the summers of 1981 and 1982 from twelve plantations of six species, all older than 40 years. Planting and managerial information were obtained from records at the Kellogg Forest and interviews with the resident forester.

Plot Selection

Thinning studies have been conducted in plantations of mixed red and white pine, red pine, Scotch pine, and European larch. Each thinning treatment was applied on permanent plots of approximately 0.0405 ha (0.1 acre). The mixed red and white pine stand has six blocks with five thinning methods; the red pine plantations have four blocks with nine thinning methods; Scotch pine and European larch stands have three blocks with three thinning methods each. The Norway spruce and white spruce plantations have not had any thinning treatment yet, so one temporary 0.0405 ha (0.1 acre) rectangular plot was randomly established in each plantation.

Among various thinning treatments, the most productive treatment, in terms of periodic volume production per unit area, was selected for comparison and analysis of growth and yield for the six species. In the red pine plantations, row thinning treatments were not included in this study, but only basal area treatments were selected.. The numbers of selected sample plots and basal areas are listed in Table 2.

Data Collection

Diameter at breast height (DBH)--137 cm (4.5 feet) above ground--was measured and recorded for each tree in each selected plot. Measurements were made with a diameter tape to the nearest 0.254 cm (0.1 inch). All basal area data and volume data were derived from the tree diameter measurements.

Ten trees in each sample plot were randomly selected for measuring total height and merchantable height. For the last usable portion of the tree stem, merchantable height was taken to a minimum top diameter of 10 cm (4 inches). Height measurements were taken to the nearest 30 cm (1 foot) with a relaskop. These measurements were used for computing tree volumes.

Edaphic and topographic data for each plot were collected to examine the effect of site condition on the growth of the species. A soil pit was dug at or near the center of each plot. For each soil horizon, depth, texture, and structure were determined, and

Table 2. Number of plots and residual basal area in thinned plots.

Plantation	Compartment number	Control plots	Thinned plots	Total no. of plots	Basal area* $m^2/ha(ft^2/ac.)$
Red pine	8A	1	1	2	30.0(130)
	9	1	1	2	30.0(130)
	15	2	2	4	30.0(130)
Red & white pine	7	6	6	12	30.0(130)
Scotch pine	18	1	1	2	19.5(85)
	20A	2	2	4	19.5(85)
European larch	8A	1	2	3	25.3(110)
	13	1		1	25.3(110)
	20A	1	1	2	25.3(110)
White spruce	17	1		1	
Norway spruce	11	1		1	
	23C	1		1	
Total		19	16	35	

* Residual basal area for selected thinned plots

the amount of gravel by volume was estimated. Depth to mottling was recorded and drainage class was also estimated. Procedures and field techniques in the 'Manual of Soil Classification' written by Lemme and Mokma (1980) of the Crop and Soil Science Department at Michigan State University were followed. Soil acidity was taken by a 'soil acidity field test kit.' Slope and aspect were observed and measured with a relaskop near the center of each plot.

Recognizable understory vascular plant species, including grasses, sedges, herbs, shrubs, and trees were recorded by frequency, coverage, and density in each plot. For this purpose, a rectangular, 10 square meters, sampling plot (2.24 m X 4.47 m) was randomly established on each selected plot. All the plants in the sampling plot were identified and listed. Selected plots for the study of understory vegetation are listed in Table 3.

Data Computation and Analysis

Volumes of ten randomly selected trees in each plot were calculated and used to compute volume per unit area. 'Volume Factor Table' (Appendix B) with 10.0 basal area factor developed by Beers and Miller (1966) and area of circles in square feet were employed for volume calculations.

Table 3. Selected plantations and number of sampling plots(10 m^2) for the study of understory vegetation.

Plantation	Compartment number	Control plots	Thinned plots	Total no. of plots
	8A	1		1
Red pine	9		1	1
	15	1	1	2
Red & white pine	7	1	1	2
Scotch pine	18		1	1
	20A	1		1
	8A	1	1	2
European larch	13	1		1
	20A		1	1
Total		6	6	12

The volume factor table was constructed by the following equation,

$$Fv = V\left(\frac{F}{G}\right)$$

where Fv = volume factor

V = tree volume in cubic feet

F = basal area factor, 10.0

G = areas of circles in square feet = $\frac{\pi D^2}{4(144)}$

D = DBH in inches

Each tree volume was simply calculated using the transposed equation

$$V = \frac{Fv \cdot G}{F}$$

For a 10.0 basal area factor, the tree volume equation taken from Beers (1964) is:

$$V = 92\left(\frac{D(D+190)}{10^5}\right)\frac{1}{10^2}\left(\frac{H(168-H)}{64} + \frac{32}{H}\right)$$

where V = tree volume

D = DBH in inches

H = tree height in feet

The CDC 6500 Computer at Michigan State University was used to analyze the results of the study. Regression, correlation, and analysis of variance for volume equations as related to diameter and merchantable height were performed for each plot and species. For every sample plot, all data for each individual tree was printed out by the computer, including diameter, total height, basal area and volume in English unit. In addition, the average diameter, number of trees, average total height, basal area and volume were obtained in English units in each diameter class and total per unit area. The computer program was modified by Rudolph (1981).

RESULTS

Because of plantation differences in ages, site conditions, and silvicultural treatment, only limited statistical methods of data analysis could be used for this study. The conventional analysis of variance could not be employed for comparing growth among selected species, for development of understory vegetation, or for site groupings for a specific species. Therefore, the study results are presented in sets of tables in which the data on growth and yield are summarized without statistical analysis for the selected species.

Growth and Yield of Selected Plantations

Number of Trees

The average number of trees per unit area varied greatly from one species to another (Table 4). In stands where no thinning practices have been carried out, stocking ranged from 857 trees per hectare (347 trees per acre) in Scotch pine plantations to 1,717 trees per hectare (695 trees per acre) in pure red pine plantations. In Scotch pine stands, an average of 296 trees per hectare (120 trees per acre) were lost as a result of a severe ice storm in 1974, but

Table 4. Average number of trees planted, thinned, residual after thinning, total produced in unthinned and thinned stands, by species.

Species		Stand age	Unthinned stands: Trees planted	Unthinned stands: Residual in 1981	Unthinned stands: SD*	Unthinned stands: survival rate	Thinned stands: Residual in 1981	Thinned stands: SD*	Thinned stands: cut by thinning	Thinned stands: SD*	Thinned stands: Total trees produced	Thinned stands: SD*	Thinned stands: survival rate
			(trees/ha)	(trees/ha)	(trees/ha)	(%)	(trees/ha)	(trees/ha)	(trees/ha)	(trees/ha)	(trees/ha)	(trees/ha)	(%)
Red pine		45	2,429	1,717	77	70.7	642	138	1,218	203	1,860	111	76.6
Red & white pine	Red	50	840	630	146	75.0	358	75	341	76	699	100	83.2
	White	50	840	247	88	29.4	82	46	160	84	242	69	28.8
	Both	50	1,680	877	106	52.2	440	43	501	84	941	116	56.0
Scotch pine		44	2,471	1,153**	185	46.7	329	14	1,267	203	1,596	262	64.6
European larch		45	2,471	1,366	299	55.3	667	74	717	65	1,384	25	56.0
White spruce		44	2,318	1,631	--	70.4							
Norway spruce		43	2,347	1,186	140	50.5							

* Standard deviation for number of trees between plots.

** Includes 296 trees damaged by ice storm in 1974.

these have been included in the residual trees shown.

The highest proportion of planted trees remaining in unthinned stands, 75 percent, was recorded for red pine in a mixed red and white pine stand. This was influenced by some supplementary planting made three years after the initial planting to replace trees which had died. Similarly, the 71 percent survival rate recorded in unthinned pure red pine stands was affected by replacing one of the stands one year after the failed initial planting. The unthinned white spruce stand, however, had 70 percent survival rate without any replanting.

Thinning treatment increased the total number of utilizable trees produced (residual trees plus trees removed in thinning) in red pine, in the red pine component of mixed red and white pine, and Scotch pine. The total number of utilizable trees produced was not affected by thinning in either the white pine component of mixed red and white pine or in European larch stands. No white spruce or Norway spruce were thinned, so no observation regarding the effect of thinning on the number of trees produced can be made for these species.

In general, it appears that thinning increases the total number of utilizable trees produced. Not only does thinning remove trees likely to be lost to mortality over an ensuing time period, but also by lessening competition in the stand it permits individual trees to survive and grow which might be lost if the stand remained unthinned.

It is likely that different species can tolerate different degrees of stand density. More tolerant species can be grown at higher stocking levels. Therefore, some of the variability associated with number of trees surviving among species should be accounted for by inherent characteristics of a specific species. For a given age and site, there is some flexibility between species in how many trees need to be on each unit area.

Diameter Growth

As expected, widely spaced trees in thinned plots have significantly greater average diameter than closely spaced trees in unthinned plots for every species (Table 5). The difference in average diameter between unthinned and thinned plots was at least 20 percent in all plantations. The greatest difference in average diameter was recorded in the Scotch pine plantations (35 percent), but this may not mean that Scotch pine stands had the largest response to the thinning practices. The two Scotch pine stands had been thinned earlier, in 1955, when the stands were 17 years old,

Table 5. Average diameter growth and average number of trees in unthinned and thinned stands, by species.

Species		Stand age	Unthinned stands: No. of trees per ha	Unthinned stands: Average DBH (cm)	Unthinned stands: MAI* (mm)	Unthinned stands: SD**for MAI (mm)	Thinned stands: No. of trees per ha	Thinned stands: Average DBH (cm)	Average DBH difference, thinned vs. unthinned stands (cm)	Increased DBH by thinning*** (%)
Red pine		45	1,717	19.7	4.4	0.1	642	25.2	5.5	28
Red & white pine	Red	50	630	25.3	5.1	0.3	358	30.3	5.0	20
	White	50	247	27.4	5.5	0.5	82	35.5	8.1	30
	Both	50	877	25.9	5.2	0.3	440	31.3	5.4	21
Scotch pine		44	1,153	22.9	5.2	0.4	329	30.9	8.0	35
European larch		45	1,367	18.6	4.1	0.3	667	22.8	4.2	22
White spruce		44	1,631	17.9	4.1	--				
Norway spruce		43	1,186	23.2	5.4	0.7				

* Mean annual diameter increment.

** Standard deviation.

*** Increase in average DBH in thinned versus unthinned stands divided by average DBH in unthinned stands.

and thinning removed a higher proportion of the original number of trees planted than in any other plantations in the forest.

Mean annual diameter increment was calculated to adjust different ages (42 to 50 years old) for each stand. Since stand density showed great variety, it is hard to determine significant differences in diameter growth among six species. However, as shown in Table 5, diameter growth in thinned stands can be related to diameter growth in unthinned control stands. It is also possible to draw some inferences for species by examining growth only in the unthinned control plots. Mean annual diameter growth in the unthinned plots was greatest in the white pine component of mixed red and white pine (5.5 mm), but this observation must be tempered by recognition of the relatively small number of residual trees in the mixed stand. Red pine also grew well in the mixed stand (averaging 5.1 mm), but again this must be appraised against the low residual stocking of 877 trees per hectare. With greater residual tree stocking, Norway spruce (1,186 trees per hectare) and Scotch pine (1,153 trees per hectare) recorded mean annual diameter growth of 5.4 mm (0.2 inch) and 5.2 mm (0.2 inch), respectively. Pure red pine lagged behind in annual diameter growth, averaging 4.4 mm (0.17 inch), but this could be considered excellent growth in view of the dense stocking of the residual stand (1,717 trees per hectare). With similar stocking level, Norway spruce outgrew Scotch pine, and red pine outgrew white spruce.

Height Growth

For each species, average tree height in thinned stands is more than in unthinned stands, but the differences are very small (Table 6). The largest apparent effect was in the white pine component of mixed red and white pine stand where thinning shows a 9-percent gain in average tree height.

Site index, expressed by average total height in feet at age 50, was estimated for each species, based on a random selection of 10 trees in each plot. The limited sample for height measurement does not offer great reliability in the site index estimates for each species in unthinned plots, but the results show little range in site index by species. The lowest site index, 67, was recorded in a white spruce stand; the highest, 86, in Norway spruce. Scotch pine was second highest, with a site index of 78. Red pine, mixed red and white pine, and European larch varied narrowly in site index between 70 and 72.

Table 6. Average height, estimated site index, and average number of trees in unthinned and thinned stands, by species.

Species		Stand age	Unthinned stands: No. of trees per ha	Unthinned stands: Average height (m)	Unthinned stands: MAI* (cm)	Unthinned stands: SD**for MAI (cm)	Unthinned stands: Site index (ft)	Thinned stands: No. of trees per ha	Thinned stands: Average height (m)	Average ht. difference, thinned vs. unthinned stands (m)	Increased height by thinning*** (%)
Red pine		45	1,717	19.4	43.1	1.4	71	642	20.1	0.7	4
Red & white pine	Red	50	630	21.7	43.4	1.3	71	358	21.9	0.2	1
	White	50	247	22.0	44.0	2.2	72	82	24.0	2.0	9
	Both	50	877	21.7	43.4	1.5	71	440	22.2	0.5	2
Scotch pine		44	1,153	20.9	47.5	1.4	78	329	21.8	0.9	4
European larch		45	1,367	19.3	42.9	1.2	70	667	20.4	1.1	6
White spruce		44	1,631	18.1	41.1	--	67				
Norway spruce		43	1,186	22.5	52.3	0.8	86				

* Mean annual height increment.

** Standard deviation.

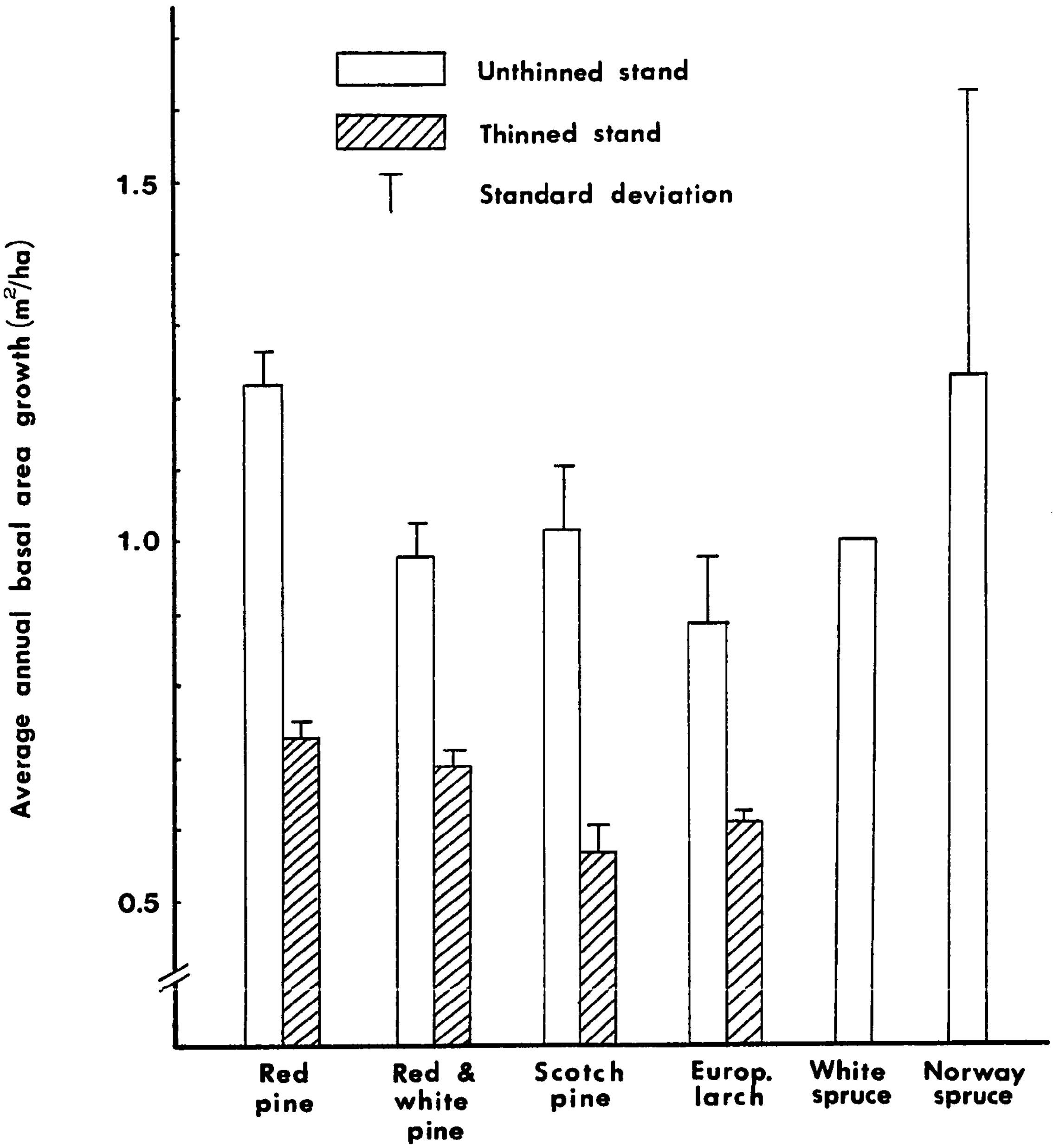
*** Increase in average height in thinned versus unthinned stands divided by average height in unthinned stands

Basal Area Growth

Annual basal area growth per unit area was significantly and positively correlated with the number of stems in a particular species, and also varied by species (Figure 3). The least basal area accumulation was in thinned Scotch pine stands, 0.57 square meter per hectare (2.47 square feet per acre) per year. The greatest basal area increment was estimated in unthinned Norway spruce plantations, 1.23 square meters per hectare (5.36 square feet per acre) per year with 1,186 growing trees per hectare (480 trees per acre).

Although no controlled comparisons are available in this study, mean annual growth differences, shown in Figure 3, can be noticed among selected species. In unthinned control plots, the plantations with larger numbers of trees per unit area and greater growing stock did not always have larger basal area increment. Norway spruce plantations had remarkable basal area growth with the same or smaller numbers of trees than other species. European larch and white spruce showed somewhat poorer basal area growth with fairly large numbers of trees per unit area.

The inventory record in unthinned stands for basal area in specified years after planting (Figure 4) indicated similar relationship to those shown in Figure 3. Red pine, in particular, has accumulated basal area



		Red pine	Red & white pine	Scotch pine	Europ. larch	White spruce	Norway spruce
No. of trees/ha	Unthinned	1,717	877	1,153	1,367	1,631	1,186
	Thinned	642	440	329	667		
Basal area removed(m^2/ha)		26.7	34.4	26.9	11.6		

Figure 3. Mean annual basal area growth, average number of trees per unit area in unthinned and thinned stands, and basal area removed by thinning, by species.

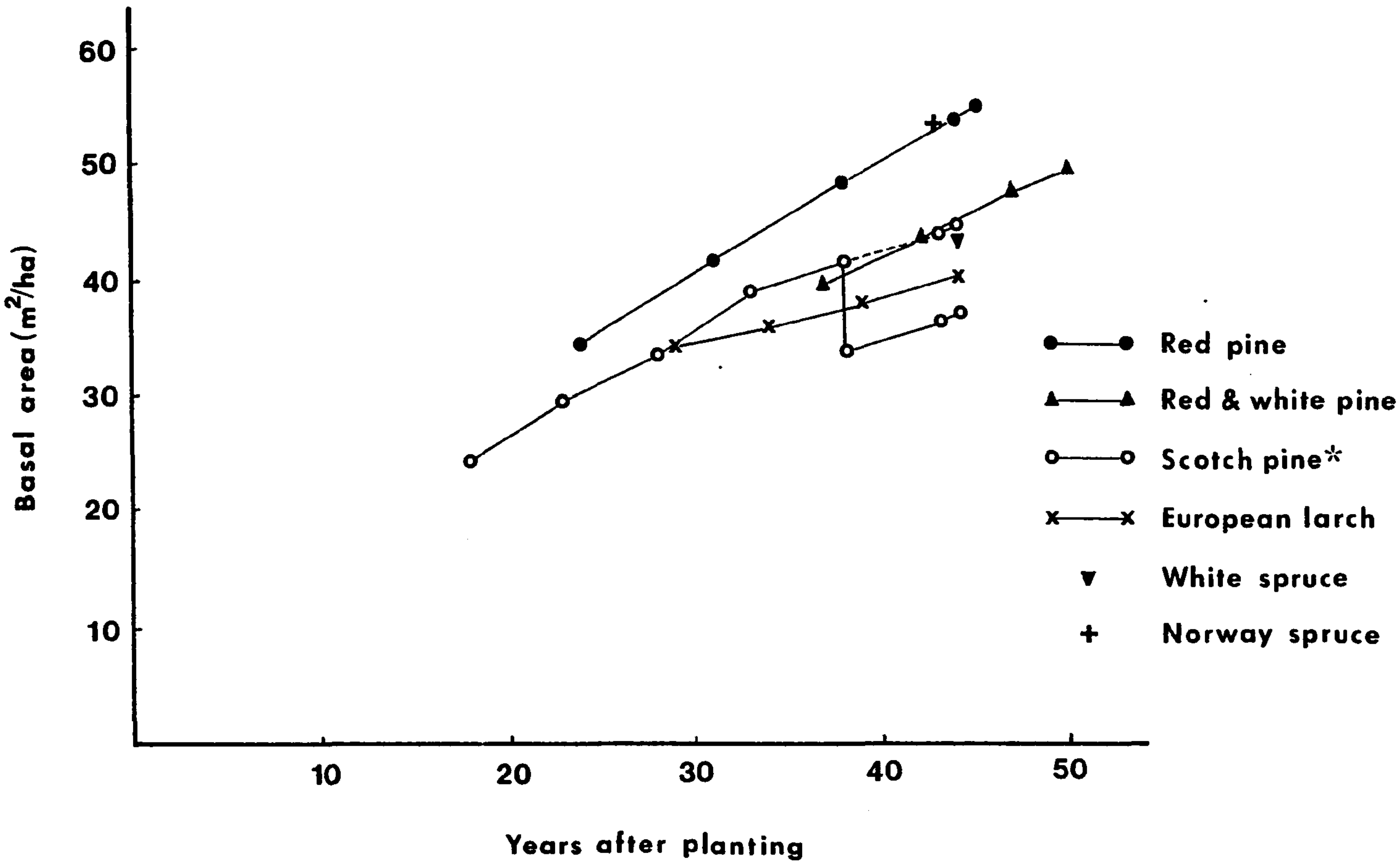


Figure 4. Basal area per unit area in specified years after planting in unthinned stands, by species.

* Abrupt reduction of basal area indicates the ice storm damage in 1974.

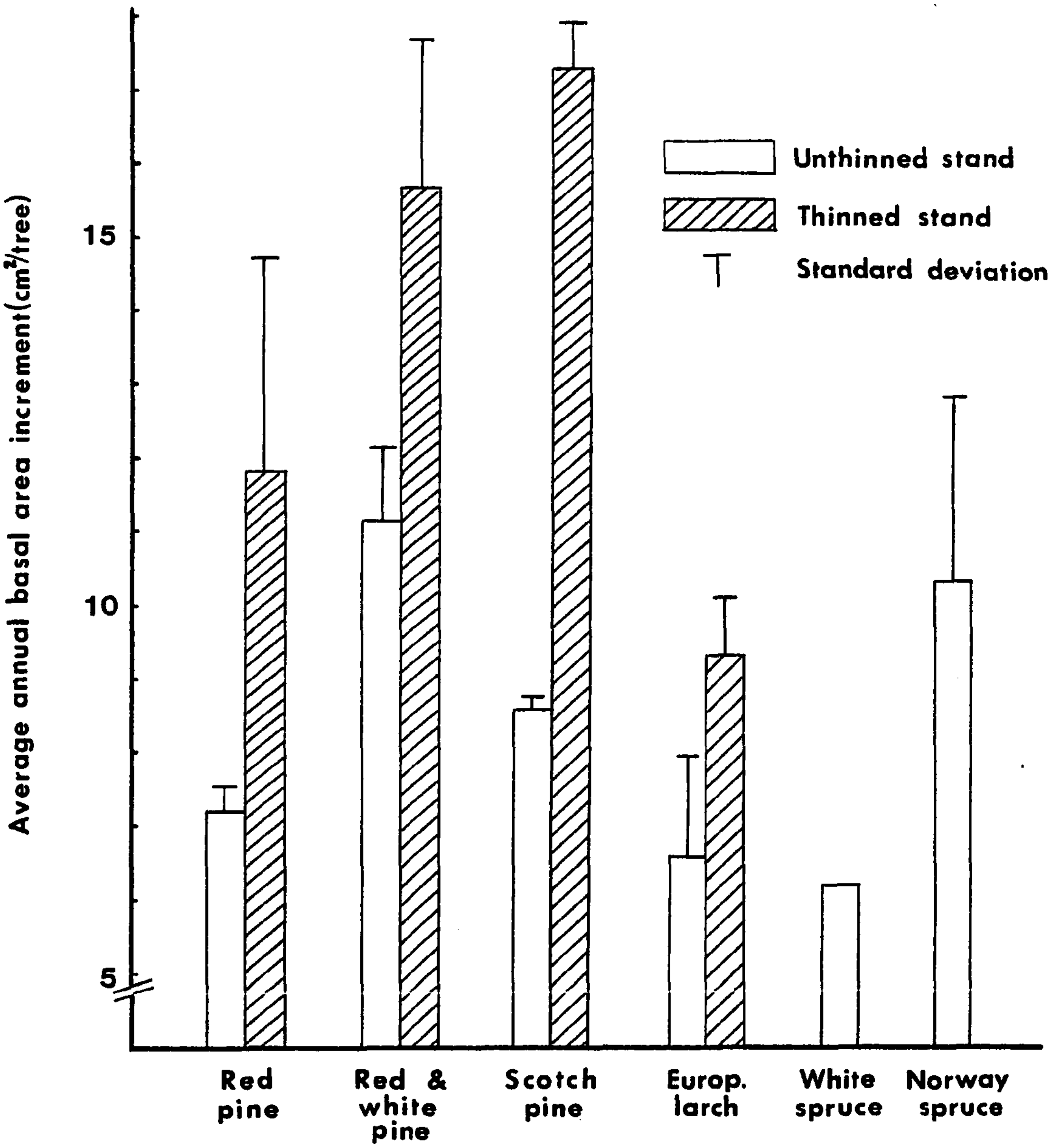
over the years with relative consistency.

Increment of basal area is of importance in thinned plots. Thinning practices have definitely accelerated the basal area growth rate per tree for all species, but lower residual densities showed lower basal area increment per unit of area.

Figure 5 presents mean annual basal area increment per tree for thinned and unthinned stands. Among pine species, stand density had a clear influence on the mean annual basal area increment per tree. The smaller the number of trees per unit area, the greater the basal area growth for individual trees in both unthinned and thinned stands. In European larch and white spruce, mean annual increment per tree fell behind that in pine stands with equivalent or fewer trees per unit area.

Volume Growth

Volume growth, the primary indicator of performance in forest management depends on the rate of height and diameter growth and the amount of taper. It varies by inherent potential of a species to accumulate wood volume as well as by environmental and genetic factors. The merchantable volume production of all plantations in the Kellogg Forest has been very satisfactory, and in some cases, outstanding. In all unthinned plantations, where no silvicultural practices have been



No. of trees/ha							
	Unthinned	1,717	877	1,153	1,367	1,631	1,186
	Thinned	642	440	329	667		

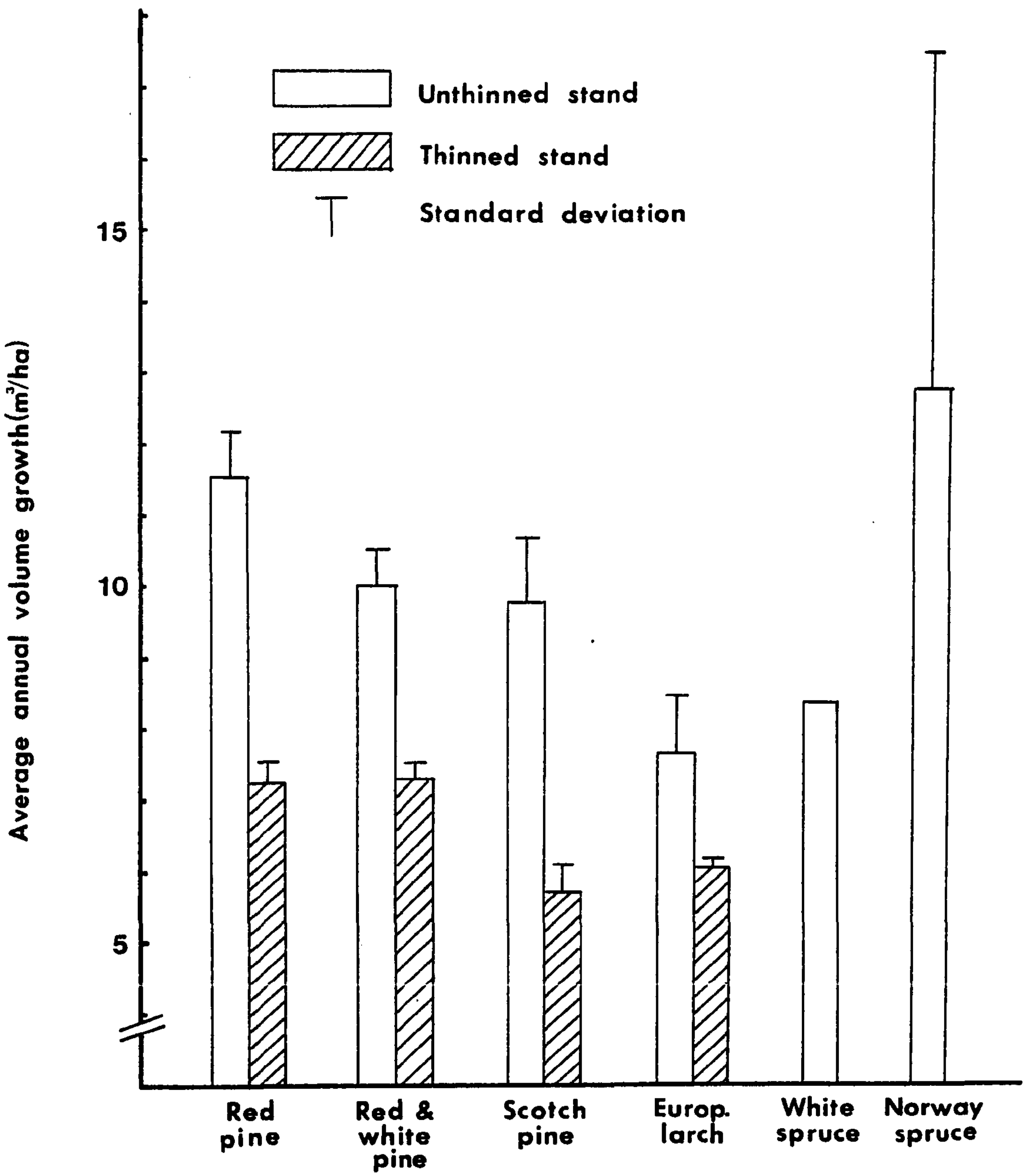
Figure 5. Mean annual basal area increment per tree, and average number of trees per unit area in unthinned and thinned stands, by species.

applied except for fertilization in the white spruce stand, volume growth exceeded 7 cubic meters per hectare (100 cubic feet per acre) per year (Figure 6). Outstanding unthinned stands of Norway spruce had an average merchantable volume of 549 cubic meters per hectare (7,846 cubic feet per acre) at age 43--a mean annual growth of 12.8 cubic meters per hectare (182.5 cubic feet per acre). The least growth was recorded in European larch and white spruce stands, where annual volume growth averaged 7.7 cubic meters per hectare (109.3 cubic feet per acre) and 8.4 cubic meters per hectare (120.2 cubic feet per acre), respectively.

Figure 7 shows the volume in specified years after planting in unthinned plantations for each species. Until the stands reach 25 years of age, there are no discernible differences by species in volume produced. Beyond that age, distinct growth differences developed. Results reflect those shown for mean annual volume growth in Figure 6.

It is obvious that volume growth per unit land area was considerably reduced by thinning (Figure 6). This can be explained by the reduction in growing stock following each thinning.

However, volume growth response to thinning was apparent from the growth rates of individual trees in thinned stands (Figure 8). The growth response of



		Red pine	Red & white pine	Scotch pine	Europ. larch	White spruce	Norway spruce
No. of trees/ha	Unthinned	1,717	877	1,153	1,367	1,631	1,186
	Thinned	642	440	329	667		
Volume removed(m^3/ha)		200.3	165.2	175.0	71.4		

Figure 6. Mean annual volume growth, average number of trees per unit area in unthinned and thinned stands, and volume removed by thinning, by species.

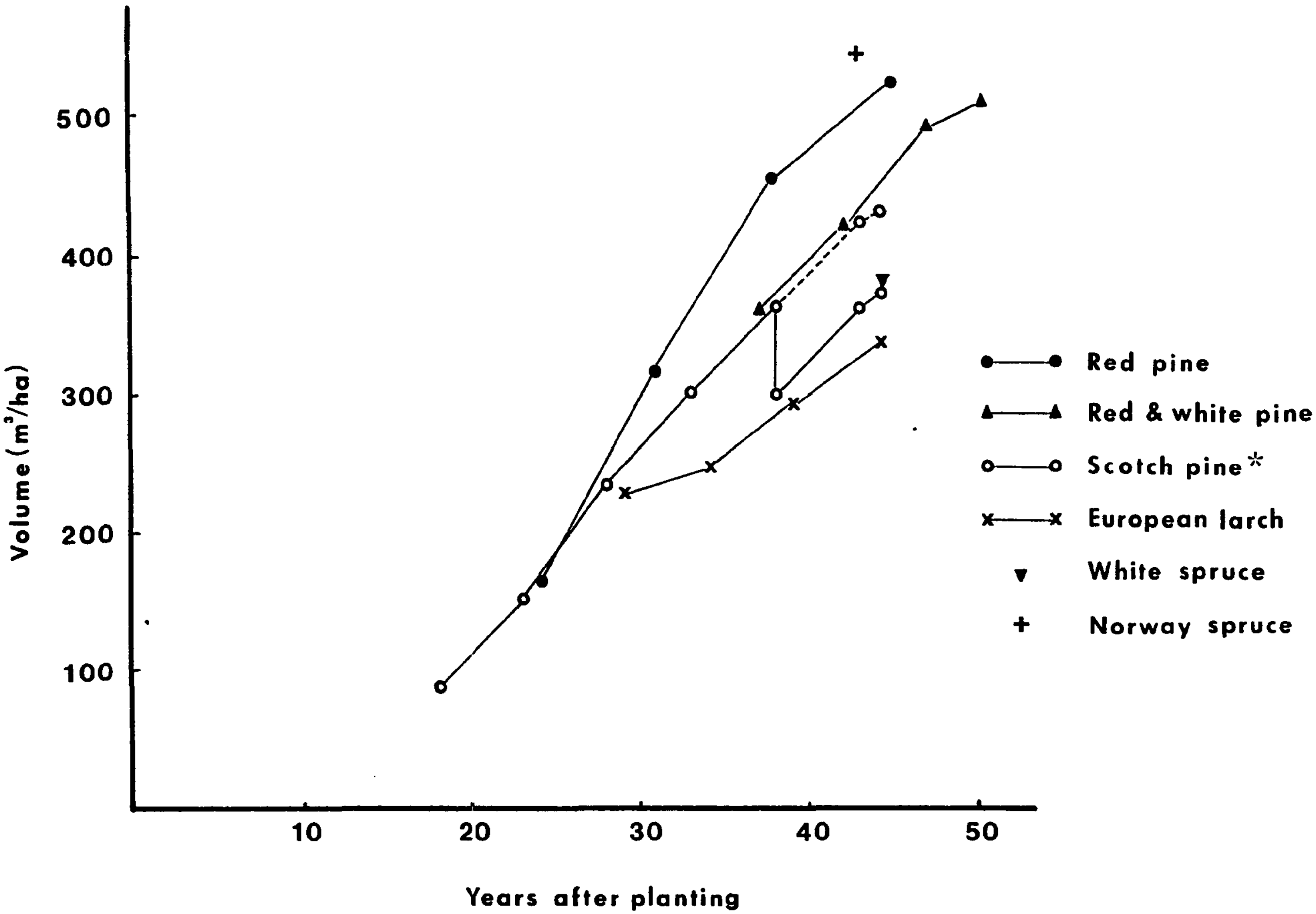
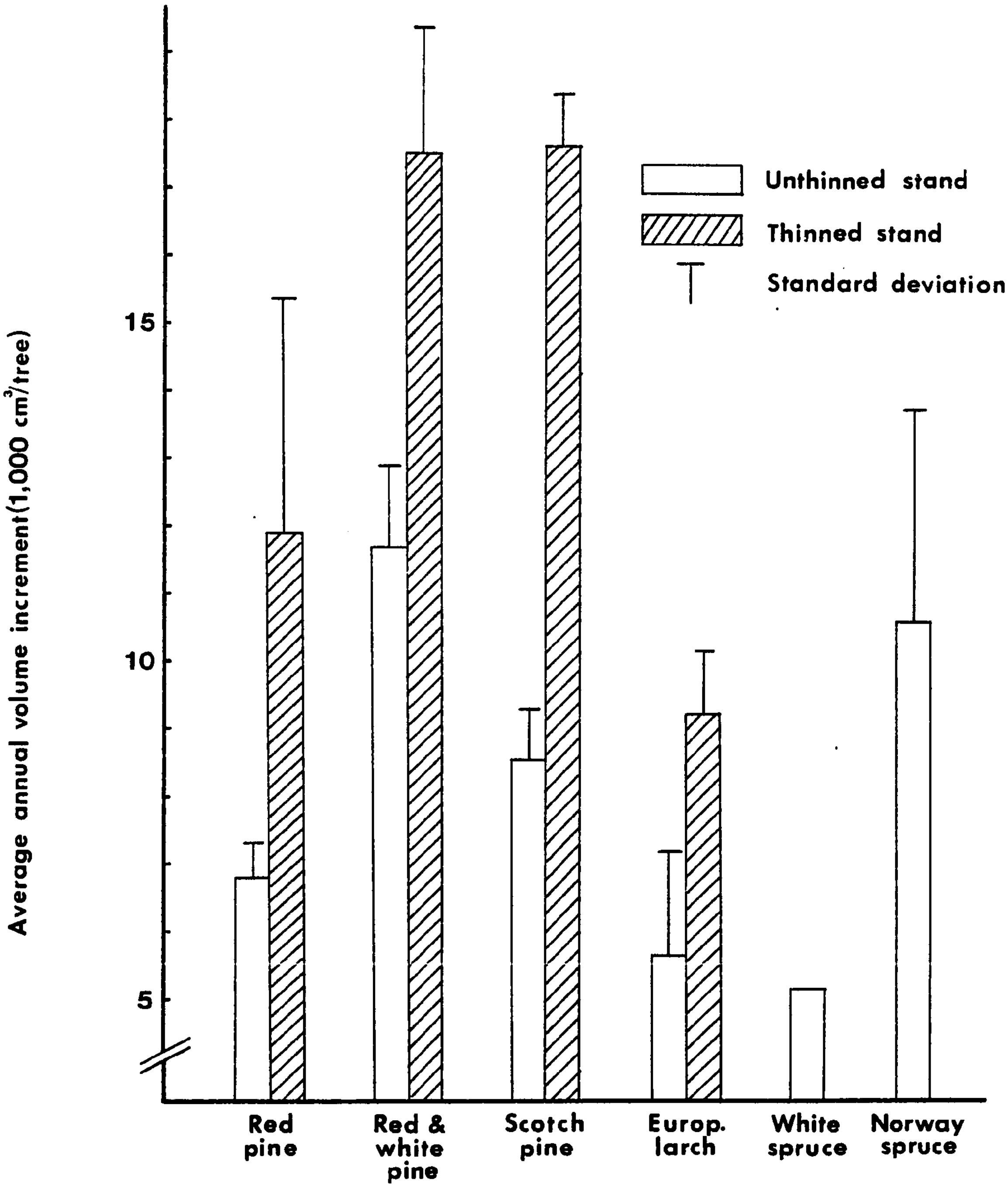


Figure 7. Volume per unit area in specified years after planting in unthinned stands, by species.

* Abrupt reduction of volume indicates the ice storm damage in 1974.



No. of trees/ha	Red pine	Red & white pine	Scotch pine	Europ. larch	White spruce	Norway spruce
Unthinned	1,717	877	1,153	1,367	1,631	1,186
Thinned	642	440	329	667		

Figure 8. Mean annual volume increment per tree, and average number of trees per unit area in unthinned and thinned stands, by species.

individual trees, affected by stand density as well as inherent characteristics, was greater in Scotch pine stands than in the mixed red and white pine stand and considerably greater than in pure red pine stands. In part, at least, this was due to earlier and heavier thinning of Scotch pine stands. In unthinned stands, volume growth was greater in the mixed red and white pine stand, followed closely by Norway spruce stands. Volume growth in unthinned Scotch pine lagged behind.

Although overall performance for the life of the plantations showed many differences among species, total volume production in thinned stands, that is volume removed by thinning plus residual volume, did not reveal significant variation between unthinned and thinned stands for each species (Figure 9). This conclusion applies to each species individually and cannot be extended to make intraspecies comparisons (see Appendix Tables C1-C4 for detailed data applying to each species).

Evaluation of Site Conditions

Field plots showed growth differences within every stand selected for the study. There was approximately 40 percent volume growth difference per unit area between the most and the least productive plots in unthinned Norway spruce stands and 30 percent difference in thinned

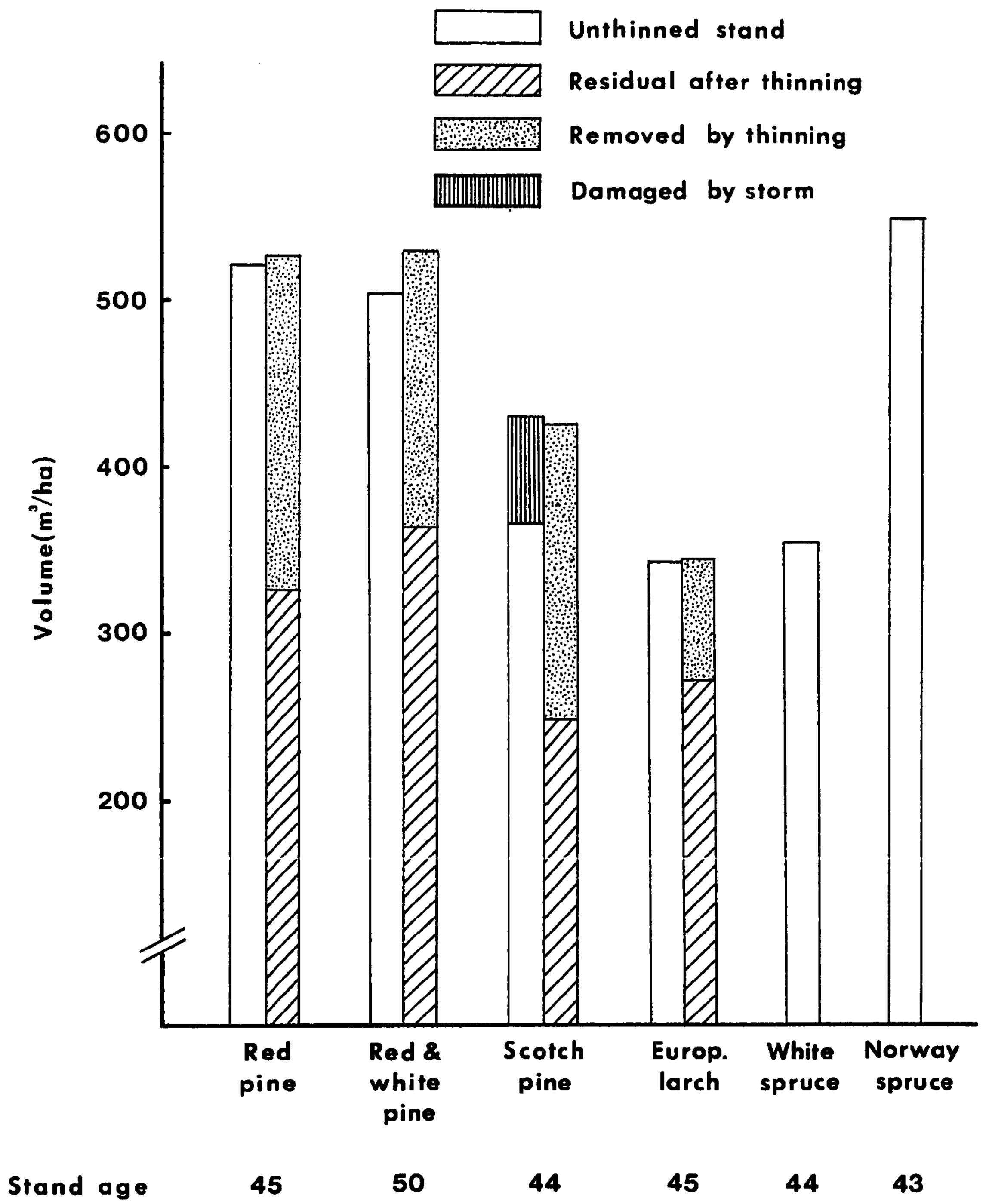


Figure 9. Total volume production per unit area between unthinned and thinned stands, by species.

red pine stands. Site quality can account for these growth differences. Site quality is largely determined by soil properties or other features of the site which influence the growth of trees qualitatively and quantitatively. However, no definite statistical analysis of growth could be attributed to site conditions in this study.

White (1958) has noted that the amount and distribution of available water is considered to be the limiting factor for forest growth. This suggests that not all soil properties are directly related to the growth of trees. It is more likely that water-holding capacity and available soil nutrients are closely associated with the performance of growing trees. Stone and his co-workers (1958) have also pointed out that soil drainage class provides a general correlation with growth, and best growth can be obtained in moderately well to well drained soils for most coniferous species. With these moisture-related points of view, differences in texture and drainage class would play a major role in determining the quality of the forest sites within uniform climate conditions.

Soil properties varied somewhat by sampling plots (detailed site conditions and corresponding growth data for all individual plots are displayed in Appendix Tables D1-D9). However, there were no abrupt differences in texture of the solum and in drainage class between plots in each stand. The soil factors were rather uniform. Most of stands were developing on sandy loam to loam soils with good drainage. Moreover, no site factors were found to correlate significantly with growth rate for any species.

Growth tended to be poorer with increasing slope gradient of the site. This trend, although not strongly evident in tabulated summaries, was indicated by interpretation of growth data by plots. Degree and extent of slope influence both surface and subsurface movement of water. Lower slopes have a greater potential supply of water than upper slopes and ridges with the same amount of precipitation.

In unthinned red pine plantations, a gently sloping stand produced 53 cubic meters per hectare (757 cubic feet per acre) more volume than a steep sloping stand in Compartment 9 (Appendix Tables D1a and D1b). The difference between slopes was even greater in thinned stands; 205 cubic meters per hectare (2,930 cubic feet per acre) (Appendix Tables D2a and D2b). Scotch pine plantations also showed apparent differences in volume growth with topography in both unthinned and thinned stands--73 and 48 cubic meters per hectare (1,043 and 686 cubic feet per acre) more volume on gentle slopes versus steep slopes in unthinned and thinned stands, respectively.

Understory Vegetation

The composition of understory vegetation in coniferous plantations depends mainly on climate and on the species available in the surrounding area to migrate into the plantations; it also depends on the soil, tree species planted, and the history of the stand (Hill, 1979). Coniferous plantations older than 40 years in the Kellogg Forest showed varying degrees of understory vegetation development. The data presented are from stands sampled in the summer of 1981 and are based on 10 m^2 (2.24 m X 4.47 m) sampling plots. Even though the size of sampling plots was large enough, the limited number of plots and uniqueness of plantations have made direct comparisons difficult. Qualitative differences of understory vegetation among plantations were considered in the study.

Species were grouped into grasses, sedges, and ferns; forbs; vines; shrubs; and trees. Table 7 shows relative coverage, relative frequency, and species richness data for vegetational groups for red pine, mixed red and white pine, Scotch pine, and European larch stands. The actual numbers of each species of understory plants found on sampling plots in red pine, mixed red and white pine, Scotch pine, and European larch stands are detailed in Appendix Table E. For the same plantations, Appendix Tables F1-F4 detail relative coverage, relative frequency and relative density of all understory plants. Nomenclature follows Voss (1972) for monocots and Fernald (1950) for dicots and ferns.

It is well known that mature stands of pines (*Pinus* species) and larches (*Larix* species) cast a lighter shade than those of spruces (*Picea* species), so that a larger density of understory vegetation is normally present in those plantations. There are virtually no ground plants, except for scattered bryophytes, under the white spruce and Norway spruce stands in the forest (Figures 18-20).

In the summer of 1979, 2,4,5-T mixed with water was sprayed on the foliage of all understory plants in the mixed red and white pine stand. Therefore, only scattered understory plants were present in the stand. However, the lower part of the slope, where moisture conditions are more favorable, showed relatively larger amounts of understory vegetation and greater species diversity than on the upper part of the slope.

As shown in Table 7, 58 different understory plant species were recorded in all selected plantations. Nine of those were exclusive to the red pine plantations, 11 species were growing only in the mixed red and white

Table 7. Relative coverage(C)*, relative frequency(F)**, and species richness(R)*** for vegetational group, by plantation species.

Plantation species	Grasses sedges & ferns			Forbs			Vines			Shrubs			Trees			Total	Total
	C (%)	F (%)	R	C (%)	F (%)	R	C (%)	F (%)	R	C (%)	F (%)	R	C (%)	F (%)	R	R	cover (m^2/m^2)
Red pine	1.8	5.3	1	26.6	41.9	12	43.1	5.3	1	7.5	10.4	4	20.7	36.9	8	26	22.5/40
Mixed red & white pine	1.5	5.9	2	30.9	47.0	14	2.2	5.9	2	19.1	11.8	4	46.3	29.4	9	31	13.6/20
Scotch pine	-	-	-	-	-	-	1.0	18.2	2	22.6	27.3	4	76.5	54.6	8	14	47.9/20
European larch	0.2	3.9	2	1.0	16.8	8	1.3	14.4	3	17.8	25.5	7	79.6	39.2	11	31	92.1/30

Definitions(after Brower and Zar, 1977)

* Relative coverage--the coverage for a species group expressed as a proportion of the total coverage for all species group.

** Relative frequency--the frequency of a given species group as a proportion of the sum of the frequencies for all species group.

*** Species richness--the number of species for a species group.

pine plantation, and 10 species were present exclusively in European larch plantations. All species occurring in Scotch pine stands were found in all other plantations. Only two shrubby species (*Berberis thunbergii* and *Rhamnus cathartica*) and three tree species (*Acer rubrum*, *Carya ovata*, and *Sassafras albidum*) were growing in all plantations.

The results indicated that understory cover was much higher in Scotch pine and European larch plantations as compared to red pine or mixed red and white pine stands. Most of the understory plants in red pine and mixed red and white pine stands were shallow herbaceous plants. The richness of species for these stands was mainly due to the large number of annual and biennual forbs. Many herbaceous species occur in the red pine and mixed red and white pine stands, but the coverage of area is light. The cover of herbaceous plants was relatively unimportant in Scotch pine and European larch stands. No herbaceous plant species were recorded on sampling plots in Scotch pine stands, but all species groups occurred in European larch stands. It is more likely that, since larches are deciduous and have short needles, ground flora under larch trees can receive relatively more light for growth and development.

The shrub and hardwood layer was particularly well developed in Scotch pine and European larch plantations. Needle length of these species is much shorter than that of red pine and white pine, and crown of these species are more open than those of red pine, white pine, or spruces. Increased light favors the reproduction, growth and spread of shrubs and hardwood trees in the understory.

A large number of woody species was present under the coniferous plantations. Some hardwoods were more than 10 meters (33 feet) tall. Crop trees have to compete for soil moisture and nutrients with these undesirable hardwoods, especially in the Scotch pine and European larch plantations. The dominant woody species included *Ramnus cathartica* (common buckthorn), *Acer rubrum* (red maple), *Cornus florida* (flowering dogwood), *Prunus serotina* (black cherry), and *Sassafras albidum* (sassafras).

DISCUSSION: PLANTATION EVALUATION

Even though this study yielded relatively comprehensive and detailed data on plantations in the Kellogg Forest, it was nevertheless only a survey of existing stands that had not been planned and laid out for the purpose of comparing selected species. Such standard experiment arrangements as replicated plots of each species of the same age on each of several specified site conditions were absent. However, the study can draw a general picture of how plantations of six coniferous species developed during their first 40 plus years on abandoned farm land can be drawn.

Red Pine

Red pine was the chief species used for reforestation in the Kellogg Forest. It has been an outstanding performer, providing excellent growth and yield with a relatively low rate of mortality. While average diameter and height growth of red pine fell somewhat behind that of the Scotch pine, the volume and basal area growth per unit area showed excellent results, better than Scotch pine, and only slightly below Norway spruce (Figures 3 and 6). Estimated site index was 71 and 73 for red pine in unthinned and thinned stands, respectively. Average annual volume growth was 11.6 cubic meters per hectare (165.5 cubic feet per acre) in fully-stocked unthinned stands (Figure 10), and 7.3 cubic meters per hectare (104.5 cubic feet per acre) in thinned stands with 30 square meters per hectare (130 square feet per acre) residual basal area (Figure 11).

The difference in volume growth between the most and least productive red pine plots in unthinned plantations was 10 percent, and in thinned plantations, 30 percent (Appendix Tables D1a and D2a). Since soil data showed relative uniformity among selected plots (Appendix Tables D1b and D2b), no specific relationships were found between volume growth and soil properties. Red pine stands established on appropriate soils, which can be characterized as well-drained sandy loams, can show high survival rates and good growth. However, it is obvious that topography had some effect on height and volume growth. Steep sloping stands, as in Compartment 9, showed considerably lower site index and smaller volume growth than did the less sloping stands in both unthinned and thinned plots.

Growing stock was significantly reduced by thinning. However, with the passage of time, residual

Figure 10. The unthinned 45-year-old red pine stand yielded a merchantable volume of 512 cubic meters per hectare(7,446 cubic feet per acre). Site index was estimated as 71.

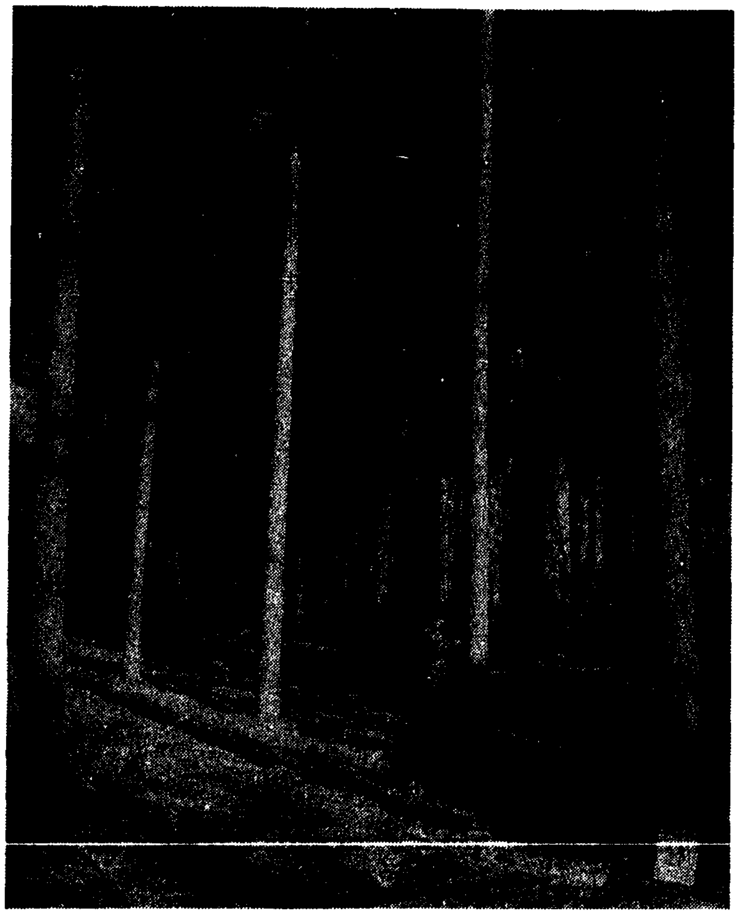


Figure 11. The thinned 45-year-old red pine stand with residual basal area of 30 square meters per hectare(130 square feet per acre). The first thinning was done at age 23.

trees in thinned plots take advantage of the site potential, and the gaps in residual volume between thinned and unthinned stands decrease. Eventually, if not thinned again, the thinned stands will become as fully stocked as the unthinned stands.

The differences in total merchantable volume production between unthinned and thinned red pine stands are slight. Similar results were obtained by Wilson (1963) and Coffman (1976) in red pine plantations. Day and Rudolph (1972) and Coffman (1976) noted that the lower residual densities, generally below 18 square meters per hectare (80 square feet per acre), resulted in considerably lower volume production than higher residual densities.

A stand with a given volume of larger diameter trees is worth much more economically than a stand with an equal volume made up of smaller diameter trees. Thinning stimulates diameter growth.

Earlier reports on thinning studies (Day and Rudolph, 1966; Day and Rudolph, 1972; Coffman, 1976) noted that heavier thinning resulted in greater diameter growth. But Coorly (1969) reported that light thinning up to 34 square meters per hectare (150 square feet per acre) had little effect on diameter growth. Consequently, optimum thinning level would range from 18 square meters to 30 square meters per hectare (80 square feet to 130 square feet per acre), depending on site conditions, stand age, and other silvicultural factors. In the same stands as this study, Lemmien and Rudolph (1964) proved that removing every third row was the most economical thinning method in terms of operation time and cost, but volume growth has been greatest in the residual basal area plots of 30 square meters per hectare (130 square feet per acre). Total volume production of the thinned stands was around 529 cubic meters per hectare (7,560 cubic feet per acre), and residual volume was about 329 cubic meters per hectare (4,702 cubic feet per acre) with average diameter of 25.2 cm (9.9 inches) at age 45 in the Kellogg Forest.

Mixed Red and White Pine

Supposed advantages for mixed species plantations in lessening pest damage (Rudolf, 1950) did not apply to the mixed red and white pine plantation in the Kellogg Forest. According to the report by Rudolph and Lemmien (1955), several insect species damaged the stand during the juvenile period. Sawflies (*Xyela* species) and tortrix (*Lambertiana* species) were observed on the white pine; and European pine shoot moth (*Rhyacionia* species) on the red pine. White pine weevil (*Pissodes* strobi) was evident until the plantation was 20 years old. Since the plantation was 10 years old, a condition described as white pine needle blight or "chlorotic dwarf" has been also observed in the stand. A large proportion of the mortality of white pine has been caused by these insects and disease.

The survival rate for red pine in the mixed stand was 70 percent, although it should be noted that this performance was aided by replanting failed spots 3 years after planting. White pine, however, had a survival rate of less than 30 percent. Rudolph and his co-workers (1956) noted that pure plantations of white pine, growing under similar site conditions in the same area, had not developed well either. Such plantations have been subjected to repeated attacks by insects and diseases, resulting in high mortality soon after planting.

However, the mixed red and white pine plantation has shown good overall growth, producing more than 500 cubic meters per hectare (7,146 cubic feet per acre) of merchantable volume at age 50 (Appendix Table C2). This represents a mean annual volume increment of 10 cubic meters per hectare (143 cubic feet per acre). Average site index was 71 for the red pine and 72 for the white pine, the same as those estimated for pure red pine and European larch stands, but less than those of Scotch pine and Norway spruce (Figure 12).

Because of the high rate of juvenile mortality, the number of living stems per unit area and overall resultant production of the white pine fell far behind those of the red pine where the two species were planted in mixture by alternate rows.

Species performance can be quite different when based on individual trees rather than unit area. As shown in Appendix Table D4a, which applies to trees in thinned plots, average diameter and height were larger for white pine than for red pine, especially on lower slopes. There is an indication here that, if growing conditions are favorable in space and site, white pine trees can outgrow red pine in mixed stands (Figure 13).

Growth differences between the two species in unthinned plots are less than in thinned plots, but they do exist. Rudolph and Lemmien (1955) found that before thinning practices had been applied to the mixed stand height growth of white pine was significantly greater than that of red pine in the lower gently sloping portion of the stand where moisture conditions were more favorable. By age 50 there was not much difference in height growth between the two species. In contrast to height growth, average diameter growth was larger for white pine than for red pine, and the differences were considerable in the lower gently

Figure 12. The unthinned 50-year-old mixed red and white pine stand yielded a merchantable volume of 501 cubic meters per hectare (7,136 cubic feet per acre). Site index estimated as 71. Red pine is the major species component of this stand.

Figure 13. The 50-year-old mixed red and white pine stand thinned to a residual basal area of 30 square meters per hectare(130 square feet per acre). The first thinning was done at age 36. The tree being measured is a red pine, while tree No. 8 to the left is a white pine.

sloping portion of the stand.

Even though white pine has shown excellent growth, the small number of growing stems reduces this species to unimportance in the stand. Rudolph and Lemmien (1955) pointed out that if the plantation had been established entirely in red pine, the site would have been fully utilized by the species and the area would have contained more volume than it does at present.

Scotch Pine

The survival rate for unthinned stands of Scotch pine was 47 percent at age 44, the lowest survival rate among the plantations studied (Table 4). This survival rate included trees damaged by a severe ice storm in 1974. The survival rate in Scotch pine stands thinned at age 17 was much higher, 67 percent. This indicates that early initial thinning can reduce substantially the high rate of natural mortality that can be anticipated in unthinned stands.

Tree diameter and height growth were excellent in the Scotch pine stands. Scotch pine plantations, the seed source of which are unknown, had fairly high growth rate with lower stand densities, compared to other species. Mean annual increment in diameter and height were 5.2 mm (0.2 inche) and 47.5 cm (1.6 feet), respectively, in unthinned stands (Figure 14). Volume yield was less than in red pine and Norway

Figure 14. The unthinned 44-year-old Scotch pine stand. This stand was damaged by an ice storm in 1974. Site index was 78, and growing stock volume was 431 cubic meters per hectare (6,152 cubic feet per acre), including the damaged trees.

spruce stands on the basis of unit area (Figure 6), but Scotch pine stands contained the largest trees, especially in thinned plots (Figures 8 and 15). The large size of the Scotch pine could have been influenced by the fact that the thinning treatment given was the heaviest given to any species--a residual basal area of 19.5 square meters per hectare (85 square feet per acre). Despite considerable differences in tree diameters, total volume production recorded in thinned and unthinned plots was nearly identical (Appendix Table C3).

Scotch pine stands typically have a relatively thin open canopy which permits a large amount of understory vegetation to develop (Grisez, 1968). Compared with the situation in red pine stands, shrubs and hardwood understories were well developed in Scotch pine plantations, but herbaceous plants were not abundant (Table 7). Twelve woody species and two vine species were present on the two 10-square-meter (108-square-foot) plots. Recorded total coverage was 48 square meters (517 square feet) in the two selected plots.

Stand growth rates were variable by plots, but no specific site factors affecting growth performance were identified in the plantations except that less sloping sites had relatively better volume growth

Figure 15. The thinned 44-year-old Scotch pine stand. Thinning was done to a residual basal area of 19.5 square meters per hectare(85 square feet per acre) beginning at age 17. A large amount of understory vegetation is noticeable.

than more sloping sites.

Since Scotch pine has great geographic variation and genetic diversity (Wright, 1976), collection of suitable seed sources is a major factor for successful plantations in the United States. The variation and diversity in seed sources govern pest resistance, growth, and stem form for timber production.

The stands in the Kellogg Forest have been fairly successful. There is an interest in managing existing Scotch pine plantations for timber production in the region, but there is still little attention to planting the species solely for timber production. There may be prospects for high quality sawlog production in this region with appropriate silvicultural practices and careful selection of seed origins.

European Larch

European larch has not shown high volume production compared to other species. Diameter and height growth of this species were slightly better than for white spruce, but annual volume and basal area increment per unit area fell behind white spruce (Figures 3 and 6). Unthinned plantations produced approximately 344 cubic meters per hectare (4,919 cubic feet per acre) of merchantable volume, and 40 square meters per hectare (175 square feet per acre) of basal area after 45 years on site index 70 (Figure 16).

European larch is being increasingly used for reforestation in the Northeastern and Northcentral United States. A number of researchers have suggested that growth of European larch exceeds that of native conifers on favorable sites, and that the species appears promising for timber production (Grisez, 1968; Cook, 1969; MacGillvrary, 1969; Sartz and Harris, 1972). The species has a reputation for its rapid growth during youth and middle age (Hunt, 1932; Cook, 1969). As shown in Figures 4 and 7, basal area and volume growth were comparable to other native or exotic species for the first 25 years. Beyond age 25, growth rates for European larch fell behind those for other species.

Height and volume growth at Kellogg Forest were almost the same as in the Harvard Forest for trees of the same age (Hunt, 1932), but, diameter growth was less. Average diameter was 26 cm (10 inches) in the Harvard Forest, but only 19 cm (7.5 inches) in the Kellogg Forest, indicating that a larger number of trees have been growing in the Kellogg Forest than in the Harvard Forest.

The European larch plantations were nearly defoliated by attacks of the larch sawfly in the early 1970s, probably accounting for the reduced growth rate.

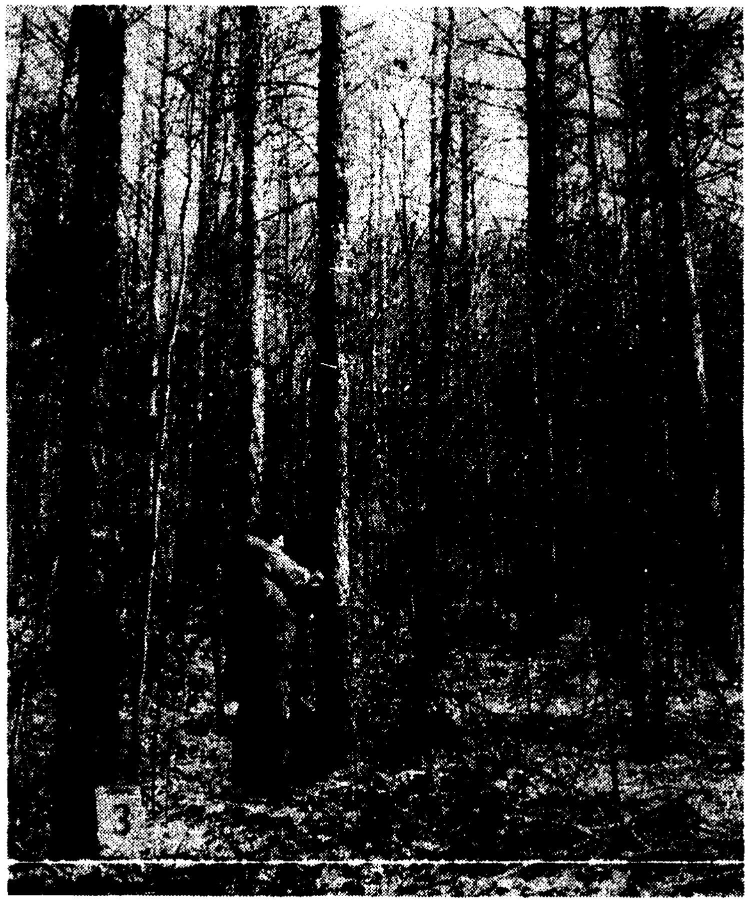


Figure 16. The unthinned 45-year-old European larch stand. The stand has been somewhat defoliated by the larch sawfly for the last 10 years or more. Site index was 70, merchantable volume was 344 cubic meters per hectare(4,919 cubic feet per acre).

Cook (1969) has noted that there is no practical artificial control without broad-scale spraying with some effective and long-lasting insecticide.

European larch is native to Europe and Asia with a broad natural range. In addition to the control of insects and diseases, appropriate seed sources should be considered to establish successful plantations in the United States. Since an unknown seed source was used for the planting in the Kellogg Forest, the species reliability and capacity of this species to grow well on good sites should not be disregarded.

European larch has thin foliage and a deciduous character which permit the passage of relatively large amounts of light for abundant understory development (Figures 16 and 17). Of all the plantations examined in this study, European larch produced the greatest species diversity and coverage of understory plants (Table 7). Estimated total coverage was 92 square meters (990 square feet) based on three 10-square-meter (108-square-foot) sampling plots. Important tree species were *Acer rubrum* (red maple), *Prunus serotina* (black cherry), and *Sassafras albidum* (sassafras). Some hardwoods were more than 10 meters tall and competed for soil moisture and nutrients with the larch crop trees. Understory competition probably reduced the growth rate of European larch.

Figure 17. The thinned 45-year-old European larch stand with residual basal area of 25.3 square meters per hectare(110 square feet per acre). The first thinning was done at age 28. Well-developed hard woods are noticeable.

White Spruce

Because the study contained only one white spruce plantation, there is some uncertainty about the extent to which the poor performance of white spruce can be generalized (Figure 3).

Tolerance of the species contributed to an excellent survival rate of more than 70 percent for 44 years (Table 4). Relatively poor diameter increment (4.1 mm per year; 0.2 inch per year) and height growth (site index 67) have made white spruce less successful than any other species evaluated in the present study.

This is the only stand to which fertilizer was applied to relieve poor foliage color and slow growth. The fertilizer treatment, at age 21, might have reduced natural mortality, but the stand has not caught up in growth to other coniferous species in the forest.

The well-drained loamy textured soil with gently sloping sites in the forest is supposed to be desirable for white spruce (Nienstaedt, 1957). However, white spruce is not native to this region, and inherent genetic factors of the species combined with other environmental factors may be responsible for the failure of white spruce to grow as well as other species at the Kellogg Forest. As shown in Figure 18, the white spruce stand is over-stocked and trees are

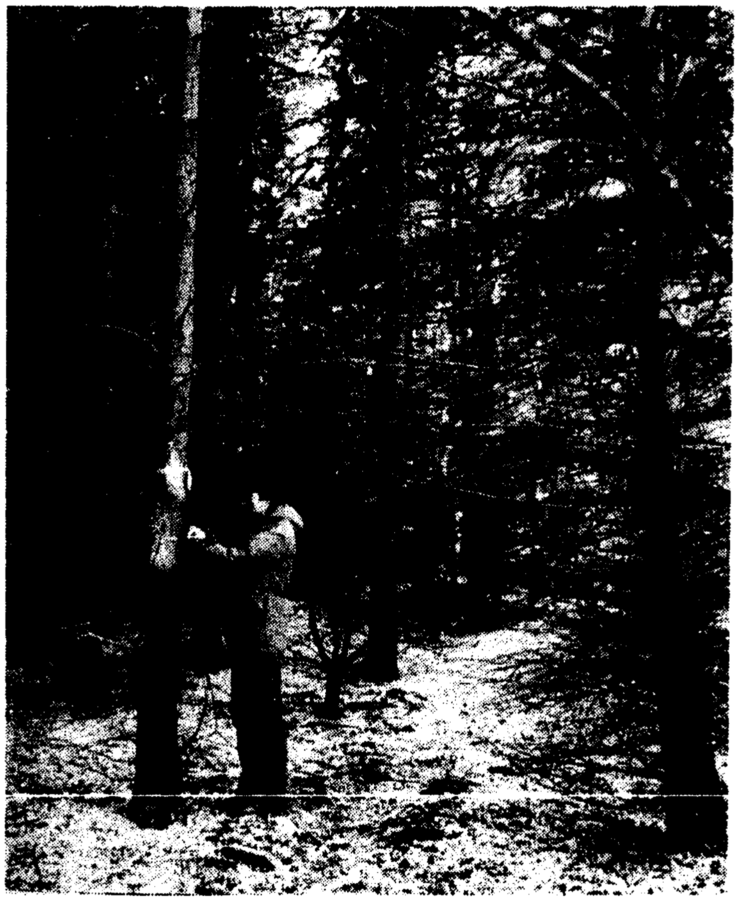


Figure 18. The unthinned 44-year-old white spruce stand yielded a merchantable volume of 370 cubic meters per hectare(5,290 cubic feet per acre). Site index was estimated to be 67.

strongly competing with one another for space, soil moisture, and nutrients. The lack of thinning may be a severe problem in the development of the stand.

Norway Spruce

The plantations of Norway spruce showed the best growth for all species, producing 12.8 cubic meters of merchantable volume per hectare (182.9 cubic feet per acre) per year. The plantations exhibit greater height, bigger average diameter, and larger mean annual volume increment than native species in Kellogg Forest. One outstanding stand in Compartment 23C, with site index of 90, yielded 695 cubic meters per hectare (9,932 cubic feet per acre) of merchantable volume at age 42 (Figure 20 and Appendix Table D9a).

Even though the seed source is not known, and stands have not had any silvicultural treatment, the growth rate is considerably more than was reported by McArther (1964) in Quebec, by Hughes and Loucks (1969) and Hughes (1970) in New Brunswick, by Grisez (1968) in Pennsylvania, and by Day (1980) in Upper Michigan.

No particular feature of the site or seed origin to achieve this outstanding growth was identified. However, the presumed reason for this excellent growth rate may be accounted for by the favorable site

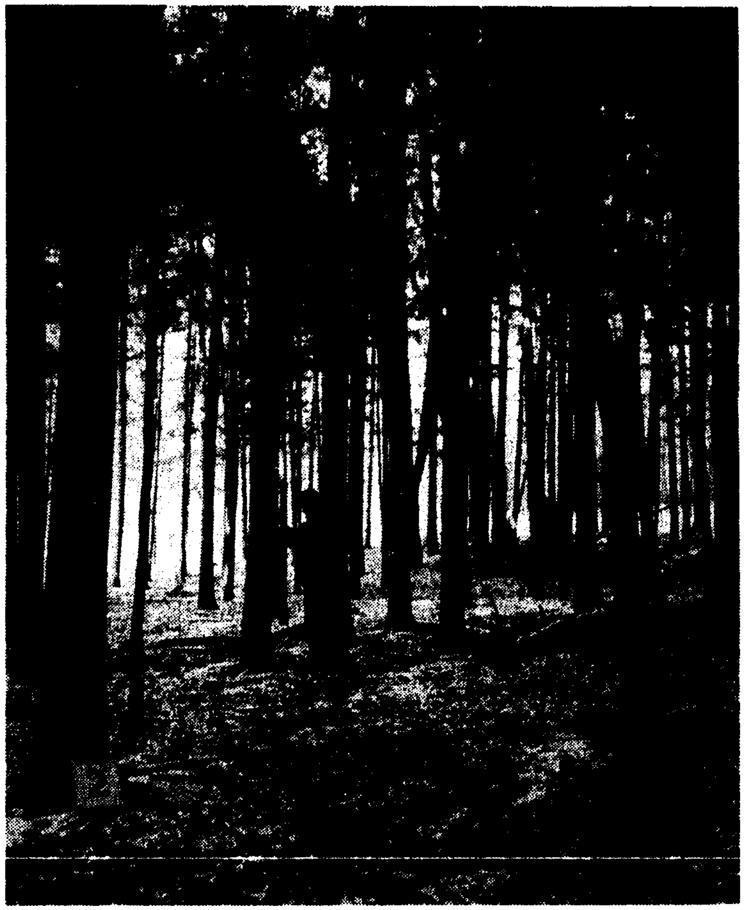


Figure 19. The unthinned 44-year-old Norway spruce stand in Compartment 11 yielded a merchantable volume of 403 cubic meters per hectare(5,759 cubic feet per acre). Site index was 81.

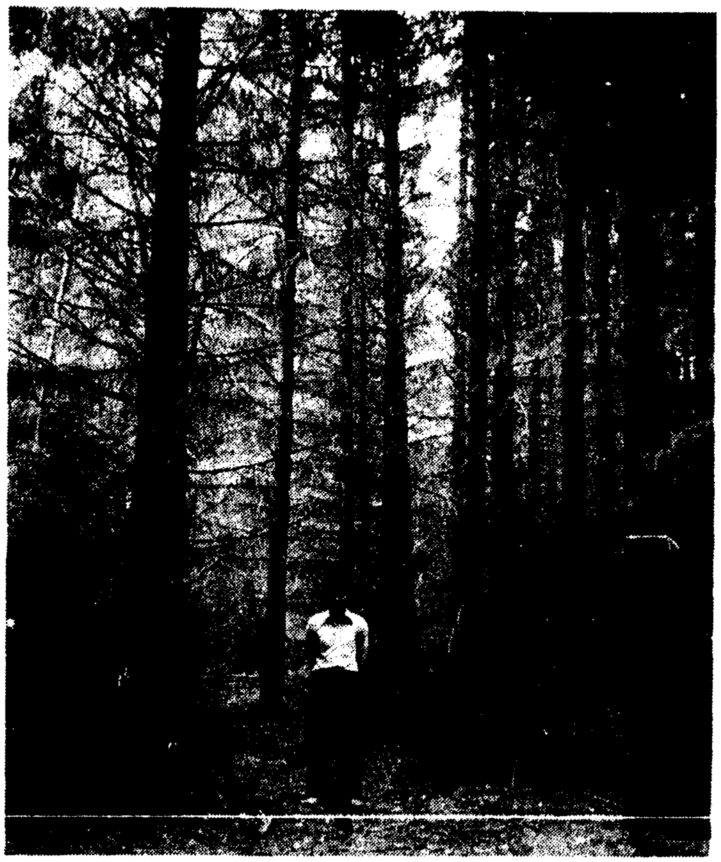


Figure 20. The 42-year-old Norway spruce stand in Compartment 23C. Growth performance has been outstanding, yielding a merchantable volume of 695 cubic meters per hectare(9,932 cubic feet per acre) without any silvicultural treatment. Site index was 90.

conditions and climate of the region. The plantations were established on loamy textured well-drained soils and on the lower parts of slopes where moisture conditions are favorable. Another unrecognized possibility is that the appropriate seed origin was introduced to the forest by chance.

Since Norway spruce is a fairly tolerant species, mortality was low and the stands formed a very dense canopy. It is likely that over-stocking tends to stagnate growth rate. Therefore, thinning is essential to produce higher quality crop trees as well as to obtain intermediate yields.

The excellent growth rate of Norway spruce at the Kellogg Forest suggests that this species should be considered in reforestation planning in the Lake States region on suitable sites with selected seed sources.

SUMMARY AND RECOMMENDATIONS

A survey type of study was conducted in 1981 and 1982 in the Kellogg Experimental Forest of Michigan State University. The area had been cultivated since the early nineteenth century and abandoned in the 1930's because of decreasing productivity as a result of soil erosion. From 1932 the Department of Forestry has managed the area and established the forest with various tree species.

The primary objective of the study was to evaluate the performance of existing plantations of six coniferous species--red pine, eastern white pine, Scotch pine, European larch, white spruce, and Norway spruce. All the plantations are more than 40 years old. Tree measurements, together with soil and topographic characteristics, were obtained from 35 field plots in unthinned and thinned stands. All understory plants were also identified in randomly selected plots within plantations.

Since different levels and times of thinning treatment were applied to each species, growth comparisons between species were made mainly in unthinned plantations. A further limitation in the growth analysis occurred because sites did not vary greatly, within species or between species. Nevertheless, some generalization can be made.

All selected plantations have been developing normally and exhibited growth rate far above those for similar plantations in other regions. There were no particular conditions which would preclude stand growth estimates.

Average survival of species varied from more than 70 percent for red pine and white spruce to less than 30 percent for white pine in the mixed red and white pine plantation. In Scotch pine, early thinning could have reduced the high rate of natural mortality through intermediate cutting of poorly developed trees.

Thinnings significantly increased diameter growth rate for all species. In spite of its high rate of mortality, white pine in the mixture stand with red pine had the greatest mean annual diameter increment based on residual trees in the forest. Poorest mean annual diameter growth was recorded in the white spruce stand.

Height growth of trees in the unthinned plots was generally comparable to growth in thinned, less dense stands. Relative differences in height were as large as those of diameter growth among species. Norway spruce, with an average site index of 86, showed outstanding height growth, whereas site index for white spruce was 67.

Basal area in unthinned stands varied by species, ranging from 40 square meters per hectare (175 square feet per acre) in 45-year-old European larch stands to 55 square meters per hectare (240 square feet per acre) in 45-year-old red pine stands. Most of the unthinned plantations were fully stocked.

Merchantable volume growth of all selected plantations exceeded 7 cubic meters per hectare (100 cubic feet per acre) per year. Red pine and Norway spruce were outstanding in volume production--averaging 512 cubic meters per hectare (7,446 cubic feet per acre) in 45-year-old unthinned red pine stands and 549 cubic meters per hectare (7,846 cubic feet per acre) in 43-year-old Norway spruce stands. European larch produced the least volume per unit area--344 cubic meters per hectare (4,919 cubic feet per acre) without thinning at age 45.

Even though thinning practices decreased residual volume, there were no distinctive differences in total volume production between thinned and unthinned stands. Nevertheless, diameter growth rate was significantly increased by thinning, and large diameter trees are more valuable than small diameter trees per unit of volume. Thinning is essential in over-stocked stands to reduce natural mortality, to yield high quality crop trees, and to obtain intermediate income.

In addition to the inherent growth characteristics, susceptibility to insects and diseases would affect the selection of species for successful plantations. Two major species, white pine and European larch, were severely attacked by insects and diseases in the forest. The number of white pine trees in the red and white pine mixture was greatly reduced by attacks of white pine weevil and needle blight in the juvenile period. In the European larch stands, defoliation by the larch sawfly has been observed for more than the last 10 years. While the insect had not caused a high rate of mortality, the stagnated growth rate of European larch may be attributed at least in part to this insect.

Because of their open crowns and short needle length, which are favorable for the growth of understory vegetation was outstanding in Scotch pine and European larch plantations. This might be considered an advantage in wildlife management, but if timber production is the main goal, competing woody species in the understory could interfere with the growth of crop trees. Compared to the other plantations, the distinctly below average growth of European larch stands might be attributed to the dense development of understory woody plants as well as attacks by larch sawfly.

Conclusions about the desirability of different species for planting on abandoned, eroded agricultural land in southern Michigan can only be drawn guardedly from this limited study of plantations in Kellogg Forest. The limitations in plantations and site variability do not permit definitive conclusions, but several tentative recommendations can be given until better research information becomes available.

Norway spruce showed best growth for all selected species. However, insufficient number of samples and small amount of the data provide no strong recommendation for plantations in the region. From an overall point of view, red pine is still recommended. This species is the most generally reliable native timber species for plantations in southern Michigan. Red pine has the capacity of surviving and making good growth on sandy loam, well-drained soils. But excellent growth from Norway spruce and Scotch pine shows that production from exotic species may exceed production from native species when the provenance of the exotic species is adapted to the soil and climate of southern Michigan. Other exotic species, specifically European larch and white spruce, cannot be recommended based on their performance at Kellogg Forest.

APPENDICES

APPENDIX A

UNIT CONVERSIONS

Table A. Unit conversions used for this study.

<u>English to Metric</u>

1 inch	= 2.54 centimeters
1 foot	= 0.3048 meter
1 mile	= 1.6093 kilometers
1 acre	= 0.4047 hectare
	= 0.004047 square kilometer
1 square foot	= 0.09290 square meter
1 cubic foot	= 0.02832 cubic meter
1 square foot per acre	= 0.2296 square meter per hectare
1 cubic foot per acre	= 0.06997 cubic meter per hectare
1 tree per acre	= 2.4711 trees per hectare
1 F degree	= 0.5556 C degree

<u>Metric to English</u>

1 centimeter	= 0.3939 inch
1 meter	= 3.2808 feet
1 kilometer	= 0.6214 mile
1 hectare	= 2.4711 acres
1 square meter	= 10.7639 square feet
1 cubic meter	= 35.3147 cubic feet
1 square meter per hectare	= 4.3560 square feet per acre
1 cubic meter per hectare	= 14.2913 cubic feet per acre
1 tree per hectare	= 0.4047 tree per acre
1 C degree	= 1.7999 C degree

APPENDIX B

VOLUME FACTORS TABLE

Table B. Volume factors for basal area factor of 10. Volume in cubic feet including bark.

DBH (inch)	Merchantable height (ft) 6	12	18	24	30	36	42	48	54	60	66	72
4	67.2	104.4	143.9	181.1	215.2	245.9	273.1	296.7	316.7	333.1	345.8	354.9
5	67.5	105.0	144.6	182.0	216.3	247.2	274.5	298.2	318.3	334.8	347.6	356.7
6	67.8	105.5	145.4	182.9	217.4	248.4	275.9	299.8	320.0	336.5	349.4	358.5
7	68.2	106.1	146.1	183.9	218.5	249.7	277.3	301.3	321.6	338.2	351.2	360.4
8	68.5	106.6	146.8	184.8	219.6	251.0	278.7	302.8	323.2	339.9	352.9	362.2
9	68.9	107.1	147.6	185.7	220.7	252.2	280.1	304.4	324.9	341.7	354.7	364.0
10	69.2	107.7	148.3	186.7	221.8	253.5	281.5	305.9	326.5	343.4	356.5	365.9
11	69.6	108.2	149.1	187.6	222.9	254.8	282.9	307.4	328.1	345.1	358.3	367.7
12	69.9	108.8	149.8	188.5	224.1	256.0	284.3	308.9	329.8	346.8	360.1	369.5
13	70.3	109.3	150.5	189.5	225.2	257.3	285.8	310.6	331.4	348.5	361.9	371.3
14	70.6	109.8	151.3	190.4	226.3	258.6	287.2	312.0	333.0	350.3	363.6	373.2
15	71.0	110.4	152.0	191.3	227.4	259.8	288.6	313.5	334.7	352.0	365.4	375.0
16	71.3	110.9	152.8	192.3	228.5	261.1	290.0	315.1	336.3	353.7	367.2	376.8
17	71.7	111.4	153.5	193.2	229.6	262.4	291.4	316.6	337.9	355.4	369.0	378.7
18	72.0	112.0	154.3	194.1	230.7	263.6	292.8	318.1	339.6	357.1	370.8	380.5
19	72.3	112.5	155.0	195.1	231.8	264.9	294.2	319.6	341.2	358.8	372.5	382.3
20	72.7	113.1	155.7	196.0	232.9	266.2	295.6	321.2	342.8	360.6	374.3	384.1
21	73.0	113.6	156.5	196.9	234.0	267.4	297.0	322.7	344.5	362.3	376.1	386.0
22	73.4	114.1	157.2	197.9	235.1	268.7	298.4	324.2	346.1	364.0	377.9	387.8
23	73.7	114.7	158.0	198.8	236.3	270.0	299.8	325.8	347.7	365.7	379.7	389.6
24	74.1	115.2	158.7	199.7	237.4	271.2	301.2	327.3	349.4	367.4	381.5	391.5

APPENDIX C

TREES AND VOLUMES REMOVED BY THINNING, AND TOTAL VOLUME PRODUCTION

Table Cl. Trees and volumes removed in various thinnings and total volume production in unthinned and thinned stands of red pine at age 45.

	Year	Number of trees/ha		Basal area (m^2/ha)		Volume (m^3/ha)	
		Average	SD*	Average	SD*	Average	SD*
Thinned stands							
	1960	457	142	8.1	2.7	39.7	14.1
Removed by thinning	1967	432	111	8.2	2.8	57.8	22.3
	1974	229	55	6.2	2.5	58.1	25.3
	1980	99	67	4.2	2.9	44.7	30.2
Residual	1981	642	138	32.8	0.8	329.1	15.7
Total production		1,859	111	59.5	8.8	529.3	90.5
Unthinned stands							
Residual		1,717	77	55.0	2.3	521.0	26.5

* Standard deviation of averages between plots.

Table C2. Trees and volumes removed in various thinnings and total volume production in unthinned and thinned stand of mixed red and white pine at age 50.

	Year		Number of trees/ha		Basal area (m^2/ha)		Volume (m^3/ha)	
			Average	SD*	Average	SD*	Average	SD*
Thinned stands								
Removed by thinning	1968	(Red	272	49	8.8	2.0	78.4	15.1
		(White	99	61	2.9	1.7	23.5	14.4
		(Both	371	66	11.7	1.2	101.9	8.8
	1973	(Red	62	41	2.7	1.8	26.7	18.0
		(White	45	43	2.3	2.0	20.4	17.1
		(Both	107	40	5.0	1.1	47.1	9.8
	1978	(Red	8	13	0.6	0.9	6.1	9.6
		(White	18	20	1.0	1.2	10.1	11.4
		(Both	26	16	1.6	0.9	16.2	8.6
Residual	1981	(Red	358	75	26.1	5.1	273.4	53.5
		(White	82	46	8.3	5.4	92.5	61.8
		(Both	440	43	34.4	1.0	365.9	15.8
Total production		(Red	700	100	38.2	5.8	384.6	54.5
		(White	244	72	14.5	4.7	146.5	58.9
		(Both	944	122	52.7	2.2	531.1	21.0
Unthinned stands								
Residual	1981	(Red	630	146	33.0	6.2	342.2	64.1
		(White	247	88	15.4	6.0	158.8	63.9
		(Both	877	106	48.4	11.5	501.2	28.1

* Standard deviation of averages between plots.

Table C3. Trees and volumes removed in various thinnings and total volume production in unthinned and thinned stands of Scotch pine at age 44.

	Year	Number of trees/ha		Basal area (m^2/ha)		Volume (m^3/ha)	
		Average	SD*	Average	SD*	Average	SD*
Thinned stands							
Removed by thinning	1955	363	136	4.9	1.6	17.9	5.4
	1960	353	29	6.2	0.6	32.0	4.2
	1965	272	25	6.2	0.4	43.3	3.9
	1970	148	49	3.8	0.8	27.8	7.5
	1975	99	25	4.1	0.4	37.1	3.5
	1980	33	12	1.7	1.5	16.9	14.7
Residual	1981	329	14	24.9	1.9	253.5	20.3
Total production		1,597	200	51.8	3.0	428.5	27.8
Unthinned stands							
Removed by storm	1974	296	24	7.7	0.9	64.2	9.0
Residual	1981	857	207	37.3	5.1	366.3	45.7
Total production		1,153	75	45.0	4.5	430.5	41.3

* Standard deviation of averages between plots

Table C4. Trees and volumes removed in various thinnings and total volume production in unthinned and thinned stands of European larch at age 45.

	Year	Number of trees/ha		Basal area (m^2/ha)		Volume (m^3/ha)	
		Average	SD*	Average	SD*	Average	SD*
Thinned stands							
	1965	412	185	6.2	3.1	35.1	19.3
Removed by thinning	1970	173	89	2.4	0.9	12.5	4.6
	1975	91	51	1.8	1.2	12.4	9.4
	1980	41	29	1.2	0.6	11.4	5.5
Residual	1981	667	74	28.1	0.5	273.1	2.8
Total production		1,384	25	39.7	1.3	344.5	15.0
Unthinned stands							
Residual	1981	1,367	299	40.1	4.1	344.2	37.9

* Standard deviation of averages between plots.

APPENDIX D

GROWTH AND YIELD DATA, AND SITE CHARACTERISTICS, BY SAMPLE PLOT

Table D1a. Number of trees, DBH, height, basal area, volume, and site index in unthinned red pine, by sample plot.

Plot No. and Compartment	No. of trees (ha^{-1})	Average DBH (cm)	Average height (m)	Basal area (m^2/ha)	Volume (m^3/ha)	Site index (ft)
5, Comp. 8A	1,804	19.2	19.1	54.1	504.7	70
7, Comp. 9	1,631	19.7	18.6	52.2	492.4	68
1, Comp. 15	1,754	19.7	20.1	57.0	541.3	73
3, Comp. 15	1,680	20.3	19.7	56.9	545.6	72

Table D1b. Site characteristics in unthinned red pine, by sample plot.

Plot No. and Compartment	pH	Texture A and B horizon	Soil depth A and B horizon (cm)	Presence of gravel**	Slope (%)	Aspect
5, Comp. 8A	5.5	SL*	45	much	9	SW
7, Comp. 9	5.3	SL	64	much	32	W
1, Comp. 15	5.5	SL	64	much	2	W
3, Comp. 15	4.8	SL	64	much	10	E

* Sandy loam.

** Presence of gravel broadly described by terms much, some, little, or none.

Table D2a. Number of trees, DBH, height, basal area, volume, and site index for residual and cut in thinned red pine, by sample plot.

Plot No. and Compartment		No. of trees (ha^{-1})	Average DBH (cm)	Average height (m)	Basal area (m^2/ha)	Volume (m^3/ha)	Site index (ft)
6, Comp. 8A	Residual	741	23.8	19.5	33.4	328.3	71
	Cut	988			21.1	157.8	
	Total	1,729			54.6	486.1	
8, Comp. 9	Residual	766	22.7	18.7	31.6	307.3	68
	Cut	1,186			19.3	121.2	
	Total	1,952			50.9	429.5	
2, Comp. 15	Residual	469	29.8	21.2	32.9	342.8	77
	Cut	1,483			37.9	291.8	
	Total	1,952			70.8	634.6	
4, Comp. 15	Residual	593	26.7	21.0	33.3	337.8	76
	Cut	1,211			28.7	229.8	
	Total	1,804			62.0	567.6	

Table D2b. Site characteristics in thinned red pine, by sample plot.

Plot No. and Compartment	pH	Texture A and B horizon	Soil depth A and B horizon (cm)	Presence of gravel**	Slope (%)	Aspect
6, Comp. 8A	5.5	SL*	76	much	5	N
8, Comp. 9	5.5	SL	114	much	31	W
2, Comp. 15	4.0	SL	79	little	3	S
4, Comp. 15	5.5	SL	71	little	0	-

* Sandy loam.

** Presence of gravel broadly described by terms much, some, little, or none.

Table D3a. Number of trees, DBH, height, basal area, volume, and site index in unthinned red and white pine, by sample plot.

Plot No. in Comp. 7	Species	No. of trees (ha^{-1})	Average DBH (cm)	Average height (m)	Basal area (m^2/ha)	Volume (m^3/ha)	Site index (ft)
	Red	519	27.1	22.3	30.7	321.1	73
1-1	White	272	30.0	22.0	19.8	208.7	72
	Both	791	28.1	22.2	50.5	529.8	73
	Red	568	26.9	22.6	33.2	346.7	74
2-4	White	222	24.1	23.0	11.4	113.2	76
	Both	790	26.1	22.6	44.6	459.9	74
	Red	519	25.7	21.5	27.5	285.4	71
3-3	White	272	28.5	22.0	17.9	186.5	72
	Both	791	26.6	21.6	45.4	471.9	71
	Red	717	26.5	21.1	41.1	429.0	69
4-1	White	173	24.3	20.7	8.4	84.1	68
	Both	890	26.1	21.0	49.5	513.1	69
	Red	890	23.2	21.0	39.3	403.9	69
5-4	White	148	29.2	20.6	11.0	114.6	68
	Both	1,038	24.1	20.7	50.3	518.5	68
	Red	568	23.6	21.9	26.0	267.7	72
6-5	White	395	27.3	23.2	23.8	245.8	76
	Both	963	25.1	22.1	49.8	513.5	73

Table D3b. Site characteristics in unthinned mixed red and white pine, by sample plot.

Plot No. in Comp. 7	pH	Texture A and B horizon	Soil depth A and B horizon (cm)	Presence of gravel**	Slope (%)	Aspect
1-1	6.9	SL*	97	some	2	W
2-4	5.0	SL	100	little	8	NW
3-3	5.4	SL	76	much	13	NW
4-1	5.0	SL	81	much	7	W
5-4	5.5	SL	89	little	2	W
6-5	5.5	SL	76	little	1	W

* Sandy loam

** Presence of gravel broadly described by terms, much, some, little, or none.

Table D4a. Number of trees, DBH, height, basal area, volume, and site index in mixed red and white pine, by sample plot.

Plot No. in Comp. 7		Species	No. of trees (ha^{-1})	Average DBH (cm)	Average height (m)	Basal area (m^2/ha)	Volume (m^3/ha)	Site index (ft)
		Red	247	31.6	23.8	19.5	206.4	78
	Residual	White	124	39.7	25.9	15.5	176.2	85
		Both	371	34.3	24.4	35.0	382.6	80
		Red	296			10.7	101.8	
1-4	Cut	White	99			6.0	60.3	
		Both	395			16.7	162.1	
		Red	543			30.2	308.2	
	Total	White	223			21.5	236.5	
		Both	766			51.7	544.7	
		Red	321	30.7	22.6	24.0	253.4	74
	Residual	White	124	33.7	23.8	11.2	122.5	78
		Both	445	31.5	22.7	35.2	375.9	74
		Red	297			11.3	110.8	
2-5	Cut	White	148			6.4	60.8	
		Both	445			17.7	171.6	
		Red	618			35.3	364.2	
	Total	White	272			17.6	183.3	
		Both	890			52.9	547.5	

Table D4a (cont'd)

Plot No. in Comp. 7		Species	No. of trees (ha^{-1})	Average DBH (cm)	Average height (m)	Basal area (m^2/ha)	Volume (m^3/ha)	Site index (ft)
	Residual	Red	321	30.3	22.2	23.3	244.5	73
		White	99	38.6	25.3	11.5	130.2	83
		Both	420	32.2	22.9	34.8	374.7	75
3-2	Cut	Red	469			14.5	137.0	
		White	99			3.0	26.0	
		Both	568			17.5	163.0	
	Total	Red	790			37.8	381.5	
		White	198			14.5	156.2	
		Both	988			52.3	537.7	
	Residual	Red	420	31.1	21.2	32.0	336.8	70
		White	25	36.3	24.4	2.6	28.5	80
		Both	445	31.4	21.4	34.6	365.3	70
4-4	Cut	Red	321			15.0	129.5	
		White	124			5.2	42.1	
		Both	445			20.2	171.6	
	Total	Red	741			47.0	466.3	
		White	149			7.8	70.6	
		Both	890			54.8	536.9	

Table D4a (cont'd).

Plot No. in Comp. 7		Species	No. of trees (ha^{-1})	Average DBH (cm)	Average height (m)	Basal area (m^2/ha)	Volume (m^3/ha)	Site index (ft)
		Red	444	30.4	20.6	32.4	339.6	68
	Residual	White	25	30.2	21.3	1.8	18.7	70
		Both	469	30.4	20.7	34.2	358.3	68
		Red	272			9.9	83.8	
5-1	Cut	White	321			11.1	87.6	
		Both	593			21.0	171.4	
		Red	716			42.3	423.4	
	Total	White	346			12.9	106.3	
		Both	1,062			55.2	529.7	
		Red	395	28.3	21.9	25.1	259.7	72
	Residual	White	99	30.3	21.0	7.4	79.0	69
		Both	494	28.7	21.6	32.5	338.7	71
		Red	395			11.1	104.6	
6-3	Cut	White	173			5.5	47.0	
		Both	568			16.6	151.6	
		Red	790			36.2	364.3	
	Total	White	272			12.9	126.0	
		Both	1,062			49.1	490.3	

Table D4b. Site characteristics in thinned mixed red and white pine, by sample plot.

Plot No. in Comp. 7	pH	Texture A and B horizon	Soil depth A and B horizon (cm)	Presence of gravel**	Slope (%)	Aspect
1-4	5.0	SL*	102	little	4	NW
2-5	5.2	SL	122	some	7	NW
3-2	6.4	SL	97	some	12	NW
4-4	5.4	SL	51	much	8	NW
5-1	5.6	SL	76	some	4	W
6-3	5.4	SL	81	some	29	W

* Sandy loam.

** Presence of gravel broadly described by terms much, some, little, or none.

Table D5a. Number of trees, DBH, height, basal area, volume, and site index for residual and cut by storm in unthinned Scotch pine, by sample plot.

Plot No. and Compartment		No. of trees (ha^{-1})	Average DBH (cm)	Average height (m)	Basal area (m^2/ha)	Volume (m^3/ha)	Site index (ft)
4, Comp. 20A	Residual	964	22.2	20.2	39.1	382.5	75
	Cut	297			8.2	70.6	
	Total	1,261			47.3	453.1	
3, Comp. 20A	Residual	988	22.4	21.2	41.2	401.7	79
	Cut	272			6.6	53.9	
	Total	1,260			47.8	455.6	
7, Comp. 18	Residual	618	25.0	21.2	31.6	314.7	79
	Cut	321			8.1	68.0	
	Total	939			39.7	382.7	

Table D5b. Site characteristics in unthinned Scotch pine, by sample plot.

Plot No. and Compartment	pH	Texture A and B horizon	Soil depth A and B horizon (cm)	Presence of gravel***	Slope (%)	Aspect
4, Comp. 20A	5.6	SL*	97	much	0	-
3, Comp. 20A	5.5	L**	89	much	0	-
7, Comp. 18	5.6	SL	91	some	10	W

* Sandy loam.

** Loam

*** Presence of gravel broadly described by terms much, some, little, or none.

Table D6a. Number of trees, DBH, height, basal area, volume, and site index for residual and cut in thinned Scotch pine, by sample plot

Plot No. and Compartment		No. of trees (ha^{-1})	Average DBH (cm)	Average height (m)	Basal area (m^2/ha)	Volume (m^3/ha)	Site index (ft)
5, Comp. 20A	Residual	321	30.9	21.9	24.3	246.7	82
	Cut	1,458			27.3	165.0	
	Total	1,779			51.6	411.7	
1, Comp. 20A	Residual	345	31.4	21.0	27.1	276.2	78
	Cut	1,285			27.8	184.4	
	Total	1,630			54.9	460.6	
9, Comp. 18	Residual	321	30.3	22.4	23.5	237.3	83
	Cut	1,063			25.3	175.8	
	Total	1,384			48.8	413.1	

Table D6b. Site characteristics in thinned Scotch pine, by sample plot.

Plot No. and Compartment	pH	Texture A and B horizon	Soil depth A and B horizon (cm)	Presence of gravel***	Slope (%)	Aspect
5, Comp. 20A	5.4	L*	81	some	1	-
1, Comp. 20A	5.5	SL**	89	much	0	-
9, Comp. 18	5.5	SL	89	some	11	W

* Loam.

** Sandy loam.

*** Presence of gravel broadly described by terms much, some, little, or none.

Table D7a. Number of trees, DBH, height, basal area, volume and site index in unthinned European larch, by sample plot.

Plot No. and Compartment	No. of trees (ha^{-1})	Average DBH (cm)	Average height (m)	Basal area (m^2/ha)	Volume (m^3/ha)	Site index (ft)
5, Comp. 8A	1,260	18.3	18.7	35.5	301.2	68
8, Comp. 13	1,137	20.4	19.8	41.3	372.8	72
1, Comp. 20A	1,705	17.6	19.2	43.5	358.6	72

Table D7b. Site characteristics in unthinned European larch, by sample plot.

Plot No. and Compartment	pH	Texture A and B horizon	Soil depth A and B horizon (cm)	Presence of gravel***	Slope (%)	Aspect
5, Comp. 8A	5.4	L*	89	some	7	W
8, Comp. 13	5.4	SL**	81	little	5	W
1, Comp. 20A	5.3	L	85	little	7	N

* Loam.

** Sandy loam.

*** Presence of gravel broadly described by terms much, some, little, or none.

Table D8a. Number of trees, DBH, height, basal area, volume, and site index for residual and cut in thinned European larch, by sample plot.

Plot No. and Compartment		No. of trees (ha^{-1})	Average DBH (cm)	Average height (m)	Basal area (m^2/ha)	Volume (m^3/ha)	Site index (ft)
6, Comp. 8A	Residual	667	22.6	20.1	27.8	271.6	73
	Cut	741			10.2	55.6	
	Total	1,408			38.0	327.2	
7, Comp. 8A	Residual	593	24.1	20.6	27.4	271.2	76
	Cut	766			13.1	82.8	
	Total	1,359			40.5	354.0	
2, Comp. 20A	Residual	741	21.8	20.5	28.6	276.3	76
	Cut	642			11.6	76.1	
	Total	1,383			40.2	352.4	

Table D8b. Site characteristics in thinned European larch, by sample plot

Plot No. and Compartment	pH	Texture A and B horizon	Soil depth A and B horizon (cm)	Presence of gravel**	Slope (%)	Aspect
6, Comp. 8A	5.4	L*	76	some	7	W
7, Comp. 8A	5.4	L	64	little	6	W
2, Comp. 20A	5.5	L	89	little	8	N

* Loam.

** Presence of gravel broadly described by terms much, some, little, or none.

Table D9a. Number of trees, DBH, height, basal area, volume, and site index in unthinned Norway spruce, by samle plot.

Compartment	No. of trees (ha^{-1})	Average DBH (cm)	Average height (m)	Basal area (m^2/ha)	Volume (m^3/ha)	Site index (ft)
Comp. 11	1,087	21.0	21.9	40.2	403.0	81
Comp. 23C	1,285	25.0	23.2	65.6	695.0	90

Table D9b. Site characteristics in unthinned Norway spruce, by sample plot.

Compartment	pH	Texture A and B horizon	Soil depth A and B horizon (cm)	Presence of gravel**	Slope (%)	Aspect
Comp. 11	5.8	L*	76	little	3	W
Comp. 23C	5.0	L	122	none	0	-

* Loam.

** Presence of gravel broadly described by terms much, some, little, or none.

APPENDIX E

NUMBERS OF EACH SPECIES OF UNDERSTORY PLANTS

Table E. Numbers of each species of understory plants found on all sampling plots, by plantation species.

Species	Red pine	Red & white pine	Scotch pine	Europ. larch
Grasses, sedges, & ferns(3)				
Carex pennsylvanica Lam		2		
Dactylis glomerata L.				1
Dryopteris spinulosa (D. F. Muell.) Watt	4	1		1
Forbs(25)				
Antennaria neglecta Greene	8			
Apocynum androsaemifolium L.		2		
Arctium minus (Hill) Bernh.				1
Asarum canadense L.	21			
Aster L.	7			
Circaea quadrisulcata (Maxim.) Franch. & Sav.		2		1
Desmodium glutinosum (Muhl.) Wood	7	9		
Fragaria L.				1
Galium circaezans Michx	2			
Galium concinnum T. & G.		1		2
Galium trifidum L.		2		
Hieracium L.	5	4		
Laspedeza repens	2			
Osmorhiza longistylis (Torr.) DC		5		2
Phryma leptostachya L.		1		
Phytolacca americana L.	2	3		
Plantago major L.		2		
Prenanthes alba L.		2		
Rumex acetocella L.	18			
Senecio L.	4	2		1

Table E (cont'd)

Species	Red pine	Red & white pine	Scotch pine	Europ. larch
Smilacina racemosa (L.) Desf.		1		4
Taraxacum officinale Weber		4		
Trillium grandiflorum (Michaux) Salisb				1
Vercina officinalis L.	1			
Vines(4)				
Parthenocissus quinqefolia (L.) Planch	28	4		9
Rhus radicans L.			5	2
Solanum dulcamara L.		1		
Vitis L.			4	2
Shrubs(9)				
Aronia Reichenb.	1			
Berberis thunbergii DC.	2	1	2	2
Lonicera tatarica L.			2	5
Prunus virginiana L.			1	1
Rhamnus cathartica L.	3	1	6	5
Rhus vernix L.				2
Rubus allegheniensis Porter	1			2
Rubus occidentalis L.		3		3
Sambuscus canadensis L.		2		
Trees(17)				
Acer platanoides L.				3
Acer rubrum L.	4	3	6	9
Acer saccharum Marsh		2	3	3

Table E (cont'd)

Species	Red pine	Red & white pine	Scotch pine	Europ. larch
Carya ovata (Mill.) K. Koch	3	1	2	3
Celtis occidentalis L.				1
Cornus florida L.			5	1
Fraxinus americana L.	2		1	3
Juglans nigra L.		1		
Pinus resinosa Aiton	2			
Pinus strobus L.	5	11		
Pinus sylvestris L.			2	
Prunus serotina Ehrh.		2	3	8
Quercus alba L.	2	2		
Quercus rubra L.	4	1		
Sassafras albidum (Nutt.) Nees	3	2	7	10
Ulmus americana L.				1

APPENDIX F

SPECIES OF UNDERSTORY VEGETATION

Table F1. Species of understory vegetation in red pine stands.

Species	Relative density (%)	Relative frequency (%)	Relative coverage (%)
Ferns			
Dryopteris spinulosa	2.8	5.3	1.8
Vines			
Parthenocissus quinquefolia	19.6	5.3	43.1
Forbs			
Antennaria neglecta	5.6	2.6	0.9
Asarum canadensis	14.7	2.6	4.0
Aster	4.9	2.6	0.9
Desmodium glutinosum	4.9	7.9	12.0
Galium circaezans	1.4	2.6	0.4
Hieracium	3.5	2.6	0.9
Laspedeza repens	1.4	2.6	0.9
Phytoracca americana	1.4	2.6	2.7
Rumex acetosella	12.6	5.3	2.2
Senocio	1.4	2.6	0.4
Solidago	2.8	5.3	0.9
Veronica officinalis	0.7	2.6	0.4
Shrubs			
Aronia melanocarpa	0.7	2.6	0.9
Berberis thunbergiii	1.4	2.6	1.3
Rhamnus cathartica	2.1	2.6	4.0

Table F1 (cont'd).

Species	Relative density (%)	Relative frequency (%)	Relative coverage (%)
Rubus allegheniensis	0.7	2.6	1.3
Trees			
Acer rubrum	2.8	5.3	4.4
Carya ovata	2.1	5.3	3.1
Fraxinus americana	1.4	2.6	1.8
Pinus resinosa	1.4	2.6	0.4
Pinus strobus	3.5	2.6	0.4
Quercus alba	1.4	5.3	2.2
Quercus rubra	2.8	7.9	5.3
Sassafras albidum	2.1	5.3	3.1

Table F2. Species of understory vegetation in the mixed red and white pine stand.

Species	Relative density (%)	Relative frequency (%)	Relative coverage (%)
Sedges			
Carex pennsylvanica	2.5	2.94	0.74
Ferns			
Dryopteris spinulosa	1.25	2.94	0.74
Vines			
Parthenocissus quinquefolia	5.0	2.94	1.47
Solanum dulcamera	1.25	2.94	0.74
Forbs			
Apocynum androsaemifolium	2.5	2.94	0.74
Circaea quadrisulcata	2.5	2.94	2.21
Desmodium glutinosum	11.25	2.94	6.62
Galium concinnum	1.25	2.94	0.74
Galium trifidum	2.5	2.94	0.74
Hieracium	5.0	2.94	0.74
Osmorhiza longistylis	6.25	5.88	5.88
Phryma leptostachya	1.25	2.94	0.74
Phytolacca americana	3.75	5.88	8.09
Plantago major	2.5	2.94	0.74
Prenanthes alba	2.5	2.94	1.47
Smilacina racemosa	1.25	2.94	0.74
Solidago	2.5	2.94	0.74
Taraxacum officinale	5.0	2.94	0.74

Table F2 (cont'd).

Species	Relative density (%)	Relative frequency (%)	Relative coverage (%)
Shrubs			
Berberis thunbergii	1.25	2.94	2.21
Rhamnus cathartica	1.25	2.94	3.68
Rubus occidentalis	3.75	2.94	5.15
Sambuscus canadensis	2.5	2.94	8.09
Trees			
Acer rubrum	3.75	2.94	7.35
Acer saccharum	2.5	2.94	4.41
Carya ovata	1.25	2.94	3.68
Juglans nigra	1.25	2.94	3.68
Pinus strobus	13.75	5.88	3.68
Prunus serotina	2.5	2.94	5.15
Quercus alba	2.5	2.94	4.41
Quercus rubra	1.25	2.94	2.21
Sassafras albidum	2.5	2.94	11.03

Table F3. Species of understory vegetation in Scotch pine stands.

Species	Relative density (%)	Relative frequency (%)	Relative coverage (%)
Vines			
Rhus radicans	10.2	9.1	0.6
Vitis	8.2	9.1	0.4
Shrubs			
Berberis thunbergii	4.1	4.55	1.7
Lonicera tatarica	4.1	9.1	2.3
Prunus virginiana	2.0	4.55	1.3
Rhamnus cathartica	12.2	9.1	17.3
Trees			
Acer rubrum	12.2	9.1	7.9
Acer saccharum	6.1	4.55	6.5
Carya ovata	4.1	9.1	4.0
Cornus florida	10.2	9.1	18.6
Fraxinus americana	2.0	4.55	2.5
Pinus sylvestris	4.1	4.55	0.2
Prunus serotina	6.1	4.55	15.7
Sassafras albidum	14.3	9.1	21.1

Table F4. Species of understory vegetation in European larch stands.

Species	Relative density (%)	Relative frequency (%)	Relative coverage (%)
Ferns			
Dryopteris spinulosa	1.1	1.8	0.1
Grasses			
Dactyris glomerata	1.1	1.8	0.1
Vines			
Parthenocissus quinquefolia	9.9	6.0	0.9
Rhus radicans	2.2	4.2	0.2
Vitis	2.2	4.2	0.2
Forbs			
Arctium minus	1.1	1.8	0.1
Circaea quadrisulcata	1.1	1.8	0.1
Fragaria	1.1	1.8	0.1
Galium concinnum	2.2	1.8	0.1
Osmorhiza longistylis	2.2	1.8	0.2
Smilacina racemosa	4.4	4.2	0.2
Solidago	1.1	1.8	0.1
Trillium grandiflorum	1.1	1.8	0.1
Shrubs			
Berberis thunbergii	2.2	1.8	0.5
Lonicera tatarica	5.5	6.0	6.4

Table F4 (cont'd).

Species	Relative density (%)	Relative frequency (%)	Relative coverage (%)
Prunus virginiana	1.1	1.8	0.2
Rhus vernix	2.2	4.2	0.5
Rhamnus cathartica	5.5	1.8	0.2
Rubus allegheniensis	2.2	4.2	0.9
Rubus occidentalis	3.3	6.0	2.1
Trees			
Acer platanoides	3.3	1.8	3.5
Acer rubrum	9.9	6.0	16.3
Acer saccharum	3.3	4.2	6.4
Carya ovata	3.3	4.2	5.3
Celtis occidentalis	1.1	1.8	0.2
Fraxinus americana	3.3	4.2	7.9
Prunus serotina	8.8	6.0	17.2
Quercus rubra	1.1	1.8	0.2
Sassafras albidum	10.1	6.0	18.8
Ulmus americana	1.1	1.8	0.4

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