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SOME BIOLOGICAL ASPECTS OF PURE AND MIXED CONIFEROUS PLANTATIONS IN LOWER MICHIGAN

by
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of the requirements for the degree of
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INTRODUCTION

The question of the desirability of pure versus mixed stands is perhaps as old as forestry. Quite frequently the controversy has been waged purely on sentimental reasoning in addition to scientific or statistical arguments. The present study concerning pure versus mixed stands can be divided into two parts. The first part deals with evaluation of pure versus mixed stands in general. It is an attempt to reconstruct the chronology of the development of the controversy, to survey the oscillation of opinion in favor of one or the other type of stand at various periods, and to give the present status of the problem in general. This part of the study is based on the available American and foreign literature going back as far as 1500 A. D. In addition to the English, pertinent literature in the German, French, Russian, Swedish, Norwegian, Danish, Finnish, Dutch, Spanish, Italian, and Croatian was consulted.

The second part of this dissertation is an examination of the growth and development of certain pure and mixed plantations of jack pine, red pine, Scotch pine, and white pine in Michigan. The data were obtained from a series of 35-

year-old plantations in lower Michigan. The purpose of this specific study is to determine some of the relative effects of the species mixture on growth and development of the various species as individual trees and as stands on some of the better and poorer sites. In addition to diameter, height, and volume growth, the present incidence of insect and disease attacks has been compared in the pure and mixed plantations.

PART I

PURE AND MIXED STANDS IN GENERAL

1. THE CONCEPTS OF 'PURE' AND 'MIXED' STANDS

It is not easy to offer a precise and rigid definition of a stand. The one accepted by the Society of American Foresters (237) reads "An aggregation of trees or other growth occupying a specific area and sufficiently uniform in composition (species), age arrangement, and condition as to be distinguishable from the forest or other growth on adjoining areas." It may be noted that the criteria ascribed to a stand in this definition, although adequate for classification purposes, are vague.

Equally vague are the concepts of 'pure' and 'mixed' stands. Pure stand, in the strictest sense of the word, is a stand that consists of only one species. Such stands are exceptions since in almost all forest stands, whether natural or artificial, more than one species is present. Probably no stand, at least at some time of its life, can be called a pure stand, if the pure stand is one with one hundred percent of its members being of one species. Consequently, a small

percent of other species is allowed in a pure stand. According to the Committee on Forest Terminology of the Society of American Foresters (237), a pure stand is "a stand in which at least 80 per cent of the trees in the crown canopy are of a single species." However, this basis cannot always be applied to classify a pure stand. Some stands containing ten or even five percent of another species in the overstory by number may be classified as mixed stands because of the economic value and/or the silvicultural importance of the minority species. For instance, a white pine and beech stand containing only five or ten percent of beech may be classified as a mixed stand because the beech exerts a marked silvicultural influence on the pine. Similarly, a white oak and sugar maple stand having only about ten percent of the latter species by number is commonly regarded a mixed stand, since the sugar maple has a high commercial value.

On the other hand, a much larger proportion (by number) of a less valuable and/or silviculturally less important minority species does not necessarily make the stand a mixed stand. For example, a stand where white pine constitutes seventy-five to eighty percent and the rest is gray birch, is usually considered a pure white pine stand because of the temporary nature (hence silviculturally insignificant) and low commercial value of gray birch.

The definition of a mixed stand accepted by the Society of American Foresters (237) reads "A stand in which less than 80 per cent of the trees in the main crown canopy are of a single species." This definition stipulates that the mixture should be in the crown canopy, which is not a universally accepted criterion of a mixed stand. It is argued that a two-storied stand where the understory has a profound effect on the character and quality of overstory should be called a mixed stand. In view of silvicultural importance of the understory, it seems that in defining pure and mixed stands, the consideration of competition involved should be confined not only to overstory or crown canopy but also to lower level.

The degree of pureness of a stand depends on the size of the area; usually the smaller the area, the greater the degree of pureness and vice versa. The relationship between the species in a stand is dependent on their relative proportion in the stand.

The relationship between the species in a stand varies all the time, since the number of trees of each species does not diminish at the same rate with advance in age.

Besides the proportions of various species in a mixed stand, the quantity and quality of the product is influenced to a great extent by the way the trees are arranged in a mixture. The various types of mixtures are discussed in the

following section.

From the above it appears that there is no arbitrary rule with regard to the proportion of minority species that may be or must be present in order to constitute a pure or mixed stand. Furthermore, the important factors, namely the degree of pureness of stand as affected by the size of area, the silvicultural role of understory, and the changing relationship of various species with advance in age, should be carefully examined while considering the matter of pure and mixed stands.

Classification of Mixed Stands

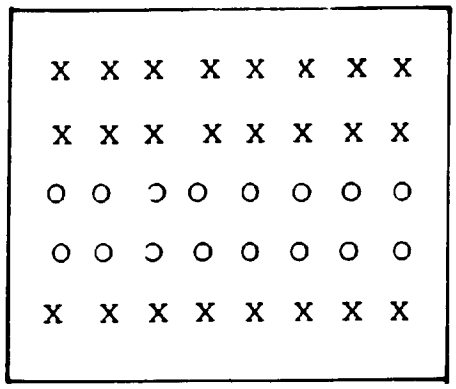
In any consideration of mixed stands, it is important to bear in mind the type of the mixed stand. Mixed stands can be classified on many bases.

A. Based on arrangement of trees:

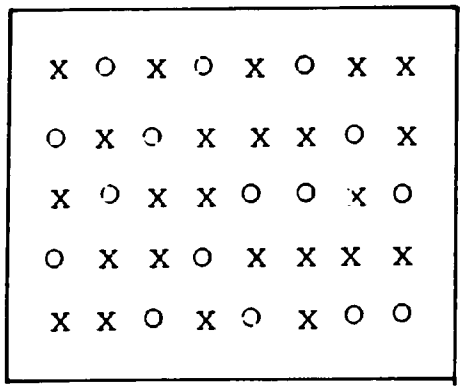
As mentioned earlier, the quality and quantity of product from a mixed stand is affected not only by the relative proportion of the component species, but also by the way the trees are arranged in the mixture. Following are the various types of mixtures based on arrangement of trees.

1. Single tree mixtures

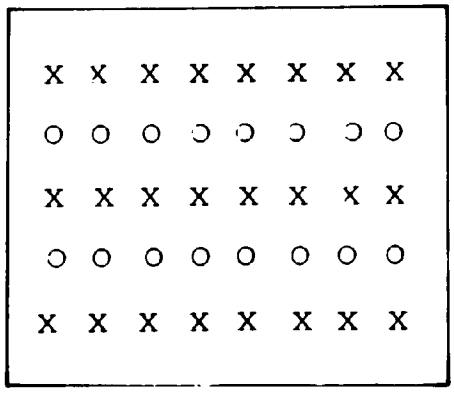
In these mixtures, the members of species A and species B are individually separated from each other (Fig. 1). In the strictest sense, the trees of one species



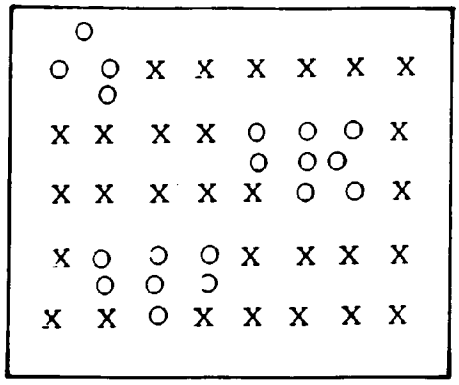
Strip or Band Mixture



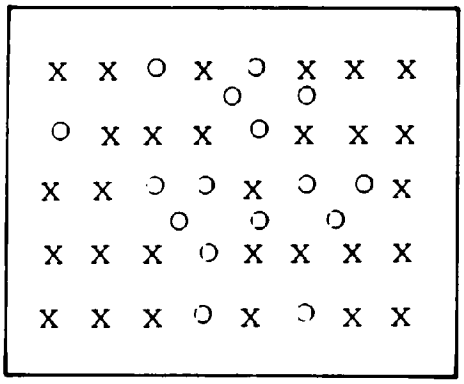
Single Tree Mixture



Line or Row Mixture



Regular Groups



Irregular Groups

Fig. 1.--Types of Mixtures Based on Arrangement of Trees

are always to be surrounded by trees of other species. The decisive feature here is the growing conditions, under which the crowns of species A should be surrounded by the crowns of Species B. A stand containing a few scattered white pines among oak trees is an example of a single tree mixture. Such stands are rarely so planted and by and large are of natural origin.

2. Group mixtures

a. Regular groups

In the group mixtures, a group of three to six or more trees of one species is surrounded by an almost equal sized group of trees of another species (Fig. 1). The trees in the group that stand on the edge are bounded on the inner side by the members of their own species and on the outside by members of the other species. Only the trees that stand inside of a group are surrounded by and compete with members of their own species. The soil under the group is influenced mainly by the trees of the group and to some extent by the trees adjacent to the group. The soil at the edge of a group is influenced partly by the trees of the group and partly by the trees outside the group. The regular group mixtures are more or less regularly spaced and hence are so termed. Such groups are almost always artificially planted. The size of group varies and there is no arbitrary rule fixing

their size. Many types of spaced-group mixtures have been suggested by several authors (4, 5, 6, 7, 46, 55, 79, 136, 152, 173, 183, 184, 203, 206, 222, 242, 243, 250, 276).

b. Irregular groups

The groups are like the regular groups so far as composition and arrangement is concerned but they are not regularly spaced (Fig. 1). They may be of artificial or natural origin.

3. Strip or band mixtures

Such mixtures are commonly the result of seeding or planting in rows. Several rows of one species are mixed with several rows of another species (Fig. 1). The broader the strips, the lesser the influence a species has on inner trees of the other species in the strip.

4. Line or row mixtures

In these mixtures, a line of one species is flanked by a line of another species. These mixtures are always artificially produced. A common type of line mixture is alternate line or row mixture, where one line of a species alternates with a line of another species. In such mixed stands, normally a tree of one species competes with a tree of another species on two sides. Next to single tree mixtures, alternate row mixtures are the highest expression of intimate mingling of component species.

B. Based on the length of time the component species remain in mixtures:

Mixed stands can be divided into two broad categories, on the basis of length of time the component species remain in the mixture.

1. Permanent mixtures

The species comprising the permanent mixtures are carried through the maturity of the crop. The exact relationship between the species, however, varies at all times because the number of trees of each component species does not decrease with advance in age at the same rate.

2. Temporary mixtures

Under certain circumstances, only one species in a mixture is carried through to maturity while the others are removed prior to harvest of the major species. Temporary mixtures can be sub-divided into two groups.

a. Nurse crops

A nurse species is provided to protect some tender species during their earlier life. The nurse species may be grown at the same time with the 'nursed' species or advantage may often be taken of a natural nurse crop in artificial regeneration. In the former case, the nurse species serve their function by virtue of their relatively more rapid growth, shade-producing qualities, or abundance in the stand.

b. Fillers

Fillers are inexpensive species in mixtures, which are removed in early thinnings. The fillers are used primarily to reduce the cost of seeding or planting an area.

C. Based on the ages of the component species:

The mixtures can be classified into two main groups on the basis of the ages of the component species:

1. Even-aged mixtures

The ages of the species in such mixtures are the same.

2. Two- or many-aged mixtures

These mixtures consist of species of two or more ages. Species of different ages are mixed because of silvicultural or financial considerations.

D. Based on the nature of origin:

There are two types of mixtures based on the nature of the origin.

1. Natural mixtures

Natural mixtures are composed of species of natural origin.

2. Artificial mixtures

Artificial mixtures consist of species which are artificially planted or seeded.

2. PURE VERSUS MIXED STANDS

A. A Historical Review

The advantages and disadvantages of pure and mixed stands have been studied with great interest by foresters and there is a vast volume of literature on the subject. We shall examine the development of the controversy in a chronological order.

Emphasis on Mixed Stands by Early Foresters:

Bühler (38) has shown that in medieval times the practice was to raise trees both in pure and mixed stands. We find detailed instructions regarding the seeding and planting of trees in the European forestry literature around 1500 A.D. (38). Seeds of several species were used, mostly deciduous, but also those of only one type of conifer. It is apparent that pure as well as mixed stands were present when some of the earliest foresters engaged themselves in growing forest trees.

Carlowitz (47) was probably the first silviculturist who, in 1712, advocated that trees should be grown in mixed stands because such stands were the common occurrence in nature. He suggested that the seeds of various species

should be sown in rows for esthetic reasons. Hohberg (131) in 1716 proposed growing of some sixteen hardwood and four conifer species in mixtures for afforestation, claiming increased growth for certain species where they were mixed. Later on, in 1746, Döbel (63) recommended that hardwoods should be removed from a mixed stand if they occupied more than half of the stand. Beckmann (19) in 1756 boasted of having grown successfully nine different species mixed thoroughly together. Although Büchting (37) did not, in the same year, refer specifically to mixed stands, he dealt with the most important species which undoubtedly occurred in mixed stands.

Preference for Pure Stands

In 1757, Moser (188) proposed that after the soil had been improved in a stand, certain species should be removed by frequent thinnings so that only one species remained in that area. Mixture of pines and fir was suggested by Geutebrück (87) because they took approximately the same time to reach maturity. But basing his argument on the difference in the ages of maturity of various hardwood and coniferous species, Cramer (58) maintained that mixing of hardwood and conifers would be detrimental. The "Police magazine" (1767) also recommended that the detrimental mixtures of hardwoods and conifers should be discouraged so as to avoid eliminating one of the two later on. Similar conclusions were reached under

"cutting wood" in the Onomatologie forestalis in 1772. Beckmann (20) claimed that the areas under mixtures of hardwood and conifers could be more advantageously utilized if they were under one species only. Consequently, he recommended that mixtures should be avoided and hardwoods or conifers should be raised only in pure stands.

While he allowed the mixing of hardwood species among themselves, Suckow (246) strongly disapproved hardwood and coniferous mixtures on the grounds that one species suppressed the other. Jung (138) in 1781 also condemned mixtures of hardwoods and conifers because of the uneven rate of growth of the two species. In his dissertation which was awarded a prize by the Swedish Patriotic Society in 1786, Brüel (36) recommended that mixed stands should be avoided. "The woods and forestry order" of the Crown Prince of Trier (1786) especially recommended oaks and beeches for reforestation and afforestation. The order stated that spruce, firs, and larch might also be tried for the above purposes but there should never be a mixture of hardwoods with the coniferous species (38). In a small pamphlet, possibly written by a forester, about public and private forests in Mainz in 1789, the author called a mixture of hardwoods and conifers a bad economy because the conifers grew faster than the hardwoods and consequently one of the species would have to be removed at a

time different from the other's (38). Similarly Nau (189) disapproved mixing of hardwood and coniferous species. He added that all types of conifers except pine could be grown in mixtures and likewise oak, beech, hornbeam, maple, ash, birch, and aspen would grow well when mixed among themselves. In 1788 and again in 1790, Burgsdorf (43, 44) strongly advocated that mixed stands be changed to pure stands. Likewise, Dätzel (60) maintained in 1788 and again in 1802 that it was a proven fact that hardwood-conifer mixtures were detrimental because the hardwood species would be suppressed by conifers. According to him only beech with Scotch pine or birch with spruce showed satisfactory growth in a mixed stand.

One of the most influential German foresters, G. L. Hartig, did not deviate from the then predominant opinion when he opposed in 1791 any mixing of hardwoods and conifers on the grounds of the suppression of the former by the latter (110). He proposed that the mixed stands should be changed to pure stands. He asserted that almost all foresters, including himself, were of the opinion that the biological qualities of hardwoods and conifers, as well as their cultural care and management, were so fundamentally different that their rational treatment in mixed stands was impossible. Four years later, he recommended that oaks be raised, wherever possible, in a mixture with beeches, but he still maintained

that all mixed stands should be changed to pure stands of the most profitable type. He further suggested that all clearings should be stocked with the surrounding species and that the number of species in an area should be kept at a minimum.[1] Later on, in 1808, Hartig (112) asserted that each stand should be as uniform as possible to facilitate proper management. He held the same point of view regarding the change of mixed to pure stands in 1809 (111), but he made one concession, i.e., if the cost of changing a mixed stand into a pure stand were prohibitive, that stand might be maintained as a mixed stand. He stated in 1832 that beeches and oaks grew advantageously with ash and maple, and that beeches, spruces and firs could be mixed together. The other mixtures he allowed were: hornbeam and beech; birch and alder; pine and larch; and spruce and fir. Thus, he no longer completely rejected mixing of hardwoods and conifers, although it was limited only to the mixing of beech with spruce or fir. He recommended the mixing of hardwoods or conifers only among themselves. Later on in 1834, he recommended that only trees of the same age of maturity and having different lengths of

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[1]Georg. L. Hartig, 1795. Anweisung zur Taxation der Forste, oder zur Bestimmung des Holzertrags der Walder; ein Beytrag zur höheren Forstwissenschaft. /Guide to forest taxation, or determination of forest yield; a contribution to advanced forestry./ Giessen: Heyer. 200 pp.

root systems should be mixed. Again, in 1834, he repeated the above conclusions about mixed stands with the addition that the trees grew better in that type of mixed stands than in pure stands (113).

Sierstorpff (233) in 1796 expounded that the common forestry axiom that every species should be grown by itself was also true for oaks in the Braunschweig-Lüneburg area. In the forests of the city of Ulm there were in 1797 partly pure and partly mixed stands. The head forester remarked that the mixed stands could not be at once changed to pure stands, but in 1804 he stated that the mixed hardwood and conifer stand had to be "purified" (232). Seckendorf (230) looked upon mixed stands as the results of poor forest management. Between 1797 and 1802, Griesheim (100) claimed that mixing of hardwoods with conifers was contrary to the principles of silviculture and that all people who knew something about forestry agreed with his opinion. Laurop (162) after visiting the forest of Frankfurt in 1802 remarked, "Many localities which previously had mixed stands of hardwoods and conifers were changed to pure hardwood stands . . . because the poor sight of the mixed stands could also be avoided; - never shall such mixing occur again." An outspoken advocate of pure stands was Zschokke (287), who, in 1806, declared that the principle of changing hardwood and coniferous mixed stands to pure stands

of single species should be followed to the utmost. Also, he disapproved of mixing firs, spruces, larches, and cembra pine. His opinion, however, was not shared in Switzerland.

Reversion to Mixed Stands

Hatzel (115) proposed in 1802 that strips of hardwood trees should be planted in a coniferous stand in order to avoid the danger of damage by birds and insects. One of the first foresters to voice notable opposition to Hartig's advocacy of changing mixed stands to pure stands was Medicus (180), who in 1802 remarked that coniferous stands occurred partly mixed and partly pure. Moreover, he claimed that mixed hardwood and conifer stands (oak, Scotch pine, beech, fir, and spruce) occur frequently and that most of the foresters opposed to such mixtures were not completely convinced of their undesirability. In his treatment of pure and mixed stands, Kasthofer (142) in 1828 did not favor one over the other. In the eighteenth century, mixed stands in Switzerland were called the best in the country (38). Gleditsch (1774) favored the maintenance of mixed stands (93). He suggested that the mixed stands should not be thinned in the usual manner and that a heavier stocking should be maintained. Mixed stands of hardwoods and conifers were raised in the Harz mountains by Zanthier, who remarked in 1795 that those stands had a "checkered" look (283). Likewise, Drais (66), the head

forester of Baden, remarked in 1807 that mixture of hardwoods and conifers occurred in nearly all counties and that the attempt had been made to keep them as such in spite of the advocacy by numerous foresters that they should be changed to pure stands. Another influential silviculturist who was vehemently opposed to the predominant opinion of his time, i.e., conversion of mixed to pure stands, was Sponeck. In most of his reports he recommended pure stands although he had visited some excellent mixed stands of beeches and firs in the Black Forest near Neuenburg (238). He dealt with those mixed stands more definitely in 1817 (239).

Even more opinionated than Sponeck in giving judgment on pure and mixed stands was Cotta - one of the most celebrated foresters. While he preferred mixed stands over pure stands, he did not recommend mixing trees having different maturity age and requiring different management (54). He asserted that attempts to create pure stands every place were very harmful, particularly if one species had to be removed and thus interrupt the canopy. He further stated that the management of mixed stands should be guided by the requirements of the most valuable species in the mixture. Wherever the maturing age, management, and the value of the species were approximately the same, all species could be maintained in the mixture. He pointed out that the opinions against mixed

stands were based mainly on prejudice. Hundeshagen (135) agreed with Cotta in 1821, and he was proud of his position in opposing Hartig (111, 112).

Pfeil in his exhaustive treatment of pure and mixed stands in 1821 and 1829 stated, "Wherever site and climate allow raising of mixed stands, they should always be preferred to pure stands" (200). Similarly, in 1860 he stated, "Mixed stands are to be preferred to pure stands in any locality" (201). Likewise, Laurop (162) remarked in 1822 that a mixed stand was not as detrimental as it was held to be by many people (18). He maintained that mixed stands grew rather fast. In Austria, Zötl (286) attributed a higher volume production to the mixed stands. Similarly, Feistmantel (75) in 1835 gave examples of useful mixed stands in Austria. He claimed that no type of management favors mixtures more than the coppice with standards system. Later on, in 1841 and 1853, Grabner (95) and Wessely (270) reported the extent of areas under pure and mixed stands in Austria.

Gwinner (106) in 1834 divided tree species into two classes according to whether they were suitable for growing in pure or mixed stands. He asserted that trees grow better in mixed stands than in pure stands. Later, in 1841, he modified his position slightly, admitting that it could not be denied that some species fared reasonably well in pure

stands and gave profitable results. But he emphasized that a suitable mixture did have advantages and was desirable for economic reasons. He pointed out that mixed stands were the rule in nature and, therefore, they should be preferred to pure stands. Nevertheless, over a certain period of time, the majority of foresters came to hold the opinion that pure stands should be preferred to mixed stands. Gwinner (106) summed up the following reasons which contributed to the predominant opinion about pure stands at that time. First, faulty management and unsuitable mixtures produced undesirable results in the mixed stands as compared to the pure stands. Second, some hardwood species such as beech were doing better in pure than in mixed stands. Third, many foresters considered it to be a goal to convert mixed stands to pure stands, irrespective of the fact that some sites (wet places, poor sand, very high elevation, etc.) and climates permitted only one species. Sangler, who put out the fourth edition of Gwinner's Silviculture, in 1858 after an extensive revision, spoke in favor of mixed stands. In 1841, Schultes (229) expressed the opinion that only the gregarious types of trees should be raised in pure stands and the others should be grown in mixtures.

Karl Heyer, one of the most prominent foresters, led an exhaustive discussion on the question of pure versus mixed

stands in the forestry conferences at Freiburg and Aschaffenburg. He incorporated his opinions in Beiträge zur Forstwissenschaft (Contributions to Forestry) (1847) (126), and later on in Waldbau (Silviculture) (1854) (127). Discussing the advantages of mixed stands, he summarized that the cases in which the pure stands seemed to be advisable were more an exception and that the mixed stands recommended themselves as being the rule. Gustav Heyer (124, 125) and Hess (122) corroborated his opinions later. One main advantage of mixed stand emphasized by Karl Heyer was that the number of the working sections could be minimized. Similarly, Stumpf (244) ascribed some definite advantages to mixed stands over pure stands.

Burckhardt (39) in 1855 dealt exhaustively with almost every species regarding their raising in pure and mixed stands, while a short treatise on mixed stands was presented by Fischbach (76) a year later. Speaking about the Swiss foresters Landolt (156) in 1866 emphasized that there had been no change in their opinions about mixed and pure stands. They considered that mixed stands should be the rule and pure stands only exceptions. A special pamphlet about mixed stands, perhaps one of the first on the subject, was written by Rörig (210) in 1867, but it was rather poorly written and was unsatisfactory.

In France mixed stands predominated in the eighteenth

century. Duhamel (67) in 1766 was concerned mainly with mixed stand. Lorentz and Parade (166) suggested in 1837 the type of mixtures for almost every species, as Broillard (33) did in 1881. Boppe (26, 27) preferred mixed to pure stands under all circumstances. Huffel (133) reported in 1893 that mixed stands in France were the silvicultural ideal.

Maxwell (176) in 1891 stated that mixed planting, in sharp contrast to pure planting, was practiced in England. He asserted that it was in itself a hindrance to profitable management because pure stands were more easily tended than mixed stands and that the timber was more readily marketable. In 1893 and again in 1894 Nisbet (194, 195), however, disapproved of Maxwell's position and emphasized that mixed stands have many advantages over pure stands. It was also pointed out by Fream (80) that both in agriculture and forestry the pests--whether insects or fungi--might be expected to become more abundant in pure stands, for they found their victims literally crowded together, and therefore extremely accessible.

The strongest opposition to G. L. Hartig's (110) ideas of favoring pure stands was led by Karl Gayer (86) (Munich). He regarded the raising of pure stands as a very harmful practice; and he took a strong stand in favor of mixed stands in 1880. In the beginning of the nineteenth century natural occurrence of pure stands was very limited as compared to

mixed stands, but the German forest management practice, particularly under the influence of G. L. Hartig (110) and his numerous pupils, had changed that condition to such an extent that the pure stands predominated in the late nineteenth century. Gayer pointed out that the quality of a mixed stand directly reflected the skill and technical knowledge of the manager. He attributed the origin of the bias against mixed stands to the type of management, which had smothered the sense for good and hard work, had led to mass production, and was the result of neglect and inadequate labor supply. Gayer compiled a more exhaustive treatise on mixing various species than any other author before him. He later published a pamphlet especially dealing with mixed stands (1886). In the fourth edition of his Waldbau, published in 1898, he maintained that mixed stands were the rule and pure stands were the exception in Central Europe. In 1905, he again expressed his opinion in favor of mixed stands (38).

While Wagener (266) was against mixed stands only wherever they reduce production, Lorey (167, 168), Ney (191, 192), and Mayr (177, 178) emphasized the advantages of mixed stands; however, Mayr recognizes only a few advantages. Borggreve (28) in 1885 did not even assign a separate chapter to the topic of pure and mixed stands. According to Weise (268, 269) pure stands were widespread over large areas of Germany

in the latter part of the nineteenth century because they required the simplest management and demanded the least amount of work. He claimed that many mixtures could only be preserved by careful and constant care. He reserved his recommendations for mixed stands to certain areas in northern Germany.

Some Twentieth-Century Opinions in Europe and the United States

Weise even believed that the future belonged to pure stands, but in 1910, Dittmar (62) expressed the opinion that mixed stands were to be preserved and new mixed stands were to be grown as far as site and climate would permit. Heyer and Hess (128) laid down certain conditions for raising pure stands and Graves (99) around the same time (1911) discussed briefly the advantages of mixed stands over pure stands. Kvapil and Nemec (154) reported in 1925 that the mixed stands of beech and spruce had a very favorable effect on the physical and chemical properties of the forest soil. In considering pure and mixed stands from the point of view of yield, Burger (40) concluded that sometimes one and sometimes the other yielded more. He recommended that if the yield were just about the same in both types of stands, mixed stands should be preferred on account of more effective soil protection, greater safety from damages caused by organic and

inorganic agents, facilitation of natural regeneration, etc. He further added that the adducing of reasons of convenience in favor of pure stands was no longer permissible.

In New England, the advantages of mixed hardwood-conifer stands in providing leaf litter and soil conditions more favorable for forest reproduction and growth were strongly claimed by Fisher (77) and Grifith et al (101), as well as others (51, 209). Furthermore, in the northeastern United States, where the forests are subject to attack by many native and introduced insect pests, the development of stable, relatively immune mixtures was considered to be an important part of good silvicultural practice in that region. Meineke (181) in the United States pointed out that the probable danger of pest epidemics in pure stands could only be overcome by better forest sanitation. Kellogg (143) concluded that haphazard mixtures were unlikely to be satisfactory in both biological and economic characteristics.

In a rather recent paper (1938) on the situation with regard to pure and mixed stands in Finland, Lappi-Sappälä (157) remarked that mixed stands were of great importance in the Finnish forestry. He pointed out some distinct advantages of certain specific mixtures and he emphasized that mixtures occurring naturally should not be converted to pure stands without adequate reasons. He later discussed the rational

silviculture for birch, and suggested some suitable mixtures (158) as did Appleroth (9).

Although no detailed mensurational data were available for mixed stands in Denmark, Sabroe (223) believed that mixtures might often be advantageous in the interest of soil improvement, better utilization of the available space and site conditions, and provision of a reserve against damage to the main crop.

In Switzerland, the experience from 1876 to 1943 has led to the abandonment, in great part. of the earlier policy of establishing pure stands of exotic and (later) indigenous conifers (45). Miegroet (182) reported that the best results were obtained when various species of pine were mixed with hardwoods. Burger (42) did not find much difference in the growth of some species in pure and mixed stands situated in six localities in Switzerland. He noted, however, that both the hardwoods and conifers tended to be less straight when mixed with the other species.

Clear (50) examined the role of mixed stands in Irish silviculture and concluded that, on the whole, on good soils, little advantage and much waste resulted from even-aged mixtures, but on poor soils such mixtures were of large, and in some cases of vital importance. Many combinations for mixed stands in England were suggested by Hiller (130).

The difficulties encountered in restoration of mixed stands adapted to the site in place of pure Scotch pine stands in the Zollbrucken forest were discussed by Vogdt (261), while a general theoretical discussion of the composition, structure, and rotation of mixed stands, and the problems of research on the growth of mixed stands was provided by Baader (13) in 1943. Zeidler (284) concluded that although spruce must continue to be one of the main species grown in southern Westphalia, large-scale pure plantations and clear felling must give way to more flexible treatments, varying according to site but chiefly involving group mixtures of spruce with hardwoods and larch. Based on a survey of the results from numerous mixed stands in central and northern Germany, which had been under observation for a long period of time, Wiedemann (271, 272) recommended continuation of the mixtures.

A monumental work on the conversion of pure coniferous stands to mixed stands in northwest Germany was presented by Lincke (163) in 1946. In addition to many other topics, the author gave an illustrated and detailed exposition of his methods, their execution, results, and costs. Similarly, Wittich (277) discussed the choice of species using the northwest German forest region as an example. He maintained that attempts to create or restore favorable soil conditions solely by manipulating stand composition could not be justified

if the same could be achieved more economically by technical means, e.g., by liming. Weck (267) attacked the tendency of some German foresters, particularly Wittich (277) and Henneck (121), to desert the principle of mixed uneven aged selection forest and to revert to the conception of pure even aged coniferous stands, trusting to soil cultivation and liming to keep the soil in good condition. He also examined the admitted difficulty of establishing and maintaining an uneven aged forest in north Germany.

Schober (228) in 1949 presented a monograph on larch plantations in northwest Germany, outside the natural range of the species. He concluded that mixed stands with larch in the upper story and hardwoods chiefly as understory considerably surpassed pure larch in yield. The dangers of monoculture of conifers based on the experiences of the last one hundred fifty years in Germany were discussed by Hedemann-Gade (118) and Hummel (134) discussed the silviculture of mixtures in the forests of Salem, Zeil, and Mengen. The various aspects of the question of pure and mixed stands were examined by Toumey and Korstian (249), who recognize both the silvicultural and economic superiorities of mixed stands if the mixtures are correctly made and maintained. Baker (15), however, asserts that the choice between the two requires careful consideration of natural forest forms,

of insect dangers, of storm severity and windfall, of the nature of the soil and its tendency to deterioration, and also a consideration of market and prices for different species and grades of lumber.

Lysenko's Theory

An important Russian school of thought led by Lysenko (169) in early nineteen-forties denounces the 'reactionary' Malthusian theory of overpopulation and the notion of intra-specific competition derived from it. It asserts the absence of intra-specific competition and is considered to have established the presence of interspecific competition and mutual aid in plant and animals and to have applied this principle successfully in practice to the cultivation of agricultural rubber plant Kok-sagyz as pure crop. Lysenko also attempted to trace the failure of many earlier steppe plantations to ignorance of the concept of mutual aid within a species. Later on, other Russian workers, namely Godnev (94), Gritsenko (102), Kharitonovich (145, 146), Labunski (155), Matyuk (174, 175), and Nesterov (190) confirmed Lysenko's concept of interspecific competition and mutual aid. They attempted to prove the concept by comparing pure and mixed plantations of several species and by the evidence from experience gained in afforestation of Chir sands in Southern Russia. This concept was further supported by Kryzhanovski (152), Ogievski

(197), Pogrebnyak (203), Pryakhin and Portnykh (206), and Yurre (282). Lysenko's views were predominant in Russia from 1948 to 1953 though the validity of his evidence was challenged in 1954 by some of his previous adherents, including Academician N. V. Turbin.[1] Lysenko's concept suffered a further decline in its popularity when he was relieved of his post as the President of the All-Union Academy of Agricultural Sciences in 1956.[2] He has somewhat modified his position since then and lately there have been some indications that his views are again receiving at least partial official support.[3,4]

Summary of the Historical Review

We shall now summarize the above historical exposition about the controversy regarding pure and mixed stands. As far as it can be established both pure and mixed stands were

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[1]"Lysenko Wrong, Russian Implies." New York Times, June 2 1957. p. 20:1.

[2]"Lysenko, Stalin's Protege out as Soviet Scientific Chieftain." News report by Wells Hangen. New York Times, April 10, 1956. p. 1:6.

[3]"Lysenko Defends his Theory Anew." Interpretive article by Harry Schwartz. New York Times, December 15, 1957. p. 36:5.

[4]"Top-level backing for Lysenko." Article by Victor Zorza. Manchester Guardian Weekly, January 22, 1959. p. 5. /Nikita S. Khrushchev favored T. D. Lysenko and criticized his opponents among the Soviet scientists during the recent

present before 1700 A. D., and the mixtures consisted of mixed conifers, mixed hardwoods, and mixed hardwoods and conifers. Carlowwitz (47) and Hohberg (131) wanted to maintain mixed stands which had been established in earlier periods. Döbel (63) began in 1746 to promote the opinions against mixed stands. This trend was followed by most authors until up to 1800. At first the mixture of hardwood and conifers was considered to be bad because of the difference in the maturing ages and the consequent suppression of the hardwoods. According to Hartig (110, 111, 112) and Burgsdorf (43) all mixed stands should be converted to pure stands. In 1834, Hartig (113) no longer completely rejected mixed stands and his advocacy of making management simple was appreciated. In spite of Hartig's strong influence, Medicus (180), Gleditsch (93), Zanthier (283), Drais (66) and Sponeck (238, 239) were in favor of mixtures. Only Cotta (54) in 1816 was able to stimulate a shift of opinion in favor of mixed stands. He was followed by Hundeshagen (135), Pfeil (200, 201), Gwinner (106), Heyer (125, 126, 127) and Stumpf (244). From 1816 to 1855 most authors were in favor of mixed stands but in practical management, as Karl Heyer remarked in 1847, pure stands were still being kept. The influence of Hartig was still very

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Soviet Communist party's Central Committee Session, but some Academicians still oppose Lysenko.7

strong and his students were still among the majority of the practicing forest managers. In Berg's (21) opinion (1844) pure stand was favored because of preference for conifers.

The gospel of pure stands was extended widely throughout Germany and it led to the establishment of pure stands, particularly of Norway spruce, on an extensive scale and so much so that some of the species were raised outside their natural range. As these stands matured and their weaknesses became clearly obvious, a strong reaction against pure stands developed led by Gayer (86) in 1880. He was widely supported in his opinion and among his supporters were Borggeve (28) and Mayr (177, 178), who doubted the advantages of pure stands. Weise (268), however, believed in 1888 that pure stands would become predominant in northern Germany in the future.

In Austria, Zötl (286) and Feistmantel (75) and in France Lorentz and Parade (166), Boppe (26, 27) and Huffel (133) spoke in favor of mixed stands. Around 1765, mixed stands were considered to be the best type of stands in Switzerland, but pure stands gained great favor during the time of Hartig (110), possibly aided by the influence of Zschokke (287). This position, however, began to change around 1860, according to Landolt (156). In England, Maxwell (176) in 1891 spoke against the establishment of mixed stands while Nisbet (194, 195) favored mixed stands. "It should be

noted at this point that foresters have changed their opinions during the course of about two hundred years from mixed stands to pure stands and back to mixed stands. The causes for the change in opinion have not been the result of a thorough examination. Economic factors usually cast the decising vote. Unequal rate of growth of various species, suppression of hardwoods by conifers (especially beech), and differences in maturing ages of various species were the main reasons cited against mixtures. According to Griesheim (100) mixed stands of hardwoods and conifers were against the principles of silviculture. Gwinner (106) and Gayer (86) believed that since mixed stands were the natural occurrence, they should be followed. Hartig (114) wanted to consider the lengths of roots of the various species in mixtures. The site condition, and tolerant and intolerant species which were emphasized by Gayer (86) later were only hinted at in the earlier literature. The advantages of mixed stands which were emphasized in the literature since Cotta (54) and Heyer (127) have been adopted with a few modifications in modern times by Weise (268) and Mayr (177, 178). Silviculturists of more recent times are still divided in their opinions on the question of pure and mixed stands.

B. Advantages and Disadvantages of Mixed and Pure Stands

The preceding section has given a broad review of pure versus mixed stand literature. As indicated, many generalizations have been made.

In this section, the literature will be summarized to bring out specific advantages and disadvantages of mixed and pure stands.

Advantages of Mixed Stands Over Pure Stands

The principle advantages claimed for mixed stands are:

1. Complete utilization of the site:

Since local variations of soil exist in any area, it is argued that the best, most complete, and most economical utilization of the soil can only be expected when each varying portion is stocked with the species best suited for growing there. Moreover, pure stands composed of an intolerant species have thin, open crowns which presumably fail to utilize light completely. The forest floor under such stands supports herbaceous or shrubby vegetation of no economic importance, which competes with the forest trees for water and plant nutrients. Foresters of central Europe are particularly concerned with this feature of pure stands of intolerant trees, for in the northern regions the characteristic

vegetation of the forest floor consists of members of the heath family, whose leathery leaves decompose slowly into an acid raw humus in which tree reproduction is very difficult to establish (29, 165).

It is also argued that, in contrast to pure stands which draw upon only certain layers of the soil, mixed stands utilize the various soil horizons because the trees in mixtures have different root lengths and they have also different requirements for light and nutrients. Consequently, mixed stands maintain a greater density, which has many advantages. Moreover, in stands of shallow-rooted species, an admixture of deep-rooted species is believed desirable to improve the yield from the area. The question of comparative yield from pure and mixed stands has been studied by many investigators. Burger (40) compared the production of wood, foliage, and needles from pure and mixed stands and arrived at the conclusion that the content of organic substance of the various species was almost exactly the same in both cases. He emphasized that it was precisely the achievement of the site which we must try to compare in terms of comparable units of production. He corroborated his conclusions with his later investigations (41, 42, 43) and with the studies of Badoux (41, 42) and Flury (78). His significant contribution to the question of comparative yield from pure and mixed stands is

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that for scientific comparisons we must express the production in absolute dry weight of organic substance, but never in terms of cubic contents. On this basis, the superiority of one kind of stand over the other is very difficult to prove conclusively. Other yield comparisons of pure and mixed stands have shown that sometimes one and sometimes the other outyields on the same site, or the yields are practically equal (25, 30, 116, 151, 255, 256, 271, 272, 285). Consequently, generalizations that a mixed stand yields more than a pure stand or vice versa should be avoided. Nevertheless pure stands offer only one kind of product as compared to the varied products from mixed stands. Again, however, a variety of products from pure stands also may be obtained by raising pure stands of many species over a large area.

2. Better maintenance of the productive capacity of the site:

Mixed stands presumably maintain the quality of the soil much better than most kinds of pure stands. Many species are known to fail in pure stands, especially on ordinary forest soils. In such cases the trees make constant and unvarying demands on the site for their particular set of requirements and consequently the site is likely to become deficient in the supply of nutrients. On the other hand, mixed stands may draw upon different depths of soil and the

component species make different demands on the site.

As mentioned before, mixed stands usually maintain a greater density of crop and thus offer protection to the soil against the exhausting and deteriorating influences of sun and wind. The intolerant species in pure stand may demand increased growing space after completing their principal height growth, and the consequent decrease in canopy and the reduction in number of stems per unit of area may cause a greater exposure of the soil to insolation and wind action, and thus decrease its quality and productive capacity.

Some exacting species, such as black walnut, black cherry, and white ash, are known to make heavy demands on the site and it has been claimed that in pure stands they gradually may deteriorate the soil, unless the soil is exceptionally fertile and well watered (143, 249). Attempts to grow these species in pure stands have often met with failure in the United States. Such pure stands may do well in youth, but as they mature and competition becomes keener, growth becomes very slow and the trees deteriorate. Except for black walnut, when these species were mixed with beech, sugar maple, or other dense shade producers on the same site, they succeeded better because, at least partly, of the effect of the latter in gradually improving the soil by enriching the humus with readily decomposed leaf fall. Similar experience with many

species has been reported in Belgium (23), Czechoslovakia (92), Denmark (132, 223), Finland (157), France (52), Germany (12, 16, 59, 83, 137, 228, 271, 272), Hungary (10), India (160, 161), Ireland (50), Norway, Sweden (132, 196), Switzerland (153, 182, 211), Russia (103), and Yugoslavia (82).

3. The formation and maintenance of favorable soil conditions:

The process of decomposition of litter in the upper layers of soil under pure forests of many species, particularly of conifers, is very much slowed down in northern latitudes and often results in the formation of the same sort of acid raw humus that is produced by undergrowths of heathers. The needles of pines and spruce in particular decompose very slowly and tend to form deep layers of this poorly decomposed raw humus material in which seedlings find it difficult to grow. The problem of regeneration in such stands has been treated again and again in forestry literature (65, 69, 77, 81, 82, 141, 154, 157, 158, 161, 165, 223, 224, 245, 247, 255, 256). Usually trees with leaves which decompose readily - largely hardwoods - in mixture with conifers, not only improve the humus layer directly, but they also tend to develop conditions in which the decomposition of the coniferous needles themselves is appreciably accelerated. The soil condition under such mixtures becomes more favorable for forest

reproduction and growth.

4. Less danger of insect and disease epidemics.

Mixing species is usually considered to be the most effective preventive measure against the occurrence and spread of insect and fungi epidemics (1, 114). Since most insects and diseases of forest trees are confined to one or a few host plants, mixed stands offer far less opportunity for epidemics than pure stands (53, 205). In the case of insects, every tree in a pure stand offers food and breeding ground, while in the case of fungi, the liberated spores find favorable substrates all over in the stand.

There is voluminous European literature to show that extensive pure stands create conditions favorable for rapid increase of destructive fungi and insects. In Scotland, pure larch stands have been subject to very heavy damage by the disease caused by Peziza willkommic, which produces a cankerous outbreak on the stems, and induces crooked growth (194, 195). Fungi such as Trametes radicipedra, Trametes pini, Aecidium elatinum, Peridermium pini, and Agaricus melleus are responsible for serious damages in the pure stands of spruce, silver fir, and Scotch pine in Great Britain.

The outbreaks of the bark beetles Ips typographus and Ips curvidens have been especially ravaging pure stands of

spruce and fir in eastern France. After a careful study of the damage, it was recommended that spruce and fir should be grown in mixture with hardwoods (171). Similarly, larch mixed with hardwood is recommended in order to minimize the insects' attack (213).

Voûte (262, 263, 264), after many extensive studies of insect-plant relationship on many species in Holland, concluded that natural control of pest is better in mixed than in pure stands because more varied plant life of the former supported a more varied fauna, which in turn helped to maintain populations of natural enemies, among which polyphagous species were especially important, at level high enough to check incipient outbreaks. Diprion pini, which is one of the worst pests of Scotch pine in Holland, was studied by Besemer (22). To prevent the outbreaks, he recommended broad belts of hardwoods in the Scotch pine areas. Douglas plantations, which are liable to severe damage by Phaeocriptopus gaeumanni in Denmark, are recommended for planting in mixture with Norway spruce to minimize the damage (159).

With the extensive conversion of mixed to pure stands in Germany during the past century, the damage done by insects and fungi increased enormously and on many occasions attained the dimensions of actual calamities (194, 195). Spruce moth (Liparis monacha) together with bark bettles devastated the

pure coniferous forests of eastern Prussia and western Russia over about seven thousand square miles in the late nineteenth century. A few years later, the spruce moth necessitated the clearance of forty thousand acres of pure spruce in southern Bavaria and western Austria (194, 195). In Prussia and Saxony, where twenty percent of beech or hornbeam is mixed with Scotch pines, the resulting stands suffer much less from insect attacks than the pure Scotch pine stands: the latter sometimes are completely destroyed (68). It was after the heavy damages by insect and disease in the pure stands in Germany and elsewhere that silviculturists led by Gayer (86) started advocating re-conversion to the former mixed stands in the late nineteenth century. More recently, Heger (119) reported that consequent to the clear cutting in the Western Beskid Mountains (borders of Poland and Czechoslovakia), the conversion to pure spruce had greatly reduced the growing stock owing largely to the susceptibility of pure spruce to damage by insect and disease. The artificial planting of pure stands of fir in Bohemia, Moravia, and Carpathia was found to have greatly favored the two main pests of fir, namely, Cacoecia murinana and Dreyfusia nordmannianae (149). A large number of trees in the pure stands of spruce in Saybusch were infected by Agaricus mellens while in mixed stands of spruce, fir, and beech the spruce trees were practically undamaged (278).

Scheneider-Orelli (227) stated that with regard to biotic factors, plantations composed of a single tree species were more likely to suffer severe damage than were mixed plantations in which the insect-predator relationship was more evenly balanced. Kapuścinki (140) recommended Sorbus aucuparia L. as a useful admixture to pure Scotch pine stands in Poland because it served as a host for certain insects which during their larval stage were hosts for parasites that keep down the insects attacking the pine. It has been shown that mixed stands encourage varied and increased bird population, which in turn keeps down the insect population (150, 172).

In North America, the white pine weevil frequently destroys the leader of every white pine in pure even-aged plantations, but when in mixture with other species this species is usually damaged to a lesser degree. In the Lake States, the hemlock looper has been responsible for the destruction of millions of board feet from time to time. Some recent studies have shown that although some defoliation occurs, little permanent damage is caused by the looper in stands where hemlock comprises less than fifty percent of the dominant trees (97, 205). These observations are in harmony with those of others in the Pacific Northwest, where the same insect or a very close relative is especially injurious to pure stands of hemlock. On the basis of these observations,

it is now recommended that pure stands of hemlock should not be encouraged.

Spruce budworm, which for a decade established its reputation as "Insect Enemy No. 1" by destroying enough timber to operate then existing pulp mills for forty years, was thoroughly studied in Canada and the Lake States. It was found that spruce-fir forests containing less than fifty percent balsam in the upper canopy were seldom killed (96, 97, 120). In several other cases, general observation indicated that the outbreaks of insects were often associated with pure or nearly pure stands of single tree species. For example, the forest tent caterpillar outbreaks of recent years in the Lake States and in Canada have been restricted to pure stands of aspen. Some previous outbreaks of the same insect have occurred in pure stands of oak or of sugar maple. The pine tussock moth, on jack pine, the birch skeletonizer, the aspen leaf roller, and the striped maple worm are all common forest insects that are associated with pure stands.

Furthermore, pure stands of black locust are, in most parts of the United States, liable to be completely destroyed by the locust borer. In recent years it has become quite apparent that certain forest types, the mixed hardwood-hemlock types of the Upper Peninsula of Michigan, for example, the mixed pine-hardwood-spruce types, the mixed forests of the

Douglas fir region, the mixed coniferous forests of the western slopes of the Rocky Mountains, and many others, are almost never severely injured by insect outbreaks. On the other hand, pure pine stands, pure hemlock stands, predominantly balsam fir, aspen or birch are usually subjected to insect outbreaks, and are consequently severely damaged or sometimes killed outright (97). The beneficial effect of mixed stands in obviating extensive injuries from fungus and insect enemies is perhaps the only point about which all silviculturists are unanimous. It must be noted, however, that some fungi and insects require two host species for the completion of a full life cycle, and to grow those species together would increase rather than decrease the risk of a serious attack (56).

5. Less wind throw and storm damage.

What is true about dangers from insect and disease may well apply to windfall and breakage from storms, and to damage wrought by accumulations of snow or ice on crowns of trees. Heavy winds may easily uproot shallow-rooted species, especially if they occupy moist site without rock. The danger of uprooting and throwing down is enhanced if the shallow-rooted species occur in pure stand, since one tree will fall against the other and so on and thus most of the stand may be uprooted. On the other hand, if the shallow-rooted species

are mixed with deep-rooted species, most of the stand may not be damaged but only irregular patches may result instead of large contiguous areas. The pure stands of balsam fir and spruce in the Adirondack Mountains in the United States suffer heavy damages from wind throw and sometimes a loss of one-tenth to one-fourth of the stand may occur. But the same species mixed with deep-rooted hardwoods suffers much less from windfall. Similarly, hemlock mixed with hickory or oak suffers less damage from windthrow than pure hemlock. In India and Pakistan, teak interplanted with Bambusa suffers much less damage from cyclones than pure teak (193).

Tender species suffer less from snow, frost, and glaze when grown in mixture. Accumulation of snow on the crowns of trees becomes diminished in mixed stands, especially when the conifers are mixed with hardwoods (24, 61). The relatively bare crowns of the latter allow the snow to reach the ground and they may afford slight support to the snow-laden crowns of the former. Even when breakage results it is usually of an individual nature and does not extend throughout large patches. Frost and glaze may cause severe injuries to tender species in pure stands particularly during its seedling stage. Mixing of such species with hardy species is likely to minimize the damage.

6. Less danger from fire.

Pure stands, particularly pure coniferous stands, offer far greater fire hazards than mixed stands of conifers and hardwoods. The severity of surface fires which burn along the ground and do not get to the roots or into the tree crowns depends primarily upon the amount of surface dry material in the forest. However, the character, in addition to the quantity, of the dry material, controls the severity of a fire. Thus coniferous leaves that are dry and resinous make a quicker and hotter fire than the hardwood leaves and therefore surface fires in coniferous forests are likely to be hotter and more destructive than a similar fire in a hardwood forest. Crown fires, which are usually more damaging than surface fires, are confined to coniferous stands, although they sometimes occur in mixed stands of conifers and hardwoods. Other things being equal, the rapidity of a crown fire and its intensity depend upon the character, density, and uniformity of the crowns. A pure, even-aged coniferous stand provides the best conditions for a destructive crown fire. When hardwood species are mixed with conifers, the danger from crown fires is less (61).

It should be pointed out that usually the damages from insect, disease, wind, snow, and fire are only minimized in mixed stands; they are never entirely prevented or eliminated.

The pure and mixed stands are equally vulnerable to intensive damages by these agents. While small damages occur in both kinds of stands often or all the time, heavy damages take place only periodically.

7. Greater variety of uses:

In multiple-use forests, mixed stands are usually of greater value. The products from intermediate operations in conifer-hardwood stands as compared to the similar products from pure coniferous stands, for example, are likely to be of more economic value. Furthermore, mixed stands usually furnish greater forage production and a greater variety of food and shelter for wild life. Also, for protective as well as aesthetic values mixed stands are usually considered more desirable.

8. More flexibility to adjust to market fluctuations and site conditions.

A fall in the price of a species in a pure stand reduces the total value of the stand, while the total value of a mixed stand may not be affected by the price changes because the fall in the price of one species may be compensated by a corresponding rise in the price of another species in the mixed stand. The manager of a mixed stand can modify or transform the crop to meet the present or the probable future requirement of the market. Moreover, if he finds that

some of the species in the mixture are unsuitable to the site, he can remove them in cleaning and thinning, leaving for the final crop only the species best adapted to the site. This elasticity of treatment is not afforded by pure stands. It should be remembered, however, that the market prices of various species do not change so radically as to make a high-value class species low-value class and there are some species which command a fairly high price rather regularly. Usually, with the price fluctuation, the margin in the prices of various species remains more or less the same and consequently the advantage viz mixed stands being more flexible to adjust to market fluctuation is rendered only academic.

9. Easier natural regeneration.

While generally it is easier to secure natural regeneration of some sort under mixed stands than pure stands (248), we cannot be sure that the regeneration in the former cases would be of the desirable species or of desirable proportions of the various species (225). Very careful attention and proper regulation of growth by means of cleaning each species in the mixture is often required to develop regneration in species proportion best fitted for superior silvicultural or economic results. Artificial regeneration under mixed stands is more difficult and expensive than under the pure stands.

10. More desirable aesthetically.

Pure stands, particularly even.aged ones, are rather monotonous and unattractive and less striking than mixed stands with variety of color and form. Mixed stands also offer better recreational attractions.

11. More protection and shelter.

Mixed stands furnish heavier watershed protection and supply a greater variety of food and shelter for wild life.

Advantages of Pure Stands over Mixed Stands

Notwithstanding the many decided advantages of mixed stands, pure stands are not to be precluded since they offer some definite and sometimes special advantages. More important advantages of pure stands are:

1. Simple and inexpensive management.

Management of mixed stands requires comprehensive knowledge of the silvical characteristics in the component species of mixtures. Moreover, more involved establishment and proper maintenance of suitable mixtures demands skill and experience. On the other hand, not only is the management of pure stands relatively simple but it is also less expensive because the operations involved are easier and often fewer. Sometimes this axiom has been carried a little farther to say

that the extent and status of the mixtures in an area is the test and standard by which we can judge the knowledge and capacity of the foresters concerned and that the formation of pure stands is indicative of insufficient knowledge on the part of the foresters (86, 249).

2. More economical intermediate operations and harvesting.

The intermediate operations such as cleaning, thinning, and pruning, etc., in pure stands can be carried out usually with less skill and labor. Similarly harvesting pure crops is much simpler and less laborious operation than mixture. Consequently these operations can be undertaken more economically in pure than in mixed stands. This practical advantage of pure stands is so obvious that it hardly needs any elaboration.

3. Cheaper artificail restocking.

Much less labor and skill is needed artificially to restock pure stands than mixed stands, and consequently this operation is cheaper to carry out in pure than in mixed stands. The cost of restocking mixed stands artificially depends upon the area and the type of mixtures, and it usually is prohibitive; and therefore natural regeneration is the most common means of restocking mixed stands. Although natural regeneration of mixed stands is easier and more ensured

than in pure stands, the resulting species in the former case usually are not in the desirable proportions.

4. Stocking with most valuable species.

The entire area can be stocked with the most valuable and desirable species, thus the area is most profitably utilized. Moreover, only pure stands permit the utilization of areas where special edaphic or climatic conditions exist. Following a severe fire, for instance, the conditions for reproduction may be so difficult that only a pure crop may be grown successfully.

From the foregoing discussion of the relative advantages and disadvantages of pure and mixed stands, it may be readily seen that there are some definite advantages and disadvantages of pure and mixed stands. As shown in the historical review of the literature, silviculturists advocated sometimes one and sometimes the other kind of stand. It cannot be denied that the total area under pure and mixed stands in Europe fluctuated with the prevailing theory about the preference of one kind over the other at that time. But never were the opinions of even the strongest advocates, such as Hartig and Cotta, strictly and fully executed. We would not have seen any mixed stand in Germany from 1850 to 1900, had Hartig's views been completely followed. Similarly, if Cotta's theories had

achieved overall recognition, we would have found only mixed stands in Germany in the nineteenth century, particularly in Saxony, where his students were most active. It is true that pure and mixed stands have occurred side by side irrespective of the prevailing theory in favor of one or the other. The forest land owners and practising foresters seem to have preferred pure stands for one reason or the other, particularly the economic reason that pure stands are simple and inexpensive to manage. On the other hand, the theorists, by and large, have advocated mixed stands on the basis of many obvious advantages. The opinions of the present-day silviculturists on the question of pure and mixed stands are still divided.

Perhaps the safest position on this question is that generalizations about the merits and demerits of pure and mixed stands should be avoided. Both have some undeniable advantages and disadvantages, and the choice between the two should be based on the specific conditions prevailing in the area. Factors such as the soil condition, dangers from insect, storm, and disease, natural forest form, and market conditions, should be evaluated. Judgment should not be based, as frequently happens, on merely theoretical thoughts and unproven hypotheses. Only the actual conditions in and around the forest should be the real criteria.

PART II

A STUDY OF PURE AND MIXED CONIFEROUS PLANTATIONS IN LOWER MICHIGAN

This part of the dissertation deals specifically with planting in the United States with particular reference to the Lake States, and consists of a general literature review, a more specific review of the Lake States plantings and information on climate, topography, soils, and silvical characteristics of the principal planted species as a background for a specific study of a certain series of plantations in the Lower Peninsula of Michigan. Thus, Part II can be divided into two major categories--the general background information, and the specific plantation study.

1. REVIEW OF STUDIES ON CONIFEROUS PLANTATIONS IN THE UNITED STATES

A rather intensive review of both American and foreign literature was made for studying the effects of mixed and pure plantations on the growth and development of individual trees. After reviewing some five hundred articles, it was found that most of the literature on this subject applied

largely to natural stands or mixtures of conifers and hardwoods. No European literature was found which adequately describes the effects of mixed and pure pine plantations.

In the United States, forestry is still practiced largely in natural stands and the planting experience is young. The literature on mixed and pure plantations is therefore rather limited also. Since most early American foresters felt the European influence, either because of European backgrounds or through close association with Continental foresters, a large number of the early forest practices adopted in this country were based on European forest concepts. This was especially true with respect to planting practices, but this period of dominance of American planting practices by European ideas yielded in time to the present-day period dominated by more realistic silvicultural and economic factors (108). The literature having an important bearing on the problem is reviewed below.

Based on the local experiences, it was recommended by Briscoe (32) that mixed stands of white pine and red pine are desirable, although he did not disfavor pure stands of red pine. Hansen (109) reported the early survival of white pine, red pine, jack pine, and Scotch pine in the planting in Minnesota. He found that white pine survival was better than the other species with a small amount of overhead shade.

Paton (199) in comparing pure and mixed plantations stated that, in mixture, slightly different growth rates of red pine and white pine stimulate growth in these trees more than would be the case if only one species were present. He believed that the crown competition tends to produce taller, straighter trees and also improves the amount of natural pruning on the component species in such mixtures. He maintained that conifers lend themselves readily to many different combinations and that success is fairly certain with the mixtures, particularly of white pine and red pine. Furthermore, he regarded mixtures by single alternate rows better than double alternate rows.

Kittredge (148) examined about four hundred plantations in the Lake States in 1924, most of them between five and twenty years old. He concluded that the plantings were still too young at that time to indicate conclusively the advantages or disadvantages of specific mixture of species. He limited the discussion of mixed planting to some general principles and suggestions of possible mixtures which then seemed most likely to prove successful. He cited many possible advantages of mixtures such as less susceptibility to insect and disease attacks, more complete and effective use of the site, maintenance or even improvement of site productivity and higher yield per acre. Most of the plantings examined for the

present study were observed by Kittredge in 1924. Rudolf (216), after studying the same plantings in 1936, concluded that there was little experience then to go on as far as mixed planting in the Lake States was concerned. In the meantime he suggested that nature should be followed as a guide for mixing coniferous species. Among the older plantations in Wisconsin he found red pine outstripping white pine on some sites and the reverse holding true on others. In Michigan, some promising red pine mixtures with jack pine holding the lead at that time were reported. He made a strong plea that a constant and sincere effort be made to study and apply the results of past planting activities and to keep the gap between knowledge and practice as narrow as possible.

Moore and Waldron (186) reported that the volume growth of Scotch pine was much poorer than that of red pine or white pine in New Jersey. The competition influence on the root systems of jack pine and red pine was studied by Adams and Chapman (2) in a twenty-eight year old plantation in Vermont. Both jack and red pine were reported to develop strong vertical roots in sandy soils, those of red pine being larger in diameter and penetrating deeper than those of jack pine. An examination of seventy-three picked plantations on old pastures and cleared sites in the northern Allegheny plateau of Pennsylvania was made by Hetzel (123). Nearly all the

plantations were twenty years or more in total age. The author, from the data obtained, computed a relative performance index, based on quality and growth rate of individual stems for each principal species, such as red pine, jack pine, white pine, and pitch pine, etc. In general, red pine showed the best survival, form, and diameter growth, although it was surpassed in annual height-growth by jack pine, European and Japanese larches. Hetzel concluded that, on the sites studied, conifers as a class produced better forest plantings than did the hardwoods and that planting in small pure blocks appeared to give better results than planting in alternate rows or other stemwise mixtures.

Young (281) reported on the growth and development of a thirty-five year old plantation composed of stripwise mixtures of Scotch pine, white pine, red pine, Norway spruce, and Douglas fir. The plantation was established on light glacial outwash sand on a tract near Negaunee, Michigan, which was covered with dense grass but had originally borne white pine and other species of unknown identity. The strips were of various widths and arrangements. He observed that placing of strips of species of rapid early height-growth adjacent to those of much slower growth had resulted in poor natural pruning on a large percentage of the trees in the stand. From the growth data, he concluded that a stripwise mixture was

inadvisable unless the species on the adjacent strips had a very similar rate of height-growth on the particular site. As would be expected, the ill effects of a serious disparity in rates of height growth were found to be greater on narrow strips. The stripwise mixture was found ineffective in preventing heavy damage to white pine by the tip weevil. He also believed that under the existing conditions, planting of white pine would not be profitable in the locality. The red pine excelled all the other species in every respect.

Hawley and Lutz (117) studied the development of a twenty-six year old plantation of white and red pines in Connecticut. In the alternate row mixture, white pine averaged a foot less than red pine in total height, which in part was attributed to weevil damage. Also, the average diameter of white pine in the mixture was slightly less than that of red pine. However, in the pure stands, white pine had somewhat higher average stem diameters but a little lower total height than red pine. Owing to the difference in rate of growth of the two species when occurring in mixture, there was a definite tendency toward asymmetry of crowns. The white pine crown diameters measured along the white pine rows were generally greater than diameters measured across the rows, while the reverse was true for red pine. In the pure stands, white pine showed a higher live-crown ratio than in mixture with

red pine, since the latter outgrew it and restricted its growth.

The authors concluded that mixtures of white pine and red pine in alternate rows, which would leave the red pine if the white pine were killed by the blister rust, are unwise because of the disparity in the early height growth of the two species. They recommended small mixed group planting of coniferous species in that region. They also concluded that, although there was no necessity to do so, yet, it was quite possible to make mixed plantations of two or more species without extra expense, though the amount of timber produced in a given time might be smaller than obtained in the pure pine or spruce stand. Whether the injury actually done to a given species by its dangerous enemies would be lessened by mixed planting, as compared to pure planting, was believed to be very doubtful. The authors maintained that what might be anticipated was that, if an enemy attacking one species became very destructive, the plantation would still be partially productive because of the mixture of other species.

Similar results, based on observations on the Cornell University plantation, were presented by Guise (105). He stated that in line mixtures of white pine and red pine after thirty years of growth, the former had been completely suppressed. The growth of red pine, whether in pure stands or

in mixture with Scotch pine, was rapid and satisfactory in every way. Allison (3), reporting the forty-year growth of planted pines in north-central Minnesota, stated that Scotch pine was severely damaged by porcupines and sap suckers and that the surviving trees had developed bad crooks. The mean annual growth of red pine had been a little over one cord per acre as compared to two-thirds of a cord per acre for white pine.

In a twenty-year-old mixed planting in the Rainbow Forest plantations in Connecticut, Hicock (129) found that white pine averaged eighteen feet in height and three inches in d.b.h., while the red pine averaged twenty-two feet in height and five inches in d.b.h. Survival was thirty-five percent for the white pine and ninety percent for the red pine. The former was rapidly being forced into subordinate position by the latter species.

Very little difference in the development of red pine mixed with Norway spruce in alternate rows and red pine in pure plantings was noticed twenty years after their establishment in the same area.

Similar results were observed by Stevenson and Barton (241) in central Pennsylvania, from which they concluded that a red pine-white pine mixture apparently allows little chance for the latter to maintain itself in the stand. Even at

seventeen years of age, the marked superiority in growth and general characteristics of red pine over white pine were clearly demonstrated. Rapid over-topping of the white pine by the red pine was aided by injury to the white pine through weevil attacks.

Haasis (107) reported that shortleaf pine was much larger in size than white pine in alternate mixtures of the two species in the forest plantation at Biltmore, North Carolina.

A success index for young forest plantations in New England based on total age, average total height, and survival percent was computed by Morey (187).

Comparing the diameter and height growths of twenty-nine year old pure jack pine, red pine and white pine on two soil classes in Minnesota, Mogran (185) concluded that jack pine showed no sensitivity to soil difference in either height or diameter growth. Red pine, however, showed preference for the better soil by real differences in diameter growth, but failed to show a significant difference in height growth. White pine, on the other hand, showed a sensitivity to soil differences in both height and diameter growths. A comparison of thirty-five year old Scotch pine plantation on the Cloquet Experimental Forest, Minnesota, with a jack pine plantation of the same age in the same area showed that Scotch

pine grew a little faster in diameter and consequently resulted in greater volume (109). Arend (11) found the growth and development of red and white pine in a mixed stand on medium site in northern Lower Michigan almost identical after forty-five years.

Several three-acre mixed red pine and white pine plantations in the Upper Peninsula of Michigan were measured by Skog (234) to determine their growth and development twenty-five years after their establishment. The plantations are located in widely separated counties on different soils. Four of these plantings are alternate row mixture and the fifth has no definite pattern. Compared with Rudolf's (219) stocking, diameter, and height curves and the success indices in terms of volume, these plantations as a whole, at least silviculturally, were found to be a success. Red pine did considerably better than white pine in height, diameter, volume, and survival in all except one plantation, where white pine made better volume and diameter growth. All white pine was attacked by weevil at least once and it was estimated that, as a result of the weevil damage, the merchantable height of white pine for pulpwood had been reduced by an average of six feet. Red pine showed no signs of insect or disease attack and was found to be straight and well formed. He also found that white pine was becoming suppressed and

slowing down markedly in diameter growth in all but one plantation. Suppression of white pine was serving the same purpose as thinning, and for that reason there was no need to thin the plantation to maintain the good red pine growth rate.

The growth of red and white pines, ranging in age from twelve to forty-one years, on old fields in the unglaciated regions of Ohio and central Indiana was studied in relation to soil and topography by Gaiser and Merz (85). The height attained by the average dominant or codominant trees was fifty-one feet for white pine and thirty-eight feet for red pine twenty-five years after planting. The white pine of these crown classes were eight inches in diameter breast high and the red pine six inches in diameter at that age. Red pine grew more rapidly in height and diameter when mixed with other species. For a time white pine grew more slowly in height when mixed with other species, but the growth accelerated and by the twentieth year trees in the mixed plantings equalled those of pure plantations in height, and thereafter were taller. Plantation composition did not affect the diameter growth of white pine.

Rudolf and Lemmien (221) examined a twenty-year-old mixed stand of red and white pines at the Kellog Forest near Augusta, Michigan. The mixtures were alternate rows and alternate strips of three rows. The number of trees per acre

and resultant volume of red pine was much greater than that of the white pine. Based on all trees of all crown classes, red pine had a significantly greater d.b.h. than the white pine.. However, based on the trees in the dominant class only, the average height of the white pine was significantly greater than that of the red pine. No difference in the height growth of red pine trees in the three rows of the strips was found while the average diameter of the outside rows was greater than that in the center rows. The latter response was attributed to the additional growing space available to the trees in the outside rows because of the small number of white pine in the adjoining three-row strips. White pine was found to have consistently grown somewhat more rapidly in height than the red pine. The survival of red pine was much higher than that of white pine and also the red pine trees had a larger and more uniform average d.b.h. than the white pine.

Although the white pine was slightly taller, especially in the dominant crown class, there were so few white pines in the stand that it was not an important component of the stand. Both species appeared to grow equally well in the alternate row and the strip mixture type of planting. However, the center row of red pine in the three-row was beginning to show the effects of competition in the form of reduced diameter

growth. The most important difference in the development of the two species was considered to be the volume per acre. The red pine had approximately two and one-half times the merchantable volume of the white pine. The authors concluded that if the area had been planted entirely to red pine, it would have contained considerably more volume than the combined volume of the two species. In that case, the site would have been more fully utilized, resulting in a more valuable stand.

The above review of literature shows that many studies involving several coniferous species, sites, and ages, etc., have been made in several regions of the United States. The results of the studies varied in different regions and at times were contrary to the results elsewhere. Like many studies in other regions, the few studies in the Lake States were of limited scope. Some comparison of pure and mixed coniferous plantings in the Lake States was made by Rudolf (219). He considered the survival, injury, and growth of white pine, red pine, jack pine, and Scotch pine under pure and mixed conditions on the plantations, which were about twenty years old. He found some differences in growth and development of the species under pure and mixed conditions,

but he concluded that further studies were needed later on, when the plantations were further developed, to bring out more clearly the advantages and disadvantages of mixed plantations in the region. Most of the plantations examined for the present study are the same on which Kittredge (148) and Rudolf (219) based their conclusions.

2. HISTORY OF PLANTING IN THE LAKE STATES

Quite early far-sighted, conservation-minded individuals protested against the ruthless exploitation of the Lake States' forests and advocated the reforestation of the area already denuded. Their protests went unheeded until they gained more support and conservation came into its own. Doubtless there were some isolated instances of forest plantings on private holdings previous to that date, but the first forest planting in the Lake States, so far as records reveal, took place in Wisconsin in 1876 and was in the form of a memorial to the centennial of American Independence (215). There was no immediate rush to follow the example, and for some ten years there was little or no additional planting. Beginning in 1898, occasional plantings were made in Minnesota, Wisconsin, and Michigan (214). In 1910 and 1911 the Federal Government and the State of Wisconsin entered the planting field. However, the rate of planting did not increase greatly until after 1915. At the end of 1926 a total acreage of 74,000 had been planted in the Lake States. By the end of 1931 this total had risen to 250,000 acres. The Civilian Conservation Corps and other emergency programs in 1933 are credited with

large-scale planting in the Lake States. When we stop to consider that this total has now reached 2,200,000 acres (254), we are struck by the accelerating tempo of this activity and by the realization that forestation has become an enterprise of no mean proportions. Approximately one-half of this area is in Michigan alone.

In the Lake States region, there has been some tendency to plant a mixture of coniferous species. Table 1 gives the area planted to mixtures of two or more coniferous species in the Lake States through 1944 (219). It may be seen from Table 1 that slightly more than one-third of the area reforested in the three Lake States through 1944 contains two or more species. In Michigan, which has more than half the total area planted in the Lake States, approximately one-half of the reforested area is under mixed plantings. On the State forests of Michigan, about ninety-five percent of the reforested land is in mixed plantings. Considering the volunteer species, such as oak and aspen, Rudolf (219) estimates that eighty percent of these established plantations are mixed stands.

The pine species most commonly planted in the Lake States region, including Lower Michigan, are red pine (Pinus resinosa Ait.), white pine (Pinus strobus L.), and jack pine (Pinus banksiana Lamb.). Other species planted less extensively

TABLE 1

TOTAL AREA PLANTED AND AREA PLANTED TO MIXTURES OF TWO OR MORE CONIFEROUS SPECIES IN THE LAKE STATES BY PUBLIC AGENCIES THROUGH 1944[a]

/Adapted from Rudolf (219)/

Agency	State	Total area planted	Area planted to mixtures	
		Acres	Acres	% of total area planted
Federal	Minnesota	100,997	22,410[b]	22.2
	Wisconsin	199,898	44,45[b]	22.2
	Michigan	467,719	90,4[illegible]	19.3
	All three states	768,614	157,26[illegible]	2[illegible].5
State	Minnesota	37,147	616[c]	1.6
	Wisconsin	30,257	16,63[illegible]	55.[illegible]
	Michigan	217,473	205,934	94.7
	All three states	284,877	223,18[illegible]	78.3
County, municipal, and other public	Minnesota	1,955	4[illegible]	2[illegible].4
	Wisconsin	74,586	26,720	35.8
	Michigan	10,503	5,[illegible]	47.6
	All three states	87,044	32,12[illegible]	36.9
All agencies	Minnesota	140,099	23,426	16.7
	Wisconsin	304,741	87,80[illegible]	28.8
	Michigan	695,695	301,334	43.3
Total, all agencies & states		1,140,535	412,56[illegible]	36.2

[a]Area planted by farmers, other small owners, and industrial organizations is not considered since it is relatively small and also data for mixed plantings by these non-public agencies is not available.

[b]Estimated on basis of partial data.

[c]Estimated, no data.

are Scotch pine (Pinus sylvestris L.), Norway spruce (Picea abies), and white spruce (Picea glauca). These species have been planted in pure stands and in a variety of combinations over a range of site conditions, varying from very poor to very good for pine. The combinations of species mixtures include interspersed trees, alternate rows, strips of varying widths, and group plantings.

3. SOME SILVICAL CHARACTERISTICS OF THE SPECIES STUDIED

Some broad silvical characteristics of the species in the plantations are given here in order to provide a background against which their interaction should be studied and the effects of competition evaluated.

Jack Pine

Habitat Conditions

Jack pine (Pinus banksiana Lamb.), a short-lived, small-to-medium coniferous forest tree, grows naturally in areas characterized by warm-to-cool summers, extremely cold winters, rather low rainfall, light sandy soils, and level-to-rolling topography (71).

Edaphic and Biotic Factors

Natural stands of jack pine are confined largely to soils of the podzol zone, melanized sands, sandy podzols, and the gleypodzolic sands such as Grayling sand. Jack pine can maintain itself on very dry sandy and gravelly soils where other species can barely survive, but it grows best on well drained loamy sands. In the northern Lake States and parts

of central and western Canada jack pine grows in extensive pure stands. Frequently, however, it occurs in mixture with, and is predominant over, one or more associate species such as paper birch (Betula papyrifera), quaking aspen (Populus tremuloides), and red pine (Pinus resinosa), etc. Not only its inherent characteristics but also many environmental factors influence the pattern of its reproduction, growth, and development.

Early Growth

Jack pine grows moderately fast in the juvenile stage. Initial growth in plantations is more rapid than in natural stands (71, 88). In well-stocked forest stands, jack pine develops into a short-to-medium-tall, rather slender tree with narrow rather open crown covering about 30 to 45 percent of the trunk; in the open it develops a stocky stem, often poor of form, and a wide, spreading crown with branches long persistent (70). For the first twenty years, jack pine, in its native range, is the fastest growing conifer other than tamarack (Larix laricina) (48).

Reaction to Competition

Jack pine is one of the most intolerant species in its native region (70, 48). Based on a scale which ranges from 10.0 for eastern hemlock (Tsuga canadensis) to 0.7 for the

aspens, jack pine rates 1.8; this places it less tolerant than red pine (2.4) (98). Other classifications include jack pine in the lowest or next to the lowest of five tolerance classes (14, 74). The species may be relatively more tolerant in the early seedling stages (17). Beyond that stage, however, it can stand considerable crowding but little overhead shade (48). As is common in intolerant species, dominance is not well expressed in dense young stands. In dense stands jack pine prunes itself moderately well, but where stocking is less it prunes itself very poorly (139).

Red Pine

Habitat Conditions

Red pine (Pinus resinosa Ait.), a medium-to-large coniferous tree native to the northeastern quarter of the United States and Canada, grows in areas characterized by cool-to-warm summers, cold winters, rather low-to-moderate rainfall, sandy soils, and level-to-rolling topography. It occurs chiefly on areas where the soil is acid and has good drainage and aeration, and where there is little severe plant competition.

Edaphic and Biotic Factors

As in case of jack pine, natural stands of red pine are confined largely to soils of the Podzol region: melanized

sands, podzolic sands, sandy podzols, and the better drained gleypodzolic sands (274). This species grows best on deep, loose, very well drained, loamy sands, or gravels, but will grow well on a variety of sites including organic debris over rock outcrops (64, 273). It requires a better soil than does jack pine, but will thrive on a poorer soil than will white pine. Except for few exceptions, red pine occurs in mixture with one or both of its common associates, jack pine and eastern white pine.

Early Growth

Red pine develops slowly in the juvenile stage but after ten or fifteen years makes rapid growth both in height and diameter unless the stand is over-stocked. Height growth normally is most rapid between the twenty-fifth and sixtieth years and it averages about a foot a year (48, 73). For the first fifty years the growth is slightly less than that of jack pine and a little more than that of white pine. Red pine would outgrow white pine in diameter by an inch in twenty years (43, 72). Its growth under partial shade is very slow.

In the forest, red pine is a tall, slender tree with a smooth, straight, clear bole of little taper. Young trees have long pyramidal crowns of stout horizontal branches in regular whorls.

Reaction to Competition

Red pine is less tolerant than its common associates other than jack pine. Based on a scale which ranges from 10.0 for eastern hemlock to 0.7 for the aspen, red pine rates 2.4 (98). Another classification includes red pine in the fourth lowest of five tolerance classes (14). The species may be relatively more tolerant in the seedling stage than later, especially where moisture is abundant, but even here growth is very slow under cover.

In dense stands dominance is well expressed by age 10 to 15 (220). At wider spacings the differentiation into crown classes occurs later, usually after twenty to thirty years. Beginning at the age of about twenty-five years in dense stands red pine prunes itself better than any other northern conifer with the possible exception of tamarack (48, 72). Even in dense stands, however, there may be relatively little natural pruning the first forty years (11). In more open stands natural pruning is delayed to a greater age. On some infertile sands, however, lower branches die off even where crown closure does not occur (220).

Generally speaking red pine is relatively free of serious enemies when growing under conditions natural to its native range. When grown on less acid, finer textured, and more poorly drained soils and under milder climatic conditions

than it is adapted to, red pine is subject to damage by a greater number of destructive pests (164, 219).

Scotch Pine

Habitat Conditions

Scotch pine (*Pinus sylvestris* L.), a native to the Old World from Europe to Siberia, thrives best on well drained sites where the soil is deep and moist but also grows on dry sandy loams and the thin soils of rocky outcrops (34).

Edaphic and Biotic Factors

Scotch pine is not exacting as to soil requirements (253). Natural stands of this species are found on soils that range from heavy peat to dry, sterile sand. The best development is found on deep, sandy loam containing considerable lime and underlaid by a fresh, well drained subsoil.

Early Growth

Although the rate of growth of this species in the United States is not well known, it is believed to grow as rapidly and equally as red pine (253). In the forest its crown is short and compact, extending not more than one-third the length of the bole. In the Midwest, planted trees of this species are often entirely different in appearance from the usual form, being scrubby and bushy. This poor development

is not attributed to unfavorable soil or climatic conditions, but to the use of some inferior variety or of seed from regions not well adapted to the growth of the tree (253).

Reaction to Competition

Scotch pine is very intolerant of shade. It demands much more light than white pine.

White Pine

Habitat Conditions

White pine (*Pinus strobus* L.), a medium-to-large coniferous species, is found in a wide range of habitat. It grows naturally and best in a cool climate on moist, well drained soils, but thrives on sandy and gravelly sites.

Edaphic and Biotic Factors

White pine is found growing on almost every type of soil (48). The flexibility of its root system undoubtedly accounts in a large measure for its adaptability to so many types of soil. Like most species, it prefers a deep loam: the deeper and loamier the soil, the better the growth (48, 92). Sand is usually the principal constituent of the soils on which white pine grows naturally (84). White pine is unable to grow successfully on the driest sands, but it is found in mixture with jack pine on quite light soils where

the water table is quite far down.

Growth

White pine grows rather slowly as a seedling, requiring four or five years to grow the first foot in height (49); but it reaches six inches in diameter at ten to twenty years and it is not unusual for it to make a growth of one-half inch a year between the twenty-fifth and thirty-fifth years. On good soils, the height growth is best after the fifteenth year; on poor soils, after about fortieth year (84). Height growth is most rapid when it receives light only from above, but the diameter growth may be less (202).

As a single tree in the open it grows a large, rounded crown, and even in a fairly dense stand the crown occupies from 15 to 35 percent of the total height (202). In dense stands the bole is much more cylindrical, though it always shows more taper than red pine. It prunes itself very slowly in pure stands.

White pine is considered slower in growth than red pine on poor soils but is faster on good soils (31). Although white pine usually grows on moister soils than does red pine, it will stand drought as well as the latter species does.

Reaction to Competition

White pine is more tolerant than jack pine or red pine

(8), but less tolerant than hemlock and spruce. It will recover somewhat if it has not been suppressed by the more tolerant species for too long. However, it never recovers entirely, and never reaches its best development after such suppression.

4. CLIMATE, TOPOGRAPHY, AND SOILS

Climate

The chief climatic features of Lower Michigan are a mean annual temperature of about 43° F.; an average precipitation (including melted snow) of about thirty-one inches annually; an average annual snowfall of fifty-eight inches; moderately high humidity; low wind movement; low evaporation; and low percentage of possible sunshine (251, 252).

The maximum temperature reaches 107° F. in the area while minima below 0° F. are recorded every winter and the latter have been as low as -48° F. The winters are long, as temperatures below freezing prevail from November to March, inclusive. The precipitation is fairly well distributed throughout the year. The growing season in the area, generally between the middle of May and the latter part of September, averages about one hundred thirty days. Climatic data compiled from the records of the United States Weather Bureau stations at places representative of the climatic conditions in the area are presented in Appendixes XXV to XXVIII.

Topography

The land surface is largely constructional in origin, since it is derived from a complete and in places very thick covering of glacial drift. The greater part of the terrain is relatively flat land. The slopes for the most part are smooth, rounded, and low in gradient.

Elevation above sea level ranges from 687 feet to 1141 feet (251, 252).

Soils

The soils of plantations studied vary widely from fine sand to clays of the old lake beds. The soils of most of the plantings are sandy or loamy and often gravelly.

Most of the soils of the plantings in Roscommon and Crawford counties and parts of Alpena and Higgins counties have been classified as Grayling sand of the podzol group (257, 258, 259). The distinguishing features of this soil are its loose consistency, incoherent structure, sandy or single-grained texture throughout, and its perviousness and non-retentiveness of moisture. Soils of some of the plantations in Roscommon and Alpena counties have been classified as Rubicon sand, also a podzol. This is an intermediate soil between Saugatuck sand and Grayling sand, with regard to

drainage and average moisture conditions. The vegetation is slightly denser than on Grayling sand, because of the slightly higher average moisture content of the Rubicon soil. Most of the plantings in the Ogemaw County and some of the plantings in Crawford County are located on Roselawn podzol sand (260). The organic matter and the moisture-holding capacity of this soil are low.

A small part of the Crawford County plantings is located on Roselawn sandy loam (257), while Saugatuck sand and Bridgman sand are the two main soil types of the plantations in Alpena County (275). In the Fife Lake area, the soils have been grouped under Bergland-Selkirk Association (gley podzols) (257). These include flat, wet, clay lands, which are lacustrine in origin and have alternate layers of silty clay and fine sands. The soil types included in this group are: Bergland, Ogemaw, Munuscong, and Selkirk (gley-podzols). Muck is a common component. Although this kind of soil has actual and potential value for agricultural use, most of it remains under tree growth.

5. THE PLANTATION STUDY

Following a statement of the specific objectives of the plantation study, background information as to the location of the plantations, their age, spacing, and composition, etc., is given below.

Objectives of the Plantation Study

The reforestation program of the Federal and State Governments in the Lake States was initiated around 1900 and accelerated around 1915. The greatest impetus to forest planting in the Lake States was given by the advent of the Civilian Conservation Corps and other emergency programs in 1933. About one-half of the two million acres of planted area in the Lake States in 1958 is located in Michigan alone. Most of these plantings were pure coniferous, but mixtures of many kinds were also employed. Since this large-scale planting was undertaken without thorough knowledge of the behavior of the species in the various types of plantations, especially in pure and mixed plantings, it has long been felt that such information be obtained by a detailed analysis in order to guide the practice of the intensive forestry.

Kittredge (148) and Rudolf (216), after examining some of these plantations in Michigan in 1924 and 1936 respectively, concluded that they were too young to indicate conclusively the advantages and disadvantages of the specific mixture of the various species. They suggested further studies on these plantations at later dates. Considering the fact that some of these plantings were thirty-five years old and mature enough to yield useful information, the present study was undertaken with the general objective of comparing the growth and development of the pure and mixed (alternate row) plantations of jack pine, red pine, white pine, and Scotch pine on various sites in Lower Michigan. The factors considered for the comparison are survival, diameter growth, height growth, yield per acre, damage caused by insects and diseases. Comparison of growth is also made of the individual trees of each species competing directly with members of the other species against those competing directly with members of their own species on similar sites. The purpose of the latter investigation is to find out the nature and extent of the influence which the four species exert on each other, where they directly compete with each other in alternate row mixtures.

Background of the Plantations Studied

The plantings examined for this study are located in

the Alpena, Grand Traverse, Crawford, Roscommon, and Ogemaw counties of Lower Michigan (Fig. 2, and Appendix XXIX). These plantings of varying acreages were planted in the spring of 1917 by the furrow method at the rate of 1,750 seedlings per acre or at a spacing of approximately 5 x 5 feet. A total of 72 plantations, all of which were 35 years old at the time of examination, were examined, although only 60 plantations were found suitable for the comparison and the analysis. The four species in pure and alternate-row mixtures of the two species are jack pine, red pine, Scotch pine, and white pine. The classes of stocks used were as follows:

Jack pine	1-0
Red pine	2-0
Scotch pine	2-0
White pine	2-0

The pure and mixed plantings suitable for the study were selected from the records at the Lower Peninsula Forest Research Center, East Lansing, Michigan, and the Division of Forestry, Department of Conservation, State of Michigan, Lansing, Michigan. Only plantations undisturbed by cultural operations or fire were chosen. These plantations were examined by Kittredge (148) and Rudolf (219) in 1924 and 1936 respectively and the information obtained by them was of great value for the present study.

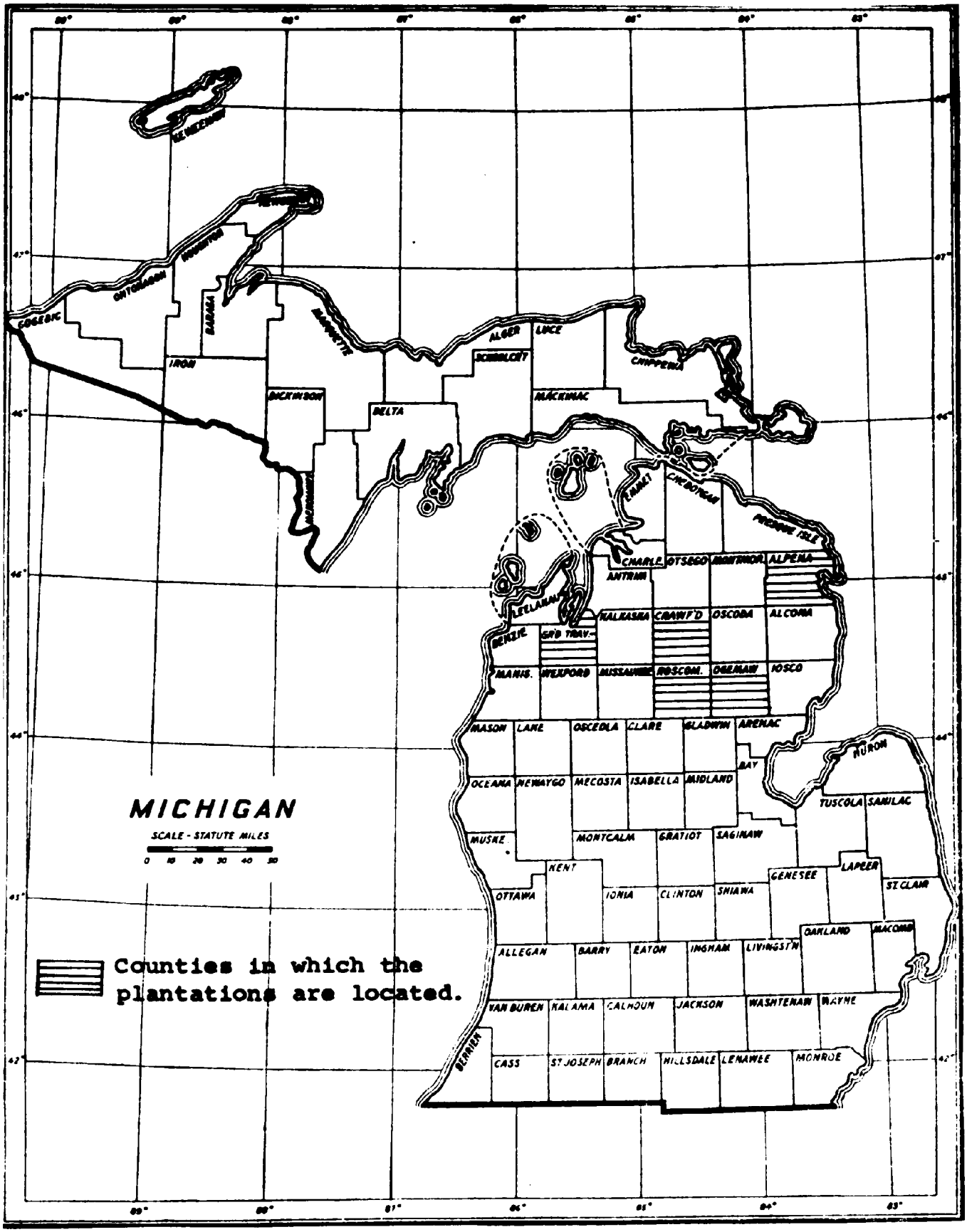


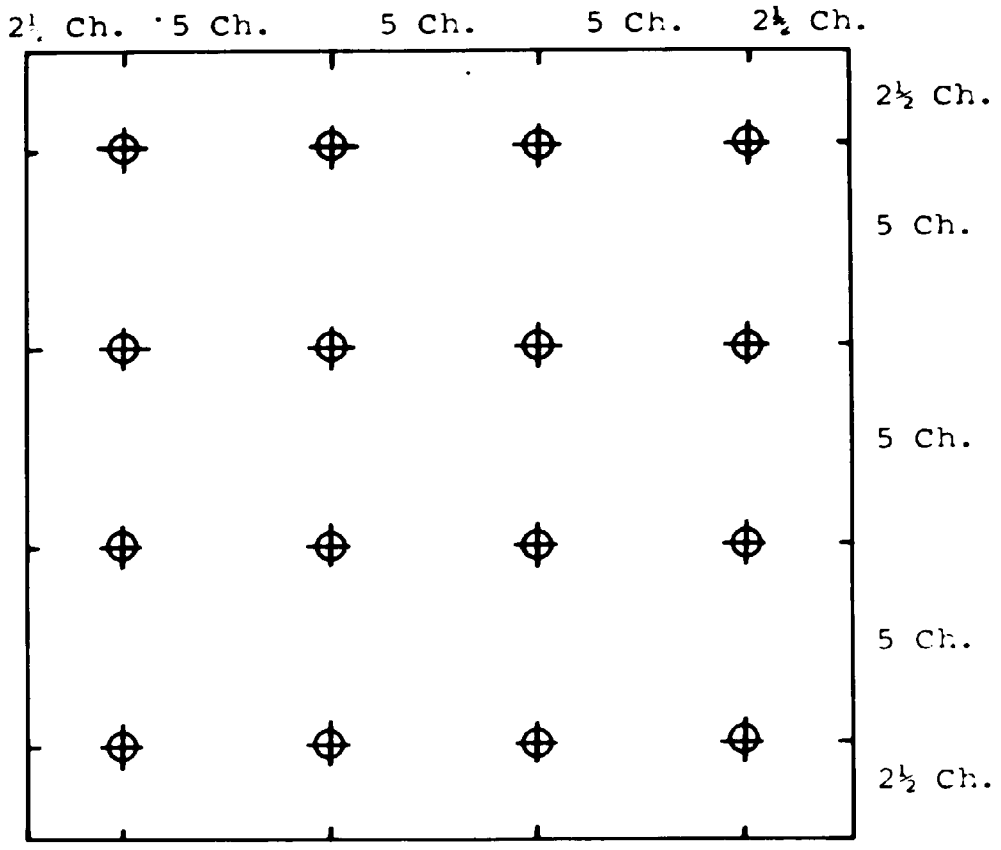
Fig. 2.--Location of Plantations

6. FIELD PROCEDURE AND DATA COLLECTED

Records at the Lower Peninsula Forest Research Center, East Lansing, Michigan, and the Division of Forestry, Department of Conservation, State of Michigan, Lansing, Michigan, provided background data and information on the plantations. The selected plantations were marked on 10" x 10" county maps, which were used to locate the area on the ground. Before going out in the fields, foresters in charge of the areas were consulted for pertinent information, and they helped also to locate the plantations. An assistant helped in collection of the data in the field.

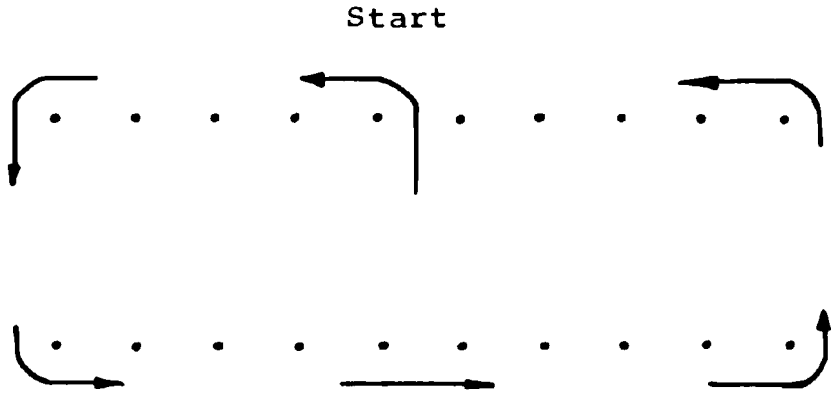
The field procedure used and the data collected are as follows:

1. Sixteen twenty-tree plots spaced five chains apart were taken on a 'forty.' The arrangement of plots on each 'forty' is shown in the following diagram:



Arrangement of Plots on a 'Forty'

The plots were located by running compass lines. At each five-chain interval, a shift was made to the nearest row to the right; the first five trees directly ahead were examined and measured; then a shift was made to the first row on the left, and the ten trees directly to the rear were examined and measured; then a shift was made back to the approximate point at which the plot was started. The procedure adopted by the examiner is illustrated by the following diagram:



Movement of Examiner on a Plot
(Shown by the Arrow)

2. Each tree was classed as present, missing, or dead. In the case of a dead tree, the cause of loss was indicated wherever possible.

3. D.b.h. of living trees was measured to the nearest one-tenth inch with calipers.

4. The total height of the living trees was measured by means of an Abney level.

5. Each living tree was crown-classed as dominant, co-dominant, intermediate, suppressed, or oppressed.

6. Injury to each tree by insect, disease, and other agents, if present, was classified as heavy, moderate, or light, depending upon the severity of the attack apparent at the time of the examination.

7. A check (x) mark was placed on the data sheet against each tree bearing on all sides the influence of the trees

planted immediately next to it. The measurements and observation on the 'checked' trees were made to determine the effect on form, vigor, and growth of individual trees as influenced by species composition.

8. Number of trees of volunteer growth was tallied on each plot.

9. Any pertinent features not provided for in data form were noted under 'remarks.'

10. A number of photographs showing certain typical situations were taken.

7. METHODS OF ANALYSIS

The plantation areas were classified into three site classes - good, medium, and poor, as follows:

1. First of all, site indices at fifty years were determined for pure jack pine, red pine, and white pine plantations in the following manner. The average diameter of the dominant trees was found by computing their average basal area and looking up in a basal area table the diameter corresponding to this average. The height of the dominant tree having this average diameter was read from the diameter-height curve. By use of this height and 35 years, the age of the stand, the site index of the area was determined (for fifty years) from the site index graphs in yield tables by Brown and Gevorkiantz (35). Since Rudolf (219) found that at given ages the average heights of planted white pine, red pine, and jack pine compared very closely with those shown in these yield tables for the same species of second-growth and age in natural stands, the site index graphs for the second growth species were used to determine site indices for the plantation areas (35, 88, 89, 99, 91).

For classifying all mixed plantations and all pure

Scotch pine plantations into the three site classes, site indices of the adjacent pure jack pine, red pine, or white pine were used. Site classification of pure Scotch pine plantations in this manner was necessary, because site index graphs for this species are not available.

The site classes used for site classification are shown below:

Site Classes for the Various Species

Site/Species	Jack pine	Red pine	White pine
Good	60	60	50
Medium	50	50	40
Poor	40	40	30

Base age is 50 years. The ranges for the ten-foot classes are as follows:

30' = 26' - 35'

40' = 36' - 45'

50' = 46' - 55'

60' = 46' - 65'

There are ten types of plantations as follows:

1. Jack pine pure
2. Red pine pure
3. Scotch pine pure
4. White pine pure

5. Jack pine and red pine mixed

6. Jack pine and Scotch pine mixed

7. Jack pine and white pine mixed

8. Red pine and Scotch pine mixed

9. Red pine and white pine mixed

10. Scotch pine and white pine mixed.

Two plantations of each type on the three sites were chosen, making a total of sixty plantations used in the analysis.

2. Average d.b.h. corresponding to the average basal area and average height, based on the sampled living trees, were computed for all plantations.

3. Present volume per acre in cubic feet was computed for all plantations in two ways:

a. By using cubic foot volume tables: For jack pine, red pine, and white pine, volume tables were used from yield tables by Brown and Gevorkiantz (35). For the sake of accuracy, consistency, and conformity with the rest of the computations, tree volumes were computed for diameter to one-tenth of an inch, and for heights to the nearest foot. This was accomplished with the use of extended volume tables, derived through extrapolation and interpolation of the volume tables.

Since volume tables for Scotch pine in this area are not available, cubic foot volume tables for this species were

constructed by converting cylinder volumes with the form factors supplied by Gevorkiantz.[1]

The per acre figures were obtained in the following manner: since the trees were spaced 5' x 5' apart and there were 16 twenty-tree plots on a 'forty,' the area actually sampled on a 'forty' was 5' x 5' x 20 x 16 or 8,000 sq. ft. or 8,000 sq. ft. ÷ 43,560 sq. ft. = 0.11836 acre. Having obtained the cubic foot volume or the number of trees for the sampled area of 0.11836 acre, the values were converted to per acre basis by method of proportions.

b. By using the formula: $Vuc = (\frac{d}{2})^2 \times \frac{h}{100} \times N$

Where Vuc = unpeeled cubic foot volume per acre

d = average breast height stand diameter in inches

h = average height of all trees in feet

N = number of trees per acre

Volume figures obtained by using this formula are used to compare with success indices set up by Rudolf (219).

4. Number of trees living, missing, or dead per acre was computed.

5. Survival percentages were obtained by computing the number of present living trees per acre as a percentage of the 1,750 trees planted per acre. Also, basal area per acre

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[1]Letter dated January 13, 1953. Appendix XXX.

determined for each plantation.

6. The percentages of living trees attacked heavily, moderately, and lightly by insects and diseases, by each causal agency, were computed, the tree sites being grouped together for every pure and mixed kind of plantation.

7. The average diameter, height, and volume of the 'checked'[1] trees in pure and mixed plantations were computed to provide a comparison under conditions of direct competition.

Statistical Methods Used

a. Differences in the number of living trees per acre, average diameter, average total height and average cubic foot volume per acre as function of pure and mixed stand were evaluated by F-test based on the analyses of variance (221). The design of the experiment is a two-way rectangular design with replications (fixed effects model). In each case the design involves twelve cells, i.e., four types of species (e.g. jack pine pure, jack pine mixed with red pine, jack pine mixed with Scotch pine, and jack pine mixed with white pine) and three kinds of sites (good, medium, and poor). The entry in each cell was based on the average of two observations

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[1]These are trees indicated on the data sheet by a check mark (x) that compete with the adjacent living trees on all sides.

taken on two different plantations. This resulted in a total of twenty-four observations. Thus, we have four sources of variance, and we obtain respectively three degrees of freedom for species, two for sites, six for the interaction between species and sites, leaving a remainder of twelve degrees of freedom for the error term, tabulated below (see also Appendexes I to XVI for analysis of variance tables, etc.).

Source of Variation	Degrees of Freedom
Species (rows)	3
Sites (columns)	2
Species and sites	6
Remainder or experimental error	12
Total	23

b. Differences in average diameter, total height, and cubic volume obtained by comparing pure and mixed stands of trees in direct competition were analysed by the t-test method (236). (See Appendixes XVII to XX.)

c. Differences in the proportions of species under insect attack obtained by comparing pure and mixed stands were analysed by the t-test method for proportions (170). (See Appendixes XXI to XXIV.)

8. RESULTS

The success of forest planting must in the long run be measured by the degree to which it results in well stocked stands of desirable forest species and consequently the degree to which it supplies valuable forest products, be they wood products watershed protection, benefits to wildlife, or recreational values. In the present case, the plantations were established for the production of wood and they are old enough to be compared in measurable terms.

A. Survival and Stocking

A major criterion for the success of a forest planting is survival. A plantation cannot be regarded successful if too many of the planted trees die, in spite of good growth by the surviving individual trees. On the other hand, good survival alone does not constitute a planting success unless it is complemented by satisfactory growth and development. The causes of mortality cannot be definitely determined since early records are nonexistent. These plantations have come through several very dry years, though, which must have exacted a heavy toll; it is probably safe to assume that much

of early mortality was caused by drought and heat (207, 208, 217, 218). There is visual evidence however, of white pine weevil damage and loss through competition.

It may be observed from Table 2 that there is little difference in pure jack pine and jack pine mixed with the other three species as far as the average number of living trees per acre, survival percentage, and basal area per acre are concerned. These differences are not significant as shown by the analysis of variance (Appendix 1). Also, no significant difference is shown in the number of living trees per acre of jack pine on good, medium, and poor sites. Assuming that the same external mortality factors prevailed over all these plantations, it is obvious that survival of jack pine does not appear to be affected either by mixing the species with red pine, Scotch pine, and white pine or by the site differences in these plantings.

On the other hand, the lower survival of red pine mixed with jack pine compared to pure red pine on medium and poor sites (Table 2, and Appendix II) indicates that jack pine has an adverse effect on red pine's survival on these sites. But on good sites to which red pine is better suited, it survives just as well in mixture with other species as in the pure plantings. Also, Scotch pine and white pine do not seem to affect the survival of red pine in mixtures on medium and

TABLE 2

THE AVERAGE NUMBER OF LIVING TREES PER ACRE, BASAL AREA PER ACRE, AND SURVIVAL PERCENTAGE OF THE VARIOUS SPECIES, AGE 35 YEARS

Type of plantation	GOOD SITE[a]			MEDIUM SITE[a]			POOR SITE[a]		
	No. of trees per acre	% survival[b]	Basal area per acre (sq.ft.)	No. of trees per acre	% survival[b]	Basal area per acre (sq.ft.)	No. of trees per acre	% survival[b]	Basal area per acre (sq.ft.)
Jack pine, pure	1005	57.4	141.35	934	53.4	97.03	877	50.1	57.55
Red pine, pure	1062	60.6	194.03	940	53.7	104.66	793	45.3	60.45
Scotch pine, pure	782	44.6	121.08	756	43.2	91.02	757	43.2	54.36
White pine, pure	748	42.7	104.38	652	37.2	55.72	560	32.0	25.14
Jack pine, mixed with red pine	1013	57.9	160.40	991	56.6	109.37	1056	60.3	70.50
Red pine, mixed with jack pine	988	56.4	137.87	720	41.1	47.25	618	35.3	33.21
Jack pine, mixed with Scotch pine	980	56.0	153.44	1029	58.8	101.30	958	54.7	65.06

TABLE 2--Continued

Scotch pine, mixed with jack pine	566	32.3	68.14	515	29.4	41.39	577	33.0	31.60
Jack pine, mixed with white pine	1035	59.1	161.45	897	51.2	97.68	882	50.4	60.24
White pine, mixed with jack pine	602	34.4	58.43	543	31.0	23.87	443	25.3	13.91
Red pine, mixed with Scotch pine	938	53.6	141.44	913	52.2	86.11	752	43.0	57.94
Scotch pine, mixed with red pine	616	35.2	83.93	712	40.7	112.73	474	27.1	46.88
Red pine, mixed with white pine	949	54.2	149.70	879	50.2	95.72	757	43.2	53.17
White pine, mixed with red pine	540	30.8	56.46	538	30.7	22.99	436	24.9	10.68
Scotch pine, mixed with white pine	801	45.8	133.98	757	43.2	80.60	705	40.3	53.81
White pine, mixed with Scotch pine	711	40.6	73.66	654	37.4	46.71	545	31.1	16.97

[a]Site classes used are as follows (50-year base):

	Good site	Medium site	Poor site
Jack pine	60	50	40
Red pine	60	50	40
White pine	50	40	30
Scotch pine	Index graphs unavailable, therefore site classes for jack pine were used.		

[b]Percent survival = $\frac{\text{number of living trees per acre} \times 100}{\text{1750 (number of trees planted per acre)}}$

poor sites. Unlike jack pine, the stocking per acre of red pine both under pure and mixed conditions decreases as the site quality changes from good to poor.

Jack pine in mixture with Scotch pine appears to exert some detrimental influence on the latter's survival on all sites, as shown by the significantly lower survival of Scotch pine in such mixtures (Table 2, and Appendix III). However, this detrimental effect is limited to good and poor sites in case of Scotch pine mixtures with red pine. Since there is no significant difference in the stocking of pure Scotch pine and Scotch pine mixed with white pine on all sites, it can be inferred that the latter species does not affect the survival of Scotch pine in mixtures.

The faster growing jack pine and red pine adversely affect the survival of white pine in mixtures on all sites (Table 2, and Appendix IV). However, it is not true in case of white pine mixed with Scotch pine, which is as slow growing as white pine in this region.

The four species in pure plantations rank in order of survival on good sites: (1) red pine, (2) jack pine, (3) Scotch pine, and (4) white pine. On medium sites, jack pine and red pine are almost equal in degree of survival, followed by Scotch pine and white pine. The order on poor sites is: (1) jack pine, (2) red pine, (3) Scotch pine and (4) white

pine, with red pine and jack pine showing practically equal survival. The stocking expressed in terms of basal area per acre shows more or less the same pattern. White pine shows the poorest survival on all sites, while jack pine and red pine rank the best in the present stocking. The degree of survival of species in pure conditions on various sites is in accordance with the popular notion of their relative hardiness.

B. Growth

The second major criterion for judging success of a plantation is its growth. A plantation may have a high survival but if its growth is poor, it cannot be considered successful. The types of growth considered for comparison of the pure and mixed plantation in this study are height, diameter, and volume growth.

a) Height Growth

Jack pine, red pine, and Scotch pine show no difference in height growth under the pure and mixed conditions (Table 3, and Appendixes V, VI, VII). In general, jack pine and red pine are of good health, vigor, and form (Fig. 3). The lower branches of red pine are dying on trees (Fig. 6). In relatively open stands, the trees are rather limby and crooked. Scotch pine, in general, is crooked, bushy, and of poor form.

TABLE 3

AVERAGE TOTAL HEIGHT AND AVERAGE DIAMETER OF THE VARIOUS SPECIES, AGE 35 YEARS
(Living Trees Only)

Species	GOOD SITE[a]		MEDIUM SITE[a]		POOR SITE[a]	
	Av. total height (ft.)	Av. diameter (in.)	Av. total height (ft.)	Av. diameter (in.)	Av. total height(ft.)	Av. diameter (in.)
Jack pine pure	28.8	5.08	24.2	4.25	22.2	3.47
Red pine pure	30.6	5.79	28.7	4.52	21.8	3.74
Scotch pine pure	28.4	5.33	22.8	4.70	16.3	3.63
White pine pure	26.4	5.06	20.4	3.96	16.4	2.87
Jack pine and	25.3	5.39	25.3	4.50	21.2	3.50
Red pine	30.4	5.06	18.8	3.47	18.2	3.14
Jack pine and	27.4	5.36	24.7	4.25	21.3	3.53
Scotch pine	22.2	4.70	17.7	3.84	17.2	3.17
Jack pine and	28.8	5.35	24.2	4.47	22.4	3.54
White pine	18.4	4.22	15.6	2.84	13.8	2.40

TABLE 3--Continued

Red pine and Scotch pine	26.6	5.26	26.3	4.16	23.5	3.76
	24.8	5.00	24.7	5.39	20.2	4.26
Red pine and White pine	26.8	5.38	23.6	4.47	21.5	3.59
	21.8	4.38	17.0	2.80	13.7	2.12
Scotch pine and White pine	26.4	5.54	21.1	4.42	20.0	3.74
	26.1	4.36	18.8	3.62	15.5	2.39

[a]Site classes used are as follows (50-year base):

	Good site	Medium site	Poor site
Jack pine	60	50	40
Red pine	60	50	40
White pine	50	40	30
Scotch pine	Index graphs unavailable, therefore site classes for jack pine were used.		



Fig. 3.----Pure jack pine on good site. Notice the lower branches are slowly dying.

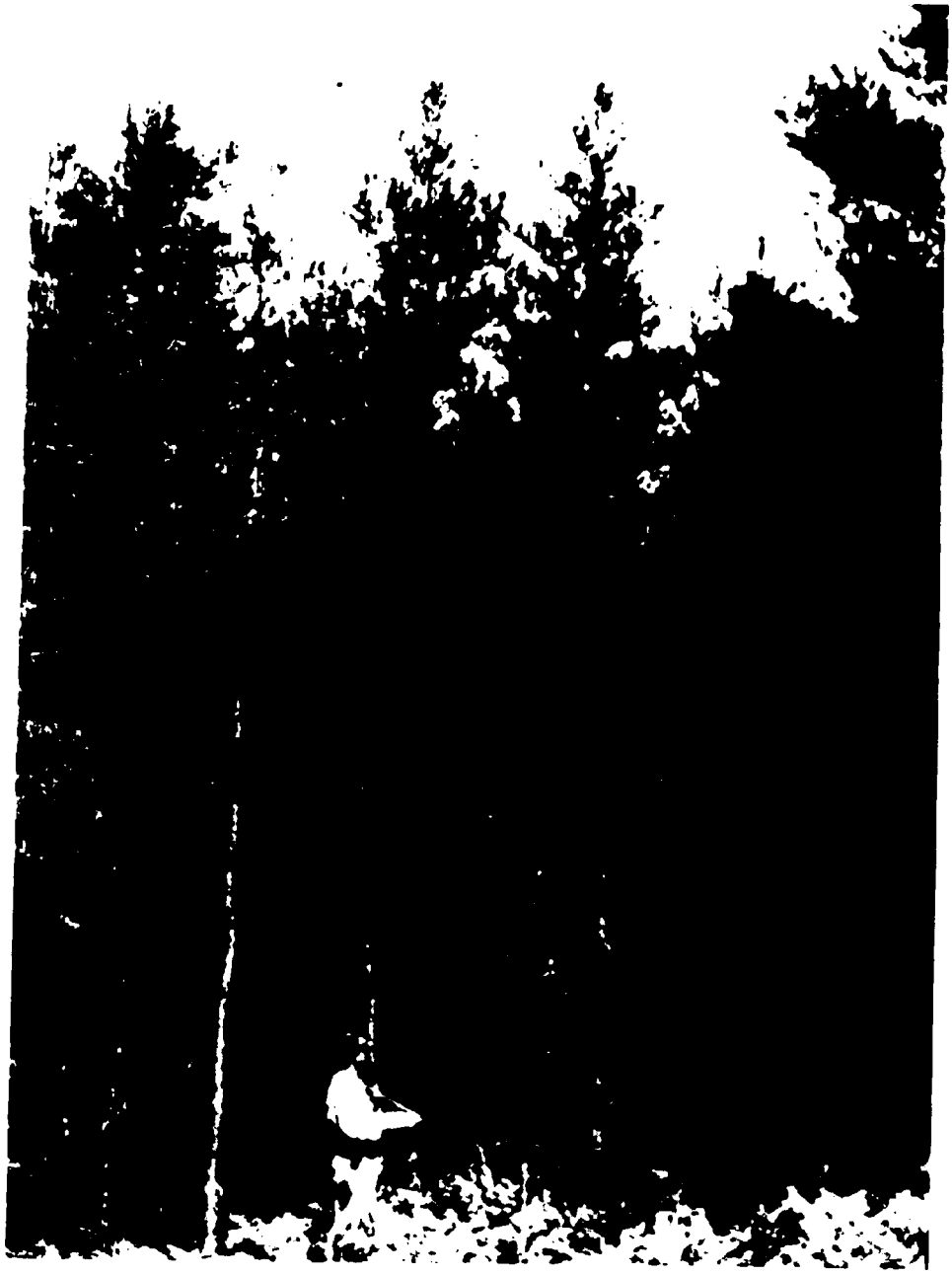


Fig. 4.----Pure jack pine on poor site.

Sickly looking and dying Scotch pine trees are a common sight in these plantations (Fig. 5). The significantly lower height of white pine in mixture with jack pine and red pine on all sites suggests the detrimental influence on its height growth by the latter species (Table 3, and Appendix VIII). Scotch pine, however, does not seem to have such curbing influence on white pine in mixtures.

The differences in the height growth of the various species are quite striking. In general, jack pine and red pine made the best height growth, followed by Scotch pine. White pine made the least height growth, which in part may be due to the highest incidence of the weevil damage, although it has been suggested that weevil attack is apparently unrelated to height growth of white pine (198). The severest effect on height growth due to mixture is shown by white pine.

b) Diameter Growth

As in case of height growth, jack pine and red pine do not show any significant difference in diameter growth under pure and mixed conditions (Table 3, and Appendixes IX and X). However, Scotch pine shows a reduced diameter growth where it is mixed with jack pine on good and medium sites (Appendix XI). No detrimental effect is apparent on the diameter growth of Scotch pine mixed with jack pine on poor sites and in mixtures with red pine and white pine on the three sites. With

TABLE 4

PRESENT AVERAGE CUBIC FOOT VOLUME PER ACRE OF THE VARIOUS SPECIES OBTAINED BY USING VOLUME TABLES (AGE 35 YEARS)

Species	GOOD SITE[a]	MEDIUM SITE[a]	POOR SITE[a]
Jack pine, pure	2491	1554	930
Red pine, pure	2389	1480	691
Scotch pine, pure	1784	1029	540
White pine, pure	1370	639	298
Jack pine, mixed with red pine	2598	1765	1130
Red pine, mixed with jack pine	2137	568	379
Jack pine, mixed with Scotch pine	2476	1660	1064
Scotch pine, mixed with jack pine	810	477	323
Jack pine, mixed with white pine	2690	1770	992
White pine, mixed with jack pine	628	240	126
Red pine, mixed with Scotch pine	1836	1282	773
Scotch pine, mixed with red pine	1097	1038	520
Red pine, mixed with white pine	1806	1178	682

TABLE 4--Continued

Species	GOOD SITE[a]	MEDIUM SITE[a]	POOR SITE[a]
White pine, mixed with red pine	665	233	88
Scotch pine, mixed with white pine	1641	860	558
White pine, mixed with Scotch pine	1034	468	165

[a]Site classes used are as follows (50-year base):

	Good site	Medium site	Poor site
Jack pine	60	50	40
Red pine	60	50	40
White pine	50	40	30
Scotch pine	Index graphs unavailable, therefore site classes for jack pine were used.		



Fig. 5.-----Pure Scotch pine on good site. Notice the branchiness.

jack pine on good and medium sites, with red pine on all sites, and with Scotch pine on good sites, the diameter of white pine is significantly lowered, indicating a restrictive effect of these species on diameter growth of white pine in such mixtures. Relatively lower stocking on medium and poor sites permits only partial interaction of the two species in mixtures and consequently the diameter growth of white pine is not adversely affected by the other component species.

Under pure conditions, red pine leads the species in diameter growth on good and poor sites and is followed closely by Scotch pine. The average diameters of pure white pine and pure jack pine are almost equal on good sites. On medium sites, Scotch pine has the largest average diameter followed closely by red pine and jack pine. White pine has the lowest average diameter of the four species under pure conditions, on medium and poor sites. This is in accordance with the popular notion about white pine: that it is not so well suited to medium and poor sites (51, 220, 279).

It should be pointed out here that in mixtures the commanding leads taken by species in height and/or diameter growth are likely to be sustained, since it appears that in the ensuing years the relationship of the species may not change.

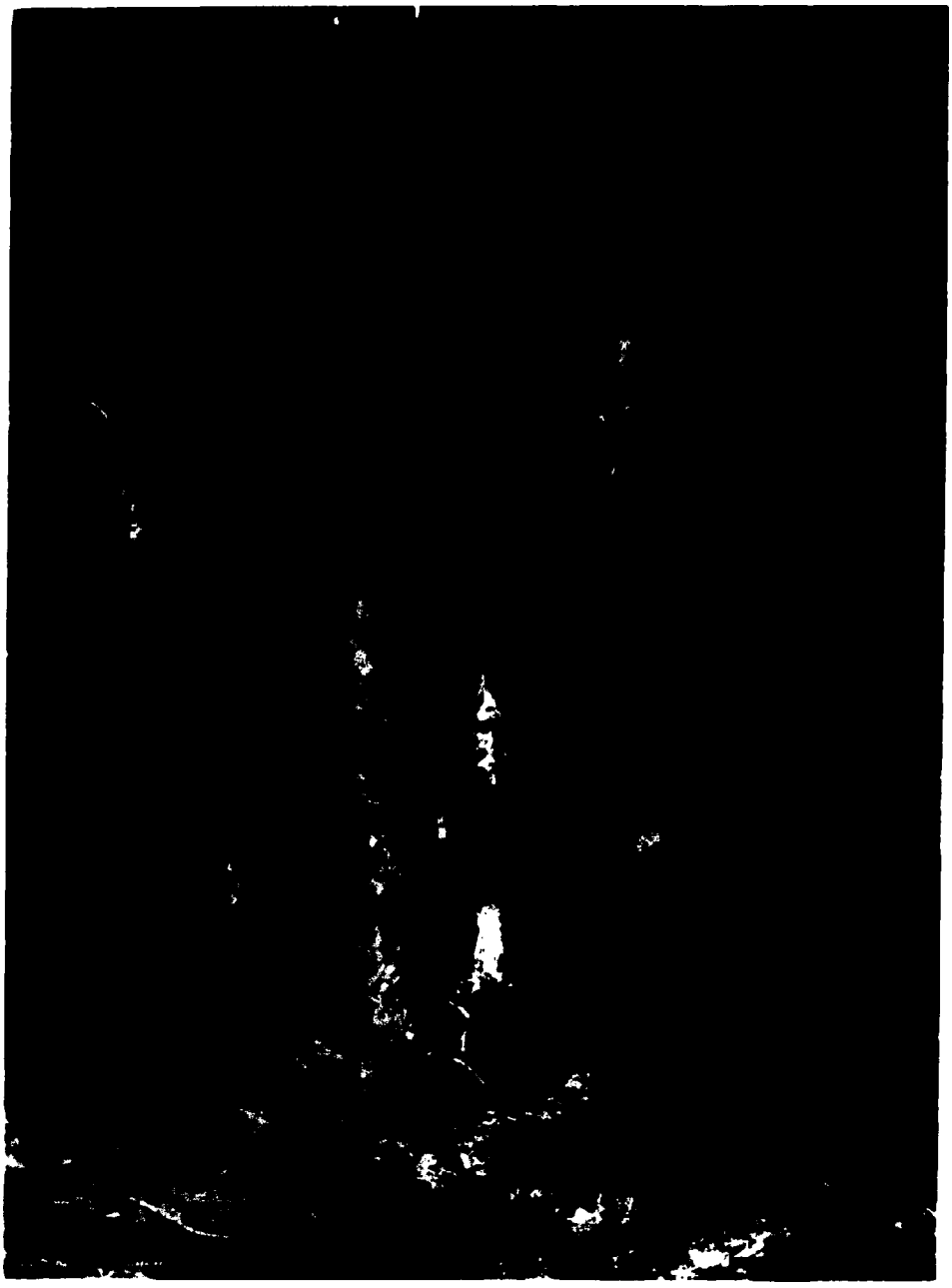


Fig. 6.----Pure red pine on good site.

c) Volume Growth.

i) Volume Growth per Acre by Using Volume Tables

Volume growth, which is the net result of height and diameter growths, is of chief importance to a forester as well as to a forest property owner. Volume per acre in cubic feet is the most practical item for comparison of the species in pure and mixed plantations.

As in the case of height and diameter growths, present volume growth of jack pine on per acre basis does not seem to be affected by mixture with the other species on all sites (Table 4, and Appendix XIII); hence it grows as well in pure as in the mixed stands. The site differences expressed in terms of cubic volume of jack pine are highly significant, illustrating the sensitivity of jack pine to the site variations. Red pine, on the other hand, reflects the effect of mixture in significantly lower volume when mixed with the other species on good site (Appendix XIV). Jack pine seems to exert this effect on red pine even on medium site, while with Scotch pine and white pine, red pine seems to grow as well in pure as in mixed stands on these sites. Like jack pine, red pine also shows significant differences in volume growth on various sites, indicating its sensitivity to variations in site.

On good sites, Scotch pine shows lower volume in mixtures

with jack pine and red pine than in pure plantations (Fig.7). The volume growth per acre of Scotch pine seems to suffer even on medium sites in jack pine-Scotch pine mixtures. On poor sites in all mixtures and on medium sites with red pine and white pine in mixtures, Scotch pine grows just as well as in pure stands (Appendix XV). Scotch pine also shows significant responses to site variations, as expressed in volume growth. White pine, however, shows significantly lower volume growth in all mixtures on good sites and jack pine-white pine mixture on medium site than in pure plantations on corresponding sites (Appendix XVI). On poor sites, white pine grows as well in the pure as in the mixtures. Like the other species, white pine shows significant differences in volume per acre on various sites both under pure and mixed conditions.

It may be seen from Table 4 that on good sites under pure conditions, red pine makes by far the best growth in volume, followed successively by jack pine, Scotch pine, and white pine successively. This is in accord with the common notion about the suitability of these species to the various sites (226, 243).

It may also be noted that in the case of jack pine, good sites carry about sixty percent more volume than medium sites, while medium sites support about twice the volume on poor sites. Red pine and white pine volume, on the other hand,



Fig. 7.-----A dead Scotch pine between two red pines, indicating result of competition.

is approximately twice as much on good sites as on medium sites, while medium sites have about twice the volume on poor sites. In the case of Scotch pine, however, the volume is about 67 percent more on good sites than medium sites, while medium site supports about twice the volume on poor sites.

ii) Cubic Foot Volume per Acre by Formula:

In the absence of adequate standards for determining success of forest plantations in the Lake States, Rudolf (219) set up some standards based on the expected average survival, total height, and diameter at breast height information obtained in a field survey of the plantations in this area. The success indices for average Lake State plantations established for production of wood are given in Table 5. Rudolf resolved the difficulty of assigning proper weights to stocking, height growth, and diameter growth in order to obtain a single expression of plantation success by using volumes per acre. The approximate unpeeled cubic volume per acre for the conifer planted in this area was obtained by the formula

$$Vuc = \left(\frac{d}{2}\right)^2 \times \frac{h}{100} \times N$$

Where Vuc = unpeeled cubic foot volume per acre

d = average breast-high stand diameter in inches

h = average height of all trees in feet

N = the number of living trees per acre

TABLE 5

SUCCESS INDICES[a] FOR AVERAGE LAKE STATES PLANTATIONS
(CUBIC FEET PER ACRE)

Age (years)	White pine	Red pine	Jack pine	Scotch pine
10	0.4	3	25	10
15	20	40	115	80
20	135	170	380	250
25	340	370	690	475
30	755	755	1,110	820
35	1,290	1,195	1,480	1,150

[a]Based on formula:

$$Vuc = \left(\frac{d}{2}\right)^2 \times \frac{h}{100} \times N$$

where Vuc = average diameter breast high in inches, h = average height of all trees in feet, and N = number of living trees per acre.

The per acre volumes on the plantations calculated by using the above formula (Table 6) were obtained to make comparisons with the corresponding success indices in Table 5.

Jack Pine

The success index for jack pine is 1,480 cubic feet, while the average cubic foot volume per acre in pure jack pine stands is 1,864, in mixture with red pine 1,258, in mixture with Scotch pine 1,906, and in mixture with white pine 1,897 cubic feet per acre (Table 6). Hence, except for jack pine mixed with red pine, all jack pine plantations on good sites are much better than the normal. On medium and poor sites all pure and mixed jack pine plantations are lower than the normal.

Red Pine

In the case of red pine the success index is 1,195 while its average volume per acre in pure stands is 2,333 cubic feet (Table 5). In mixture with jack pine, Scotch pine, and white pine, red pine averages 1,900, 1,718, and 1,812 cubic feet per acre respectively. Thus red pine on good sites, both in pure and in mixture, is much better than the normal. Pure red pine on medium sites has an average of 1,414 cubic feet, indicating that these plantations are also better than the average. The rest of the red pine plantations are poorer than the average.

TABLE 6

AVERAGE CUBIC FOOT VOLUME OF THE VARIOUS SPECIES OBTAINED BY FORMULA[a]

Species	GOOD SITE[b]	MEDIUM SITE[b]	POOR SITE[b]
Jack pine, pure	1864	1014	588
Red pine, pure	2333	1414	609
Scotch pine, pure	1733	948	557
White pine, pure	1258	544	190
Jack pine, mixed with red pine	1258	544	190
Red pine, mixed with jack pine	1900	405	300
Jack pine, mixed with Scotch pine	1906	1152	633
Scotch pine, mixed with jack pine	718	33[illegible]	255
Jack pine, mixed with white pine	1897	1219	623
White pine, mixed with jack pine	492	200	92
Red pine, mixed with Scotch pine	1718	1050	676
Scotch pine, mixed with red pine	957	1283	467
Red pine, mixed with white pine	1812	1038	572

TABLE 6--Continued

Species	GOOD SITE[b]	MEDIUM SITE[b]	POOR SITE[b]
White pine, mixed with red pine	604	185	163
Scotch pine, mixed with white pine	1586	814	500
White pine, mixed with Scotch pine	885	397	124

[a] $Vuc = \left(\frac{d}{2}\right)^2 \times \frac{h}{100} \times N$

Where Vuc = Unpeeled cubic foot volume per acre
d = Average breast-high stand diameter in inches
h = Average height of all trees in feet
N = Number of living trees per acre

[b] Site classes used are as follows (50-year base):

	Good site	Medium site	Poor site
Jack pine	60	50	40
Red pine	60	50	40
White pine	50	40	30
Scotch pine	Index graphs unavailable, therefore site classes for jack pine were used.		

Scotch Pine

The success index for Scotch pine is 1,150 cubic feet. The only plantations containing higher volume than this index are pure Scotch pine (1,733), Scotch pine mixed with white pine (1,586) on good sites, and Scotch pine mixed with red pine (1,283) on medium sites (Table 6). The rest of the Scotch pine stands are poorer than the average.

White Pine

Compared to the success index of 1,290, all white pine plantations are poorer than the average (Table 6). As in the case of volume computed by using volume tables, the white pine volume obtained by the formula is the lowest of all on comparable sites.

C. Comparative Growth of Individual Trees in Direct Competition

As mentioned before, the trees competing on all sides with adjacent trees were measured and observed in order to determine how the various species are affected when directly competing with members of the other species. It should be noted that in alternate row mixtures, for our definition of direct competition, a tree competes on two sides with two members of its own species and with two members of another species on the other two sides. In pure stands the trees in

direct competition, of course, compete with members of their own species on all four sides. The data obtained on direct competition trees yield valuable information about the manner and extent to which alternate row mixing affects the various species on the different sites.

Jack pine

A significantly lower average diameter, height, and volume of jack pine trees in direct competition with red pine trees than pure jack pine trees, on good site (Table 7, and Appendix XVII), indicates that red pine exerts a detrimental influence on the growth of jack pine where the two species directly compete with each other in alternate row mixtures. Red pine outgrows jack pine on good sites and the latter is forced into subordinate position under the conditions of intense competition (Fig. 8). But this effect is not extended to medium and poor sites, where jack pine holds its own against the red pine competition. Also, Scotch pine and white pine on all sites appear to have no detrimental influence on the growth of actively competing jack pine (Appendix XVII).

Red pine

The average diameter, total height, and volume of red pine trees competing directly with the other species is not significantly different from the jack pine trees in direct

TABLE 7

AVERAGE DIAMETER, AVERAGE TOTAL HEIGHT, AND AVERAGE VOLUME OF TREES IN DIRECT COMPETITION

Species	GOOD SITE[a]			MEDIUM SITE[a]			POOR SITE[a]		
	Diameter (inches)	Total height (feet	Volume (cubic feet)	Diameter (inches)	Total height (feet)	Volume (cubic feet)	Diameter (inches)	Total height (feet)	Volume (cubic feet)
Jack pine, pure	5.09	29.03	2.623	4.28	25.81	1.695	3.96	24.78	1.193
Red pine, pure	5.88	32.45	3.025	4.72	30.34	1.748	3.71	22.82	0.872
Scotch pine, pure	5.57	28.00	2.237	4.42	22.64	1.238	3.28	19.50	0.610
White pine, pure	5.07	28.28	2.041	3.87	20.64	1.030	3.14	18.50	0.505
Jack pine, mixed with red pine	4.32	25.45	1.610	4.19	27.95	1.520	4.13	23.76	1.410
Red pine, mixed with jack pine	5.54	28.03	1.990	3.69	19.37	0.796	3.08	18.00	0.605
Jack pine, mixed with Scotch pine	5.12	26.75	2.180	4.38	24.88	1.387	4.02	23.23	1.214

TABLE 7--Continued

Scotch pine, mixed with jack pine	4.26	22.23	1.168	3.75	17.53	0.850	2.80	16.57	0.549
Jack pine, mixed with white pine	5.14	32.01	2.834	5.10	27.00	1.674	4.12	24.84	1.512
White pine, mixed with jack pine	4.31	24.90	1.530	3.02	16.84	0.600	2.33	14.44	0.200
Red pine, mixed with Scotch pine	5.98	27.17	2.385	5.05	26.45	2.008	4.31	23.85	1.274
Scotch pine, mixed with red pine	4.89	23.08	2.385	4.48	24.77	1.628	3.24	21.23	0.868
Red pine, mixed with white pine	6.38	30.65	3.033	4.74	24.95	1.400	3.56	18.56	1.016
White pine, mixed with red pine	4.07	21.94	1.326	3.08	16.68	0.710	2.29	14.10	0.210
Scotch pine, mixed with white pine	5.23	25.09	1.778	4.68	22.80	1.285	3.74	20.50	0.778
White pine, mixed with Scotch pine	4.06	18.91	0.949	4.06	20.85	1.000	2.84	15.33	0.331

TABLE 7--Continued

[a]Site classes used are as follows (50-year base):

	Good site	Medium site	Poor site
Jack pine	60	50	40
Red pine	60	50	40
White pine	50	40	30
Scotch pine	Index graphs unavailable, therefore site classes for jack pine were used.		

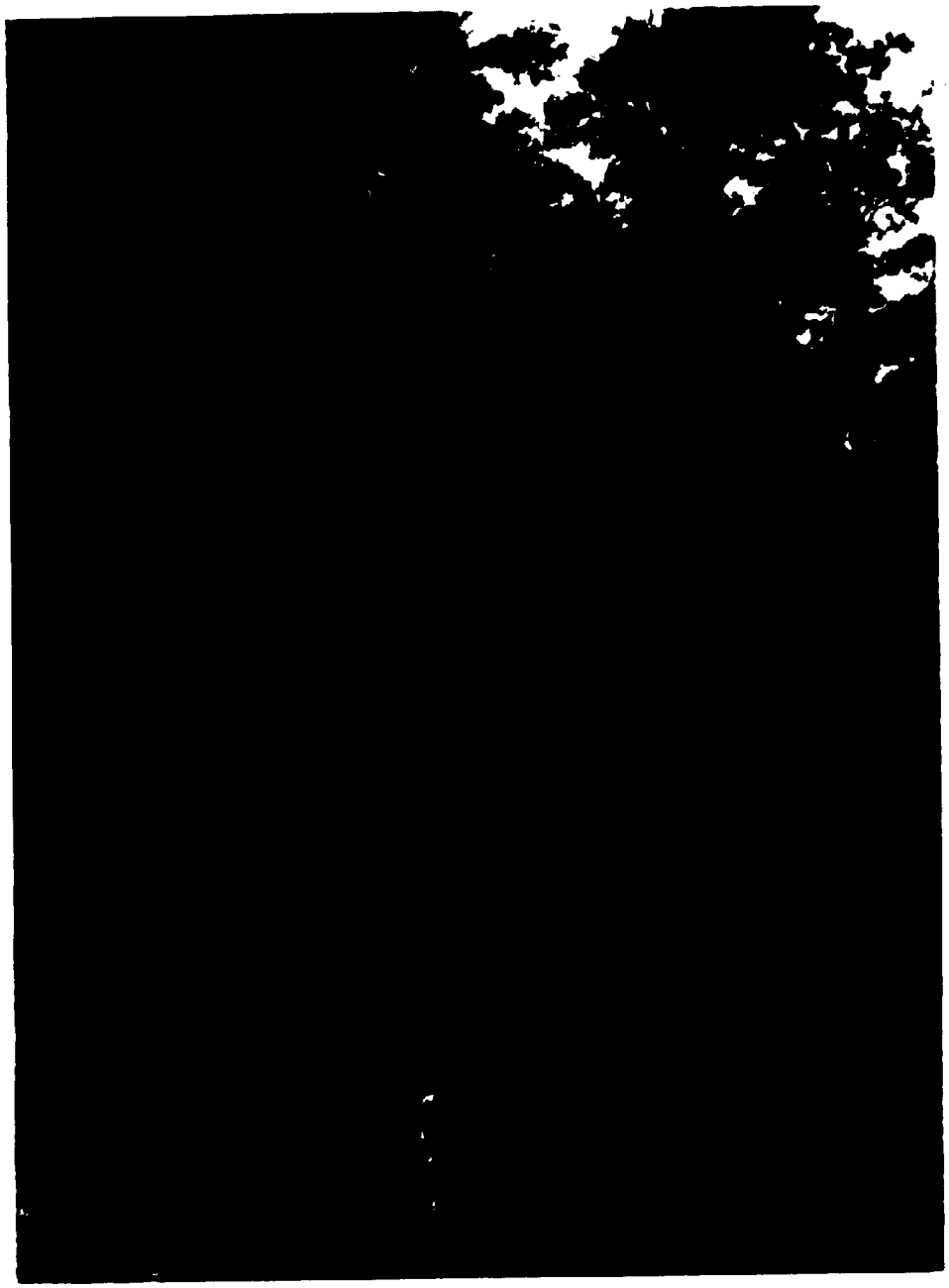


Fig. 8.---Red pine (left) dominating jack pine on good site.

competition among themselves on good site (Table 7, and Appendix XVIII). Consequently, the growth of red pine does not appear to be affected by direct competition with jack pine, Scotch pine and white pine on good sites. However, on medium and poor sites jack pine does adversely affect the growth of competing red pine, while Scotch pine and white have no such influence on these sites (Fig. 9).

Scotch pine

As in case of red pine, Scotch pine also shows harmful effect of direct competition with jack pine on good sites only (Table 7; Fig. 10; and Appendix XIX). On other sites and with other species, Scotch pine does not suffer from direct competition.

White pine

White pine trees competing directly with jack pine on all sites show a lower average diameter and total height than white pine trees competing directly among themselves. But this suppressive effect of jack pine is not shown in the average volume of the white pine trees (Table 7, and Appendix XX). Except on poor sites, red pine, likewise, appears to adversely affect the directly competing white pine as far as diameter and height growths are concerned, but not the volume growth. White pine trees competing directly with



Fig. 9.---Jack pine dominating red pine (center) on medium site.



Fig. 10.--Jack pine (center) mixed with Scotch pine on medium site. Notice their relative size.

Scotch pine on good sites show significantly lower growth in diameter, height, and volume than the white pine trees competing among themselves. On medium and poor sites, Scotch pine does not suppress the white pine growth (Figs. 11 to 13).

D. Comparative Incidence of Insect and Disease Damage

Every species of trees has plant pests (mainly insect or fungi) which attack it during some stage of its life. Usually only a few of these enemies assume major importance, while the majority play a minor role. Only the enemies of major importance, whose symptoms could be readily recognized at the time of field examinations, are considered here. These include, among insects: White pine weevil, Spruce budworm, Jack pine sawfly, Redheaded sawfly, Pine spittlebug, Saratoga spittlebug, and Nantucket pine tip moth; and among fungi: White pine rust, and Sweet fern rust. The damage caused to the trees by the various agencies was divided into three categories: heavy, medium, and light.

It should be pointed out that since, in the absence of the past record and history, the comparison of the insect and disease damage to the species is based on a single observation at the age of 35, the significance of the comparison is limited. By virtue of the fact that these plantations are located in the same area, it is reasonable to assume they were subject

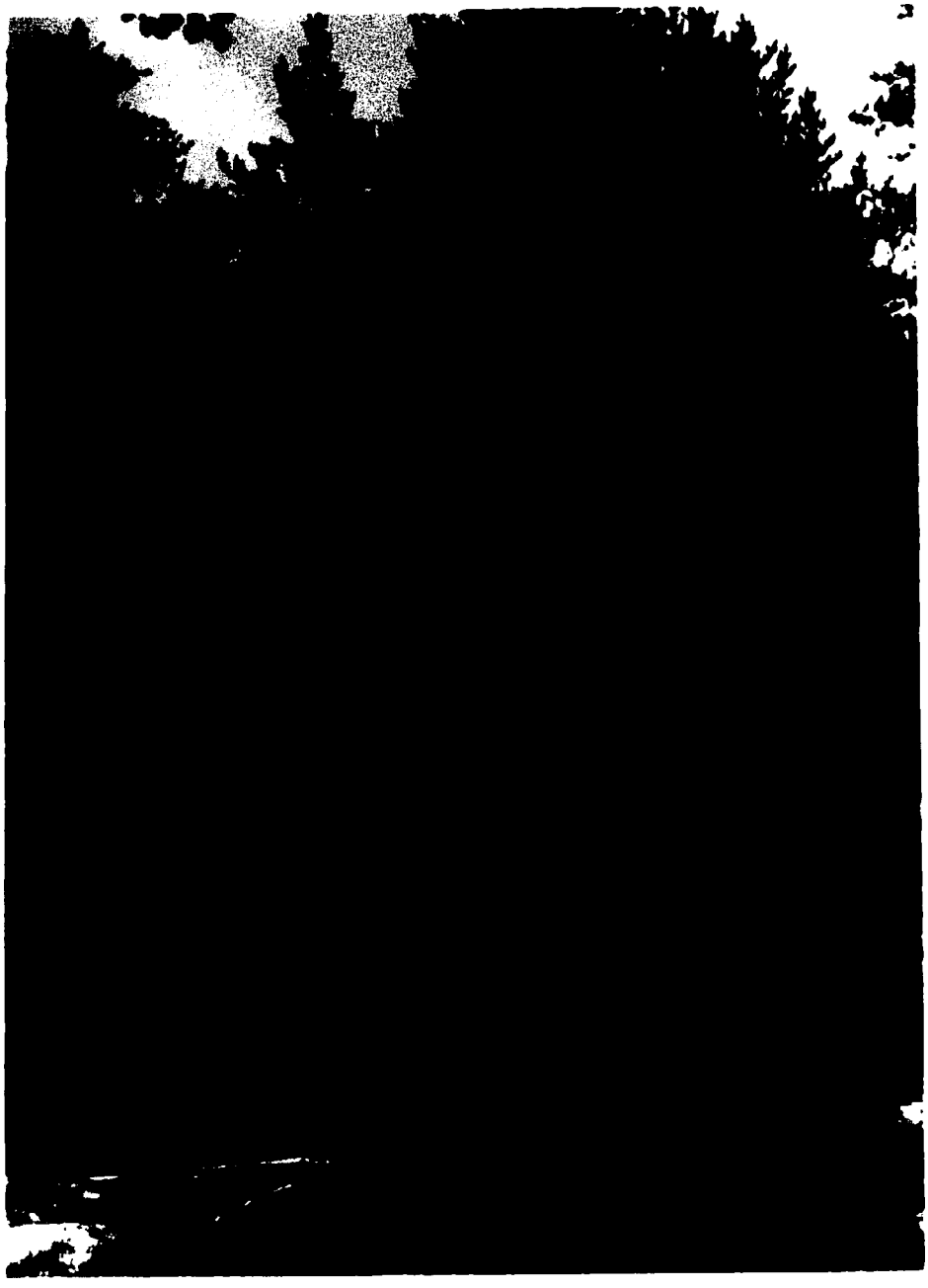


Fig. 11.--Jack pine dominating white pine (left foreground) on medium site. Notice branchiness of both species.



Fig. 12.--Red pine (left) dominating white pine on good site.



Fig. 13.--White pine (right foreground), dominated by two Scotch pines.

to common enemies and the incidence of attack was similar on comparable plantings. The comparisons based on the present observations are indicative only of trend.

White Pine Weevil (*Pissodes strobi* Peck)

The white pine weevil is a serious obstacle to the reproduction of high-grade pine lumber in planted stands. After the death of the leading shoot of the tree, resulting from the larvae attack, one or more of the lateral branches from the uppermost living whorl assume more or less a perpendicular position and the function of the killed leader. This produces a definite crook in the bole. The same type of injury repeated several times may destroy the timber value of the tree, but the attack is seldom fatal. Although a weevil attack causes slight losses in the growth, these losses are insignificant compared with the depreciation in the quality of timber due to crooked or forked boles.

It may be seen in Tables 8 to 11 that white pine, under pure and mixed conditions, has the highest percentage of weeviled trees (over ninety percent). It has also the largest number of trees severely attacked by the weevil. A large number of white pine trees are so crooked and deformed by repeated weeviling that they are worthless as timber. The percentage of Scotch pine trees affected by the weevil is second only to white pine, followed closely by jack pine.

Like white pine, many Scotch pine trees exhibit severe weevil attacks. Red pine shows the least incidence of the attack.

In the case of pure jack pine, 67 per cent of the trees were attacked by the white pine weevil one time or the other, while the percentages of the weeviled trees of jack pine mixed with red pine, Scotch pine, and white pine are 64, 69, and 71 respectively (Table 8). The 't' test (Appendix XXI) reveals that only the percentage of weeviled trees of jack pine mixed with white pine is significantly higher (at five percent level) than in the pure jack pine plantings. It seems that the spread of white pine weevil on jack pine, which is relatively less susceptible to the weevil, is facilitated when it is grown in alternate rows with the more susceptible species like white pine. Mixing jack pine with equally or less susceptible species like red pine and Scotch pine does not appear to affect the incidence of weevil attack.

Only with jack pine, the incidence of weevil attack on red pine seems to increase, while with Scotch pine and white pine (more susceptible species than red pine) the incidence of the attack is unchanged, i.e., about the same as in the pure red pine (Table 9, Appendix XXII).

Mixing Scotch pine with the other species appears neither to increase nor decrease the incidence of the white pine weevil attack (Table 10, and Appendix XXIII). Only

white pine mixed with Scotch pine shows significantly higher percentage of weeviled trees than pure white pine (Table 11, and Appendix XXIV). It appears that, in general, the incidence of the weevil attack tends to increase on a less susceptible species when it is mixed with a more susceptible species.

Spruce Budworm (Archips fumiferma Grote)

The attack of the pine form of the spruce budworm in these plantations is not serious, and consequently insignificant as far as the growth of the attacked trees is concerned. Scotch pine exhibits the highest incidence of the budworm attack, followed successively by jack pine, white pine, and red pine. These results follow the pattern of earlier finding on the budworm attack in this region (96).

Jack pine does not appear to be affected by mixing as far as the attack of Spruce budworm is concerned (Table 8, Appendix XXI). Although red pine is the species least affected by the budworm, the incidence of the attack seems to increase on it where it is mixed with Scotch pine (Table 9, and Appendix XXII), but in mixture with the other species the incidence of the attack is the same as in the pure red pine. There is no significant difference in the percentage of the attacked Scotch pine and white trees under the pure and mixed

TABLE 8

INSECT AND DISEASE INCIDENCE ON THE JACK PINE

Percentage of Trees Affected[a]

Type of plantation	White pine weevil.				Spruce budworm				Sawflies			
	Heavy[b]	Medium[c]	Light[d]	Total[e]	Heavy[b]	Medium[c]	Light[d]	Total[e]	Heavy[b]	Medium[c]	Light[d]	Total[e]
Jack pine, pure	10	34	23	67	2	5	9	11	2	8	18	28
Jack pine and red pine	13	38	13	64	2	4	7	13	4	6	21	31
Jack pine and Scotch pine	15	40	14	69	3	8	10	21	2	5	19	26
Jack pine and white pine	21	43	7	71	3	6	9	18	3	3	18	24

[a]All sites grouped together.

[b]Percentage of trees attacked heavily.

[c]Percentage of trees attacked moderately.

[d]Percentage of trees attacked lightly.

[e]Percentage of trees attacked heavily, moderately, and lightly.

TABLE 8--Continued

Pine spittlebug				Saratoga spittlebug				Nantucket pine tip moth				White pine rust				Sweet fern rust			
Heavy[b]	Medium[c]	Light[d]	Total[e]	Heavy[b]	Medium[c]	Light[d]	Total[e]	Heavy[b]	Medium[c]	Light[d]	Total[e]	Heavy[b]	Medium[c]	Light[d]	Total[e]	Heavy[b]	Medium[c]	Light[d]	Total[e]
[illegible]	0	6	6	0	0	8	8	0	0	11	11	0	0	0	0	0	0	1	1
0	0	4	4	0	0	5	5	0	0	10	10	0	0	0	0	0	0	1	1
0	0	4	4	0	0	6	6	0	0	12	12	0	0	0	0	0	0	1	1
0	0	3	3	0	0	5	5	0	0	7	7	0	0	0	0	0	0	1	1

TABLE 9

INSECT AND DISEASE INCIDENCE ON THE RED PINE

Percentage of Trees Affected[a]

Type of plantation	White pine weevil				Spruce budworm				Sawflies			
	Heavy[b]	Medium[c]	Light[d]	Total[e]	Heavy[b]	Medium[c]	Light[d]	Total[e]	Heavy[b]	Medium[c]	Light[d]	Total[e]
Red pine pure	3	11	21	35	0	2	3	5	0	8	12	20
Red pine and jack pine	5	12	26	43	0	2	4	6	4	8	12	24
Red pine and Scotch pine	8	17	15	40	2	2	5	9	4	4	15	23
Red pine and white pine	7	19	13	39	0	1	3	4	2	5	11	18

[a]All sites grouped together.

[b]percentage of trees attacked heavily.

[c]percentage of trees attacked moderately.

[d]percentage of trees attacked lightly.

[e]percentage of trees attacked heavily, moderately, and lightly.

TABLE 9--Continued

Pine spittlebug				Saratoga spittlebug				Nantucket pine tip moth				White pine rust				Sweet fern rust			
Heavy[b]	Medium[c]	Light[d]	Total[e]	Heavy[b]	Medium[c]	Light[d]	Total[e]	Heavy[b]	Medium[c]	Light[d]	Total[e]	Heavy[b]	Medium[c]	Light[d]	Total[e]	Heavy[b]	Medium[c]	Light[d]	Total[e]
0	0	3	3	0	0	6	6	0	0	9	9	0	0	0	0	0	0	.5	.5
0	0	2	2	0	0	4	4	0	0	8	8	0	0	0	0	0	0	.5	.5
0	0	2	2	0	0	4	4	0	0	7	7	0	0	0	0	0	0	.5	.5
0	0	2	2	0	0	4	4	0	0	7	7	0	0	0	0	0	0	0	0

conditions (Tables 10, 11, and Appendixes XXIII, XXIV), hence it may be said that mixing of Scotch pine and white pine with the other species does not intensify or abate the attack of spruce budworm.

Sawflies

Jack pine sawfly (Neodiprion banksianae Roh) and Red-headed sawfly (Neodiprion lecontei Fitch)

Of the many sawflies found on the pine species in Lower Michigan, jack pine sawfly and the red-headed sawfly are of major importance. While the jack pine fly is found exclusively on jack pine, the red-headed sawfly extends its attack on red pine and Scotch pine also. The former sawfly defoliates a previous season's growth and the latter strips both old and new foliage. The damage caused by the sawflies in these plantations is only minor.

Jack pine shows the highest percentage of the trees affected by the sawflies, followed by red pine and Scotch pine. In case of white pine, the attack is almost negligible. There is no significant difference in the incidence of the sawflies' attack in the pure and mixed plantings of the four species (Tables 8 to 11 and Appendixes XXI to XXIV).

Pine spittlebug (Aphrophora parallela Say)

The damage caused by the pine spittlebug in these plantations is of minor nature, unwarranting any control measures.

TABLE 10

INSECT AND DISEASE INCIDENCE ON THE SCOTCH PINE

Percentage of Trees Affected[a]

Type of plantation	White pine weevil				Spruce budworm				Sawflies			
	Heavy[b]	Medium[c]	Light[d]	Total[e]	Heavy[b]	Medium[c]	Light[d]	Total[e]	Heavy[b]	Medium[c]	Light[d]	Total[e]
Scotch pine, pure	56	17	13	86	15	15	6	36	0	2	9	11
Scotch pine and jack pine	60	15	9	84	12	16	11	39	0	1	7	8
Scotch pine and red pine	55	17	10	82	18	13	9	40	0	2	9	11
Scotch pine and white pine	61	16	11	88	16	10	7	33	0	1	7	8

[a]All sites grouped together.

[b]Percentage of trees attacked heavily.

[c]Percentage of trees attacked moderately.

[d]Percentage of trees attacked lightly.

[e]Percentage of trees attacked heavily, moderately, and lightly.

TABLE 10--Continued

Pine spittlebug				Saratoga spittlebug				Nantucket pine tip moth				White pine rust				Sweet fern rust			
Heavy[b]	Medium[c]	Light[d]	Total[e]	Heavy[b]	Medium[c]	Light[d]	Total[e]	Heavy[b]	Medium[c]	Light[d]	Total[e]	Heavy[b]	Medium[c]	Light[d]	Total[e]	Heavy[b]	Medium[c]	Light[d]	Total[e]
0	0	4	4	0	0	2	2	0	0	6	6	0	0	0	0	0	0	1	1
0	0	3	3	0	0	2	2	0	0	5	5	0	0	0	0	0	0	2	2
0	0	3	3	0	0	1	1	0	0	1	1	0	0	0	0	0	0	.5	.5
0	0	3	3	0	0	1	1	0	0	4	4	0	0	0	0	0	0	.5	.5

TABLE 11

INSECT AND DISEASE INCIDENCE ON THE WHITE PINE

Percentage of trees affected[a]

Type of plantation	White pine weevil				Spruce budworm				Sawflies			
	Heavy[b]	Medium[c]	Light[d]	Total[e]	Heavy[b]	Medium[c]	Light[d]	Total[e]	Heavy[b]	Medium[c]	Light[d]	Total[e]
White pine pure	59	23	12	94	0	2	8	10	0	0	3	3
White pine and jack pine	63	19	10	92	0	2	6	8	0	1	4	5
White pine and red pine	58	20	18	96	0	1	4	5	0	0	2	2
White pine and Scotch pine	70	21	6	97	2	2	7	11	0	0	2	2

[a]All sites grouped together.

[b]percentage of trees attacked heavily.

[c]percentage of trees attacked moderately

[d]percentage of trees attacked lightly.

[e]percentage of trees attacked heavily, moderately, and lightly.

TABLE 11--Continued

Pine spittlebug				Saratoga spittlebug				Nantucket pine tip moth				White pine rust				Sweet fern rust			
Heavy[b]	Medium[c]	Light[d]	Total[e]	Heavy[b]	Medium[c]	Light[d]	Total[e]	Heavy[b]	Medium[c]	Light[d]	Total[e]	Heavy[b]	Medium[c]	Light[d]	Total[e]	Heavy[b]	Medium[c]	Light[d]	Total[e]
0	0	2	2	0	0	1	1	0	0	0	0	0	0	1	1	0	0	1	1
0	0	1	1	0	0	1	1	0	0	0	0	0	0	.5	.5	0	0	.5	.5
0	0	1	1	0	0	1	1	0	0	1	1	0	0	.8	.8	0	0	0	0
0	0	2	2	0	0	1	1	0	0	0	0	0	0	1	1	0	0	0	0

The pine spittlebug nymphs secrete a foamy fluid, resembling spittle, that covers and hides them. This white spittle on the twigs is the most conspicuous feature of their attack. The necrotic spots, which develop at each point of attack, later become infiltrated with resin and leave a permanent mark of injury in the wood. There is no difference in the incidence of the pine spittlebug attack in the pure and mixed plantations of the four species (Tables 8 to 11 and Appendixes XXI to XXIV).

Saratoga spittlebug (Aphrophora saratogensis Fitch)

Unlike the pine spittlebug, the adults of the Saratoga spittlebug feed on the twigs of pine trees. They suck the plant sap by puncturing through the bark with their beaks. When the necrotic spots at the points of attack become numerous, the twigs die and the needles turn red. The bark and wood underneath are covered by droplets of resin. Death is caused partly by the loss of sap and partly by the girdling effect produced by resin blocking the conducting tissues. In the course of several years, the "flagging" of twigs may involve the entire tree and cause its death. More commonly, however, the tree becomes deformed but still lives. The feeding punctures are invaded by a fungus that may also contribute to mortality (57, 231).

Only a small percentage of trees in these plantations have been attacked by the Saratoga spittlebug, and the damage caused appears to be slight (Tables 8 to 11). There is no significant difference in the incidence of attack in the pure and mixed plantations of the various species (Appendixes XXI to XXIV).

Nantucket tip moth (Rhyacionia frustrana Comst)

The larvae of the Nantucket tip moth work on the soft tissue of the new shoots, tunneling through them and later emerging from the buds or shoots. The infected buds or shoots are killed and consequently the tree's growth suffers. The tip moth attack on pine trees can be diagnosed during summers by the presence of a small pitch mass or a dead needle at the base of the bud. Later the color of the tip turns brown and they are brittle because of being hollow.

The Nantucket tip moth attack on the various species in these plantations is not serious. Furthermore, mixing of these species in alternate rows does not seem to affect incidence of the attack (Appendixes XXI to XXIV). Relatively speaking, jack pine seems to be more affected by the tip moth than the other species.

White pine blister rust (Cronartium ribicola Fischer)

The white pine blister rust was seen on only a few

white pine trees in these plantations (Tables 8 to 11). Hence, no control measure is warranted in these plantations at the present time.

Sweetfern blister rust (Cronartium comptoniae Arth)

A negligible fraction of the trees were found to have symptoms of the sweetfern blister rust attack (Tables 8 to 11). No control measure seems necessary at the present time.

9. CONCLUSIONS AND RECOMMENDATIONS

The problem of pure versus mixed stands is one of the most widely discussed in the silvicultural literature and the views of the foresters have fluctuated in the course of the past two hundred years. An examination of the rich and varied literature on pure versus mixed stands reveals that it still is one of the most controversial subjects in forestry. It is significant to note that many of the questions which gave rise to argument in the early days of forestry practice still find an important place in the literature on pure and mixed stands today.

The obvious conclusion from the review of literature, presented in Part I of this dissertation, is that generalizations about the merits or demerits of pure or mixed stands should be made with much care. Each specific situation or condition should be considered and evaluated in the light of desired aims and specific objectives of the management.

Part II of this dissertation provides specific information as to how the 35-year-old mixed plantations of jack pine, red pine, Scotch pine, and white pine have developed as compared to the pure plantations of the same species on similar

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Part II of this dissertation provides specific information as to how the 35-year-old mixed plantations of jack pine, red pine, Scotch pine, and white pine have developed as compared to the pure plantations of the same species on similar

sites in Lower Michigan. Also, the study furnishes information about the effects the individual trees of the various species have on each other when directly competing in alternate row mixtures. On the basis of the findings, some general recommendations can be made about the use of mixtures in coniferous plantations under various planting conditions in Lower Michigan.

Survival and Stocking

Mixing jack pine with red pine, Scotch pine, and white pine in alternate rows does not appear to affect jack pine's survival and stocking on good, medium, and poor sites after 35 years. Also, jack pine, as shown by the present stocking, survives as well on good as on medium or poor sites, both in pure and mixed stands. Since jack pine is capable of adapting and maintaining itself on a wide range of soils, it does not seem to show sensitivity to the site differences as far as survival is concerned. On the other hand, lower survival and present stocking of red pine mixed with jack pine as compared to pure red pine on medium and poor sites reflects at least in part the detrimental influence of jack pine on the red pine's survival. The faster growing jack pine forces the red pine into subordinate position on these sites and in many cases the members of the latter species lose out in

the competition, resulting in the lower survival of red pine in such mixtures than the pure red pine on the comparable sites. However, red pine on good sites, to which it is better suited, holds its own against jack pine, Scotch pine, and white pine in the mixtures and it survives as well in the mixtures as in the pure plantings. Moreover, Scotch pine and white pine do not seem to affect the survival of red pine on medium and poor sites. Because red pine grows at least as well as Scotch pine, if not better, on medium and poor sites and also grows better there than does white pine, it does not suffer from any loss in stocking in red pine-Scotch pine and red pine-white pine mixtures. Unlike jack pine, red pine stocking decreases with decrease in the site quality, indicating its sensitivity to the site differences.

The survival of Scotch pine is lowered when it is mixed with jack pine on all sites, since the latter species overtakes it in the early years and suppresses it. Red pine also has the same effect on the survival of Scotch pine in mixtures but only on good sites. It appears that on the medium sites Scotch pine keeps up with jack pine without suffering any loss in survival. Jack pine and red pine both seem to lower the survival of white pine on all sites, while Scotch pine does not show such effect on white pine in alternate row mixtures.

In general, red pine and jack pine rank the best in survival and present stocking, while white pine shows the poorest survival and stocking on all sites.

Growth

With regard to the height growth, jack pine, red pine, and Scotch pine show no difference in the average total height under the pure and mixed conditions. But white pine seems to suffer, as far as the height growth is concerned, from competition with jack pine and red pine on all sites, while Scotch pine shows no such curbing influence on white pine in mixtures on any site.

The diameter-growth of jack pine and red pine is not affected by mixing these two species either with Scotch pine or with white pine on good, medium, and poor sites. However, Scotch pine mixed with jack pine on good and medium sites shows reduced diameter growth. Also, red pine seems to curb Scotch pine's diameter-growth on good and poor sites. As in the case of the height-growth, white pine shows the most adverse effect of mixtures on its diameter-growth also. Jack pine on good and medium sites, and Scotch pine on good sites only seem to reduce the diameter-growth of white pine.

Volume-growth, which is the net result of height and diameter growths, is the most practical item for comparison

of the species in pure and mixed plantings. Jack pine grows in volume as well in the pure stands as in the mixtures. Red pine appears to suffer a loss in volume-growth in mixtures with the other species on good sites and with jack pine on medium sites. On poor sites, red pine shows no effect of mixing on its volume-growth.

Jack pine and red pine reduce the volume-growth of Scotch pine on good sites, while jack pine extends this influence on medium sites also. A significantly lower volume of white pine in mixture with jack pine, red pine, and Scotch pine on good sites than the pure white pine indicates that these species have an adverse effect on the volume-growth of white pine. Moreover, white pine suffers in volume-growth on medium sites with jack pine and red pine.

In the pure plantings on good sites red pine has the highest volume per acre, followed by jack pine, Scotch pine, and white pine. Jack pine leads the other species in volume-growth on medium and poor sites, followed by red pine, Scotch pine, and white pine. Most of the findings on volume-growth of the species concur with the results obtained by Allison (3), Reed (209), and Slabaugh and Rudolf (235) under similar conditions.

A more clear picture of the interaction of the species is revealed by the trees engaged in direct competition. Only

on good sites jack pine trees competing directly with red pine show reduction in the average total height, average diameter, and average volume. On the other sites and with the other species jack pine does not suffer from direct competition as far as the growth is concerned. Red pine, in turn, suffers from direct competition with jack pine on medium and poor sites. Scotch pine and white pine seem to reduce the height growth of red pine on medium sites, but this effect is not shown in the diameter and volume growths. Jack pine also reduces the height-, diameter-, and volume-growths of Scotch pine on all sites, where the two species are engaged in direct competition. The detrimental influence of red pine on the directly competing Scotch pine is limited to height growth only. As for white pine in direct competition, its growth in height is reduced in mixture with jack pine on medium and poor sites and with red pine on good and medium sites. However, its diameter-growth suffers in direct competition with jack pine and red pine on all sites. But neither with jack pine nor with red pine on any site does the volume growth of white pine seem to suffer from the direct competition. Only Scotch pine on good sites adversely affects the height-, diameter-, and volume-growths of white pine engaged in direct competition with it. It should be pointed out that the common contention that white pine makes a better growth than red

pine on good sites is not borne out in these plantings. Excessive damage by the white pine weevil may be responsible for the poorer growth of white pine in this area.

Comparative Incidence of Insect and Disease

The value of the comparison of the incidence of insect and disease on the various species under pure and mixed conditions is limited because this comparison is based on only a single observation. White pine shows the most (over 90% of the trees affected) and severest damage by the white pine weevil both in pure and mixed plantings. Scotch pine ranks only second to white pine as far as the incidence of weevil attack is concerned. There is evidence to show that the incidence of the weevil attack on a less susceptible species increases when such a species is mixed with a more susceptible species in alternate rows although it does not hold in all cases.

Scotch pine shows the highest (ca. 37%) incidence of spruce budworm attack, followed by jack pine, white pine and red pine. The incidence of the budworm attack increases on red pine (a less susceptible species) when it is mixed with Scotch pine, while white pine mixed with red pine shows lower incidence than pure white pine. On the other species there is no difference in the budworm attack in the pure and mixed

plantings. There is no significant difference in the incidence of attack by the jack pine sawfly and the red-headed sawfly in the pure and mixed plantings of all species. Jack pine shows the highest incidence of the sawfly attack (ca. 28%) followed by red pine and Scotch pine. White pine seems to be almost unaffected by the sawflies. The attacks by the pine spittlebug, Saratoga spittlebug and Nantucket tipmoth are of minor nature (1-10% trees affected) in these plantings and there appears to be no difference in incidence of these attacks under the pure and mixed conditions. Only a few trees show signs of white pine blister rust and sweet fern rust.

The alternate row mixture gives the most intimate mixture and results in very severe competition between the component species, so that if one species lags behind it is likely to be seriously suppressed or even killed. The four pine species in these plantations have different requirements and different rates of growth. Usually one of the two species in the alternate row mixture crowds the other and in some cases almost completely represses it. The consequent low stocking in such cases means partial utilization of the site and lower volume per acre. If good sites, for instance, had been planted to pure red pine, the sites would have now contained considerably more volume than the combined volume of red pine and any one of the three species mixed with it.

Similarly, poor sites would have yielded more volume if they had been planted to pure jack pine rather than mixtures of red pine, Scotch pine, or white pine. Besides its poor form and growth, Scotch pine has proved to be highly susceptible to severe attacks by many insects. This consideration renders the species unsuitable for the area. White pine neither in pure nor in mixed plantings has shown as good a growth as in other regions, partly due to poor survival.

The results of the study of these plantations suggest certain recommendations for planting in this area:

1. In the past, jack pine, red pine, Scotch pine, and white pine were planted in this area indiscriminately, without much consideration of the silvicultural nature of the species, particularly their site requirements for optimum growth and their growth habits and reaction to the other species in mixtures. These plantings were made as a part of a large-scale program of reforestation in the area. Species of unequal growth were planted in intimate mixtures partly in the hope that one or the other species would survive, although at that time precise information about the behavior of these species in mixtures was not available. However, had proper account been taken of the known silvical nature of the species, two compatible species in mixture could have been planted and

the site more fully utilized. Today we have on many sites much less volume per acre than we could have had if pure plantings suited to the sites had been made. Although the foresters in the area have known for some time, from their casual observations, about the poor growth of the pine species in the mixtures, no effort had been made to show the inadvisability of such mixtures through a planned study. The present study shows that the mixed plantings of jack pine, red pine, Scotch pine, and white pine by alternate row are not advisable in this area since they have shown no economic or biological advantage. On the contrary, alternate row mixtures have generally shown poorer growth than the pure plantings. It is, therefore, recommended that these four species of pine should not be grown in alternate row mixtures but instead pure plantings be made in this area. Mixing by blocks may prove more profitable than alternate row mixtures.

2. As pointed out before, plantings were made without much regard to the suitability of a site for a particular species even in case of pure plantings. Jack pine has been planted too liberally in the past on good sites, which could have grown more valuable species such as red pine. Jack pine should be limited to poor sites only, since it is capable of maintaining itself well and also of making a better growth than the other pine species on such sites.

3. For the best utilization of good and medium sites in this area, red pine is recommended in pure plantings. Unlike in other areas, white pine has made a poor showing both in pure plantings and in mixtures on good sites in this area. A very poor survival and a very high and severe incidence of white pine weevil attack on white pine in these plantations seem to be responsible for the poor volume-growth per acre. Based on the poor performance in these plantings, white pine cannot be recommended for this area.

4. Scotch pine, at least the variety of seed used in these plantations, is subject to many insect attacks and it makes poor growth. It is scrubby and bushy and has undesirable form. Based on the poor performance, it is not recommended in this area. The poor performance of Scotch pine in this area was noticed earlier and it is rarely used for planting in the area now.

APPENDIX I

NUMBER OF LIVING JACK PINE TREES PER ACRE, AND THE ANALYSIS OF VARIANCE

Number of Living Trees Per Acre

SPECIES	Good site		Medium site		Poor site	
	Rep. 1	Rep. 2	Rep. 1	Rep. 2	Rep. 1	Rep. 2
J/J	986	1024	997	871	839	915
J/R	969	1057	1034	948	1045	1067
J/S	1111	850	1045	1013	1024	893
J/W	1034	1035	1035	958	980	784

Analysis of Variance Table

Sources of variation	Sum of squares	d.f.	Mean square	'F' ratio	
Rows	20,868	3	6,956	.9856	Not sig.
Columns	17,580	2	8,790	1.2450	Not sig.
Interaction	33,643	6	5,607	.7940	Not sig.
Subtotal	72,091	11			
Within grps	84,686	12	7,057		
Total	156,777	23			

Note: In Appendices I to XVI, the 'F' values for significance are as follows:

	d.f.	'F' value	
		At .01	At .05
Rows	3	5.05	3.49
Columns	2	6.93	3.88
Interaction	6	4,82	3.00

APPENDIX II

NUMBER OF LIVING RED PINE TREES PER ACRE, AND THE ANALYSIS OF VARIANCE

Number of Living Trees Per Acre

SPECIES	Good site		Medium site		Poor site	
	Rep. 1	Rep. 2	Rep. 1	Rep. 2	Rep. 1	Rep. 2
R/R	1095	1029	954	927	828	757
R/J	991	985	762	679	573	664
R/S	948	928	922	904	807	698
R/W	928	970	896	862	784	730

Analysis of Variance Table

Sources of variation	Sum of squares	d.f.	Mean square	'F' ratio	
Rows	73,859	3	24,620	13.497	Sig.
Columns	258,514	2	129,257	70.864	Sig.
Interaction	38,507	6	6,384	3.500	Not sig.
Subtotal	370,680	11			
Within gps.	21,866	12	1,824		
Total	392,560	23			

SE diff. between any pair of column means

$$= \sqrt{\frac{1824}{8} + \frac{1824}{8}} = \sqrt{456} = 21 \text{ approx.}$$

't' at .01 for 12 d.f. = 3.06. Observed diff. 21 x 3.06 - 64

	Good vs medium	Good vs poor	Medium vs poor
R/R	Sig.	Sig.	Sig.
R/J	Sig.	Sig.	Sig.
R/J	Not sig.	Sig.	Sig.
R/W	Sig.	Sig.	Sig.

SE diff. between any pair of row means

$$= \sqrt{\frac{1824}{6} + \frac{1824}{6}} = \sqrt{608} = 25 \text{ approx.}$$

't' at .01 for 12 d.f. = 3.06. Observed diff. = 25 x 3.06 = 76

	Site	R/J	R/S	R/W
R/R	Good	Not sig.	Not sig.	Not sig.
R/R	Medium	Sig.	Not sig.	Not sig.
R/R	Poor	Sig.	Not sig.	Not sig.

APPENDIX III

NUMBER OF LIVING SCOTCH PINE TREES PER ACRE, AND THE ANALYSIS OF VARIANCE

Number of Living Trees Per Acre

SPECIES	Good site		Medium site		Poor site	
	Rep. 1	Rep. 2	Rep. 1	Rep. 2	Rep. 1	Rep. 2
S/S	779	784	724	778	784	730
S/J	501	632	436	594	642	512
S/R	609	624	627	697	479	468
S/W	785	817	795	719	729	681

Analysis of Variance Table

Sources of variation	Sum of squares	d.f.	Mean square	'F' ratio	
Rows	205,842	3	68,614	21.880	Sig.
Columns	19,074	2	9,537	3.042	Not sig.
Interaction	53,246	6	8,873	2.830	Not sig.
Subtotal	278,162	11			
Within groups	37,616	12	3,135		
Total	315,778	23			

SE diff. between any pair of row means

$$= \sqrt{\frac{3135}{6} + \frac{3135}{6}} = 32 \text{ approx.}$$

't' at .01 for 12 d.f. = 3.06. Observed diff. = 32 x 3.06 = 98

	Site	S/J	R/S	R/W
S/S	Good	Sig.	Sig.	Not sig.
S/S	Medium	Sig.	Not sig.	Not sig.
S/S	Poor	Sig.	Sig.	Not sig.

APPENDIX IV

NUMBER OF LIVING WHITE PINE TREES PER ACRE, AND THE ANALYSIS OF VARIANCE

Number of Living Trees Per Acre

SPECIES	Good site		Medium site		Poor site	
	Rep. 1	Rep. 2	Rep. 1	Rep. 2	Rep. 1	Rep. 2
W/W	711	784	628	677	550	569
W/J	595	610	538	548	436	450
W/R	436	642	511	566	436	436
W/S	740	682	577	730	513	577

Analysis of Variance Table

Sources of variation	Sum of squares	d.f.	Mean square	F' ratio	
Rows	100,604	3	33,535	9.422	Sig.
Columns	98,212	2	49,106	13.797	Sig.
Interaction	5,690	6	948	.266	Not sig.
Subtotal	204,506	11			
Within groups	42,707	12	3,559		
Total	247,213	23			

SE diff. between any pair of row means

$$= \sqrt{\frac{3559}{6} + \frac{3559}{6}} = 34 \text{ approx.}$$

't' at .01 for 12 d.f. = 3.06. Observed diff. = 34 x 3.06 = 104

	Site	W/J	W/R	W/S
W/W	Good	Sig.	Sig.	Not sig.
W/W	Medium	Sig.	Sig.	Not sig.
W/W	Poor	Sig.	Sig.	Not sig.

SE diff. between any pair of columns means

$$= \sqrt{\frac{3559}{8} + \frac{3559}{8}} = \sqrt{890} = 30 \text{ approx.}$$

't' at .01 for 12 d.f. = 3.06. Observed diff. = 30 x 3.06 = 92

	Good vs medium	Good vs poor	Medium vs poor
W/W	Sig.	Sig.	Sig.
W/J	Not sig.	Sig.	Sig.
W/R	Not sig.	Sig.	Sig.
W/S	Not sig.	Sig.	Sig.

APPENDIX V

AVERAGE TOTAL HEIGHT OF JACK PINE AND THE ANALYSIS OF VARIANCE

Average Total Height in Feet

SPECIES	Good site		Medium site		Poor site	
	Rep. 1	Rep. 2	Rep. 1	Rep. 2	Rep. 1	Rep. 2
J/J	29.0	28.5	24.0	24.3	22.4	22.1
J/R	23.9	26.7	24.5	26.1	20.0	22.4
J/S	27.0	27.9	25.3	24.1	23.9	18.7
J/W	27.5	30.1	24.6	23.7	24.2	20.7

Analysis of Variance Table

Sources of variation	Sum of squares	d.f.	Mean square	'F' ratio	
Rows	5.61	3	1.870	.682	Not sig.
Columns	133.47	2	66.730	24.350	Sig.
Interaction	14.81	6	2.470	.901	Not sig.
Subtotal	153.89	11			
Within groups	32.85	12	2.470		
Total	186.74	23			

SE diff. between any pair of column means

$$= \sqrt{\frac{2.74}{6} + \frac{2.74}{6}} = \sqrt{.685} = .83 \text{ approx.}$$

't' at .01 level for 12 d.f. = 3.06. Observed diff. = .83 x 3.06 = 2.54

	Good vs medium	Good vs poor	Medium vs poor
J/J	Sig.	Sig.	Not sig.
J/R	Not sig.	Sig.	Sig.
J/S	Sig.	Sig.	Sig.
J/W	Sig.	Sig.	Not sig.

APPENDIX VI

AVERAGE TOTAL HEIGHT OF RED PINE AND THE ANALYSIS OF VARIANCE

Average Total Height in Feet

SPECIES	Good site		Medium site		Poor site	
	Rep. 1	Rep. 2	Rep. 1	Rep. 2	Rep. 1	Rep. 2
R/R	24.8	36.4	25.7	31.7	22.5	21.1
R/J	27.9	32.8	17.1	20.5	16.6	19.9
R/S	26.5	26.6	26.2	26.4	23.6	23.4
R/W	22.6	30.9	23.4	23.7	20.9	21.7

Analysis of Variance Table

Sources of variation	Sum of squares	d.f.	Mean square	'F' ratio	
Rows	70.14	3	23.38	1.940	Not sig.
Columns	217.70	2	108.85	9.050	Sig.
Interaction	96.29	6	16.05	1.334	Not sig.
Subtotal	384.13	11			
Within groups	144.34	12	12.03		
Total	528.47	23			

SE diff. between any pair of column means

$$= \sqrt{\frac{12.03}{8} + \frac{12.03}{8}} = \sqrt{3.007} = 1.73 \text{ approx.}$$

't' at .01 for 12 d.f. = 3.06. Observed diff. = 3.06 x 1.73 = 5.29

	Good vs medium	Good vs poor	Medium vs poor
R/R	Not sig.	Sig.	Sig.
R/J	Sig.	Sig.	Not sig.
R/S	Not sig.	Not sig.	Not sig.
R/W	Not sig.	Sig.	Not sig.

APPENDIX VII

AVERAGE TOTAL HEIGHT OF SCOTCH PINE AND THE ANALYSIS OF VARIANCE

Average Total Height in Feet

SPECIES	Good site		Medium site		Poor site	
	Rep. 1	Rep. 2	Rep. 1	Rep. 2	Rep. 1	Rep. 2
S/S	30.1	26.6	22.7	22.8	18.4	14.2
S/J	22.3	22.2	16.2	19.2	18.3	16.2
S/R	24.2	25.3	23.9	25.5	23.9	16.6
S/W	26.5	24.4	23.6	18.6	20.3	19.8

Analysis of Variance Table

Sources of variation	Sum of squares	d.f.	Mean square	'F' ratio	
Rows	61.24	3	20.62	3.804	Not sig.
Columns	18.262	2	91.31	16.847	Sig.
Interaction	56.73	6	9.46	1.745	Not sig.
Subtotal	300.59	11			
Within groups	65.02	12	5.42		
Total	355.61	23			

SE diff. between any pair of column means

$$= \sqrt{\frac{5.42}{8} + \frac{5.42}{8}} = \sqrt{1.35} = 1.16 \text{ approx.}$$

't' at .01 for 12 d.f. = 3.06. Observed diff. = 1.16 x 3.06 = 3.55

	Good vs medium	Good vs poor	Medium vs poor
S/S	Sig.	Sig.	Sig.
S/J	Sig.	Sig.	Not sig.
S/R	Not sig.	Sig.	Sig.
S/W	Sig.	Sig.	Not sig.

APPENDIX VIII

AVERAGE TOTAL HEIGHT OF WHITE PINE AND THE ANALYSIS OF VARIANCE

Average Total Height in Feet

SPECIES	Good site		Medium site		Poor site	
	Rep. 1	Rep. 2	Rep. 1	Rep. 2	Rep. 1	Rep. 2
W/W	26.9	25.8	22.5	18.2	15.4	17.3
W/J	17.7	19.1	16.0	15.2	14.6	13.1
W/R	20.0	23.7	16.6	17.5	12.7	14.7
W/S	24.7	27.5	18.7	18.8	15.2	15.8

Analysis of Variance Table

Sources of variation	Sum of squares	d.f.	Mean square	'F' ratio	
Rows	98.05	3	32.68	14.27	Sig.
Columns	283.71	2	141.86	63.65	Sig.
Interaction	23.78	6	3.96	1.732	Not sig.
Subtotal	405.54	11			
Within group	27.44	12	2.287		
Total	432.98	23			

SE diff. between any pair of column means

$$= \sqrt{\frac{2.29}{8} + \frac{2.29}{8}} = \sqrt{.572} = .76 \text{ approx.}$$

't' at .01 for 12 d.f. = 3.06. Observed diff. = .76 x 3.06 = 2.32

	Good vs Medium	Good vs poor	Medium vs poor
W/W	Sig.	Sig.	Sig.
W/J	Sig.	Sig.	Not sig.
W/R	Sig.	Sig.	Sig.
W/S	Sig.	Sig.	Sig.

SE diff between any pair of rows

$$= \sqrt{\frac{2.29}{6} + \frac{2.29}{6}} = \sqrt{.763} = .87$$

't' at .01 for 12 d.f. = 3.06. Observed diff. = 3.06 x .87 = 2.7

	Site	W/J	W/R	W/S
W/W	Good	Sig.	Sig.	Not sig.
W/W	Medium	Sig.	Sig.	Not sig.
W/W	Poor	Sig.	Sig.	Not sig.

APPENDIX IX

AVERAGE DIAMETER OF JACK PINE AND THE ANALYSIS OF VARIANCE

Average Diameter in Inches

SPECIES	Good site		Medium site		Poor site	
	Rep. 1	Rep. 2	Rep. 1	Rep. 2	Rep. 1	Rep. 2
J/J	5.17	4.99	4.08	4.42	3.56	3.38
J/R	5.42	5.35	4.77	4.22	3.53	3.46
J/S	4.64	6.08	3.97	4.54	3.45	3.60
J/W	5.36	5.34	4.71	4.24	3.47	3.61

Analysis of Variance Table

Sources of variation	Sum of squares	d.f.	Mean square	'F' ratio	
Rows	.1439	3	.0479	.5680	Not sig.
Columns	12.7686	2	6.3845	45.9600	Sig.
Interaction	.0916	6	.0153	.1101	Not sig.
Subtotal	13.0041	11			
Within groups	1.6667	12	.1389		
Total	14.6708	23			

SE diff. between any pair of column means

$$= \sqrt{\frac{.1389}{8} + \frac{.1389}{8}} = \sqrt{.0335} = .183 \text{ approx.}$$

't' at .01 for 12 d.f. = 3.06. Observed diff. = .183 x 3.06 = .56

	Good vs Medium	Good vs Poor	Medium vs Poor
J/J	Sig.	Sig.	Sig.
J/R	Sig.	Sig.	Sig.
J/S	Sig.	Sig.	Sig.
J/W	Sig.	Sig.	Sig.

APPENDIX X

AVERAGE DIAMETER OF RED PINE AND THE ANALYSIS OF VARIANCE

Average Diameter in Inches

SPECIES	Good site		Medium site		Poor site	
	Rep. 1	Rep. 2	Rep. 1	Rep. 2	Rep. 1	Rep. 2
R/R	5.16	6.42	4.13	4.92	3.85	3.62
R/J	5.09	5.04	3.58	3.36	2.65	3.62
R/S	5.74	4.79	4.02	4.30	4.58	2.04
R/W	5.67	5.09	4.00	4.93	3.82	3.35

Analysis of Variance Table

Sources of variation	Sum of squares	d.f.	Mean square	'F' ratio	
Rows	2.04	3	.68	2.61	Not sig.
Columns	13.78	2	6.89	26.50	Sig.
Interaction	.43	6	.07	.20	Not sig.
Subtotal	16.25	11			
Within groups	4.17	12	.35		
Total	20.42	23			

SE diff. between any pair of column means

$$= \sqrt{\frac{.26}{8} + \frac{.26}{8}} = \sqrt{\frac{.52}{8}} = \sqrt{.065} = .25 \text{ approx.}$$

't' at .01 for 12 d.f. = 3.06. Observed diff. = .25 x 3.06 = .76

	Good vs Medium	Good vs Poor	Medium vs Poor
R/R	Sig.	Sig.	Sig.
R/J	Sig.	Sig.	Not sig.
R/S	Sig.	Sig.	Not sig.
R/W	Sig.	Sig.	Sig.

APPENDIX XI

AVERAGE DIAMETER OF SCOTCH PINE AND THE ANALYSIS OF VARIANCE

Average Diameter in Inches

SPECIES	Good site		Medium site		Poor site	
	Rep. 1	Rep. 2	Rep. 1	Rep. 2	Rep. 1	Rep. 2
S/S	5.90	4.76	4.65	4.76	3.60	3.66
S/J	4.27	5.12	3.88	3.81	3.28	3.06
S/R	4.73	5.26	5.31	5.47	4.84	3.68
S/W	6.02	5.07	4.83	4.66	3.83	3.64

Analysis of Variance Table

Sources of variation	Sum of squares	d.f.	Mean square	'F' ratio	
Rows	3.0401	3	1.0134	4.528	Sig. at .05
Columns	8.4751	2	4.2376	18.935	Sig.
Interaction	1.4772	6	.2462	1.100	Not sig.
Subtotal	12.9924	11			
Within group	2.6854	12	.2238		
Total	15.6778	23			

SE diff. between any pair of column means

$$= \sqrt{\frac{.22}{8} + \frac{.22}{8}} = \sqrt{.055} = .23 \text{ approx.}$$

't' at .01 for 12 d.f. = 3.06. Observed diff. = 23 x 3.06 = .70

	Good vs Medium	Good vs Poor	Medium vs Poor
S/S	Sig. at .05	Sig.	Sig.
S/J	Sig.	Sig.	Not sig.
S/R	Not sig.	Sig.	Sig.
S/W	Sig.	Sig.	Sig. at .05

SE diff. between any pair of row means

$$= \sqrt{\frac{.22}{6} + \frac{.22}{6}} = \sqrt{\frac{.44}{6}} = \sqrt{.073} = .27$$

Observed diff.: at .01 = 3.06 x .27 = .83
at .05 = 2.18 x .27 = .59

	Site	S/J	S/R	S/W
S/S	Good	Sig.	Not sig.	Not sig.
S/S	Medium	Sig.	Sig. at .05	Not sig.
S/S	Poor	Not sig.	Sig. at .05	Not sig.

APPENDIX XII

AVERAGE DIAMETER OF WHITE PINE AND THE ANALYSIS OF VARIANCE

Average Diameter in Inches

SPECIES	Good site		Medium site		Poor site	
	Rep. 1	Rep. 2	Rep. 1	Rep. 2	Rep. 1	Rep. 2
W/W	5.21	4.92	4.60	3.31	3.31	2.43
W/J	4.18	4.25	3.60	2.07	2.78	2.03
W/R	4.06	4.71	3.01	2.59	2.14	2.10
W/S	4.23	4.50	3.88	3.36	2.09	2.69

Analysis of Variance Table

Sources of variation	Sum of squares	d.f.	Mean square	'F' ratio	
Rows	2.82	3	.940	4.27	Sig. at .05
Columns	17.15	2	8.580	39.0	Sig.
Interaction	.62	6	.010	.36	Not sig.
Subtotal	20.59	11			
Within groups	3.37	12	.280		
Total	23.96	23			

SE diff. between any pair of columns means

$$=\sqrt{\frac{.28}{8}+\frac{.28}{8}}=\sqrt{.07}=\ .27 \text{ approx.}$$

't' at .01 for 12 d.f. = 3.06. Observed diff. = .27 x 3.06 = .83

	Good vs Medium	Good vs Poor	Medium vs Poor
W/W	Sig.	Sig.	Sig.
W/J	Sig.	Sig.	Not sig.
W/R	Sig.	Sig.	Not sig.
W/S	Sig.	Sig.	Sig.

SE diff. between any pair of row means

$$=\sqrt{\frac{.28}{6}+\frac{.28}{6}}=\sqrt{\frac{.56}{6}}=\sqrt{.093}=\ .30 \text{ approx.}$$

't' at .05 for 12 d.f. = 2.18. Observed difference = 2.18 x .30 = .65. 3.06 x .30 = .92 at .01

	Site	W/J	W/R	W/S
W/W	Good	Sig. at .05	Sig. at .05	Sig. at .05
W/W	Medium	Sig. at .01	Sig. at .01	Not sig.
W/W	Poor	Not sig.	Sig. at .05	Not sig.

APPENDIX XIII

AVERAGE CUBIC FOOT VOLUME PER ACRE OF JACK PINE AND THE ANALYSIS OF VARIANCE

Average Cubic Foot Volume per Acre

SPECIES	Good site		Medium site		Poor site	
	Rep. 1	Rep. 2	Rep. 1	Rep. 2	Rep. 1	Rep. 2
J/J	2437	2545	1494	1615	904	957
J/R	2523	2672	1437	2093	1066	1195
J/S	2233	2720	1557	1763	1096	1032
J/W	2647	2732	2027	1514	1137	847

Analysis of Variance Table

Sources of variation	Sum of squares	d.f.	Mean square	'F' ratio	
Rows	115,793	3	38,598	.815	Not sig.
Columns	9,480,520	2	4,740,260	137.619	Sig.
Interaction	51,801	6	8,634	.182	Not sig.
Subtotal	9,648,114	11			
Within group	568,241	12	47,353		
Total	10,216,355	23			

SE diff. between any pair of column means

$$=\sqrt{\frac{34,449}{8}+\frac{34,449}{8}}=\sqrt{\frac{68,894}{8}}=\sqrt{8,612}=93 \text{ approx.}$$

't' at .01 for d.f. = 3.06. 't' at .05 for 12 d.f. = 2.18

observed difference at .01 = 93 x 3.06 = 284
observed difference at .05 = 93 x 2.18 = 203

	Good vs Medium	Good vs Poor	Medium vs Poor
J/J	Sig.	Sig.	Sig.
J/R	Sig.	Sig.	Sig.
J/S	Sig.	Sig.	Sig.
J/W	Sig.	Sig.	Sig.

APPENDIX XIV

AVERAGE CUBIC FOOT VOLUME PER ACRE OF RED PINE AND THE ANALYSIS OF VARIANCE

Average Cubic Foot Volume Per Acre

SPECIES	Good site		Medium site		Poor site	
	Rep. 1	Rep. 2	Rep. 1	Rep. 2	Rep. 1	Rep. 2
R/R	2620	3958	1167	1814	776	606
R/J	1996	2278	543	594	234	524
R/S	2177	1494	1235	1329	1099	447
R/W	1819	1794	1004	1352	830	533

Analysis of Variance Table

Sources of variation	Sum of squares	d.f.	Mean square	'F' ratio	
Rows	2,080,633	3	693,544	4.736	Sig. at .05
Columns	11,248,138	2	5,624,069	38.470	Sig.
Interaction	1,959,576	6	326,596	2.230	Not sig.
Subtotal	15,288,347	11			
Within grps	1,757,173	12	146,431		
Total	17,045,520	23			

SE diff. between any pair of rows means

$$= \sqrt{\frac{146,431}{6} + \frac{146,431}{6}} = \sqrt{48,810} = 220 \text{ approx.}$$

't' at .01 for 12 d.f. = 3.06
't' at .05 for 12 d.f. = 2.18

Observed difference at .01 = 220 x 3.06 = 673
Observed difference at .05 = 220 x 2.18 = 480

	Site	R/J	R/S	R/W
R/R	Good	Sig.	Sig.	Sig.
R/R	Medium	Sig.	Not sig.	Not sig.
R/R	Poor	Not sig.	Not sig.	Not sig.

SE diff. between any pair of column means

$$= \sqrt{\frac{146,431}{6} + \frac{146,431}{6}} = \sqrt{36,608} = 192$$

Observed diff at .01 = 192 x 3.06 = 588 and at .05 = 192 x 2.18 = 418

	Good vs Medium	Good vs Poor	Medium vs Poor
R/R	Sig.	Sig.	Sig.
R/J	Sig.	Sig.	Not sig.
R/S	Sig. at .05	Sig.	Sig. at .05
R/W	Sig.	Sig.	Sig. at .05

APPENDIX XV

AVERAGE CUBIC FOOT VOLUME PER ACRE OF SCOTCH PINE AND THE ANALYSIS OF VARIANCE

Average Cubic Foot Volume per Acre

SPECIES	Good site		Medium site		Poor site	
	Rep. 1	Rep. 2	Rep. 1	Rep. 2	Rep. 1	Rep. 2
S/S	2038	1529	970	1088	561	520
S/J	536	1084	348	606	406	241
S/R	993	1201	1041	1034	662	377
S/W	1925	1357	1042	677	596	519

Analysis of Variance Table

Sources of variation	Sum of squares	d.f.	Mean square	'F' ratio	
Rows	1,159,883	3	386,628	7.393	Sig.
Columns	2,892,008	2	1,446,004	27.650	Sig.
Interaction	578,242	6	96,374	1.842	Not sig.
Subtotal	4,630,133	11			
Within grps	627,547	12	52,296		
Total	5,257,680	23			

SE diff. between any pair of rows means

$$= \sqrt{\frac{52,296}{6} + \frac{52,296}{6}} = \sqrt{17,432} = 132 \text{ approx.}$$

't' at .01 for 12 d.f. = 3.06. Observed diff. = 132 x 3.06 = 404

	Site	S/J	S/R	S/W
S/S	Good	Sig.	Sig.	Not sig.
S/S	Medium	Sig.	Not sig.	Not sig.
S/S	Poor	Not sig.	Not sig.	Not sig.

SE diff. between any pair of column means

$$= \sqrt{\frac{52,296}{8} + \frac{52,296}{8}} = \sqrt{18,074} = 114$$

Observed diff. at .01 = 3.06 x 114 = 349 and at .05 = 2.18 x 114 = 246

	Good vs Medium	Good vs Poor	Medium vs Poor
R/R	Sig.	Sig.	Sig.
R/J	Sig. at .05	Sig.	Not sig.
R/S	Not sig.	Sig.	Sig.
R/W	Sig.	Sig.	Sig. at .05

APPENDIX XVI

AVERAGE CUBIC FOOT VOLUME PER ACRE OF WHITE PINE AND THE ANALYSIS OF VARIANCE

Average Cubic Foot Volume per Acre

SPECIES	Good site		Medium site		Poor site	
	Rep. 1	Rep. 2	Rep. 1	Rep. 2	Rep. 1	Rep. 2
W/W	1411	1330	877	401	336	259
W/J	586	670	360	120	85	166
W/R	381	949	261	204	82	95
W/S	963	1105	473	462	106	224

Analysis of Variance Table

Sources of variation	Sum of squares	d.f.	Mean square	'F' ratio	
Rows	799,438	3	266,479	8.300	Sig.
Columns	2.404,832	2	1,202,416	37.451	Sig.
Interaction	163,127	6	27,188	.847	Not sig.
Subtotal	3,367,397	11			
Within groups	385,267	12	32,106		
Total	3,752,664	23			

SE diff. between any pair of rows means

$$= \sqrt{\frac{32,106}{6} + \frac{32,106}{6}} = \sqrt{10,702} = 103 \text{ approx.}$$

't' at .01 for 12 d.f. = 3.06. Observed diff. = 103 x 3.08 = 315

	Site	W/J	W/R	W/S
W/W	Good	Sig.	Sig.	Sig.
W/W	Medium	Sig.	Sig.	Not sig.
W/W	Poor	Not sig.	Not sig.	Not sig.

SE diff. between any pair of rows means

$$= \sqrt{\frac{32,106}{8} + \frac{32,106}{8}} = \sqrt{8,027} = 89$$

Observed diff. at .01 = 3.06 x 89 = 272 and at .05 = 2.18 x 89 = 194

	Good vs Medium	Good vs Poor	Medium vs Poor
W/W	Sig.	Sig.	Sig.
W/J	Sig.	Sig.	Not sig.
W/R	Sig.	Sig.	Sig.
W/S	Sig.	Sig.	Sig.

APPENDIX XVII

AVERAGE DIAMETER, TOTAL HEIGHT, AND CUBIC VOLUME OF THE JACK PINE TREES IN DIRECT COMPETITION AND THE 't' TESTS

		Jack pine pure		
		Good site	Medium site	Poor site
Number of trees		61	37	36
Diameter (inches)	M	5.090	4.280	3.960
	't' value			
	't' for significance at .01			
Total height (feet)	M	29.030	25.810	24.780
	't' value			
	't' for significance at .01			
Cubic volume	M	2.623	1.694	1.193
	't' value			
	't' for significance at .01			

APPENDIX XVII--Continued

JP mixed with RP			JP mixed with SP			JP mixed with WP		
Good site	Medium site	Poor site	Good site	Medium site	Poor site	Good site	Medium site	Poor site
22	22	34	20	18	30	27	20	19
4.320	4.190	4.120	5.120	4.380	4.020	5.410	5.100	4.120
3.208	.029	.924	.142	.388	.760	1.194	1.767	.606
2.648	2.660	2.638	2.638	2.678	2.660	2.632	2.638	2.638
Sig.	Not Sig.	Not Sig.	Not Sig.	Not Sig.	Not Sig.	Not Sig.	Not Sig.	Not Sig.
25.450	27.950	23.760	26.750	24.880	23.230	32.010	27.000	24.840
2.733	1.431	1.760	1.507	.663	1.360	2.245	1.111	.004
2.648	2.660	2.638	2.638	2.678	2.660	2.632	2.638	2.638
Sig.	Not Sig.	Not Sig.	Not Sig.	Not Sig.	Not Sig.	Not Sig.	Not Sig.	Not Sig.
1.610	1.520	1.410	2.180	1.387	1.240	2.834	1.674	1.512
3.303	.057	1.735	1.486	1.247	.121	.661	1.850	1.110
2.648	2.660	2.638	2.638	2.678	2.660	2.632	2.638	2.638
Sig.	Not Sig.	Not Sig.	Not Sig.	Not Sig.	Not Sig.	Not Sig.	Not Sig.	Not Sig.

APPENDIX XVIII

AVERAGE DIAMETER, TOTAL HEIGHT, AND CUBIC VOLUME OF THE RED PINE TREES IN DIRECT COMPETITION AND THE 't' TESTS

		Red pine pure		
		Good site	Medium site	Poor site
Number of trees		33	41	23
Diameter (inches)	M	5.880	4.720	3.720
	't' value			
	't' for significance at .01			
Total height (feet)	M	32.450	30.340	22.820
	't' value			
	't' for significance at .01			
Cubic volume	M	3.025	1.748	.872
	't' value			
	't' for significance at .01			

APPENDIX XVIII--Continued

RP mixed with JP			RP mixed with SP			RP mixed with WP		
Good site	Medium site	Poor site	Good site	Medium site	Poor site	Good site	Medium site	Poor site
26	27	28	17	20	14	20	20	28
5.540	3.690	3.080	5.980	5.050	4.310	6.380	4.740	3.560
.740	3.678	3.214	.306	1.241	1.863	1.424	.098	.816
2.660	2.648	2.678	2.678	2.704	2.724	2.678	2.660	2.678
Not Sig.	Sig.	Sig.	Not Sig.	Not Sig.	Not Sig.	Not Sig.	Not Sig.	Not Sig.
28.030	19.370	18.000	27.170	26.450	23.850	30.650	24.950	18.780
1.334	8.543	4.555	2.592	2.983	.712	.829	3.890	2.558
2.660	2.648	2.678	2.678	2.704	2.724	2.678	2.660	2.678
Not Sig.	Sig.	Sig.	Not Sig.	Sig.	Not Sig.	Not Sig.	Sig.	Not Sig.
1.990	.796	.605	2.385	2.008	1.274	3.033	1.400	1.016
2.125	5.348	2.840	1.400	1.576	1.511	.167	1.256	.973
2.660	2.648	2.678	2.678	2.704	2.724	2.678	2.660	2.678
Not Sig.	Sig.	Sig.	Not Sig.	Not Sig.	Not Sig.	Not Sig.	Not Sig.	Not Sig.

APPENDIX XIX

AVERAGE DIAMETER, TOTAL HEIGHT, AND CUBIC VOLUME OF THE SCOTCH PINE TREES IN DIRECT COMPETITION AND THE 't' TESTS

		Scotch pine pure		
		Good site	Medium site	Poor site
Number of trees		20	33	22
Diameter (inches)	M	5.570	4.420	3.280
	't' value			
	't' for significance at .01			
Total height (feet)	M	28.000	22.640	19.500
	't' value			
	't' for significance at .01			
Cubic volume	M	2.237	1.238	.610
	't' value			
	't' for significance at .01			

APPENDIX XIX--Continued

SP mixed with JP			SP mixed with RP			SP mixed with WP		
Good site	Medium site	Poor site	Good site	Medium site	Poor site	Good site	Medium site	Poor site
21	17	21	13	13	13	11	20	12
4.260	3.750	2.800	4.890	4.480	3.210	5.240	4.680	3.740
6.093	2.780	2.436	2.361	.233	.236	1.118	1.187	1.933
2.740	2.678	2.704	2.750	2.690	2.724	2.750	2.678	2.750
Sig.	Sig.	Not Sig.	Not Sig.	Not Sig.	Not Sig.	Not Sig.	Not Sig.	Not Sig.
22.230	17.530	16.570	23.080	24.770	21.230	25.090	22.800	20.500
3.376	2.715	2.171	2.831	1.377	.938	1.293	.136	.645
2.740	2.678	2.704	2.750	2.690	2.724	2.750	2.670	2.750
Sig.	Sig.	Sig.	Sig.	Not Sig.	Not Sig.	Not Sig.	Not Sig.	Not Sig.
1.168	.850	.549	1.423	1.628	.868	1.778	1.285	.778
4.127	2.425	.792	2.528	1.726	1.602	1.370	.286	1.527
2.740	2.678	2.704	2.750	2.690	2.724	2.750	2.678	2.750
Sig.	Not Sig.	Not Sig.	Not Sig.	Not Sig.	Not Sig.	Not Sig.	Not Sig.	Not Sig.

APPENDIX XX

AVERAGE DIAMETER, TOTAL HEIGHT, AND CUBIC VOLUME OF THE WHITE PINE TREES IN DIRECT COMPETITION AND THE 't' TESTS

		White pine pure		
		Good site	Medium site	Poor site
Number of trees		21	31	10
Diameter (inches)	M	5.070	3.870	3.140
	't' value			
	't' for significance at .01			
Total height (feet)	M	38.280	20.640	18.500
	't' value			
	't' for significance at .01			
Cubic volume	M	2.041	1.030	.505
	't' value			
	't' for significance at .01			

APPENDIX XX--Continued

WP mixed with JP			WP mixed with RP			WP mixed with SP		
Good site	Medium site	Poor site	Good site	Medium site	Poor site	Good site	Medium site	Poor site
20	19	18	17	19	18	12	20	9
4.310	3.020	2.330	4.070	3.085	2.290	4.060	4.060	2.844
3.004	3.057	3.000	3.311	2.917	3.794	3.088	.648	.860
2.704	2.678	2.779	2.724	2.687	2.779	2.750	2.678	2.898
Sig.	Sig.	Sig.	Sig.	Sig.	Sig.	Sig.	Not Sig.	Not Sig.
24.900	16.840	14.000	21.940	16.680	14.100	18.910	20.850	15.330
1.830	2.714	2.792	4.384	3.077	2.621	5.473	.150	2.330
2.704	2.678	2.779	2.724	2.687	2.779	2.750	2.678	2.898
Not Sig.	Sig.	Sig.	Sig.	Sig.	Not Sig.	Sig.	Not Sig.	Not Sig.
1.530	.600	.200	1.326	.710	.210	.949	1.000	.331
2.012	2.575	2.061	2.687	1.780	2.105	4.403	.172	1.740
2.704	2.678	2.779	2.724	2.687	2.779	2.750	2.678	2.898
Not Sig.	Not Sig.	Not Sig.	Not Sig.	Not Sig.	Not Sig.	Sig.	Not Sig.	Not Sig.

APPENDIX XXI

INCIDENCE OF INSECT ATTACK ON JACK PINE AND THE 't' TESTS

Insect	J/J	J/R	J/J	J/S	J/J	J/W
White pine weevil 't'[b]	67%[a]	64%	67%	69%	67%	71%
	1.470		.960		1.990	
	Not Sig.		Not Sig.		Not Sig.	
Spruce budworm 't'	16%	13%	16%	21%	16%	18%
	1.930		2.980		.750	
	Not Sig.		Not Sig.		Not Sig.	
Sawflies 't'	28%	31%	28%	26%	28%	24%
	1.550		1.040		2.094	
	Not Sig.		Not Sig.		Not Sig.	
Pine spittlebug 't'	6%	4%	6%	4%	6%	4%
	2.240		2.120		2.220	
	Not Sig.		Not Sig.		Not Sig.	
Saratoga spittlebug 't'	8%	5%	8%	6%	8%	5%
	2.830		1.800		2.800	
	Significant		Significant		Significant	
Nantucket pine tip moth 't'	11%	10%	11%	12%	11%	7%
	.760		.721		2.400	
	Not Sig.		Not Sig.		Not Sig.	

[a]percentage of trees attacked.

b't' value =

$$\frac{P_1 - P_2}{\sqrt{\frac{P_1Q_1}{N_1} + \frac{P_2Q_2}{N_2}}}$$

Where P_1 and P_2 = percentages of trees attacked

$Q = 100 - P$

N_1 and N_2 = total number of trees

Note: Unless otherwise specified, all 't' values are at .01 and 't' for significance at .01 is 2.58.

APPENDIX XXII

INCIDENCE OF INSECT ATTACK ON RED PINE AND THE 't' TESTS

Insect	R/R	R/J	R/R	R/S	R/R	R/W
White pine weevil	35%[a]	43%	35%	40%	35%	39%
't'	3.54		2.29		1.84	
'b'	Significant		Not Sig.		Not Sig.	
Spruce budworm	5%	6%	5%	9%	5%	4%
't'	.99		3.48		1.72	
	Not Sig.		Significant		Not Sig.	
Sawflies	20%	24%	20%	23%	20%	18%
't'	2.08		1.62		1.14	
	Not Sig.		Not Sig.		Not Sig.	
Pine spittlebug	3%	2%	5%	2%	3%	2%
't'	1.41		1.46		1.43	
	Not Sig.		Not Sig.		Not Sig.	
Saratoga spittlebug	6%	4%	6%	4%	6%	4%
't'	2.00		2.06		2.15	
	Not Sig.		Not Sig.		Not Sig.	
Nantucket pine tip moth	9%	8%	9%	7%	9%	7%
't'	.78		1.65		1.70	
	Not Sig.		Not Sig.		Not Sig.	

[a]percentage of trees attacked.

b 't' value =

$$\frac{P_1 - P_2}{\sqrt{\frac{P_1 Q_1}{N_1} + \frac{P_2 Q_2}{N_2}}}$$

Where P_1 and P_2 = percentages of trees attacked

Q = 100 - P

N_1 and N_2 = total number of trees

Note: Unless otherwise specified, all 't' values are at .01 and 't' for significance at .01 is 2.58.

APPENDIX XXIII

INCIDENCE OF INSECT ATTACK ON SCOTCH PINE AND THE 't' TESTS

Insect	S/S	S/J	S/S	S/R	S/S	S/W
White pine weevil	86%[a]	84%	86%	82%	86%	88%
't'[b]	1.05		2.09		1.22	
	Not Sig.		Not Sig.		Not Sig.	
Spruce budworm	36%	39%	36%	40%	36%	33%
't'	1.16		1.59		1.49	
	Not Sig.		Not Sig.		Not Sig.	
Sawflies	11%	8%	11%	11%	11%	8%
't'	1.95		--		--	
	Not Sig.		--		Not Sig.	
Pine spittlebug	4%	3%	4%	3%	4%	3%
't'	1.04		1.29		1.71	
	Not Sig.		Not Sig.		Not Sig.	
Saratoga spittlebug	2%	2%	2%	1%	2%	1%
't'	--		1.61		1.69	
	--		Not Sig.		Not Sig.	
Nantucket pine tip moth	6%	5%	6%	4%	6%	4%
't'	.85		1.80		1.89	
	Not Sig.		Not Sig.		Not Sig.	

[a]percentage of trees attacked.

b 't' value =

$$\frac{P_1 - P_2}{\sqrt{\frac{P_1 Q_1}{N_1} + \frac{P_2 Q_2}{N_2}}}$$

Where P_1 and P_2 = percentages of trees attacked

Q = 100 - P

N_1 and N_2 = total number of trees

Note: Unless otherwise specified, all 't' values are at .01 and 't' for significance at .01 is 2.58.

APPENDIX XXIV

INCIDENCE OF INSECT ATTACK ON WHITE PINE AND THE 't' TESTS

Insect	W/W	W/J	W/W	W/R	W/W	W/S
White pine weevil	94%[a]	92%	94%	96%	94%	97%
't'[b]	1.40		1.65		2.73	
	Not Sig.		Not Sig.		Significant	
Spruce budworm	10%	8%	10%	5%	10%	11%
't'	1.26		3.45		0.92	
	Not Sig.		Sig.		Not Sig.	
Sawflies	3%	5%	3%	2%	3%	2%
't'	1.83		1.16		1.22	
	Not Sig.		Not Sig.		Not Sig.	
Pine spittlebug	2%	1%	2%	1%	2%	2%
't'	1.51		1.49		--	
	Not Sig.		Not Sig.		--	
Saratoga spittlebug	1%	1%	1%	1%	1%	1%
't'	--		--		--	
	--		--		--	
Nantucket pine tip moth	--	--	--	1%	--	--
	--		2.36		--	
	--		Not Sig.		--	

[a]percentage of trees attacked.

^{b}'t' value =

$$\frac{P_1 - P_2}{\sqrt{\frac{P_1Q_1}{N_1} + \frac{P_2Q_2}{N_2}}}$$

Where P_1 and P_2 = percentages of trees attacked

$Q = 100 - P$

N_1 and N_2 = total number of trees

Note: Unless otherwise specified, all 't' values are at .01 and 't' for significance at .01 is 2.58.

APPENDIX XXV

NORMAL MONTHLY, SEASONAL, AND ANNUAL TEMPERATURE AND PRECIPITATION AT HIGGINS LAKE, CRAWFORD COUNTY, MICHIGAN[a]

(Elevation 1,141 feet)

Month	TEMPERATURE			PRECIPITATION			
	Mean	Absol. max.	Absol. min.	Mean	Tot. amt. for driest yr. 1935	Tot. amt. for wettest yr. 1940	Snow av. depth
				Inches	Inches	Inches	Inches
Dec.	22.3°F	56°F	-27°F	2.07	0.95	2.12	10.6
Jan.	16.5	52	-32	2.13	1.85	3.54	12.1
Feb.	15.4	61	-39	1.56	1.19	2.21	12.3
WINTER	18.1	61	-39	5.76	3.99	8.37	35.0
March	26.1	81	-32	2.05	1.02	2.47	9.0
April	39.7	86	-15	2.25	0.71	1.85	4.3
May	51.6	92	12	2.84	0.73	3.47	0.8
SPRING	39.1	92	-32	7.14	2.46	7.79	14.1
June	61.6	99	24	3.32	2.66	4.88	0.0
July	66.0	103	26	3.93	1.01	3.90	0.0
Aug.	63.4	99	27	3.17	4.71	6.08	0.0
SUMMER	63.7	103	24	9.92	8.38	14.86	0.0
Sept.	57.3	93	18	3.67	2.52	2.92	0.1
Oct.	46.3	90	5	3.01	1.84	3.94	1.4
Nov.	33.9	77	- 6	2.07	1.88	4.51	6.9
FALL	45.8	90	- 6	8.75	6.24	11.37	8.4
YEAR	41.7	103	-39	32.53	21.07	42.39	57.5

[a]Based on the climatic data from 1889, when the records were started, to 1952, inclusive (251, 252).

APPENDIX XXVI

NORMAL MONTHLY, SEASONAL, AND ANNUAL TEMPERATURE AND PRECIPITATION AT HOUGHTON LAKE, ROSCOMMON COUNTY, MICHIGAN[a]

(Elevation 1,138 feet)

Month	TEMPERATURE			PRECIPITATION			
	Mean	Absol. max.	Absol. min.	Mean	Tot. amt. for driest yr. 1930	Tot. amt. for wettest yr. 1928	Snow av. depth
				Inches	Inches	Inches	Inches
Dec.	23.2°F	55°F	-28°F	2.19	0.80	1.34	10.4
Jan.	18.1	58	-30	2.67	1.36	1.25	12.4
Feb.	17.5	64	-48	2.07	1.29	1.77	8.4
WINTER	19.6	64	-48	6.93	3.45	4.36	31.2
March	28.5	75	-21	1.79	1.49	1.93	10.6
April	40.7	89	-15	2.34	1.19	5.21	3.6
May	53.1	96	12	2.73	2.87	3.38	0.2
SPRING	40.8	96	-21	6.86	5.50	10.52	14.0
June	63.2	100	23	3.31	3.61	5.98	0.0
July	66.7	105	26	2.92	2.64	1.87	0.0
Aug.	64.2	100	26	3.16	0.39	3.55	0.0
SUMMER	64.7	105	23	9.39	6.64	11.40	0.0
Sept.	58.1	100	19	3.30	1.26	3.24	trace
Oct.	47.1	88	7	2.41	2.01	3.61	0.5
Nov.	34.7	77	- 3	2.93	1.20	3.96	3.7
FALL	46.6	100	- 3	8.64	4.47	10.81	4.2
YEAR	42.9	105	-48	31.82	20.06	37.09	4.8

[a]Based on the climatic data from 1913, when the records were started, to 1952, inclusive (251, 252).

APPENDIX XXVII

NORMAL MONTHLY, SEASONAL, AND ANNUAL TEMPERATURE AND PRECIPITATION AT FIFE LAKE, TRAVERSE COUNTY, MICHIGAN[a]

(Elevation 1,035 feet)

Month	TEMPERATURE			PRECIPITATION			
	Mean	Absol. max.	Absol. min.	Mean	Tot. amt. for driest yr. 1925	Tot. amt. for wettest yr. 1945	Snow av. depth
				Inches	Inches	Inches	Inches
Dec.	22.8°F	55°F	-29°F	2.07	1.66	1.97	13.7
Jan.	17.5	48	-36	2.07	1.00	2.19	13.8
Feb.	18.3	63	-34	1.49	1.46	1.84	9.9
WINTER	19.5	63	-36	5.63	4.12	6.00	37.4
March	27.7	73	-32	1.82	1.20	2.67	12.9
April	40.1	86	-16	2.08	1.90	4.03	4.4
May	52.3	97	16	2.97	0.36	2.22	trace
SPRING	33.4	97	-32	6.87	3.46	8.92	17.3
June	62.4	99	26	3.34	1.99	1.86	0.0
July	67.1	104	32	3.08	1.25	4.53	0.0
Aug.	64.1	94	32	3.09	1.94	4.56	0.0
SUMMER	64.5	104	26	9.51	5.18	10.95	0.0
Sept.	58.6	96	24	3.38	4.17	2.83	trace
Oct.	46.9	85	11	3.02	4.07	5.51	2.2
Nov.	34.1	70	- 5	2.96	2.10	3.25	9.3
FALL	46.5	96	- 5	9.36	10.34	11.59	11.5
YEAR	42.7	104	-36	31.37	23.10	37.46	66.2

[a]Based on the climatic data from 1919, when records were started, to 1952, inclusive (251, 252).

APPENDIX XXVIII

NORMAL MONTHLY, SEASONAL, AND ANNUAL TEMPERATURE AND PRECIPITATION AT WEST BRANCH, OGEMAW COUNTY, MICHIGAN[a]

(Elevation 973 feet)

Month	TEMPERATURE			PRECIPITATION			
	Mean	Absol. max.	Absol. min.	Mean	Tot. amt. for driest yr. 1903	Tot. amt. for wettest yr. 1922	Snow av. depth
				Inches	Inches	Inches	Inches
Dec.	22.6°F	56°F	-24°F	1.71	1.75	1.16	9.7
Jan.	17.3	58	-22	1.53	2.21	0.64	12.0
Feb.	17.1	60	-36	1.34	1.64	5.83	11.8
WINTER	19.0	60	-36	4.58	5.60	7.63	33.5
March	27.9	60	-18	1.83	0.55	2.31	9.0
April	41.9	84	-11	2.04	3.01	3.32	2.9
May	53.4	90	16	3.13	2.91	2.87	0.5
SPRING	41.1	90	-18	7.00	6.47	8.50	12.4
June	62.4	98	27	3.30	2.10	4.71	0.0
July	67.4	101	32	2.96	2.18	5.02	0.0
Aug.	64.7	103	30	2.97	3.08	3.85	0.0
SUMMER	64.8	103	27	9.23	7.36	13.58	0.0
Sept.	57.9	94	21	3.31	0.69	3.59	trace
Oct.	46.9	86	9	2.72	1.36	2.04	0.7
Nov.	34.9	71	- 8	2.56	0.92	2.22	4.9
FALL	46.4	99	- 8	8.59	2.97	7.85	5.6
YEAR	42.8	103	-36	29.40	22.40	37.56	51.5

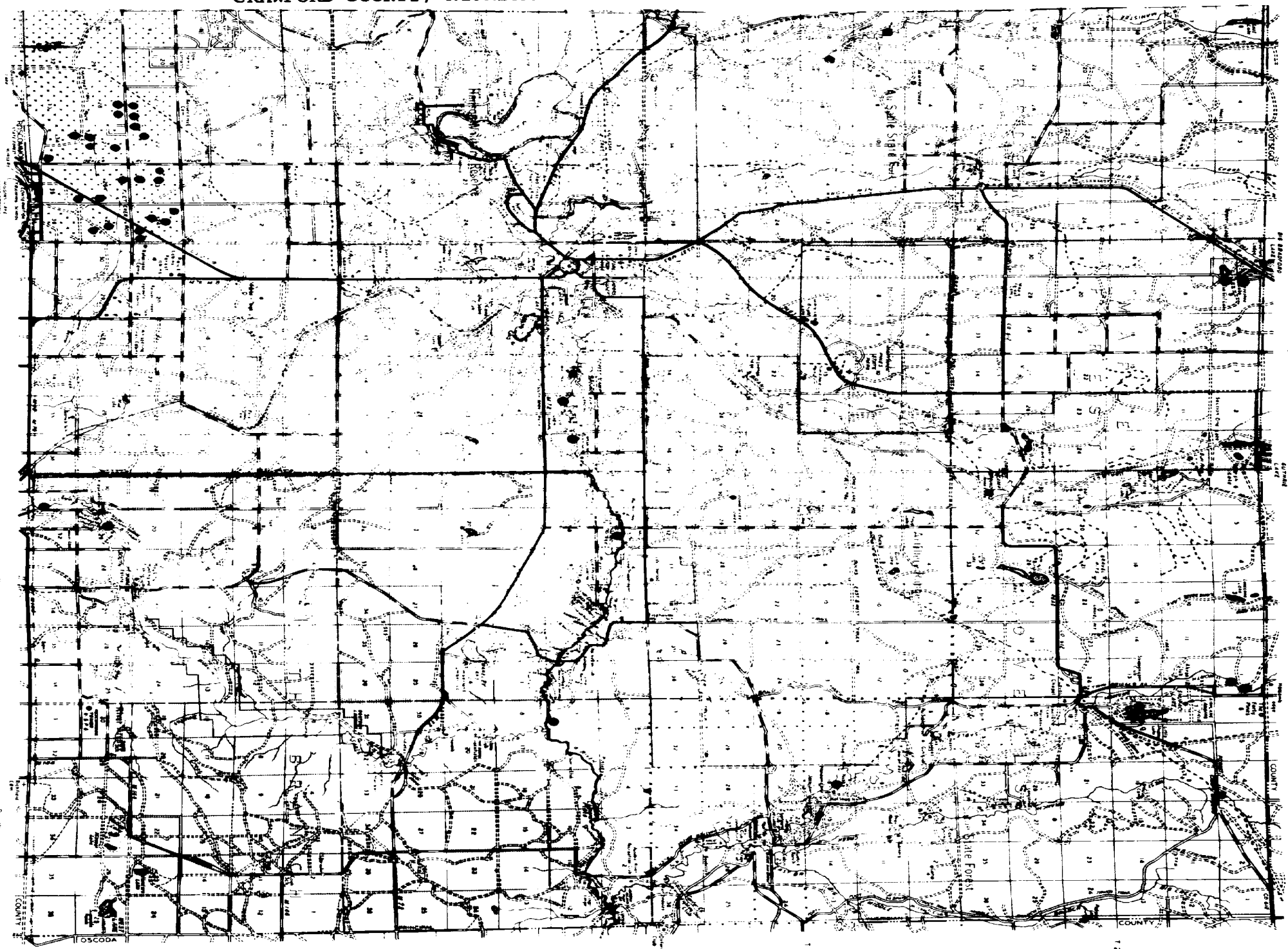
[a]Based on the climatic data from 1900, when the records were started, to 1952, inclusive (251, 252).

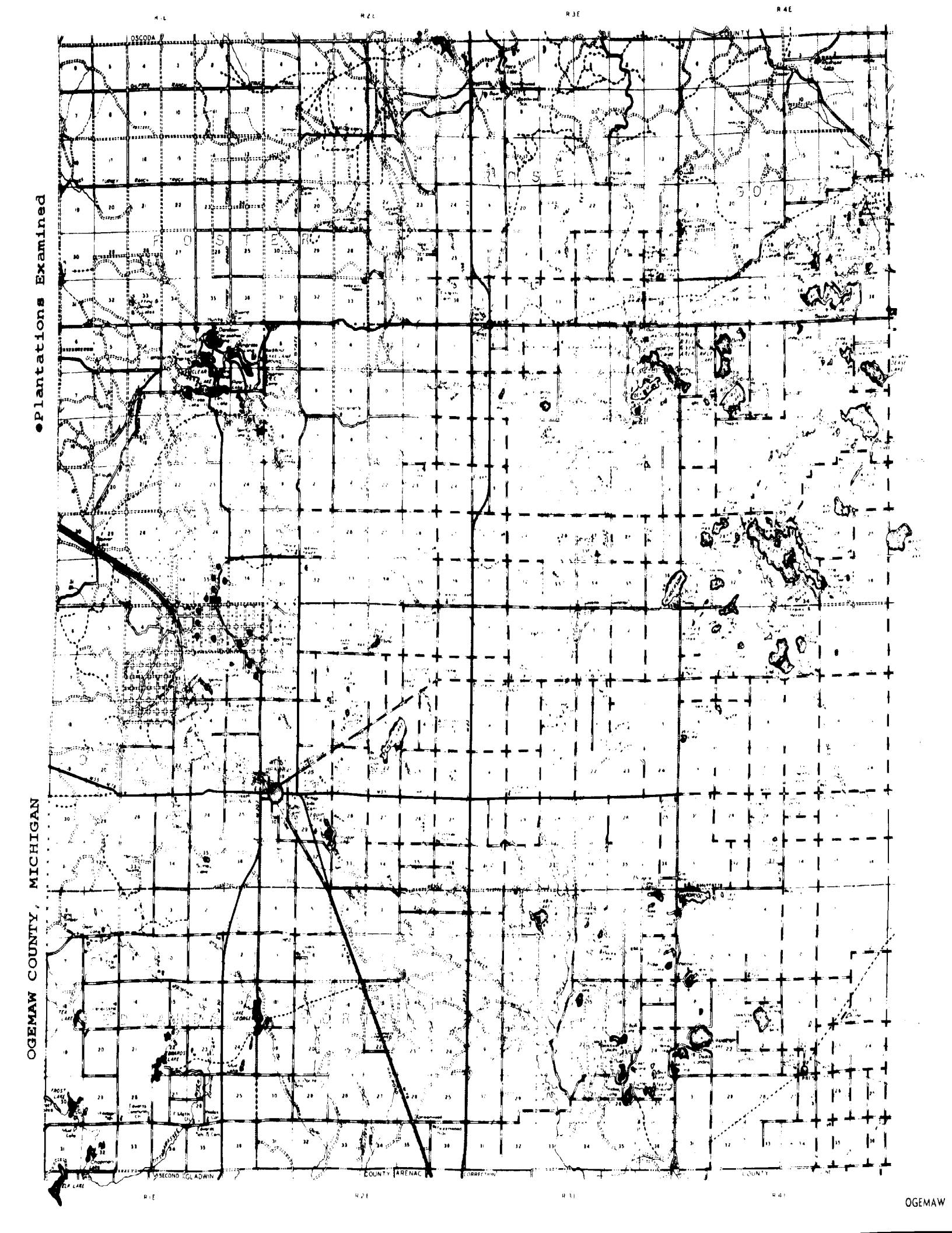
APPENDIX XXIX

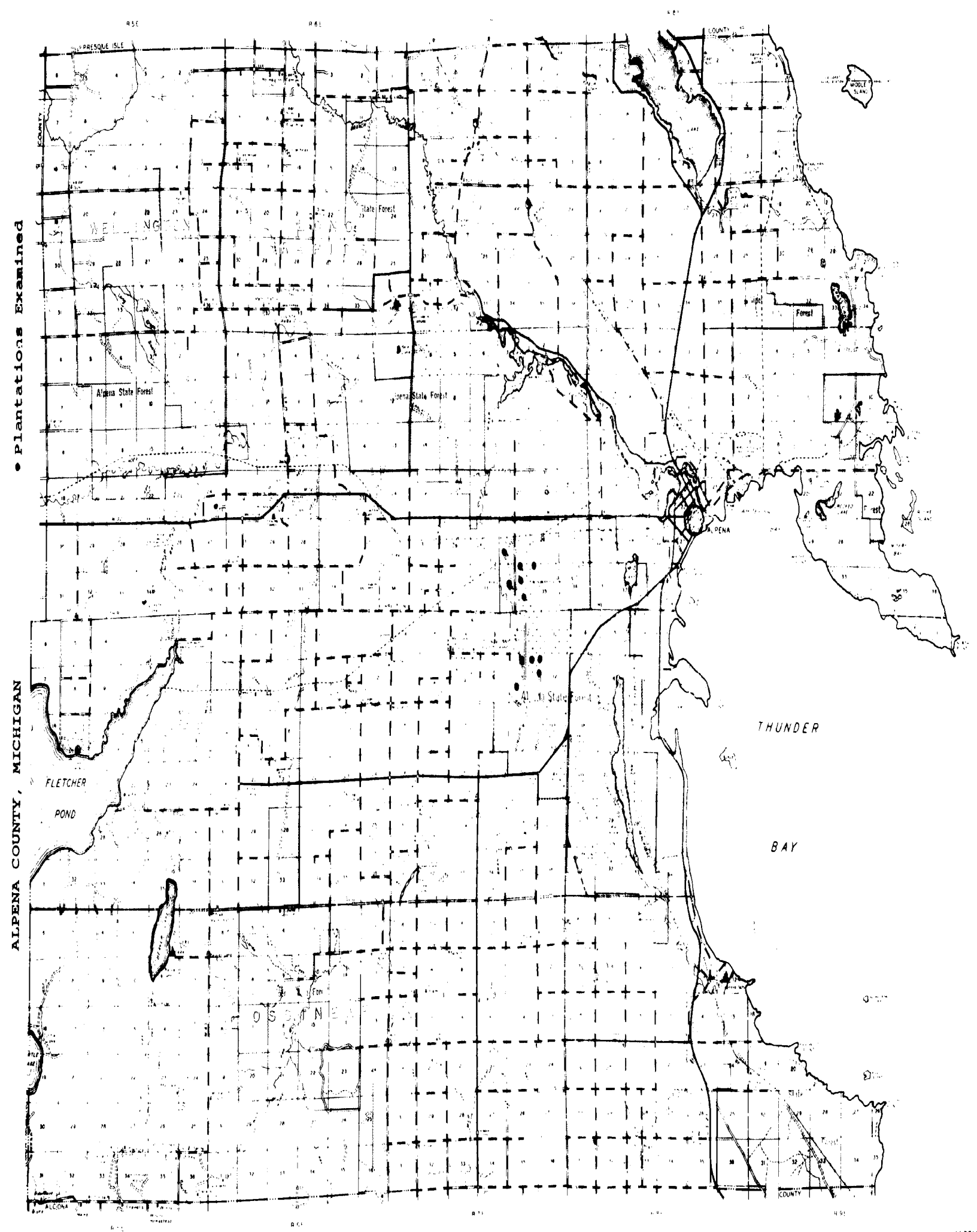
MAPS OF MICHIGAN COUNTIES IN WHICH THE PLANTATIONS EXAMINED ARE LOCATED

CRAWFORD COUNTY, MICHIGAN

●Plantations Examined



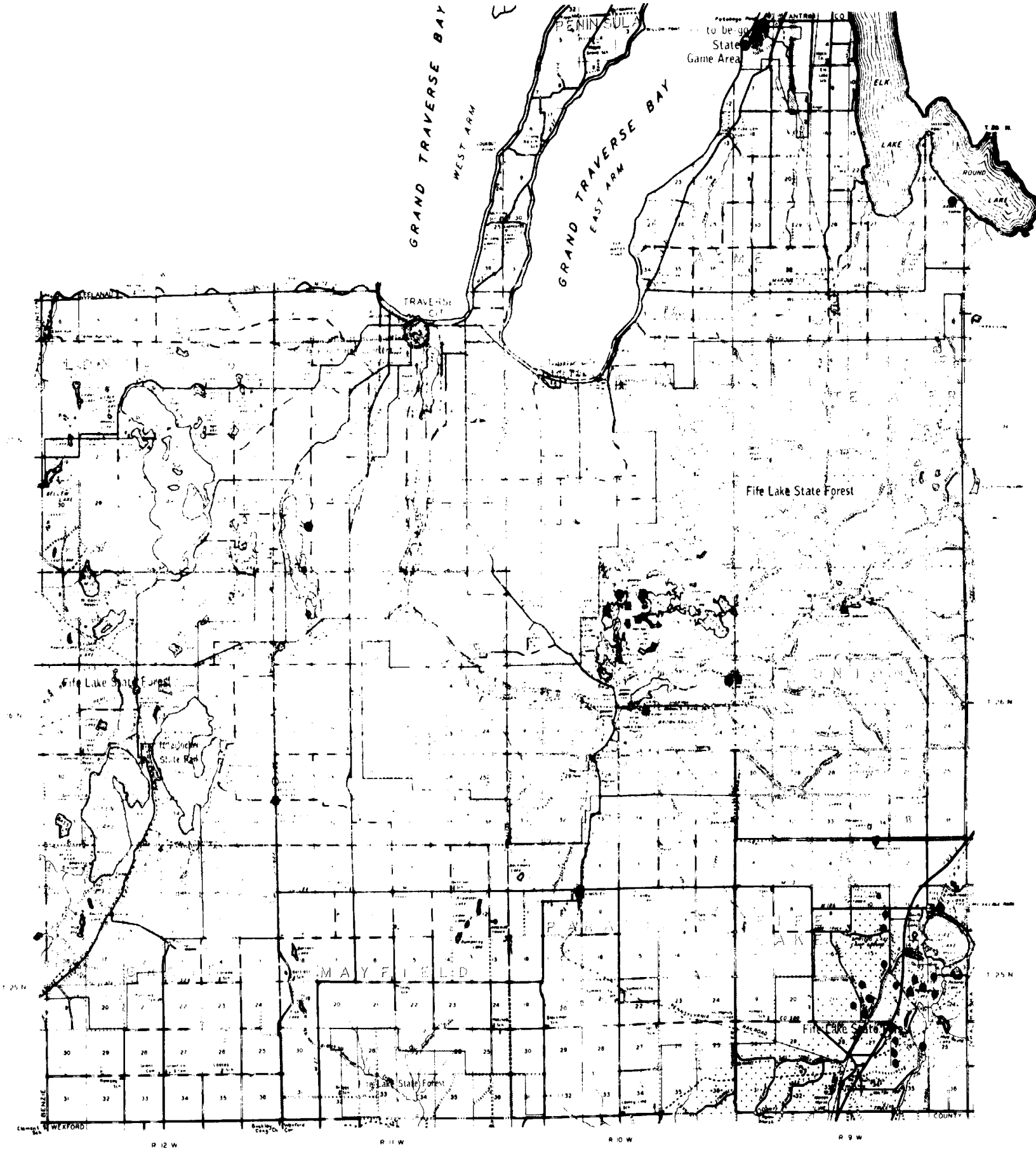

R1E
R2E
R3E
R4E
OSCODA
COUNTY
FOSTER
DISTRICT
GOOD
SECOND
GLADWIN
COUNTY
ARENAC
CORRECTION
COUNTY
R1E
R2E
R3E
R4E
OGEMAW COUNTY, MICHIGAN
•Plantations Examined
OGEMAW


• Plantations Examined
ALPENA COUNTY, MICHIGAN
PRESQUE ISLE
COUNTY
MIDDLE BLANC
State Forest
Alpena State Forest
Forest
ALPENA
THUNDER
BAY
FLETCHER
POND
OSTEN
ALCONA
COUNTY

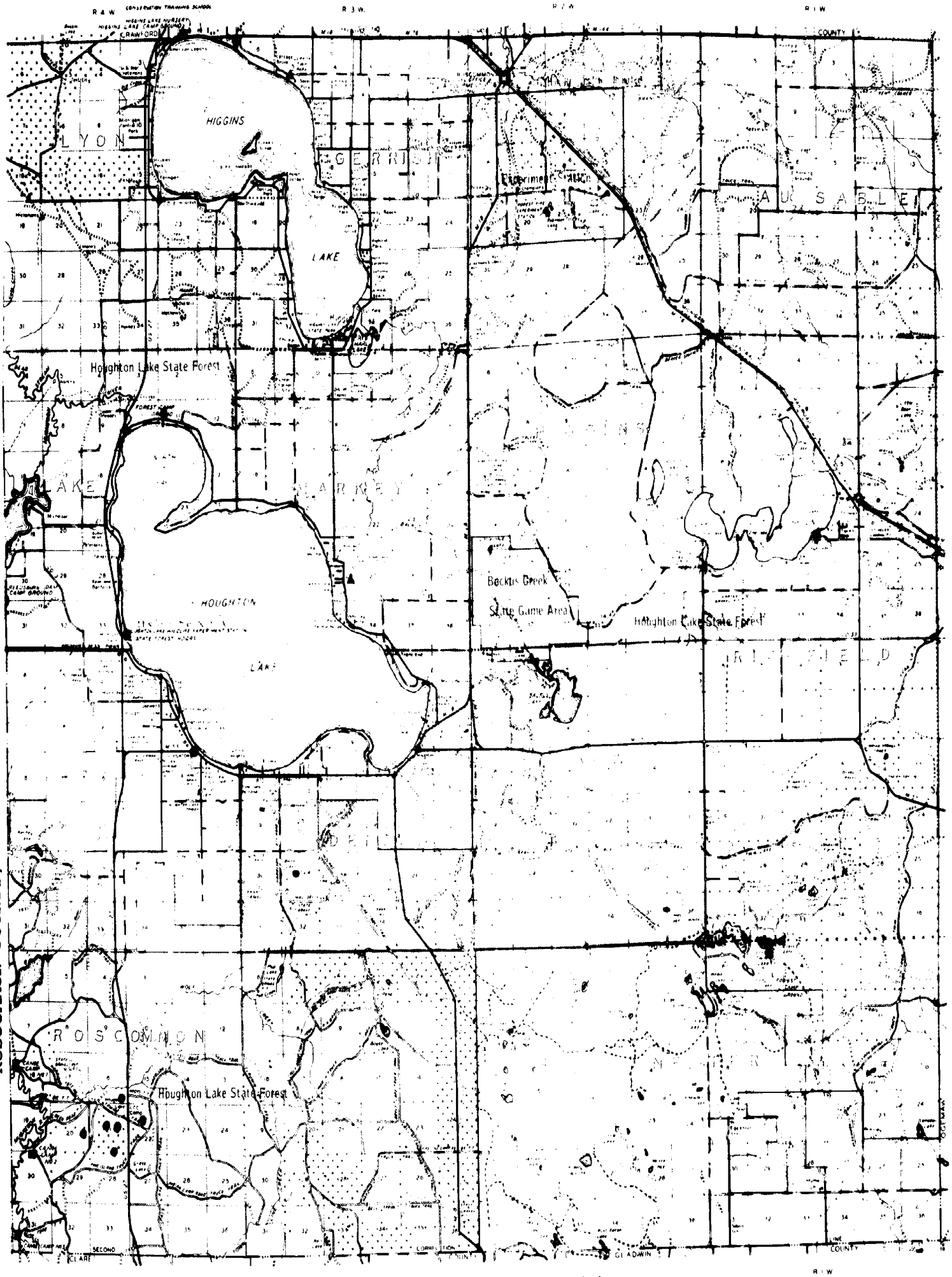
ALPEN

GRAND TRAVERSE COUNTY, MICHIGAN

●Plantations Examined



HELP PREVENT FOREST FIRES



• Plantations Examined

ROSCOMMON COUNTY, MICHIGAN

HELP PREVENT FOREST FIRES

C O P Y APPENDIX XXX C O P Y

UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE
Lake States Forest Experiment Station

Address reply to
DIRECTOR
and refer to
RS - LS
MENSURATION
Tree Studies

University Farm
St. Paul 1, Minn.
January 13, 1953

Mr. M. Sulaiman Kakli
1024 Hill Street
Ann Arbor, Michigan

Dear Mr. Kakli:

This is in reply to your letter of January 5.

We have no volume tables available for Scotch pine at the present time. In the absence of the tables, I would suggest to use the following form factors to obtain total cubic-foot volume.

Total height of tree	Form factor to convert cylinder volume to cubic feet	
Feet	Inside bark	Outside bark 1/
15	.565	.655
20	.480	.558
25	.435	.505
30	.420	.488
30+	.420	.488

1/ Bark approximately 16 percent by volume.

Thus, a 5-inch tree 40 feet tall would have a volume of .136 x 40 x .42 = 2.28 cubic feet inside bark. The figure .136 is the basal area of 5 inches at breast height in square feet.

In this way you can prepare a volume table which would show volume by d.b.h. and total height. The table should apply to the general run of plantations where form quotient outside bark at half way above ground is .68.

Very sincerely yours,

/s/ S. R. GEVORKIANTZ, Forester

C O P Y

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