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Silvicultural Aspects of Woodland Management in Southeastern Minnesota

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CONTENTS

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INTRODUCTION

THERE are three principal plant formations in Minnesota, the northern conifer forest occupying the northeastern part of the state, the tall grass prairie covering the southwestern and westerly portions, and between these two a belt of deciduous forest extending diagonally across the state from southeast to northwest (figure 1). This bulletin deals with the deciduous forest, with special reference to southeastern Minnesota.

Practically all of the land within the deciduous forest belt is in farms. Clearing of the timber began with settlement of the region, mainly from 1850 to 1870. In the period of rapid agricultural expansion which followed, almost all suitable land was placed under cultivation. Remaining forests, therefore, are confined very largely to noncultivable areas. Few farms, however, are without some wooded area, many having half or more of their total acreage in woods.

With the change from wheat farming to a more diversified type of farming, including dairying, a strong demand for pasture developed. This change, beginning the latter part of the nineteenth century, has led to the pasturing of almost all woodland and has greatly accelerated the pace of deforestation.

The situation is similar to that existing generally throughout the corn belt and deciduous forest region of eastern and central United States *(9, 17, 43, 49)*. Under past treatment, forest values, as a rule, have been liquidated and forests have deteriorated. Destruction of forest cover on many steep watershed areas has contributed greatly to the present critical soil conservation and flood control problems.

By any reasonable standard of land use, a high percentage of the present woodland areas in southeastern Minnesota, as well as many deforested slopes, would be classified as absolute forest

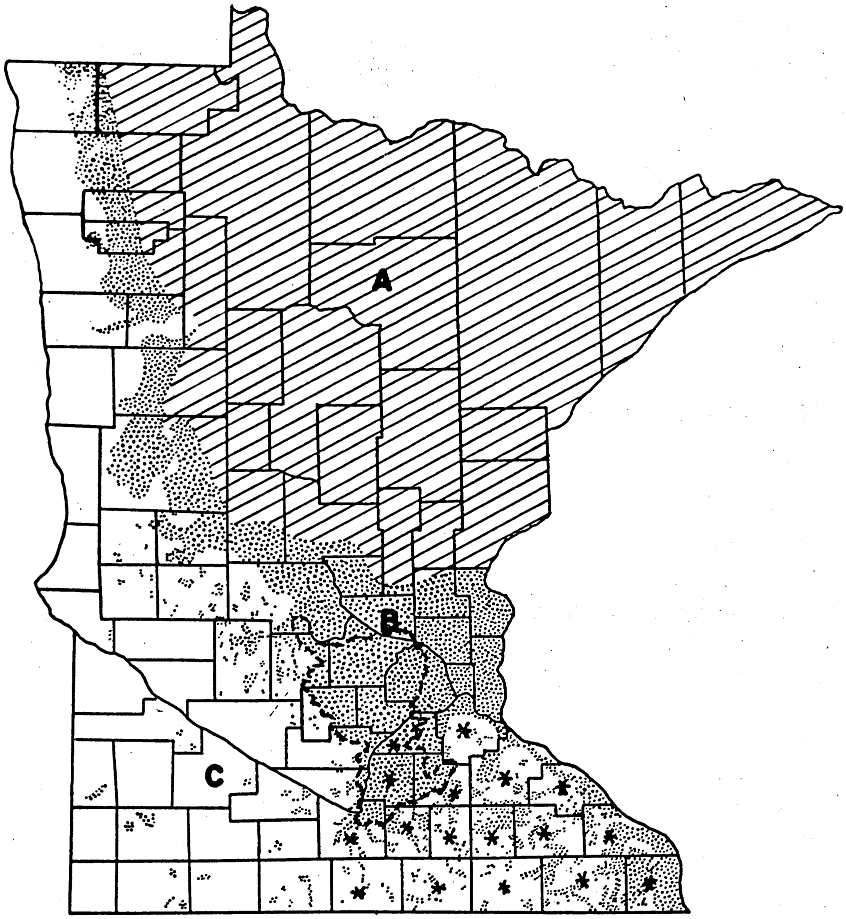

FIG. 1. Principal plant formations of Minnesota after Upham *(46)*. A. Northern conifer region, characterized by pines, spruce-fir-birch. B. Deciduous forest region, principally oak-hickory and maple-basswood. Big woods area after Daubenmire *(8)* indicated by broken line. Asterisks indicate counties in which work was done. C. Tall grass prairie region.

land. The permanent and highest purpose of this land probably would be served by forest production, under which it would yield numerous values including timber products, soil and water conservation, wild-life production, recreation, and the high aesthetic value of woodlands in the hilly parts bordering the Mississippi River. Most fundamental to society and essential to permanent land use are soil and water conservation. The economic values of timber production are of greatest significance to farmers and other owners of woodlands.

As a result of the rapid, more or less unplanned development of land resources within the hardwood region, it is widely recognized that many adjustments in land use will have to be made in the future. Where the land and the forest base have been depleted, the task will be more difficult and of longer duration than where productive lands and forests still exist. General programs for land management can be formulated readily, but the details for such a program should be based upon facts determined by scientific investigation.

The object of the studies here reported is the presentation and analysis of data considered essential to the planned management of these forests. Phases of the problem which were most significant and which could be worked out with the time and resources available were selected.

For purposes of practical management, knowledge of the growth of the various commercial species is highly important. Determination of growth rates, therefore, was selected as a major objective of this study.

An understanding of the silvical characteristics of the important tree species is likewise vital to forest management problems. Investigations were designed to determine these characteristics for the commercial trees of the southeastern Minnesota region.

The different forest communities, representing the natural reaction to various ecological factors, provide a means of interpreting the interrelationships between forest and habitat conditions. Since many principles of management are based upon such interrelationships, they were studied as a part of the problem. Detailed studies of the sociology of the forests, their origin and character, were planned in this connection.

The Region Studied

The region covered by this study consists of 17 counties of southeastern Minnesota. These are given in table 1. It is the area north of the Minnesota-Iowa state line, south of the Minnesota River, and west of the Mississippi River to and including Blue Earth and Faribault counties. It has a total acreage of 6,530,560.

Small amounts of data were taken from the tier of counties bordering this area on the northwest, namely Nicollet, Carver, and Wright counties. However, so few data were gathered there that it was not thought desirable to include these counties in the region.

Only a relatively small part of the region is forested, 12.3 per cent. It includes much prairie with which the hardwood forest

Table 1. Land Areas and Areas of Woodland Pasture and Woodland Not Pastured in Counties of Southeastern Minnesota* in Acres

County	Total land area	Woodland pasture	Woodland not pastured	Woodland pasture and woodland
			Acres	
Houston	364,800	120,687	20,067	140,754
Fillmore	555,520	80,540	15,717	96,257
Mower	455,040	12,431	2,403	14,834
Freeborn	470,400	11,971	2,911	14,882
Faribault	460,160	10,409	2,883	13,292
Blue Earth	487,680	40,045	5,009	45,054
Waseca	275,840	8,395	2,003	10,398
Steele	275,840	8,618	3,008	11,626
Dodge	281,600	10,569	2,207	12,776
Olmsted	426,240	39,783	6,711	46,494
Winona	407,680	111,885	12,320	124,205
Wabasha	346,240	66,217	11,006	77,223
Goodhue	490,880	38,059	14,795	52,854
Rice	316,800	27,273	5,713	32,986
Le Sueur	298,240	20,479	5,309	25,788
Scott	234,240	43,030	3,480	46,510
Dakota	383,360	31,144	6,428	37,572
TOTALS	6,530,560	681,535	121,970	803,505

* U. S. Census of Agriculture, 1935.

forms a broad transition on the west. Woodlands are scattered over most of this prairie, and they were sampled sufficiently to include this predominantly nonwooded area as part of the region studied. Since conditions vary somewhat between the southeastern and northwestern parts of the state, results obtained in this study apply specifically only to the southeastern area.

Forests

There are two main divisions of the deciduous forest in southeastern Minnesota: the oak-hickory association described by Schantz and Zon *(36)*, Transeau *(44)*, and the committee on forest types of the Society of American Foresters *(40)*; and the maple-basswood association, commonly known in Minnesota as the "big woods." The latter has been well described by Daubenmire *(8)*.

The oak-hickory association occupies the slopes and ridges of the relatively rough topography in the southeastern section of the state. It also forms the transition with the prairie region. Most of the prairie groves and woodlots are part of this association. In general the oak-hickory woods are found on the drier, well-drained sites. The maple-basswood forests are found on soils of high moisture-retaining capacity. Protection against prairie fires, which formerly burned frequently in this region, is given as an important factor affecting present distribution of maple-basswood woods *(8)*.

The distribution of the woodlands may be seen in figure 1. Table 1 gives the areas of woodland classified as pastured or not pastured in the 17 counties. According to these data, 681,535 acres of woods are pastured and 121,970 are not. This makes a total of 803,505 acres of forest, equivalent to 12.30 per cent of the total land area. In reality the area of unpastured woods is much smaller than shown. The figures taken from the U. S. census of agriculture for 1935 show the area of woodland unpastured during the current year. Since many areas may be pastured one year and not the next, the figure of 121,970 acres is much too high if taken to mean woodland that does not show the effects of pasturing. Ungrazed, unburned woodland areas were found to be very rare. Probably less than 10 per cent of the unpastured woodland could be classed as representing more or less undisturbed, natural woodland communities.

Many of the forests pastured for long periods of time have become parklike in appearance, the native herbaceous flora has been replaced by grass sod, young trees have been killed by browsing, and death of older trees has been hastened. Fires have burned in many stands destroying reproduction and smaller trees, and damaging larger ones. Cutting and culling in most woodlots have left them understocked, with a preponderance of poorly formed trees of the less desirable species. In short, most deciduous forests of southeastern Minnesota are in a much deteriorated condition.

Tree Species

Fifty-four species and varieties of trees[1] have been recognized as sufficiently important to be included in a list of tree species for southeastern Minnesota (table 2). A number of these are relatively rare and others are of little or no commercial importance, as is indicated in table 2. One species, the black locust, is not native to the region but has been so widely planted that it is included in the list. A number of other tree species have been introduced, principally for ornamental purposes, but, to some extent, also for windbreak and woodlot plantings. This group of species has not been included since it has little or no silvicultural significance.

Twenty-eight of the 54 species were abundant enough to be well represented in the sample plots used in studying growth. The natural occurrences of chinquapin oak, *Quercus prinoides*

[1] The nomenclature for woody plants follows Rosendahl and Butters *(35)*, and for herbaceous plants, Robinson and Fernald *(34)*.

Table 2. Tree Species of Southeastern Minnesota

1. *Acer negundo* L.—boxelder
2. *Acer nigrum* Michx.—black sugar maple
3. *Acer rubrum* L.—red maple*
4. *Acer saccharinum* L.—silver maple
5. *Acer saccharum* Marsh.—sugar maple
6. *Amelanchier canadensis* (L.) Medic.—Juneberry†
7. *Betula lutea* Michx.*—yellow birch
8. *Betula nigra* L.—river birch
9. *Betula papyrifera* Marsh.—paper birch
10. *Carpinus caroliniana* Walt.—blue beech†
11. *Carya cordiformis* (Wang.) K. Koch—bitternut hickory
12. *Carya ovata* (Mill.) K. Koch—shagbark hickory
13. *Celtis occidentalis* L. var. *crassifolia* (Lam.)—hackberry
14. *Crataegus* sp.—hawthorn†
15. *Fraxinus americana* L.—white ash*
16. *Fraxinus nigra* Marsh.—black ash
17. *Fraxinus pennsylvanica* Marsh.—red ash
18. *Fraxinus pennsylvanica lanceolata* (Borckh.) Sarg.—green ash
19. *Gleditsia triacanthos* L.—honey locust*
20. *Gymnocladus dioica* Lam.—Kentucky coffee tree*
21. *Juglans cinerea* L.—butternut
22. *Juglans nigra* L.—black walnut
23. *Larix laricina* (Du Roi) Koch—tamarack*
24. *Malus ioensis* (Wood) Britton—wild crab†
25. *Morus rubra* L.—red mulberry*†
26. *Ostrya virginiana* (Mill.) Koch—ironwood†
27. *Pinus banksiana* Lamb.—jack pine*
28. *Pinus strobus* L.—white pine*
29. *Populus deltoides* Marsh.—cottonwood
30. *Populus grandidentata* Michx.—large-toothed aspen
31. *Populus tremuloides* Michx.—aspen
32. *Prunus americana* Marsh.—wild plum†
33. *Prunus nigra* Ait.—wild plum†
34. *Prunus pennsylvanica* L.—pin cherry†
35. *Prunus serotina* Ehr.—black cherry
36. *Quercus alba* L.—white oak
37. *Quercus bicolor* Willd.—swamp white oak*
38. *Quercus borealis* Michx.—red oak
39. *Quercus borealis* var. *maxima* (Marsh.) Ashe—northern red oak
40. *Quercus ellipsoidalis* E. J. Hill—pin oak
41. *Quercus macrocarpa* Michx.—bur oak*
42. *Quercus macrocarpa* var. *olivaeformis* (Michx. f.) Gray—northern bur oak
43. *Quercus velutina* Lam.—black oak
44. *Quercus coccinea* Muench.—scarlet oak
45. *Quercus prinoides* Willd.—chinquapin oak*†
46. *Robinia pseud-acacia* L.—black locust*
47. *Sabina virginiana* (L.) Antoine—red cedar†
48. *Salix nigra* Marsh.—black willow
49. *Salix amygdaloides* Anders—peach-leaved willow
50. *Thuja occidentalis* L.—arbor vitae*
51. *Tilia americana* L.—basswood
52. *Ulmus americana* L.—American elm
53. *Ulmus fulva* Michx.—slippery elm
54. *Ulmus racemosa* Thomas—rock elm

* Rare or occasional in southeastern Minnesota.
† Small tree—little or no commercial value.

Willd., honey locust, *Gleditsia triacanthos* L., and red mulberry, *Morus rubra* L., in southeastern Minnesota were not verified. Rosendahl and Butters *(35)*, however, record these species as being native there.

Climate

The climate of this area is relatively uniform *(25)*. The mean annual precipitation varies from 28 to 32 inches, being highest toward the east and decreasing slightly toward the west. Rainfall is well distributed during the growing season, approximately 80 per cent of the total annual precipitation coming during April to October. Snowfall averages about 36 inches annually and as a rule covers the ground from November to March. Mean annual temperatures for the region are very close to 44° F. Maxima of 95° to 100° F. occur in most summers and minimum temperatures of —30° to —40° F. have been recorded at stations throughout the region. The mean growing period is from 140 to 160 days, being longest in a narrow strip along the Mississippi River valley in the southern part of the region. The precipitation-evaporation ratio of Transeau *(44)*, as computed by Livingston and Shreve *(26)*, for stations within or near the region shows the following values: St. Paul 1.02; La Crosse, Wisconsin 0.94; and Dubuque, Iowa 0.95. The ratio undoubtedly is close to 1.0 for stations in southeastern Minnesota. It is probably slightly lower in the western part of the region than in the eastern part. According to the classification of Merriam *(28)*, the region comes almost wholly within the transition zone. A narrow strip along the Mississippi River as far north as Winona comes within the Carolinian zone.

On the whole, the climatic differences within the region are small and insufficient to account for the variations in forest growth that occur. Local site conditions in a region of such uniform climate would be expected to play the determining role.

Geology and Soils

Most of southeastern Minnesota has been glaciated. Drift from four different glacial invasions is found within the area. Topographic features are those typical of glacial deposits characterized by moraines and till plains. Scattered lakes are found throughout the drift areas but are absent in the unglaciated part.

Soils are principally of a loam type although sands, gravels, and clays also are found. Most of the soils have developed from the gray drift brought by glaciers from the Keewatin center in Canada. The gray drift is calcareous and forms the clayey, limey soils characteristic of western and southern Minnesota. It is of two ages known as the old and the young gray drifts. The former has undergone more erosion and leaching than the latter.

The red drifts, derived from the hard crystalline rocks of the Canadian highlands, occupy limited areas south of the Twin Cities. Compared with the gray drift, soils developed from these drifts are generally red in color, coarser textured, and lower in lime. As a rule they are more acid in reaction.

Because the southeastern corner of the state, principally Houston and Winona counties, was not glaciated, it is known as the driftless area. It is part of a much larger area including adjacent territory in northeastern Iowa, southwestern Wisconsin, and northwestern Illinois. Here the topography is rough, the deeply eroded valleys of preglacial times not having been filled with drift as was the case in the glaciated region—deep valleys, steep slopes, narrow ridges, and small plateaulike formations characterize this area. A mantle of wind-deposited loess soil covers the uplands, often to considerable depths. On the steeper slopes this layer of soil is thin or absent. Instead, rocky residual soils developed mainly from limestone prevail. The loessial soils also overlie a considerable part of the old gray drift area. Where this is the case, the topography is more rolling because the drift has leveled off the preglacial topography.

In distribution the young gray drift occupies approximately the western 40 per cent of the region studied, loess the eastern 30 per cent. Between these two the old gray drift covers about 20 per cent and the young and old red drifts about 10 per cent in the north.

Uplands of the region are principally between 1,100 and 1,200 feet in elevation. The bluffs, highest along the Mississippi River, are 400 to 500 feet above the valleys. Most of the drainage is eastward to the Mississippi through the Root, Whitewater, Zumbro, Cannon, and Minnesota rivers. A number of smaller streams head into the rough, much dissected territory bordering the Mississippi River.

Glacial deposits and loess cover most of the bedrock, but in the driftless area the steep slopes and ridges have many outcroppings of limestone and sandstone of paleozoic age *(25)*.

Soils show the influence of having developed under forest and prairie conditions. The northern and eastern parts of the region, in the main, are forest soils; the southeastern part has predominantly prairie soils. There are many transition areas, however, where forest and prairie have competed for dominance. Because of other factors which have affected this balance, notably fire, it is impossible to classify environment as strictly forest or prairie upon the basis of soil alone.

Origin of the Oak Forests

Origin of the forest communities in southeastern Minnesota goes far back into geological history. For the most part, however, the vegetation has been determined by the major events of glaciation and climatic changes. During the periods of glacial invasion Minnesota was covered by a series of vast ice sheets which must have destroyed existing forests in all but a small unglaciated area in the southeast corner. Climatic changes accompanying the glaciers caused a southward advance of boreal elements far beyond their present extensions. *Abies-Picea* forests followed retreat of the glaciers *(7)* and were succeeded by oaks and other deciduous elements during an apparently xerothermic period *(50)*. At the present time deciduous elements are found throughout the state and the spruce-fir forests are prominent only in the north. The northward advance of the deciduous species probably continues at the present time. The xerothermic period favored the prairie elements and brought about their advance into the forest region; but more recently, conditions of increased rainfall have resulted in the advance of deciduous species northwestward and westward into the prairies. A broad transition zone is formed where the oak-hickory forests and the prairies meet *(45)*. A trend toward more mesic conditions favors extension of the forest; more xeric periods favor the prairie.

At the present time oak forests, abundant along the deciduous forest border, may be found on scattered, protected sites over most of the Minnesota prairie, especially on uplands in the vicinity of lakes or streams. Distribution and character of the oak forests are quite different today from what they were before the period of settlement, principally from 1850 to 1880. Complete agreement of descriptions was obtained from over a score of original homesteaders and long-time residents of the region to the effect that most of the original upland oak forests were of the savanna type. Stands were made up of scattered large trees with thick, fire-resisting bark. Bur oak was prevalent but white, northern red, and northern pin oaks were well represented. Reproduction had little opportunity to develop except in the better-protected ravines and valley slopes. These were always much more heavily forested than the upland.

Much timber was cut by the early settlers, and no trace remains today of large stands which existed at the time of settlement. Early pioneers described vividly the prairie forest which burned extensively every year or at least every few years. Not until roads were built and sufficient land placed under cultivation did the fires cease. With their cessation the oaks reproduced abundantly, giving rise to the present woodlands. Occasional stands remain today showing the large, old, open-growth oaks surrounded by dense young stands.

Age Class Distribution

Ages of 340 randomly selected oak stands were determined and classified by ten year age classes. Fifty-one per cent of all stands were found to be in the 50 to 60 and 60 to 70 year groups; 19 per cent were over 70 years; and 30 per cent were less than 50 years of age. Almost all of the younger stands, however, represented sprout growth originating from the cutting of older timber, most of which probably would have now been in the

50 to 70 year group. Had there been no cutting, the percentage of 50 to 70 year old timber, therefore, would be far larger than shown. The distribution of age classes thus corroborates the historical evidence that present forests were established following settlement and the stopping of prairie fires. Few stands have originated during the last 50 years because lands were either under cultivation or pastured. While settlement permitted extension of the woodlands on some areas, it still more effectively prevented establishment on cultivated or heavily grazed lands.

The rapidity and completeness with which the savanna and smaller oak openings were reproduced to oak during a short period of protection supports the conclusion that the deciduous forest was strongly held in check by fire. If given the opportunity to seek its natural balance, the forest would be extended considerably in the present forest-prairie tension zone.

The rather extensive reproduction of heavy-seeded oaks in even-aged stand form raises the question of how the oaks could spread so widely and rapidly. It does not seem possible that during a short period of protection the acorns were disseminated sufficiently in distance and number to give rise to the present stands. It is more probable that reproduction was established fairly abundantly throughout the savanna and adjacent to oak stands but because of the repeated fires never had opportunity to develop. Oak seedlings or saplings may be burned repeatedly, killing the portions of the tree above ground, but new sprouts arise after each fire making possible a long continued existence *(20, 27)*. As soon as periodic fires were stopped the advance reproduction was able to make unhampered development, thereby giving rise to the stands now from 50 to 80 years so commonly found in this region. The frequent occurrence of multiple stems found in stands of these age classes further confirms the sprout origin of many stands.

Previous Work

There have been very few investigations dealing with the silviculture or phytosociology of forest communities in southeastern Minnesota.

Rosendahl and Butters *(35)* present taxonomic descriptions of the trees and shrubs of this region and give other valuable notes on ecology and distribution.

Daubenmire *(8)* has made an excellent study of several big woods communities. He presents a phytosociological analysis of the maple-basswood association and discusses the influence of fire, climate, and soil as related to present distribution of the forests.

Recently the U. S. Forest Service *(48)* published the results of its forest survey in the hardwood and prairie region of Minnesota. This publication gives figures on present timber volumes, growth, and depletion as well as an analysis of the general forestry situation.

Cheyney and Brown *(6)* investigated a number of specially selected woodlots in southeastern Minnesota. They present diameter growth data for a number of species and an analysis of the composition of the woodlots sampled. The present study, based upon more extensive sampling, is an enlargement of the work of these two authors.

A valuable presentation of yield, stand, and volume tables for even-aged upland oak forests has been given by Schnurr *(37)*. Although no plots upon which this work was based were taken in Minnesota, the results should be generally applicable to the oak forests of this state.

Methods of Collecting Data

The field data were collected entirely by the writer during the summers of 1931 and 1932 and shorter periods of the 1936, 1937, and 1939 field seasons.

The entire region was covered in considerable detail. All major roads and most of the secondary roads were traversed by car. Almost every woodlot of any consequence was at least observed. Each county was taken as a unit and sampled more or less in proportion to the amount of woodland area.

Most of the data were collected from temporary sample plots. A special attempt was made to sample the virgin, undisturbed woodland areas, but a variety of other conditions was sampled in accordance with objectives.

Sample plots were one chain square, one-tenth acre in size. They were laid out with the aid of a staff compass and measured with a steel tape or chain. A complete description of each plot including location, aspect, slope, soil, and other pertinent information, such as recent treatment and grazing and fire history, was recorded and filed with other records for the plot. Data were recorded for each plot according to the purpose or purposes which it would serve.

The Swedish increment borer was used to obtain increment cores and determine ages of all trees on plots used for growth studies. Bark thickness was measured with the Swedish bark measuring instrument. Two measurements, at opposite sides of the tree, were taken for double bark thickness. Heights were taken with a Forest Service hypsometer or an abney level, measuring horizontal distances with a steel tape. In some cases where the range of heights was small, a number of sample trees were measured and heights of the remaining trees estimated. Crown spread was determined by averaging two measurements taken at right angles, usually in the narrow and wide directions. A plumb bob was used to sight in the horizontal extension of the crown and distances were measured with a steel tape.

Sufficient growth data for some of the species could not be obtained from the plots. In such cases growth data were collected wherever the species happened to occur. By taking the same records for each tree as were taken on the plots, essential uniformity in the methods of collection was obtained.

A total of 320 tenth-acre plots was sampled. Some of them were sampled for specific purposes, while others furnished a variety of data. For example, a plot for studying the composition of reproduction on a cutover area would give no data useful for other parts of the study. Other samples, however, such as 50 plots located in natural, undisturbed forest communities, furnished detailed information useful for determination of stand composition, growth, site index, composition of herbaceous flora, age character, and reproduction.

Complete diameter growth records were obtained for 2,410 trees of the 23 commercially most important tree species. Some species, because of their greater abundance and importance, were represented by many more sample trees than others. Those species which occurred infrequently naturally would not be sampled so often. Special effort was made to obtain adequate samples of some poorly represented but potentially important species. Species of very limited distribution and minor importance were not sampled. For instance, hop hornbeam, blue beech, and wild plum were well represented but of such small size and limited importance that growth data for them were not collected. Several species, notably the Kentucky coffee tree and swamp white oak, attain merchantable sizes but were so poorly represented in the larger size classes that they could not be sampled adequately without an unwarranted amount of effort. White pine, jack pine, and larch are relict in southeastern Minnesota and of such limited importance that no time was devoted to them.

Data were collected throughout the region, the distribution probably corresponding fairly closely to the distribution of the woodlands. Special attention, however, was given to the oak-hickory type, and almost 60 per cent of the plots were taken in Houston, Winona, and Fillmore counties. Since these counties contain the best remaining woodlands and almost half the total woodland area in the region, it is proper that they should be sampled heavily.

Records were kept of the number of plots of different kinds sampled so that special effort could be made to locate the proper number of plots for each purpose and to fill in any deficiencies which, by examination of collected data, were found to occur.

Reliability of the data is best expressed by the use of statistical methods. For all of the important data the statistics necessary for adequate description have been calculated. Methods recommended by Snedecor *(38)* were used. In general, reliability was assured by obtaining sufficiently large samples. In the growth statistics for certain species the number of observations is small, but in many instances the deficiencies in certain places are strengthened by more favorable numbers of adjacent samples. The average number of years required to grow each two inches of diameter provides curves with surprisingly smooth and well-defined trends.

A possible defect in using the past growth history of large dominant trees as a basis for predicting average growth rate of smaller trees is that the better, more successful trees make up a large part of the sample. However, the average growth rates as found in this study could probably be achieved in managed stands. The average growth figures are not for fully stocked stands. In fact, many of the stands sampled were markedly understocked if compared with normal yield table standards. Since normal stands occur very rarely and the approach in this study is from the standpoint of individual trees or tree classes, this should not be a serious objection.

A slight error may have been introduced in reading D.B.H. values with the diameter tape. The diameter inside bark determined by subtracting double bark thickness from diameter breast height gave higher average values than diameter inside bark calculated by doubling the radial length of the increment cores. A comparison of actual and calculated diameters made for 10 species of trees is discussed more fully with the presentation of growth data. A possible cause for the differences between actual and calculated diameters may be that in "sizing up" the trees preparatory to boring, there may have been a bias in favor of the shorter radius. The correction to actual diameter inside bark, however, would prevent any but very minor errors in diameter growth analysis due to eccentricity in form.

The phytosociological character of the forest communities has been analyzed quantitatively mainly by frequency studies. Wherever possible the communities have been classified for this purpose according to the physiographic sites, and it is believed that satisfactory uniformity was obtained by such a division of environments.

Plots for the study of the herbaceous species represent, as far as possible, undisturbed natural forest communities. Since the occurrence of such communities was limited to north slopes, coves, or upland areas, these data give a cross section of only the more mesic conditions. The undisturbed communities are rare, and it was necessary to sample them where found, precluding any planned selection of these areas.

The size of plots, one-tenth acre for trees and one-hundredth acre and mil-acre plots for shrubs and ground vegetation, appears to be appropriate if judged from the frequency tables. The minimal areas needed for any of the species is considerably exceeded by the plots.

Most of the plots were sampled during late June, July, August, and early September. The herbaceous species prominent in the vernal aspect, therefore, are not well represented in the data. This must be considered in judging the validity and frequency percentages of the species listed. The summer flora has been appropriately sampled, but the lists include only the more persistent of the vernal flora, a number of which are ephemeral. Earlier sampling to include the spring flora would have missed the more important and characteristic species of the summer flora. Permanent sample plots could have included both types, but this was beyond the limitations placed upon the field work.

RESULTS OF STUDY

Sociology of the Forest

The sociology of the forest communities has been analyzed mainly on a basis of the presence of the tree species on sample plots of one-tenth acre and of the shrub and herbaceous vegetation on one-hundredth and mil-acre plots. A species, for example, which occurs on 10 out of a total of 20 plots has a frequency percentage of 50. By means of the frequency studies it is possible to determine the communities in which, or sites on which, the species occur and the degree to which species tend to be associated in the various communities. Braun-Blanquet *(3)* gives a detailed discussion regarding the concept of frequency.

Other criteria used in the sociological analysis of the forests are age-character, amount and kind of tree reproduction, and density of vegetation on the forest floor.

Age-Character of Oak-Hickory Stands

Studies of the age-character of 37 typical oak and oak-hickory stands were made on tenth-acre plots. Most oak and oak-hickory stands are more or less even-aged. Younger stands, especially those less than 80 years, are more even-aged than older stands. This probably can be explained by the fact that as long as fires burned periodically, dense, even-aged stands could not be established and maintained. The older trees most likely represent the scattered trees which were able to effect establishment during the period of burning. Younger trees resulted from regeneration of the stands following protection. Even-aged young stands contain remnants of the previous open stands.

In a number of plots one species is found to be several years older or younger than other species. Differences in growth rate undoubtedly account at least in part for this situation. Because in this case ages were counted at breast height, the variation in age would be greater than if ages had been determined at stump height or at ground level. Some of the differences also may be due to comparative growth rates of seedlings and sprouts. Oak sprouts reach breast height in two or three years whereas seedlings require perhaps six years. Considering these factors which cause variation in age at D.B.H., it is clear that the main body of trees on each of the plots must have started at about the same time. The length of the reproduction period for most oak or oak-hickory stands is approximately 10 years. Practically all trees in each stand are included in a 20-year period.

Frequency of Species on Different Sites

It is evident that in an area as rough as southeastern Minnesota there are a number of different physiographic sites. For purposes of study the sites were classified on a basis of physiography into five categories. These are: (1) valley and cove, which include the ravines and floors of the larger valleys; (2) moist slope, principally the north to east slopes; (3) upland, which includes the broader ridges and plateaus of the unglaciated area and the level to rolling parts of glaciated sections; (4) narrow ridge, the narrower and better-drained ridges of the unglaciated area, usually with shallow soil; and (5) dry slope, similar to site 4, but represents more severe exposures and lower site quality. These sites, as will be shown later, are significantly different in site quality. From 1 to 5 they represent a decreasing order of productivity.

Table 3 presents the frequency percentages of tree species found on tenth-acre plots on these five sites. All plots were taken in well-developed stands reasonably free from any recent serious disturbance.

As might be anticipated, the more mesic species have higher frequencies on moist slope and valley and cove sites, while the more xerophytic species predominate on ridges and dry slopes. Valley and cove, moist slope, and level to rolling upland sites show certain similarities as do the ridge and dry slope habitats. Yet marked differences are present. Valley and cove situations are characterized by basswood, slippery elm, red oak, sugar maple, and ironwood if frequencies of 25 per cent or higher may be considered as a satisfactory criterion. The moist slope sites are characterized by red oak, white oak, basswood, ironwood, and shagbark hickory; level to rolling upland by white oak, red oak, shagbark hickory, and pin oak; narrow ridges by white oak, bur oak, red oak, pin oak, shagbark hickory, and aspen. The dry slope type has bur oak, shagbark hickory, white oak, pin oak, aspen, and white birch as characteristic species.

On the more moist sites, especially the valley and cove, the data indicate a tendency toward the maple-basswood climax association. This is not evident on the drier sites. Red and white oak have very high frequencies on the moist slopes. Here frequency values of the maple-basswood climax species, compared with valley and cove, are sharply reduced. Progressively, on the upland sites frequency percentages of white oak, shagbark hickory, and pin oak are increased, red oak and basswood decreased. This situation undoubtedly is influenced by a high percentage of

Table 3. Frequency Percentages* of Tree Species on Tenth-Acre Plots on Different Sites

Species	Site				
	Valley and cove	Moist slope	Upland (level to rolling)	Ridge (narrow)	Dry slope
	Frequency percentage				
Ash, black	20	7	15	......	......
Ash, green	5	17	......	......	5
Aspen	......	10	15	30	30
Aspen, large-toothed	5	......	8	15	10
Basswood	75	37	17	......	......
Beech, blue	5	......	......	......	......
Birch, paper	15	20	2	5	25
Butternut	20	10	2	5	......
Cedar, eastern red	......	......	......	......	10
Cherry, black	5	......	8	......	......
Elm, American	20	7	5	......	5
Elm, slippery	45	20	22	10	10
Elm, rock	5	......	......	......	......
Hackberry	5	......	......	......	......
Hickory, bitternut	10	10	2	5	......
Hickory, shagbark	10	27	38	35	40
Ironwood	25	27	6	......	......
Maple, sugar	35	20	8	......	......
Oak, black	......	7	10	10	5
Oak, bur	10	10	22	50	70
Oak, pin	......	7	27	35	30
Oak, red	45	90	52	40	5
Oak, scarlet	......	......	2	5	10
Oak, white	5	67	75	65	30
Walnut, black	15	3	......	......	......
BASIS—number of plots	20	30	40	20	20

* Frequency percentage—the percentage of plots in which that species is present.

the plots having been taken on the loessial soil uplands, where white oak and hickory are prominent. Neither of these species occurs abundantly on the drift soils.

On the ridge and dry slope sites bur oak becomes the most prominent species along with shagbark hickory and pin oak. Aspen and paper birch are increased here while white oak and red oak are reduced. The drier sites thus are dominated by the oak or oak-hickory types. It should be recognized, however, that few of the forest communities sampled have had an undisturbed development. Fire, grazing, and cutting undoubtedly have played important roles in determining present composition of a large proportion of the stands.

Frequency of Associates of Six Main Species

To further analyze the sociological relationships, frequencies were determined for the tree species associated with each of the six most important species. Plots were selected in each of which one of the six leading species dominated to the extent of 50 per cent or more of the total number of trees. One hundred and sixty-five plots were sampled. The results are given in table 4. Not all species are represented by equal numbers of plots but a mini-

Table 4. Frequency Percentages of Tree Species Associated with the Six Principal Species on Tenth-Acre Plots

Associated species	Principal species					
	White oak	Red oak	Pin oak	Bur oak	Bass-wood	Sugar maple
	Frequency percentage					
Ash, black	4	6	......	......	20	30
Ash, green	......	6	8	4	15	15
Aspen	12	14	16	16	......	......
Aspen, large-toothed	......	4	4	......	......	......
Basswood	20	24	8	4	......	60
Beech, blue	......	2	......	......	10	10
Birch, paper	......	12	4	12	10	......
Boxelder	......	......	8	......	......	......
Butternut	......	10	......	......	25	10
Cherry, black	......	2	8	......	5	......
Elm, American	......	6	4	4	15	25
Elm, slippery	12	14	4	4	30	40
Elm, rock	......	......	......	......	5	5
Hackberry	......	2	......	......	10	......
Hickory, bitternut	......	8	......	......	......	5
Hickory, shagbark	32	24	12	16	15	10
Ironwood	4	16	......	......	45	35
Maple, sugar	4	10	4	......	60	......
Oak, black	12	6	8	4	......	......
Oak, bur	24	18	44	......	15	15
Oak, pin	24	6	......	28	......	10
Oak, red	60	......	8	8	50	45
Oak, white	......	64	36	16	10	5
Walnut, black	......	......	......	......	10	5
BASIS—number of plots	25	50	25	25	20	20

mum of 20 was set for each. There are 50 plots for red oak compared with 25 or 20 for the other species. This may account in part for the larger number of species listed as associates of red oak. Had there been only 25 plots for this species, the number of associates undoubtedly would have been smaller. No attempt was made to sample more plots of red oak than of other species, but because of the abundance of this species and its dominance on plots established for other purposes, there were more data available.

Although 11 species are associated with both the bur oak and white oak, frequency values for associates of bur oak generally are less than for white oak. Only pin oak and aspen have slightly greater frequencies with bur oak. Like white oak, the bur oak is found on a variety of sites, but it dominates only the drier ones where it often occurs in pure stands. Only the other oaks, shagbark hickory, aspen, and birch are significantly represented at all on the bur oak plots. These are all species capable of growing on dry situations. Green ash, basswood, American elm, slippery elm, and black oak were each found on only one of the bur oak plots. These species occur infrequently on the dry sites and their presence may be regarded as more or less incidental. Black oak might be expected to be more abundant but it is close to the northern limit of its range. The association of paper birch with bur oak may appear somewhat unusual. It is accounted for by the fact that paper birch in southeastern Minnesota occurs in two forms, one on dry sites growing on the most severe exposures, the other a more mesophytic form found on moist sites. Thus bur oak tends to have few associates in the stands it dominates.

Frequency values for species associated with white oak are generally greater than for species associated with bur oak, indicating a higher degree of fidelity. Red oak, shagbark hickory, pin oak, and bur oak are well represented in the frequency values of species associated with white oak. Red oak, especially, with a frequency of 60 per cent, is a close associate. The occurrence of basswood, sugar maple, and ironwood indicates that moisture conditions are probably much less limiting on white oak situations than in the case of bur oak stands.

The plots dominated by pin oak were found to have a few more species than either the bur oak or white oak plots. Only bur oak and white oak, however, have significantly high frequency values. The typical habitat of pin oak appears to be intermediate between those of bur oak and white oak. This is substantiated by their distributions. Bur oak extends farthest into the prairie-forest transition zone. Pin oak is next and often is mixed with the bur oak in the region of prairie groves. Eastward pin oak occurs on ridges and south slopes mixing with the white oak but seldom with the red oak of the moist slopes.

On the red oak plots, white oak appears as the outstanding associate, occurring on 64 per cent of all the plots. This supports the relationship brought out for these species on the white oak plots and also in table 3. Red oak and white oak thus appear as the key species of the mixed oak-hickory woods. The sites occupied by red oak are somewhat more favorable than those occupied by pin and bur oaks. This makes it possible for a number of the more exacting species to be associated with the red oak.

The basswood and sugar maple plots show striking similarities in regard to the composition and frequency percentages of associated tree species. Basswood is well represented in the sugar maple plots and conversely sugar maple is well represented in the basswood plots. Both have frequency values of 60 per cent. Red oak, ironwood, slippery elm, and American elm appear as the leading associates, with numerous other deciduous species present in lower frequencies. Composition of the maple and basswood communities agrees closely with that given by other investigators *(2, 8, 13)*. These two series of plots could well be combined as representative of the maple-basswood community without significantly changing the values of either series.

A majority of both the basswood and maple plots was selected from the valley and cove sites. A few plots were located on a sandy loam, residual, upland soil or on very shallow loess underlain by sandy loam, with a few more plots taken on young gray drift. Significantly, none of the plots was taken on upland loess soil, which is dominated almost entirely by the oak or oak-hickory forests. Had the maple-basswood occurred on the deep upland loess soils it almost certainly would have been sampled there.

Summarizing the information given in tables 3 and 4, it appears that southeastern Minnesota has two principal forest associations, oak-hickory and maple-basswood. The oak-hickory association is distinguished by various communities. On the drier sites bur oak, often in consociation form, is the most important. Pin oak forms a transition with the bur oak and the two species commonly occur in combination. Pin oak also forms pure stands. White oak may form pure stands, particularly on deep loess upland soils, but it is associated, as a rule, with red oak and, to a lesser extent, shagbark hickory. On the drier sites white oak prevails over red oak but on moist sites the red oak becomes the more abundant. Bur oak may be scattered among the red oak–white oak stands, and occasionally there are oak stands in which red, white, bur, pin, and black oak are heterogeneously mixed. The red oak–white oak type, however, remains the key grouping of the oak-hickory forests. It occupies a large part of the north and east facing slopes and the level to rolling upland areas of the unglaciated section.

The maple-basswood association in the unglaciated section is limited largely to the moist protected valley and cove situations. Occasional specimens of basswood and maple are found in the oak stands on loess soil. Several upland sandy soils support well-developed maple-basswood forests with site index values higher than on adjacent deep loess soils. Soil conditions, therefore, may be important in limiting the present distribution of the maple-basswood community. Several possibilities might be suggested to account for this. Valley and cove soils are composed of loess or residual limestone soils mixed with limestone fragments. Upland loess is a heavy silt loam soil from which the lime has been leached in the upper horizons. It is acid in reaction, approximately *p*H 5.0. Acid reaction and absence of lime thus may be unfavorable to maple-basswood on upland loess soils, although one would not expect these conditions to be strongly limiting if other factors were favorable. Following the suggestion of Daubenmire *(8)*, an apparent correlation was found to exist between water table levels and the forest type. Maple-basswood stands were found on sandy loam soils through which water could penetrate readily but were practically absent on the relatively impermeable loess soil.

The present oak-hickory forests represent the first stands to have comparative freedom from fire. If maple-basswood represents the climax association, there has been insufficient time for it to develop through the process of plant succession. Each of these points seems to be substantiated by the evidence of composition and distribution of the various communities. Probably all are important in influencing the present forest situation.

Number of Trees Occurring as Reproduction

To measure the successional tendencies of the forest communities under different physiographic conditions and to ascertain the extent to which the various species can reproduce successfully, a series of 10 one-tenth acre plots was studied for each of the five situations. All plots were relatively undisturbed by fire or grazing, and represented good stocking as determined by density of the forest canopy. Reproduction was classified in three size classes: 0-12 inches in height, 12-36 inches in height, and 36 inches in height to 1.0 inch in diameter at breast height. Results are shown in table 5.

Table 5. Number of Trees per Acre by Species in Three Size Classes Occurring as Reproduction under Different Physiographic Site Conditions*

Species	Size class			
	0-12 inches high	12-36 inches high	36 inches high-1.0 inch D.B.H.	Total
	Number of trees			
	VALLEY AND COVE			
Aspen, large-toothed	0	14	12	26
Basswood	56	23	0	79
Beech, blue	0	2	0	2
Butternut	0	5	4	9
Cherry, black	44	6	0	50
Elm, slippery	210	19	11	240
Hickory, bitternut	18	3	0	21
Ironwood	75	17	14	106
Maple, sugar	184	43	12	239
Oak, bur	6	0	0	6
Oak, red	68	0	0	68
Walnut, black	16	10	2	28
TOTAL	677	142	55	874

* Ten tenth-acre plots for each site condition.

Table 5—Continued

Species	Size class: 0-12 inches high	12-36 inches high	36 inches high-1.0 inch D.B.H.	Total
	Number of trees			
MOIST SLOPE				
Aspen	15	6	0	21
Basswood	23	19	3	45
Butternut	26	11	2	39
Cherry, black	3	2	0	5
Elm, slippery	14	17	11	42
Hickory, bitternut	18	9	0	27
Hickory, shagbark	65	7	0	72
Ironwood	5	12	10	27
Maple, sugar	102	13	7	122
Oak, bur	4	0	0	4
Oak, red	108	1	0	109
Oak, white	13	0	0	13
TOTAL	396	97	33	526
UPLAND				
Ash, green	11	0	0	11
Aspen	0	49	30	79
Basswood	42	26	0	65
Elm, slippery	25	18	9	52
Hickory, bitternut	4	0	0	4
Hickory, shagbark	52	5	1	58
Ironwood	34	9	7	50
Maple, sugar	33	1	0	34
Oak, bur	21	0	0	21
Oak, pin	6	0	0	6
Oak, red	59	0	0	59
Oak, white	28	1	0	29
TOTAL	315	109	47	471
RIDGE				
Aspen	10	35	51	96
Butternut	0	2	4	6
Elm, slippery	13	4	5	22
Hickory, bitternut	4	9	0	13
Hickory, shagbark	104	28	3	135
Oak, bur	14	0	0	14
Oak, pin	6	0	0	5
Oak, red	66	0	0	66
Oak, white	89	7	0	96
TOTAL	306	85	63	454
DRY SLOPE				
Aspen	0	69	84	153
Elm, slippery	0	7	5	12
Hickory, shagbark	58	14	10	82
Oak, bur	40	0	0	40
Oak, pin	12	0	0	12
Oak, white	68	0	0	68
TOTAL	178	90	99	367

The number of trees per acre occurring as reproduction varied from 874 to 367, the more moist sites having more than the drier sites. Likewise the number was greater on the high quality sites and smaller on the low quality sites. The number of trees in the reproduction classes, however, was relatively very small. Many other forest communities have thousands of young trees per acre *(2, 9)*. Wood *(51)*, however, reports a lack of oak seedlings in New Jersey, and Korstian *(22)* points out the difficulties of germination and survival in oaks. Abundant seedling reproduction of oaks evidently cannot be expected except under particularly favorable conditions.

In almost all cases there was a marked reduction in numbers of trees in proceeding from the smallest to the largest size class. This, of course, is characteristic in most forest communities because of high mortality of seedlings during the first few years.

An analysis of reproduction in the valley and cove forests shows that nine species were present in reproduction of the smallest size class, ten in the second size class, and six in the largest. Of the species in the largest size class, ironwood, sugar maple, slippery elm, large-toothed aspen, butternut, and black walnut were represented, but only by 55 trees. Butternut and black walnut, having only four and two individuals, respectively, were represented least well. The presence of large-toothed aspen appears somewhat anomalous. Reproduction of this species was by suckers and probably resulted from the cutting of a tree near one of the plot locations. All of the suckers were found on a single plot, and it is improbable that they could have continued development for long.

Slippery elm, sugar maple, and ironwood had the best representation in all size classes and the successional trend, if one can judge from these data, is definitely toward the sugar maple–basswood association. Although basswood was not represented by reproduction over 36 inches tall, it ranks fourth in total number of seedlings. Reproduction other than maple-basswood is of species which are common associates of that type. Reproduction of red and bur oak occurred only in the first size class and that of other oak species was absent entirely. Had more plots been sampled some reproduction of white oak and shagbark hickory undoubtedly would have been found, as these species are fairly common associates of sugar maple and basswood. It is believed that the major characteristics of reproduction trends are indicated by the series of 10 plots. Species of the oak-hickory type were so poorly represented in the reproduction that they cannot possibly be considered capable of maintaining or increasing their importance in competition with maple and basswood on valley and cove sites.

Reproduction data on moist slope sites indicate conditions similar to those prevailing on the valley and cove situations. Seedlings, however, are only about 60 per cent as abundant. Slippery elm, ironwood, and sugar maple prevail in the larger reproduction while sugar maple and red oak have the highest total values because of their abundance in the small seedling stage. Compared with the valley and cove site, aspen, white oak, and shagbark hickory are added to the list of species, while large-toothed aspen, blue beech, and black walnut have disappeared. Since red oak is the most prominent species on moist slopes an increase in the number of seedlings of this species is not surprising. The occurrence of white oak and shagbark hickory may be explained, in part at least, by the relatively greater abundance of these two species on moist slopes. It is notable, however, that neither the oaks nor the hickories were found in class three reproduction in the predominantly oak-hickory forests of the moist slope type. Evidently these species are incapable of development under the canopies of well-stocked even-aged stands.

Although sugar maple is not well represented by dominant trees on moist slope sites, it leads all species in amount of reproduction. Both ironwood and slippery elm show a strong ability to survive, as the numbers of seedlings show no marked drop from the smallest to the largest size class. Basswood may be able to survive somewhat better under the oak-hickory than under the maple-basswood canopy since a higher proportion of larger seedlings was found on the moist slopes.

Except for the more important differences noted, reproduction on the moist slopes is similar to that under valley and cove conditions. The same successional trends are indicated, but in both cases the scarcity of reproduction detracts from the strength of this conclusion.

The amount of reproduction on upland areas is slightly less than on moist slopes. There is a reduction in the amount of reproduction of species prominent on the two previously considered sites, especially in the largest size class. Aspen is somewhat increased in amount, making up 39 of the total 47 individuals of large size reproduction. The aspen again were of sucker origin and have no important significance. They probably indicate a slight disturbance of some kind. Any major disturbances would have resulted in far greater numbers of aspen shoots than were found on the plots. Excluding aspen, the principal species in the reproduction were basswood, red oak, shagbark hickory, slippery elm, and ironwood. Sugar maple was reduced to an average of 34 seedlings per acre; pin oak appeared in limited numbers.

If the presence of species like elm, basswood, and ironwood in the reproduction may be taken to signify a succession from oak-hickory to maple-basswood, a slow trend in this direction appears probable. However, development of the reproduction on upland sites seems to be so uncertain that it would be impossible to predict the direction of succession. It is characteristic, perhaps, that tree reproduction is markedly deficient in even-aged oak-hickory stands from 50 to 80 years of age.

The ridge type showed a further reduction of seedlings per acre to 454. Maple, basswood, and ironwood were absent. Shagbark hickory, white oak, and red oak were most prominent in the reproduction, but mainly in the smallest and middle size classes. Slippery elm persisted but was much less abundant than in the three more mesic site classes. On the undisturbed sites, increases of aspen were due entirely to root sprouts. Several butternut seedlings are listed but their occurrence on the ridge type was probably incidental, as this species is not well represented on the drier situations.

The number of species dropped from 12 on the upland to 9 on the ridge type probably due to the absence of maple, basswood, and ironwood on the latter; thus the ridge sites provide one basis for separating oak-hickory and potential maple-basswood habitats. Although the present composition of level to rolling upland sites is predominantly oak-hickory, key species of the maple-basswood association, to some extent at least, are able to reproduce there but not on the ridge sites.

Reproduction on the dry slopes was considerably more limited than on the ridges, there being an average of only 367 seedlings per acre. The number of species dropped from nine to six. Red oak, bitternut hickory, and butternut, present in reproduction on the ridge sites, were absent on the dry slopes. Aspen reproduction was more abundant, 153 per acre, than on other sites, probably because of the more open stands and the higher frequency of aspen in the dominant stands.

Bur oak, white oak, and pin oak appeared in reproduction of the 0-12 inch class only. Evidently these species are unable to make appreciable growth or to persist for long under the canopy of an older stand. These seedlings, however, might be able to develop satisfactorily if the overhead stand were removed. In the reproduction, shagbark hickory was more abundant than the oaks. It was present in the three size classes, demonstrating an ability to reproduce and persist under the oak-hickory stands on dry sites. However, growth of the hickory seedlings under these conditions was extremely slow, seedlings less than 36 inches high sometimes being 10 to 20 years old.

Slippery elm reproduction occurred also on the dry slope sites but in smaller numbers than on the other site classes. It exhibited a marked ability to reproduce under practically all stands and under all site conditions within the region. Its role appears comparatively more important in reproduction than in the composition of older stands. It may, therefore, become increasingly important in new stands.

Like the ridge sites, the dry slopes support an oak-hickory type with little or no evidence to indicate that the maple-basswood association will replace it.

Frequency of Species in Reproduction

To measure the changes in composition which might take place after cutting, a series of 85 tenth-acre plots was sampled on the five different physiographic sites. Selection of areas was limited to those cut over within the last 10 years. Heavily grazed areas were avoided but a few plots were on lightly pastured ground. In these cases the pasturing did not appear to have seriously affected reproduction. Results are presented in table 6.

Both seedling and sprout growth were counted as reproduction. While general observation showed that unpastured cutover lands eventually reproduced to trees, the amount of seedling reproduction noted on the plots was very limited. Sprout growth

Table 6. Frequency Percentages of Tree Species Occurring in Reproduction on Tenth-Acre Cutover Plots on Different Sites

Species	Valley and cove	Moist slope	Upland	Ridge	Dry slope	All sites
			Frequency percentage			
Ash, black	30	20	5	0	0	11
Ash, green	10	8	5	0	0	5
Aspen	50	72	65	60	80	68
Aspen, large-toothed	0	12	10	10	10	9
Basswood	60	16	10	0	0	14
Birch, paper	20	44	0	20	20	22
Boxelder	10	8	10	20	0	8
Butternut	30	12	5	0	10	11
Cherry, black	0	4	25	30	30	22
Elm, American	20	8	20	0	5	13
Elm, slippery	30	16	30	0	15	19
Hawthorn	0	0	10	0	5	4
Hickory, bitternut	0	4	10	10	15	8
Hickory, shagbark	0	20	25	20	30	21
Ironwood	20	16	15	0	0	11
Juneberry	0	0	10	0	0	2
Oak, bur	10	4	15	20	30	15
Oak, pin	0	0	30	30	25	16
Oak, red	10	56	40	10	20	33
Oak, scarlet	0	0	5	20	10	6
Oak, white	0	16	20	30	30	20
Walnut, black	30	8	0	0	5	7
BASIS—number of plots	10	25	20	10	20	85

accounted for slightly over 92 per cent of the reproduction, seedlings less than 8 per cent. Wide variations in the density of reproduction were characteristic. Young stands of most species usually sprouted vigorously and provided good stocking. Older trees failed to sprout in many cases. *Corylus, Cornus,* and *Rubus* generally formed a dense shrub cover where reproduction failed to get started.

Because of sprout reproduction there was a strong tendency for composition of the new stand to be similar to that of the cut stand. Some species often failed to reproduce, however, and their frequencies therefore were lower on the cutover areas. This is illustrated by a comparison of frequencies in tables 6 and 3.

Some species, notably aspen, paper birch, and black cherry, have become more abundant on the cutover areas. Aspen, when present in the old stand, often dominated the reproduction to the practical exclusion of other species. It is shown to occur on all sites, but its highest frequency is on the dry slopes, where it occurred on 80 per cent of cutover plots. The low frequencies of many species on the reproduction plots may be explained also by the fact that only one or two species were found on a number of plots.

The principal effect of clear cutting on stand composition has been to increase markedly the aspen and paper birch at the expense of other species. Hawthorn, boxelder, and Juneberry were found in small amounts. These species are found, as a rule, only on more open sites.

Frequency of Vegetative Species in Virgin Oak

Frequency percentages were determined for the flowering plant and fern species associated with undisturbed oak type forests on 50 hundredth-acre and 500 mil-acre plots. Ten one-milacre plots were laid out on alternate sides of the centerline on the tenth-acre plots located in virgin forest. Such forests were limited to moist slope and upland sites and the data therefore do not represent an average of what may be found in most stands. Indeed, virgin forest areas were found to be extremely rare and the entire region had to be searched carefully to locate and sample the 50 areas. They are really representative of red oak or red oak–white oak stands.

Plant records were made for each mil-acre plot and the results from each 10 of these summarized for hundredth-acre plots. (See table 7.) Doubtful specimens were checked with herbarium material of the Botany Department, University of Minnesota.

Table 7. Frequency Percentages for Species of Associated Vegetation on One-Hundredth- and One-Thousandth-Acre Plots in the Oak Type of Southeastern Minnesota

Species	Hundredth-acre plots	Mil-acre plots
	Frequency percentage	
SHRUBS		
Celastrus scandens L.	22	7
Cornus alternifolia L.	10	5
Cornus candidissima Marsh.	40	18
Cornus rugosa Lam.	26	10
Corylus americana Walt.	58	25
Diervilla lonicera Mill.	6	2
Lonicera dioica glaucescens (Rydberg) Butters	6	1
Lonicera prolifera (Kirchner) Rehder	6	1
Menispermum canadensis L.	16	5
Parthenocissus quinquefolia (L.) Planch.	52	20
Physocarpos opulifolius (L.) Maxim.	6	1
Prunus virginiana L.	30	8
Rhus glabra L.	4	1
Rhus toxicodendron L.	38	18
Ribes americanum Mill.	6	1
Ribes cynosbati L.	16	2
Ribes missouriense Nutt.	4	.....
Rubus nigrobaccus L. H. Bailey	18	8
Rubus occidentalis L.	10	2
Rubus strigosus Michx.	28	8
Smilax hispida Muhl.	4	.....
Vitis vulpina L.	50	50
Xanthoxylum americanum L.	4	1
HERBS		
Achillea millefolium L.	2	.....
Actaea alba (L.) Mill.	4	1
Actaea rubra (Ait.) Willd.	14	4
Agrimonia striata Michx.	16	5
Amphicarpa pitcheri T. & G.	62	28
Anemone canadensis L.	12	5
Anemone virginiana L.	20	6
Anemone cylindrica Gray	10	3
Antennaria plantaginifolia (L.) Richards	8	2
Apocynum androsaemifolium L.	8	2
Aquilegia canadensis L.	10	2
Aralia nudicaulis L.	76	36
Aralia racemosa L.	18	5
Arisaema triphyllum (L.) Schott	10	3
Asarum canadense (Tourn.) L.	12	5
Aster sagittifolius Wedemeyer	12	5
Carex pennsylvanica Lam.	74	42
Caulophyllum thalictroides (L.) Michx.	24	7
Circaea lutetiana L.	20	7
Cryptotaenia canadensis (L.) DC.	20	9
Cypripedium parviflorum pubescens (Willd.) Knight	20	3
Desmodium grandiflorum (Walt.) DC.	86	27
Eupatorium urticaefolium Richard.	54	22
Fragaria americana Porter	30	11
Galium triflorum Michx.	42	21
Galium aparine L.	6	3
Geranium maculatum L.	14	5
Heliopsis scabra Dunal.	10	4
Hepatica triloba Chaix.	14	6
Heuchera hispida Pursh.	20	6
Hydrophyllum virginianum L.	8	3
Hystrix patula Moench.	10	3
Impatiens biflora Walt.	4	1
Impatiens pallida Nutt.	2	1
Laportea canadensis (L.) Gaud.	6	3
Lappula virginiana (L.) Greene	14	5
Lathyrus venosus Muhl.	4	1
Maianthemum canadense Desf.	6	1

Table 7—Continued

Species	Hundredth-acre plots	Mil-acre plots
HERBS—Continued		
Melampyrum lineare Lam.	4	1
Mitella diphylla L.	8	2
Monarda fistulosa L.	8	3
Monotropa uniflora L.	4	1
Osmorhiza claytoni (Michx.) Clarke	30	11
Oxalis violacea L.	4	1
Panax quinquefolium L.	2	.....
Petasites palmatus (Ait.) Gray	6	1
Phryma leptostachya L.	16	5
Plantago major L.	2	.....
Poa pratensis L.	10	5
Podophyllum peltatum L.	4	1
Polemonium reptans L.	8	2
Polygonatum biflorum (Walt.) Ell.	12	4
Polygonatum commutatum (R. & S.) Dietr.	4	1
Prenanthes alba L.	10	1
Prunella vulgaris L.	4	.....
Ranunculus abortivus L.	14	5
Sanguinaria canadensis L.	18	6
Sanicula gregaria Bicknell	44	15
Smilacina racemosa (L.) Desf.	58	21
Smilax herbacea (L.)	28	8
Solidago canadensis L.	16	5
Solidago latifolia L.	36	15
Taraxacum officinale Weber	4	1
Thalictrum dioicum L.	58	24
Tiarella cordifolia L.	8	2
Trillium grandiflorum (Michx.) Salisb.	10	2
Triosteum aurantiacum Bicknell	4	1
Uvularia grandiflora Sm.	44	15
Viola conspersa Reichenb.	2	.....
Viola nephrophylla Greene	4	1
Viola pubescens Ait.	10	2
Viola sororia Willd.	4	1
FERNS		
Adiantum pedatum L.	42	16
Aspidium spinulosum (O. F. Muller) Sw.	6	2
Asplenium Filix-femina (L.) Bernh.	26	9
Botrychium virginianum (L.) Sw.	4	1
Onoclea sensibilis L.	4	1
Osmunda claytoniana L.	30	15
Polypodium vulgare L.	2	.....
Pteris aquilina L.	38	11

Basis: 50 hundredth-acre plots and 500 mil-acre plots.

The primary purpose of this part of the study was to define the natural oak forest community and to furnish a measure by which it could be compared with other forest communities.

Twenty-three species of shrubs, 72 species of herbs, and 8 species of ferns were found on the plots. Frequency percentages varied widely, but are considerably higher on the hundredth- than on the mil-acre plots. If species with frequency percentages of 50 or more on the hundredth-acre plots are selected as typical, the list includes *Corylus americana, Parthenocissus quinquefolia, Vitis vulpina, Amphicarpa pitcheri, Aralia nudicaulis, Carex pennsylvanica, Desmodium grandiflorum, Eupatorium urticaefolium, Smilacina racemosa,* and *Thalictrum dioicum.* If those above 40 per cent are selected, then the following are added to the above list: *Cornus candidissima, Galium triflorum, Sanicula gregaria, Uvularia grandiflora,* and *Adiantum pedatum.* Lowering the percentage to 30 adds *Prunus virginiana, Rhus toxicodendron, Fragaria americana, Osmorhiza claytoni, Solidago latifolia, Osmunda claytoniana,* and *Pteris aquilina.* Together the above species may be considered as the most representative of the plant species associated with the oak forests of southeastern Minnesota.

The associated vegetation was analyzed according to the numbers of species of flowering herbs, shrubs, and ferns found on the individual hundredth-acre plots. The range in numbers of species on the plots was found for the flowering herbs to be from 5 to 22, for shrubs from 0 to 8, for ferns from 0 to 4, and all plants from 6 to 26 (see table 7). On the average, there were 19 species of plants associated with the trees on hundredth-acre plots—14 flowering herbs, 4 shrubs, and 1 fern.

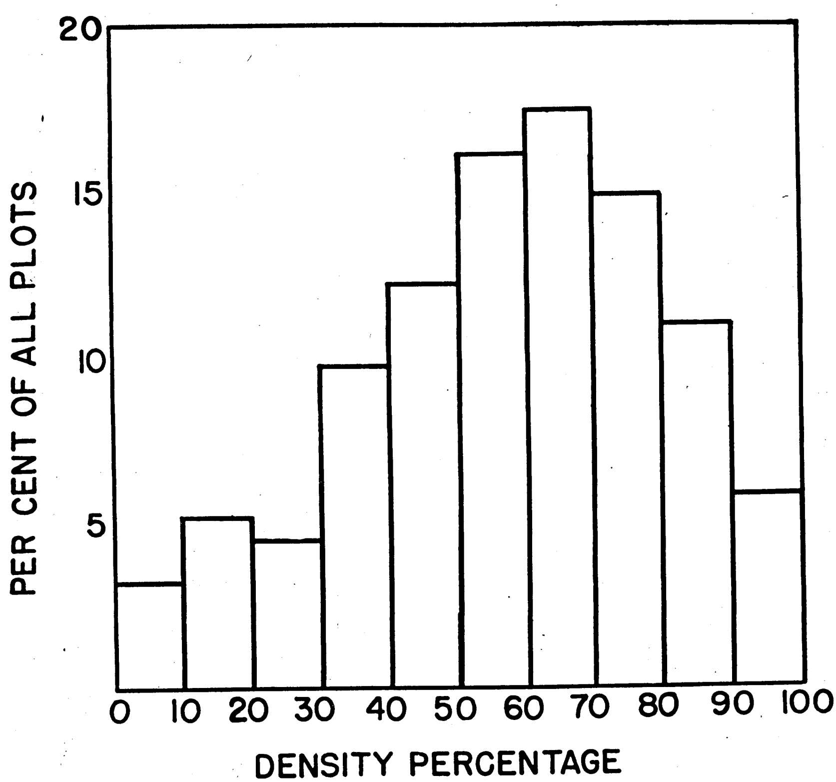

FIG. 2. Frequency distribution of density percentages of herbaceous vegetation in the oak-hickory forests of southeastern Minnesota.

Density of Herbaceous Vegetation

To describe further, quantitatively, the oak community, density of herbaceous vegetation was estimated on 200 plots one meter square. They were located on the virgin tenth-acre plots and selected by systematic location on alternate sides of the centerline of the plot, 10 to a tenth acre.

A frame one meter square divided by strings into 100 equal squares was used to facilitate estimates of density determined as the percentage of surface area covered by vegetation.

Results are given in figure 2. The 60 to 70 per cent density class has the greatest frequency of occurrences, almost 18 per cent of all plots falling in this class. The frequency distribution is quite regular; however, it has a positive skewness because of the small number of plots falling into the 0 to 30 per cent density classes.

A relatively high density of herbaceous vegetation is shown for the oak community. Few plots contained bare soil. The openings consisted mainly of leaf litter or bare rock. Had no rock outcrop occurred in some of the plots the average density would have been higher. The density is affected also by slope. Although no careful measurements were made, field notes indicate that steeper slopes have lower densities of herbaceous vegetation than more level areas.

Forest Growth

The productive capacity of any area for forest growth can best and most conveniently be measured by determining its site index and site quality. Site index is defined as the height in feet of average-diameter dominant and codominant trees at the age of 50 or 100 years, used as an indicator of site quality or productivity class.

Based upon extensive data from oak stands in central and eastern United States, Schnurr *(37)* has prepared detailed yield tables.

Site Index

Site index values were determined in the conventional manner *(39)* for oak stands on the five physiographic site classes previously recognized. An additional site class was recognized in the undisturbed (unpastured, unburned, and uncut) upland and moist slope situations. This sixth category was set up for the purpose of determining differences in site quality resulting from

Table 8. Site Index Values for Different Physiographic Site Conditions

	(1) Dry slope	(2) Ridge (narrow)	(3) Upland (level to rolling)	(4) Moist slope	(5) Valley and cove	(6) Upland and moist slope (undisturbed)
	20	35	40	48	54	58
	23	36	41	50	57	60
	26	38	44	51	58	62
	28	40	44	52	58	63
	29	41	45	52	60	64
	30	41	46	53	60	65
	31	41	46	54	66	65
	32	42	47	54	70	66
	34	42	47	54	70	68
	34	43	48	54	71	......
	34	44	48	55	......	......
	35	45	49	55	......	......
	35	46	49	55	......	......
	36	......	49	55	......	......
	36	......	50	56	......	......
	37	......	50	56	......	......
	38	......	50	58	......	......
	40	......	50	59	......	......
	43	......	50	60	......	......
	......	......	50	60	......	......
	......	......	51	62	......	......
	......	......	51	......	......	......
	......	......	53	......	......	......
	......	......	53	......	......	......
	......	......	53	......	......	......
	......	......	54	......	......	......
	......	......	54	......	......	......
	......	......	55	......	......	......
	......	......	55	......	......	......
	......	......	56	......	......	......
	......	......	56	......	......	......
	......	......	57	......	......	......
	......	......	58	......	......	......
	......	......	60	......	......	......
	......	......	60	......	......	......
	......	......	61	......	......	......
	......	......	65	......	......	......
I*	32.7	41.1	51.2	54.3	62.4	63.4
n†	19	13	37	21	10	9

* Mean site index.
† Number of observations.

disturbances. A total of 109 determinations were made with the results given in table 8. A progression of increasing site quality is shown to occur from sites 1 to 6. Dry slope situations have a mean site index value of 32.7, narrow ridge 41.1, upland 51.2, moist slope 54.3, valley and cove 62.4, and undisturbed upland and moist slope 63.4. This arrangement evidently is in good agreement with the physical aspects of the sites. Growing conditions would be expected to be most severe on the steep south and west facing slopes with shallow, rocky soil, and relatively more favorable on the less severe exposures with deeper soils and better conditions of soil and moisture.

Schnurr *(37)* found in his studies that white oaks decrease and black oaks increase in number with increasing site quality.

Also the white oaks were found to grow more slowly than the members of the black oak group. Both of these conclusions are corroborated by results of this study and give added explanation for the lower site index values on the drier sites.

It is noteworthy that site index values for totally undisturbed upland and moist slopes are about the same as for the valley and cove locations, but higher than upland and moist slope sites that have been subjected to varying amounts of disturbance. Evidently disturbances such as grazing and fire have caused a certain amount of site deterioration.

Oak Stands Compared with Normal Yield Values

Since oak forests on the better sites in southeastern Minnesota contain a high proportion of red oak or northern red oak and since these species are among the most vigorous and rapidly growing of the black oak group, a comparison of values from a number of selected stands was made with the normal yield table values.

The stands were compared with yield table values regarding number of trees per acre, basal area per acre, and average D.B.H. Average diameters were compared by the ratios of the basal areas. Values are expressed as a percentage of the normal, and the pertinent data for a comparison of the 14 selected plots are shown in table 9.

The 14 plots were selected from a larger available number as representing the best stand conditions, having especially a favorable basal area and a practically complete crown canopy. All of the sample stands contained a high proportion of red oak or, more commonly, northern red oak. White oak and shagbark hickory were present in lesser amounts, with occasional individuals of other species.

It is strikingly evident from table 9 that the stands do not have similar normality percentages with respect to number of trees, basal area, and average D.B.H. All 14 of the stands were markedly understocked on a basis of number of trees per acre. Actual normalities varied from 23 to 81 per cent but were mostly around 50 per cent, indicating about half normal stocking. Basal areas, on the other hand, compared very favorably with normal yield table values and in five of the 14 stands actually exceeded the normal basal area, in the most extreme case, plot 8, by 21 per cent. In all cases the average diameter of trees on the sample plots exceeded the normal. The extreme case is plot 14, a 90-year stand with 23 per cent of the normal number of trees, 91 per cent

Table 9. Comparison of Some Oak Stand Values from Southeastern Minnesota with Normal Yield Table Values

	Age (years)	Site index	Trees per acre	Basal area per acre	Average D.B.H.
Normal	16	65	2,343	59	2.2
Plot 1	16	65	950	56	3.3
Per cent of normal	......	......	41	95	......
Normal	40	56	682	91	5.0
Plot 2	40	56	340	68	6.1
Per cent of normal	......	......	50	75	149
Normal	47	52	636	95	5.5
Plot 3	47	52	330	71	6.3
Per cent of normal	......	......	52	75	131
Normal	48	56	592	96	5.4
Plot 4	48	56	480	106	6.4
Per cent of normal	......	......	81	110	140
Normal	54	53	536	100	5.9
Plot 5	54	53	280	79	7.2
Per cent of normal	......	......	52	79	149
Normal	56	55	488	103	6.2
Plot 6	56	55	280	97	8.4
Per cent of normal	......	......	57	94	183
Normal	60	57	425	106	6.8
Plot 7	60	57	260	98	8.3
Per cent of normal	......	......	61	92	149
Normal	65	60	353	112	7.6
Plot 8	65	60	160	136	12.5
Per cent of normal	......	......	45	121	270
Normal	68	53	408	110	7.0
Plot 9	68	53	110	55	9.6
Per cent of normal	......	......	27	50	188
Normal	70	55	372	112	7.4
Plot 10	70	55	150	138	13.0
Per cent of normal	......	......	40	114	308
Normal	72	55	362	114	7.6
Plot 11	72	55	200	132	10.5
Per cent of normal	......	......	55	116	191
Normal	72	50	408	111	7.1
Plot 12	72	50	200	93	9.2
Per cent of normal	......	......	49	84	168
Normal	82	55	330	121	8.2
Plot 13	82	55	230	129	10.2
Per cent of normal	......	......	70	107	154
Normal	90	50	346	124	8.1
Plot 14	90	50	80	113	16.1
Per cent of normal	......	......	23	91	395

normal basal area, but 395 per cent normal with respect to basal area of the mean tree diameter of the normal stand.

There are a number of factors which might account for the marked departures from normal. The size of plot, only one-tenth acre, is somewhat small for yield plots, and slight errors of sampling would be magnified when expressed on a per acre basis. It is believed that the errors involved here, if any, are insufficient to account for the differences. Plots were carefully checked to balance the areas of crowns of trees within each plot, which extended over the plot boundaries, with crown area inside the plot occupied by trees outside.

The high percentage of rapidly growing northern red oak and the small percentage of slower growing white oak and hickory occurring on the sample plots, as compared with the greater proportion of white oak on the yield table plots used by Schnurr, probably accounts in part for the greater mean diameters as well as the smaller numbers of trees.

Furthermore, there were fewer small understory trees and a much smaller number of associated species than on plots used in construction of the normal yield tables. The occurrence of small understory trees tends to reduce mean stem diameter and increase the number of trees per acre without adding appreciably to basal area. As a number of the plots had good-sized dominants almost exclusively, this must be an important reason for the marked differences.

Since many of the plots were so markedly understocked with respect to number of stems, it is highly probable that they always have been so. Understocked stands have more growing space per tree, and diameter growth rate would therefore be more rapid than on fully stocked stands where competition among individual trees would be much more intense. Evidence in support of this is the increased rate of diameter growth brought about by thinnings, demonstrated and corroborated by many carefully planned experiments *(1, 18, 41)*. The work of Meyer *(31)* in showing that understocked Douglas fir stands grow toward normality also is significant.

Normal stands actually represent an unusual condition. Very few sample plots would be expected to conform closely to yield table values. The marked departures from the normal condition illustrated by the 14 sample plot records may or may not be unusual, but they nevertheless have important implications regarding stand management, particularly as applied to the oak forests of this region. The evidence supports the statement of Gevorkiantz and Hosley *(15)* in quoting several Russian investigators to the effect that full stocking and utilization of site factors depend more on crown density than on number of trees per acre. Schnurr *(37)* likewise found no significant correlation between stand volume and density measured as number of trees per acre.

These conditions explain in large part the differences found in mean growth rates of dominant trees presented in this study as compared with the rate of mean diameter increase for normal stands.

Methods of Growth Study Used

The entire diameter growth history of the trees was obtained in this study by taking increment borings to the pith or first annual ring of each tree, where this was possible, with the use of 10- or 12-inch Swedish increment borers. Where trees were larger than 20 to 24 inches D.B.H., the complete increment could not be obtained.

The number of annual rings required to grow each inch of radius or each two inches of diameter was counted and the results compiled in table form along with the other tree records. Thus a complete record of diameter growth was obtained for each tree where the entire increment core was available. Tables were made for each species and values for the different crown or tree classes were kept in separate columns. Statistical information then could be summarized readily on a calculator.

Since the diameter growth of trees is often eccentric, the distance from the pith to the cambium was frequently not equal to one half the diameter inside bark. A correction for eccentricity therefore was made by taking the tree diameter inside bark as equal to the D.B.H. outside bark less double bark thickness. If the length of the increment core did not correspond to one half the true diameter inside bark, a correction factor was determined from the relationship, length of increment divided by true radius. If the increment core equalled the true radius, no correction was necessary. Assuming that with a true radius of 10 inches the increment core were only 8 inches, then in place of counting the number of rings in the successive inches of radial growth, they were counted in each successive 0.8 inch from the first to the last ring. In case the core were longer than the true radius, the distance for each ring count would be greater than one inch. The correction in this way is distributed throughout the period of diameter growth. While growth may be eccentric for only a part of the tree's life, observations indicated that it usually was continued through all or a considerable proportion of the time.

Fractional parts of an inch, often remaining in the ring counts, were not considered unless there was at least one-half inch in cases where rings per inch did not exceed 10, or at least one-quarter inch where number of rings exceeded 20 per inch.

Current growth was always classified according to the current tree or crown classification. However, trees at present dominant may have been suppressed earlier in life, or trees now suppressed may have been dominant at another time. Crown class may change several times during the lifetime of a tree. To aid in the classification of trees for past periods, growth tables based upon current crown or tree class and D.B.H. were constructed. For example, a 14-inch dominant red oak tree was found to have 12 rings in the last inch of radial growth, but in growing from 4 to 6 inches in diameter 19 years were required. Since currently classified codominant red oak trees were found to require from 15 to 28 years in growing from 4 to 6 inches in diameter, it seems probable that the 14-inch tree was codominant while in the 4- to 6-inch class. Furthermore, the changes in tree class are clearly shown on the increment cores. Usually the changes are quite abrupt and growth history can be judged with considerable accuracy through a study of the increment cores, even without detailed data on each tree. It is even probable that the increment core may be a more accurate criterion than the forester's judgment for placing trees in their proper classes.

Where trees were larger than 24 inches D.B.H., the first ring could not be reached with the increment borer. It was assumed in such cases that an average cross section was taken. Obviously, any correction for eccentricity would be impossible without having the entire radius to the first ring.

A possible defect in using the past growth history of large dominant trees as a basis for predicting average growth rates of the dominant class is that the growth rate of the better, more successful trees probably is greater than the average. Meyer *(30)*, for instance, has shown that even-aged stands of trees have a more or less normal distribution of trees around mean stand diameter. If only the trees above mean diameter were measured, the resulting rate of diameter growth would be greater than for the stand as a whole. However, since the trees smaller than the average are often eliminated by competition in the developing stand, their influence on the growth rate of final crop trees may be small. The effect of increasing mean stand diameter by elimination of the smaller, slower growing trees has been referred to by Meyer *(33)* as "false diameter increment." The use of past growth records of successful dominant trees, probably in larger proportion than they would occur in younger stands, therefore does not seem undesirable. The average growth rates obtained in this study probably could be achieved in managed stands.

Table 10. Average Number of Years Required for Various Tree Species of Different Diameter to Grow Two Inches

	Diameter class of trees—inches*																Basis No. trees
	1	3	5	7	9	11	13	15	17	19	21	23	25	27	29	31	
	Average number of years to grow 2 inches																
Acer saccharinum																	
Dominant—flood plain	7	6	5	6	6	7	7	7	7	8	......	......	......	......	......	......	333
Dominant—upland	9	8	9	9	10	12	10	......	......	......	......	......	......	......	......	......	61
Codominant—flood plain	10	12	13	17	......	......	......	......	......	......	......	......	......	......	......	......	8
Acer saccharum																	
Predominant	12	9	8	7	8	8	8	10	12	......	......	......	......	......	......	......	75
Open growth—dominant	11	9	9	7	7	7	7	8	10	10	10	......	......	......	......	......	106
Dominant—exclusive of open growth	14	13	11	10	10	11	12	12	13	14	......	......	......	......	......	......	529
Dominant—all trees	13	12	11	10	10	10	11	11	13	14	14	15	......	......	......	......	638
Codominant	17	17	17	......	......	......	......	......	......	......	......	......	......	......	......	......	25
Intermediate	21	23	22	......	......	......	......	......	......	......	......	......	......	......	......	......	24
Betula nigra																	
Dominant	8	6	6	6	7	7	8	10	9	8	......	......	......	......	......	......	177
Betula papyrifera																	
Dominant	9	10	11	12	13	13	14	15	......	......	......	......	......	......	......	......	470
Codominant	17	19	21	24	......	......	......	......	......	......	......	......	......	......	......	......	20
Dominant—moist sites	9	9	10	12	12	13	14	15	......	......	......	......	......	......	......	......	413
Dominant—dry sites	10	13	15	15	20	......	......	......	......	......	......	......	......	......	......	......	57
Carya cordiformis																	
Dominant	11	11	11	13	13	11	16	......	......	......	......	......	......	......	......	......	170
Codominant	15	17	17	18	19	......	......	......	......	......	......	......	......	......	......	......	17
Intermediate	22	26	33	......	......	......	......	......	......	......	......	......	......	......	......	......	10
Carya ovata																	
Dominant—all sites	13	13	14	15	17	22	23	27	32	......	......	......	......	......	......	......	601
Open growth—dominant	10	11	11	13	13	12	14	......	......	......	......	......	......	......	......	......	121
Dominant—moist sites	12	12	13	14	17	22	23	27	32	......	......	......	......	......	......	......	553
Dominant—dry sites	17	17	20	21	......	......	......	......	......	......	......	......	......	......	......	......	48
Dominant—old growth	......	......	29	32	31	34	......	......	......	......	......	......	......	......	......	......	18
Codominant	22	23	23	24	......	......	......	......	......	......	......	......	......	......	......	......	26
Intermediate	22	23	40	......	......	......	......	......	......	......	......	......	......	......	......	......	22
Suppressed	33	39	......	......	......	......	......	......	......	......	......	......	......	......	......	......	12

* Diameter in inches at breast height inside bark.

Table 10—Continued

	Diameter class of trees—inches*																
	1	3	5	7	9	11	13	15	17	19	21	23	25	27	29	31	Basis No. trees
	Average number of years to grow 2 inches																
Celtis occidentalis																	
Dominant	8	9	9	9	10	10	11	9	9	10	......	......	......	......	......	......	65
Codominant	20	19	20	20	......	......	......	......	......	......	......	......	......	......	......	......	6
Intermediate to suppressed	31	33	25	......	......	......	......	......	......	......	......	......	......	......	......	......	6
Fraxinus nigra																	
Dominant	11	10	10	11	11	11	10	12	12	......	......	......	......	......	......	......	28
Codominant	17	17	17	17	25	......	......	......	......	......	......	......	......	......	......	......	14
Intermediate	22	20	......	......	......	......	......	......	......	......	......	......	......	......	......	......	9
Suppressed	34	32	......	......	......	......	......	......	......	......	......	......	......	......	......	......	7
Fraxinus pennsylvanica lanceolata																	
Predominant and open growth dominant	7	5	6	6	6	7	7	7	7	7	......	......	......	......	......	......	166
Dominant	9	8	8	8	9	9	10	10	11	9	8	......	......	......	......	......	346
Codominant	16	17	20	20	25	30	......	......	......	......	......	......	......	......	......	......	8
Intermediate	21	22	25	......	......	......	......	......	......	......	......	......	......	......	......	......	5
Suppressed	32	42	......	......	......	......	......	......	......	......	......	......	......	......	......	......	4
Juglans cinerea																	
Predominant and open growth dominant	7	5	5	6	6	6	6	7	7	......	......	......	......	......	......	......	138
Dominant—all trees	7	7	7	8	8	8	8	9	8	9	10	......	......	......	......	......	542
Dominant—exclusive of open growth	8	7	8	8	8	8	9	10	9	......	......	......	......	......	......	......	399
Codominant	13	13	15	14	14	15	......	......	......	......	......	......	......	......	......	......	19
Intermediate	13	15	......	......	......	......	......	......	......	......	......	......	......	......	......	......	4
Juglans nigra																	
Predominant and open growth dominant	5	5	5	6	6	6	7	8	8	......	......	......	......	......	......	......	374
Dominant—all trees	7	6	6	7	7	8	9	8	9	11	13	14	......	......	......	......	807
Dominant—exclusive of open growth	8	8	8	7	8	9	10	9	11	......	......	......	......	......	......	......	428
Codominant	12	12	15	14	......	......	......	......	......	......	......	......	......	......	......	......	9
Populus deltoides																	
Dominant	4	4	4	4	4	5	5	6	5	6	5	7	7	7	6	......	480

* Diameter in inches at breast height inside bark.

Table 10—Continued

	Diameter class of trees—inches*																Basis No. trees
	1	3	5	7	9	11	13	15	17	19	21	23	25	27	29	31	
	Average number of years to grow 2 inches																
Populus tremuloides																	
Dominant	8	9	9	10	13	14	18	......	......	......	......	......	......	......	......	......	315
Prunus serotina																	
Dominant	7	6	7	9	8	10	9	11	11	......	......	......	......	......	......	......	120
Quercus alba																	
Predominant—maximum growth rate of single tree	10	8	7	7	7	8	7	6	8	11	......	......	......	......	......	......	....
Open growth—dominant	9	9	9	10	10	10	11	11	12	12	14	14	15	16	......	......	315
Dominant	11	12	14	14	14	15	17	18	16	15	17	15	17	16	......	......	1,060
Codominant	23	25	27	30	31	34	33	......	......	......	......	......	......	......	......	......	102
Intermediate	27	30	45	38	......	......	......	......	......	......	......	......	......	......	......	......	32
Suppressed	42	49	54	......	......	......	......	......	......	......	......	......	......	......	......	......	13
Quercus borealis																	
Predominant	8	7	7	7	7	7	8	7	8	9	10	11	......	......	......	......	202
Open growth—dominant	8	7	7	7	7	8	8	8	8	8	9	11	......	......	......	......	166
Predominant—maximum growth rate of single tree	6	5	4	5	5	4	6	6	7	6	......	......	......	......	......	......	....
Dominant	10	10	11	11	11	11	11	10	11	12	13	14	12	13	......	......	1,876
Codominant	17	19	22	23	22	25	25	......	......	......	......	......	......	......	......	......	173
Intermediate	20	24	27	30	......	......	......	......	......	......	......	......	......	......	......	......	39
Suppressed	26	28	36	......	......	......	......	......	......	......	......	......	......	......	......	......	18
Quercus ellipsoidalis																	
Predominant	8	7	7	7	7	8	8	9	9	9	8	12	......	......	......	......	178
Predominant—maximum growth rate of single tree	8	7	9	7	5	5	5	6	7	......	......	......	......	......	......	......	....
Dominant	9	9	10	10	10	11	10	10	9	9	8	12	......	......	......	......	1,163
Codominant	16	16	17	18	......	......	......	......	......	......	......	......	......	......	......	......	27
Quercus macrocarpa																	
Predominant and open growth dominant	11	9	9	9	9	10	10	10	11	13	16	......	......	......	......	......	128
Dominant	13	14	13	13	13	13	13	12	13	13	16	......	......	......	......	......	562
Predominant—maximum growth rate of single tree	12	10	8	7	7	9	8	7	7	9	......	......	......	......	......	......	....

* Diameter in inches at breast height inside bark.

Table 10—Continued

	Diameter class of trees—inches*																Basis No. trees
	1	3	5	7	9	11	13	15	17	19	21	23	25	27	29	31	
	Average number of years to grow 2 inches																
Quercus macrocarpa (Continued)																	
Dominant—moist sites	13	12	12	12	12	11	13	12	13	13	16	......	......	......	......	......	500
Dominant—dry sites	21	24	22	22	24	33	......	......	......	......	......	......	......	......	......	......	59
Codominant	19	18	22	......	......	......	......	......	......	......	......	......	......	......	......	......	33
Intermediate	23	26	28	......	......	......	......	......	......	......	......	......	......	......	......	......	15
Suppressed	31	41	42	......	......	......	......	......	......	......	......	......	......	......	......	......	18
Salix nigra																	
Dominant	5	4	4	4	5	5	6	5	5	6	......	......	......	......	......	......	188
Tilia americana																	
Dominant	2	8	8	9	9	9	9	10	9	10	9	11	......	......	......	......	508
Predominant—maximum growth rate of single tree	7	7	6	7	8	7	6	8	9	12	......	......	......	......	......	......	....
Codominant	13	13	14	15	16	17	......	......	......	......	......	......	......	......	......	......	23
Intermediate	14	14	16	16	......	......	......	......	......	......	......	......	......	......	......	......	54
Ulmus americana																	
Dominant	8	7	7	8	8	7	9	9	9	9	......	......	......	......	......	......	80
Codominant	12	12	15	16	15	14	......	......	......	......	......	......	......	......	......	......	15
Intermediate	16	20	20	19	......	......	......	......	......	......	......	......	......	......	......	......	10
Ulmus fulva																	
Predominant and open growth dominant	6	5	5	5	5	5	5	6	7	7	9	9	10	9	10	11	152
Dominant—all trees	7	6	7	7	7	8	8	8	9	9	9	10	10	9	10	11	451
Dominant—exclusive of open growth	7	7	7	8	8	9	10	11	13	14	......	......	......	......	......	......	294
Codominant	13	13	16	16	15	17	......	......	......	......	......	......	......	......	......	......	34
Intermediate	18	17	16	......	......	......	......	......	......	......	......	......	......	......	......	......	....
Ulmus racemosa																	
Dominant	14	12	13	12	12	14	16	16	......	......	......	......	......	......	......	......	127
Predominant—maximum growth rate of single tree	9	7	6	6	7	7	8	9	......	......	......	......	......	......	......	......	......
Codominant	22	28	22	21	......	......	......	......	......	......	......	......	......	......	......	......	9
Intermediate	30	34	33	......	......	......	......	......	......	......	......	......	......	......	......	......	11
Suppressed	48	51	......	......	......	......	......	......	......	......	......	......	......	......	......	......	6

* Diameter in inches at breast height inside bark.

Table 11. Average Number of Years Required for Various Species to Reach Different Diameters Inside of Bark at Breast Height

	Diameter class of trees—inches															
	1	3	5	7	9	11	13	15	17	19	21	23	25	27	29	31
	Average number of years															
Acer saccharinum																
Dominant—flood plain	7	13	18	24	30	37	44	51	58	66	......	......	......	......	......	......
Dominant—upland	9	17	26	35	45	57	67	......	......	......	......	......	......	......	......	......
Codominant—flood plain	10	22	35	57	......	......	......	......	......	......	......	......	......	......	......	......
Acer saccharum																
Predominant	12	21	29	36	44	52	60	70	82	......	......	......	......	......	......	......
Open growth—dominant	11	22	29	36	43	50	57	65	75	85	95	......	......	......	......	......
Dominant—exclusive of open growth	14	27	38	48	58	69	71	83	96	114	......	......	......	......	......	......
Dominant—all trees	13	25	36	46	56	66	77	88	101	115	129	144	......	......	......	......
Codominant	17	34	51	......	......	......	......	......	......	......	......	......	......	......	......	......
Intermediate	21	44	66	......	......	......	......	......	......	......	......	......	......	......	......	......
Betula nigra																
Dominant	8	14	20	26	33	40	48	58	67	75	......	......	......	......	......	......
Betula papyrifera																
Dominant	9	19	30	42	55	68	82	97	......	......	......	......	......	......	......	......
Codominant	17	36	57	81	......	......	......	......	......	......	......	......	......	......	......	......
Dominant—moist sites	9	18	28	40	52	65	79	96	......	......	......	......	......	......	......	......
Dominant—dry sites	10	23	38	53	73	......	......	......	......	......	......	......	......	......	......	......
Carya cordiformis																
Dominant	11	22	33	46	59	70	86	......	......	......	......	......	......	......	......	......
Codominant	15	32	49	67	86	......	......	......	......	......	......	......	......	......	......	......
Intermediate	22	48	81	......	......	......	......	......	......	......	......	......	......	......	......	......
Carya ovata																
Dominant—all sites	13	26	40	55	72	94	117	144	176	......	......	......	......	......	......	......
Open growth—dominant	10	21	32	45	58	70	84	......	......	......	......	......	......	......	......	......
Dominant—moist sites	12	24	37	51	68	90	113	140	172	......	......	......	......	......	......	......
Dominant—dry sites	17	34	54	75	......	......	......	......	......	......	......	......	......	......	......	......
Dominant—old growth		...	29	61	92	126	......	......	......	......	......	......	......	......	......	......
Codominant	22	45	68	92	......	......	......	......	......	......	......	......	......	......	......	......
Intermediate	22	45	85	......	......	......	......	......	......	......	......	......	......	......	......	......
Suppressed	33	72	......	......	......	......	......	......	......	......	......	......	......	......	......	......

Table 11—Continued

	Diameter class of trees—inches															
	1	3	5	7	9	11	13	15	17	19	21	23	25	27	29	31
	Average number of years															
Celtis occidentalis																
Dominant	8	17	26	35	45	55	66	75	84	94	......	......	......	......	......	......
Codominant	20	39	59	79	......	......	......	......	......	......	......	......	......	......	......	......
Intermediate to suppressed	31	64	89	......	......	......	......	......	......	......	......	......	......	......	......	......
Fraxinus nigra																
Dominant	11	21	31	42	53	64	74	86	98	......	......	......	......	......	......	......
Codominant	17	34	51	68	93	......	......	......	......	......	......	......	......	......	......	......
Intermediate	22	42	......	......	......	......	......	......	......	......	......	......	......	......	......	......
Suppressed	34	66	......	......	......	......	......	......	......	......	......	......	......	......	......	......
Fraxinus pennsylvanica lanceolata																
Predominant and open growth dominant	7	12	18	24	30	37	44	51	58	65	......	......	......	......	......	......
Dominant	9	17	25	33	42	51	61	71	82	91	99	......	......	......	......	......
Codominant	16	33	53	73	98	128	......	......	......	......	......	......	......	......	......	......
Intermediate	21	43	68	......	......	......	......	......	......	......	......	......	......	......	......	......
Suppressed	32	74	......	......	......	......	......	......	......	......	......	......	......	......	......	......
Juglans cinerea																
Predominant and open growth dominant	7	12	17	23	29	35	41	48	55	......	......	......	......	......	......	......
Dominant—all trees	7	14	21	29	37	45	53	62	70	79	89	......	......	......	......	......
Dominant—exclusive of open growth	8	15	23	31	39	47	56	66	75	......	......	......	......	......	......	......
Codominant	13	26	41	55	69	74	......	......	......	......	......	......	......	......	......	......
Intermediate	13	28	......	......	......	......	......	......	......	......	......	......	......	......	......	......
Juglans nigra																
Predominant and open growth dominant	5	10	15	21	27	33	40	48	56	......	......	......	......	......	......	......
Dominant—all trees	7	13	19	26	33	41	50	58	67	78	91	105	......	......	......	......
Dominant—exclusive of open growth	8	16	24	31	39	48	58	67	78	......	......	......	......	......	......	......
Codominant	12	24	39	53	......	......	......	......	......	......	......	......	......	......	......	......
Populus deltoides																
Dominant	4	8	12	16	20	25	30	36	41	47	52	59	66	73	79	......
Populus tremuloides																
Dominant	8	17	26	36	49	63	81	......	......	......	......	......	......	......	......	......
Prunus serotina																
Dominant	7	13	20	29	37	47	58	69	80	......	......	......	......	......	......	......

Table 11—Continued

	Diameter class of trees—inches															
	1	3	5	7	9	11	13	15	17	19	21	23	25	27	29	31
	Average number of years															
Quercus alba																
Predominant—maximum growth rate of single tree	10	18	25	32	39	47	54	60	68	79	......	......	......	......	......	......
Open growth—dominant	9	18	27	37	47	57	68	79	91	103	117	131	146	162	......	......
Dominant	11	23	37	57	65	80	97	115	131	146	163	178	195	211	......	......
Codominant	23	48	75	105	136	170	203	......	......	......	......	......	......	......	......	......
Intermediate	27	57	102	140	......	......	......	......	......	......	......	......	......	......	......	......
Suppressed	42	91	145	......	......	......	......	......	......	......	......	......	......	......	......	......
Quercus borealis																
Predominant	8	15	22	29	36	43	51	58	66	75	85	96	......	......	......	......
Open growth—dominant	8	15	22	29	36	44	52	60	68	74	83	94	......	......	......	......
Predominant—maximum growth rate of single tree	6	11	15	20	25	29	35	41	48	54	......	......	......	......	......	......
Dominant	10	20	31	42	53	64	75	85	96	108	121	135	157	170	......	......
Codominant	17	36	58	81	103	128	153	......	......	......	......	......	......	......	......	......
Intermediate	20	44	71	101	......	......	......	......	......	......	......	......	......	......	......	......
Suppressed	26	54	90	......	......	......	......	......	......	......	......	......	......	......	......	......
Quercus ellipsoidalis																
Predominant	8	15	22	29	36	44	52	61	70	79	87	99	......	......	......	......
Predominant—maximum growth rate of single tree	8	15	24	31	36	41	46	52	59	......	......	......	......	......	......	......
Dominant	9	18	28	38	48	59	69	79	88	97	105	117	......	......	......	......
Codominant	16	32	49	67	......	......	......	......	......	......	......	......	......	......	......	......
Quercus macrocarpa																
Predominant and open growth dominant	11	20	29	38	47	57	67	77	88	101	117	......	......	......	......	......
Dominant	13	27	40	53	66	79	92	104	117	130	146	......	......	......	......	......
Predominant—maximum growth rate of single tree	12	22	30	37	44	53	61	68	75	84	......	......	......	......	......	......
Dominant—moist sites	13	25	37	49	61	72	85	97	110	123	139	......	......	......	......	......
Dominant—dry sites	21	45	67	89	113	146	......	......	......	......	......	......	......	......	......	......
Codominant	19	37	59	......	......	......	......	......	......	......	......	......	......	......	......	......
Intermediate	23	49	77	......	......	......	......	......	......	......	......	......	......	......	......	......
Suppressed	31	72	114	......	......	......	......	......	......	......	......	......	......	......	......	......

Table 11—Continued

	Diameter class of trees—inches															
	1	3	5	7	9	11	13	15	17	19	21	23	25	27	29	31
	Average number of years															
Salix nigra																
Dominant	5	9	13	17	22	27	33	38	43	49	......	......	......	......	......	......
Tilia americana																
Dominant	2	10	18	27	36	45	54	64	73	83	92	103	......	......	......	......
Predominant—maximum growth rate of single tree	7	14	20	27	35	42	48	56	65	77	......	......	......	......	......	......
Codominant	13	26	39	55	71	88	......	......	......	......	......	......	......	......	......	......
Intermediate	14	28	44	60	......	......	......	......	......	......	......	......	......	......	......	......
Ulmus americana																
Dominant	8	15	22	30	38	45	54	63	72	81	......	......	......	......	......	......
Codominant	12	24	39	55	70	84	......	......	......	......	......	......	......	......	......	......
Intermediate	16	36	56	75	......	......	......	......	......	......	......	......	......	......	......	......
Ulmus fulva																
Predominant and open growth dominant	6	11	16	21	26	31	36	42	49	56	65	74	84	93	103	114
Dominant—all trees	7	13	20	27	34	42	80	88	97	106	115	125	135	144	154	165
Dominant—exclusive of open growth	7	14	21	29	37	46	56	67	80	94	......	......	......	......	......	......
Codominant	13	26	42	58	73	90	......	......	......	......	......	......	......	......	......	......
Intermediate	18	35	51	......	......	......	......	......	......	......	......	......	......	......	......	......
Ulmus racemosa																
Dominant	14	26	39	51	63	77	83	99	......	......	......	......	......	......	......	......
Predominant—maximum growth rate of single tree	9	16	22	28	35	42	50	59	......	......	......	......	......	......	......	......
Codominant	22	50	72	93	......	......	......	......	......	......	......	......	......	......	......	......
Intermediate	30	64	97	......	......	......	......	......	......	......	......	......	......	......	......	......
Suppressed	48	99	......	......	......	......	......	......	......	......	......	......	......	......	......	......

Average growth figures do not represent fully stocked stand conditions. In fact, many stands sampled were markedly understocked if compared with normal yield table standards. Since average growth rates are presented for different crown and tree classes, the understocked condition of the stands is not a serious criticism. Actually conditions were sampled as they occurred and results therefore should be applicable to present conditions.

Silvical Characteristics of 23 Species

Growth statistics were compiled for each of the commercially important tree species in southeastern Minnesota and for the different crown classes in which each species was well represented. Where the species grew on markedly contrasting sites, data are presented for those conditions.

The statistics given are the mean number of years required to grow each two inches of diameter inside bark.

Crown classes follow the classification given by Hawley *(19)* in which dominant, codominant, intermediate, and suppressed are the four important divisions. It was found desirable, however, to use two additional categories: (1) "open growth" to take care of trees having developed in open stands and (2) "predominant" to indicate trees of exceptionally strong dominance grown under stand conditions. Such trees usually have excellent form with long boles and large crowns. They are generally the largest and most rapidly growing trees in the stand. Evidence from growth analyses indicates that predominant trees may be genetically superior. In some cases they were younger in age than surrounding smaller trees in the same stand. Such superior individuals should be selected as final crop trees and favored to permit maximum development.

In general, the growth data give remarkably smooth curves, varying with the growth characteristics of the species and graphically giving a clear picture of these growth characteristics.

A point of particular interest in the growth curves is the relative uniformity of growth rate of trees of different sizes in a given crown class. The dominant crown class especially is typified by growth curves approximating a straight line. In most species, however, the curves do fall slightly with increase in age.

It should be made clear that curves for the lower crown classes in few cases represent trees that have been in the same crown class during their entire lives. Only the most tolerant trees would be able to live for long as members of the lower crown classes.

Generally trees in these classes were capable of growing only one or at the most several inches in diameter without release. The average number of rings per inch of radius obscures the decline in rate of growth characteristic of these trees. Likewise the rate of growth of the larger dominant trees tends to compensate for the diminishing rate of diameter growth of smaller dominants.

The marked superiority in growth rates of dominant trees as compared with other crown classes indicates the advantages of maintaining strong, well-spaced dominant trees in managed stands, at least for the final crop trees. Because codominant and intermediate trees cannot reach large commercial sizes, their value in the stand should be primarily for trainers, to assist pruning, and to maintain satisfactory stand density.

Growth characteristics and other silvical information for the important tree species were determined from the growth statistics, the phytosociological data in this bulletin, field observations, and, in the case of silver maple and red oak, additional detailed studies. These are included in the summaries which follow for each of the various species listed in tables 10 and 11 (see pages 40-47).

Silver or Soft Maple

Silver maple in southeastern Minnesota occurs principally on river flood plains. Occasionally it is found on poorly drained upland. As a rule it grows in pure even-aged stands. Cottonwood, black ash, green ash, river birch, black willow, American elm, slippery elm, red maple, and boxelder are its common associates. It reproduces by seed only on open areas with high moisture content. This species coppices well when young stands are clear cut. Sprouting ability, however, is weak in mature or overmature trees. Silver maple is intolerant, and trees cannot survive for long in the lower crown classes. It is succeeded most commonly by American elm, slippery elm, green ash, and black ash.

Silver maple grows rapidly, especially in early life, in stands attaining maximum diameters of approximately 24 inches at breast height and heights of 80 to 90 feet. Mature trees are generally from 10 to 18 inches D.B.H. Maximum ages seldom exceed 100 years. In stands it has good form but in the open it has a short bole and a large, wide-spreading crown. The formative period is practically ended after 30 to 40 years. Dominant trees have a growing space ratio[2] requirement of 1.2 to 1.5 and trees

[2] $\frac{\text{Average crown spread (feet)}}{\text{D.B.H. (inches)}}$

seldom are found for which it is less than 1.0. At maturity, clear lengths of 20 to 40 feet are characteristic, with bole lengths from 20 to 50 feet. Rotations of 60 to 80 years seem to be most appropriate for the production of commercial timbers.

Growth characteristics of silver maple were studied in more detail than for most species. Since a large amount of data were on hand the opportunity was used to make a number of correlations. Measurements for 57 silver maples selected from 20- to 60-year-old, even-aged well-stocked stands in the Mississippi River bottom were taken for this purpose.

Correlations were worked out between D.B.H. and crown spread; growing space and current growth rate; total height and bole length; age and bole length; age and clear length; total height and clear length; D.B.H. and clear length; D.B.H. and bole length; growing space ratio and bole length; bole length and clear length.

The first three correlations were statistically significant; the next two were without significance. There was a good correlation between total height and clear length, but none between D.B.H. and either clear length or bole length. There was no correlation between growing space and bole length, but there was a very significant correlation between bole length and clear length.

These data are inserted merely because someone may see a silvicultural value in them and want to pursue the study further.

Sugar Maple

Sugar maple in this region is limited in its distribution by physiographic factors, including soil. In the unglaciated section it is found on moist, protected sites, especially valley and cove locations. It is uncommon on loess uplands or on south and west slopes but abundant on certain sandy loam soils within the loess area. Sugar maple is most abundant on the young gray drift soils of the big woods area. It is fairly abundant in the vicinity of lakes within the adjacent prairie region.

Basswood, slippery elm, American elm, red oak, ironwood, butternut, green ash, black ash, bur oak, and bitternut hickory are its principal associates. It is very tolerant, often developing under suppression for 30 to 40 years. It reproduces abundantly from seed on favorable sites. Strong coppice shoots develop from stumps of young trees, but stumps of old trees coppice weakly or not at all.

Growth is slow to moderately rapid. Dominant trees average 10 to 15 annual rings per inch of radius. Diameters of 30 to 36 inches are attained, and heights of 70 to 80 feet. Mature trees usually are clear for about two logs. Ages of 200 to 300 years are often reached. The crowns are usually large and wide-spreading. Open-growth trees have rounded crowns and short boles.

River Birch

The range of river birch in Minnesota is very limited, being confined for the most part to the flood plains of the Mississippi River. It is fairly abundant south of Winona but rare north of this city. Occasional trees are found along the Root River for a short distance above its junction with the Mississippi. River birch occurs as scattered trees or groups, or may form small even-aged stands. The most characteristic location for this species is the river bank, only a few feet above the water level. It is not found growing naturally on the uplands but grows well when planted there.

Common associates of the river birch are black willow, silver maple, cottonwood, green ash, black ash, American elm, and slippery elm. It is intolerant and grows rapidly, reaching diameters of 24 to 30 inches and heights of 70 to 80 feet. Under favorable conditions it attains ages of 100 to 150 years, possibly more.

Apparently the seedlings are able to become established only on open areas with moist bare soil such as would occur from silt deposits along river flood plains. Coppicing is vigorous from young and middle-aged trees but weak from mature trees.

Paper Birch

Paper birch is found on a variety of upland sites in the unglaciated section, principally on slopes with rocky, residual soil, on dry ridges or slopes, or where cutting and fire have destroyed the previous forest cover. It is rare on gray drift soils in this region. Apparently there are two forms of paper birch. One is found on mesic sites, where it makes good development. The other is found on severe south and west exposures, and has a gnarled, stunted form often not more than 10 to 15 feet high at maturity. Paper birch is a pioneer tree and often forms pure stands on burned or cutover areas. It is unable to reproduce in competition with other timber species and is soon crowded out of mixed stands. On the severe south and west exposures it is able to persist because other species are unable to compete there.

On moist sites the paper birch is mixed with red oak, basswood, ironwood, butternut, and elm. On dry sites its principal associate is bur oak, and, on disturbed areas, aspen.

Paper birch is intolerant and rather short lived, most trees dying between ages of 60 and 100 years. Growth is quite rapid in young trees but older trees, as a rule, have declining growth rates. On good sites trees reach diameters of 12 to 16 inches and heights of 50 to 60 feet, but on the poorest sites diameters of only 4 to 5 inches and heights of 10 to 20 feet indicate mature specimens. Coppicing is abundant as long as trees maintain good vigor.

Birch, like aspen, has increased considerably in recent years because of cutting and fires.

Bitternut Hickory

Bitternut hickory is scattered through the upland forests of the region, occurring with both the oak-hickory and the maple-basswood types. It is never very abundant and is not found in pure stands.

Mature trees attain diameters of 8 to 14 inches D.B.H. and maximum heights of 50 to 60 feet. Growth is moderately rapid on good sites but slow on poor sites and in the lower crown classes. Ages seldom exceed 100 years although occasional specimens reach 150 years.

Bitternut hickory is intolerant to moderately tolerant. Suppressed or intermediate specimens are not able to persist for long. Reproduction is not abundant but seedlings are able to persist for a number of years and effect establishment if conditions are favorable. Coppice from young trees develops vigorously but in mature trees the ability to sprout from the stumps is much reduced.

Shagbark Hickory

The range of shagbark hickory in this region is limited to Houston, Fillmore, and Winona counties. It is most abundant in the oak-hickory forests of Houston County and much less so in the other two counties. Its frequency is greatest on the warmer, drier sites although it may be found on any upland site with loess or rocky residual soil. The growth of shagbark hickory is usually slow. Trees reach maximum diameters of 16 to 18 inches. Mature dominant trees more commonly are 8 to 12 inches when forest grown. Heights of 50 to 60 feet are attained on the better sites. Few trees exceed 150 to 200 years in age.

Except on lower quality sites, shagbark hickory is unable to grow as rapidly as its associates. Especially in stands where red oak is abundant the hickory is overtopped and suppressed. It is able, however, to withstand suppression for as long as 30 to 40 years and to make satisfactory recovery when released. Its reproduction in mixed stands is much more abundant than that of the oaks.

Young trees coppice vigorously but older trees sprout weakly. Heavy pasturing of woods inhibits coppicing.

Hackberry

Hackberry is found throughout this region, principally on flood plain sites, where it is associated with the elms and ashes. To a slight extent it is found on particularly moist sites in the maple-basswood forests, or as scattered trees in the oak stands of the prairie border area.

The growth characteristics of hackberry are very similar to those of elm. Growth is usually rapid, although intermediate, suppressed, or low vigor trees may have long periods with very slow diameter increase. A majority of hackberry trees begins growth under favorable conditions, but occasionally they may spend the first 20 to 30 years under suppression.

Mature trees usually range from 12 to 24 inches in diameter but sometimes are larger. Heights of 70 to 80 feet are reached. Trees mature at 100 to 150 years, and few specimens exceed 200 years in age.

Reproduction is almost entirely from seed although young trees coppice well. This species is fairly tolerant, and once established can grow well under a variety of moisture conditions as demonstrated by its occurrence in oak stands of the prairie border area as well as on river flood plains.

Black Ash

Black ash is primarily a species of river flood plains but occurs also on moist sites or poorly drained areas within the region. On the flood plains its principal associates are American elm, slippery elm, river birch, silver maple, green ash, cottonwood, and willow. It occurs as scattered individuals or in small groups on moist areas in the maple-basswood forests, and occasionally in red oak stands. It occurs also along drainage lines or on the borders of swampy depressions on upland areas. Altogether it is not sufficiently abundant to have great importance.

Most trees get started in openings but some, because of suppression, grow slowly for 20 to 40 years before they are released. Black ash, therefore, is tolerant to moderately tolerant.

Strong dominant trees grow rapidly but in the lower crown classes growth is very slow. Mature trees are usually 12 to 18 inches in diameter, but maximum diameters of 20 to 24 inches and heights from 60 to 70 feet are attained. Black ash matures at 100 to 120 years. Some individuals reach 160 years or more. Under management a rotation of 80 years should suffice to produce sawlogs of high quality.

Reproduction is chiefly by seed but coppice shoots develop well after clear cutting, even from large stumps.

Green Ash

Green ash and red ash here are considered as one because their growth characteristics apparently are identical and the many intermediate forms often make it impossible to distinguish between the two. Green ash occurs on both flood plain and upland sites throughout the region. It is prominent in the later stages of the flood plain succession and occasional in the maple-basswood community. It occurs infrequently in the oak-hickory forest, at times on rather dry sites.

On moist fertile sites growth is very rapid and even on relatively dry sites this species makes good growth. Dominant trees mature at 12 to 18 inches D.B.H. Maximum diameters of approximately 24 inches are attained and maximum heights of 60 to 70 feet. Although most trees mature at 80 to 100 years, trees 120 to 160 years old are not uncommon.

Trees of this species, with few exceptions, get established in openings and maintain an unusually uniform rate of growth. They are principally dominant or codominant, with very few individuals in the intermediate or suppressed classes. There is little evidence that green ash is capable of withstanding heavy suppression. It should be classed as intermediate in tolerance.

Reproduction is mainly by seed, but the species coppices well.

Butternut

In this region butternut is found along valleys and ravines on moist slopes or valley bottoms. It grows typically on the better sites mixed in stands of other species or in small groups. Sometimes it is found on upland sites where it is comparatively dry. It requires well-drained soils and therefore is absent from flood plains of the larger rivers which are subject to overflow.

Growth is very rapid, averaging for dominants 8 to 10 annual rings per inch of radius. Trees generally have wide-spreading crowns. In the open a large, rounded crown and a short bole are characteristic. When forest grown, however, the butternut often has very good form with clear lengths of 30 to 40 feet.

Trees mature at 80 to 100 years, and ages seldom exceed 150 years. Diameters at maturity are 12 to 20 inches, occasionally reaching 24 to 30 inches. Heights of 60 to 80 feet are attained on the better sites.

This species is moderately tolerant and will develop in small openings or beneath the canopies of open stands. It fails to effect establishment under dense stands.

Most reproduction develops as seedlings. Young trees coppice well but mature trees when cut seldom yield vigorous shoots.

Black Walnut

Black walnut grows on moist valley and ravine sites and to a limited extent is mixed with other species of the maple-basswood type. It has about the same site requirements as butternut but its range in the region is not so great. Its distribution follows the main drainage valleys extending through the three southern tiers of counties.

On favorable sites black walnut grows very rapidly to maximum diameters of 30 to 36 inches. Forest-grown trees are well formed with merchantable lengths of 30 to 40 feet, but more often trees of this species are found in open stands and have wide, rounded crowns and short boles. Mature trees generally range from 16 to 24 inches D.B.H. Heights are from 50 to 60 feet and occasionally to 70 feet or more.

Black walnut is relatively intolerant and can reproduce only under rather open conditions. It demands a large growing space and will not persist in the lower crown classes against strong competition. Reproduction is mainly from the nuts, but coppice sprouts develop vigorously from the stumps of young trees when cut. Mature trees do not coppice effectively.

Cottonwood

Cottonwood is primarily a species of the river flood plains. It is a pioneer, becoming established on fresh silt deposits of flood plains or, less frequently, on bared upland soils. As a rule it grows in pure, even-aged stands or in small groups. Stands are open and the crowns wide-spreading. Silver maple, black willow, American elm, black ash, green ash, and river birch are its common associates.

No other species in the region grows to the large sizes reached by cottonwood. Growth is best on the flood plain sites. Diameters of 24 to 36 inches are common among mature trees, and occasional specimens reach 48 inches or more. Dominant trees have from 4 to 7 annual rings per inch of radius growth, but there may be as few as 2. Heights of over 100 feet are reached. Trees may have clear lengths of 50 to 60 feet.

Few trees over 50 years of age were found. They probably do not often exceed ages of 80 to 100 years. Rotations of 40 to 60 years appear to be most appropriate.

Cottonwood is very intolerant and must be dominant to grow successfully. It is succeeded after one generation by any or all other species of the flood plain forest with the exception of black willow.

Only the younger trees appear to coppice effectively.

Aspen

Aspen is found throughout the region under practically all site conditions except the river flood plains. Even here it may occur sparingly. It is prominent on areas where cutting or fire have opened up other stands. Once established on an area, it is increased by further disturbances and tends to dominate any openings which are made. It characteristically occurs in pure, even-aged stands, but is found often with paper birch.

Aspen is a very intolerant species, and cannot reproduce successfully beneath other stands. Where there are no marked disturbances it is usually replaced by other species. It must be dominant or at least codominant to survive beyond the sapling stage. The small wind-blown seeds are almost omnipresent during late spring and germinate readily on moist, bare soil. Once present on an area, reproduction takes place mainly by sucker sprouts.

Young trees, especially the sucker shoots, grow rapidly. Early height development enables the aspen to maintain a dominant position, which it usually holds throughout its lifetime. Mature trees are 50 to 70 feet tall. Diameter growth for the first 6 inches is at the rate of 2 inches in 7 to 10 years and for the next 6 inches at the rate of 2 inches in 10 to 15 years. There is a gradual slowing down in the rate of diameter growth with increased age. Trees mature at from 6 to 12 inches in diameter and sometimes reach 16 to 18 inches. Decadence sets in early, usually between 40 and 60 years. Sixty to 80 years is the average maximum age. Rotations therefore should not exceed 40 to 60 years.

Black Cherry

Black cherry is a minor component of the southeastern Minnesota forests. It is most abundant on cutover lands and along fence rows, where it develops from seeds distributed by birds.

Older stands of other species seldom contain specimens of black cherry. It occurs on well-drained sites but not on severe exposures.

Growth is usually rapid, but form and development are poor on all but the best sites. On such sites well-spaced dominants may make exceptionally good development. Mature black cherry trees commonly are 10 to 16 inches in diameter and 40 to 60 feet in height. Exceptional trees reach 20 to 24 inches D.B.H. and heights up to 90 feet. Ages infrequently may exceed 100 years. Rotations approximating 80 years appear to be appropriate.

Black cherry is intolerant and will not withstand severe crowding or overtopping by other species. It is unable to effect establishment beneath other stands although seedlings sometimes get started there.

White Oak

White oak is one of the most important and abundant tree species in this region. It occurs on almost all well-drained upland sites and is seldom absent from an oak-hickory type woodlot. It is associated principally with the red oak, with which it forms the most characteristic forest type. Shagbark hickory, within its range, is also a common associate. Upland loess soil seems the most favorable habitat for its development. In fact, white oak is confined largely to the loessial and red drift soils. It is practically absent on the gray drift soils which are present in the western part of the region. Perhaps the distribution of this species is determined by soil acidity. It appears to be abundant only on acid soils and virtually absent on soils containing an abundance of lime in the upper horizons.

White oak tends to occupy the moderately dry sites. It is not well represented on moist sites. This is probably due to the fact that red oak and many other species grow much more rapidly than white oak and soon overtop it. Thus white oak is able to develop on moist sites only in understocked stands where sufficient growing space is available. However, it is able to grow in competition with red oak in a codominant or intermediate position for long periods of time and to take over the area when the shorter-lived red oak is eliminated. White oak often persists in a suppressed state for 20 to 30 years.

In well-stocked stands white oak has a narrow columnar crown and a long straight bole, but in the more open stands, where it is most prominent, the crown is large and rounded. Open growth trees develop large, heavy limbs and short, thick boles.

On the whole, white oak grows slowly, and heavy competition makes growth still slower. Only strong dominant trees grow more than an inch in diameter in 10 years. However, individual trees occasionally are encountered which have exceptionally rapid growth rates and good form, supporting the theory that the species is made up of a number of forms or races with somewhat different growth characteristics.

Dominant trees reach diameters of 12 to 18 inches, but exceptional veterans and open-grown trees may exceed 36 inches. On dry sites heights of 40 to 50 feet are characteristic. Better sites have trees 50 to 60 feet or occasionally 70 feet high. Mature trees are usually 120 to 200 years old, but ages of 250 to 300 years are reached, probably making it the longest-lived species in the region. In managed stands rotations of at least 80 to 100 years will be required to produce high quality timbers.

Seedling reproduction in limited quantities becomes established under open stands and is able to persist for a number of years. Unless released, these seedlings become suppressed and die. Seedling mortality is greatest the first winter after germination, which takes place in the fall. White oak coppices vigorously from all but mature trees or from trees on heavily pastured areas.

Red Oak

Red oak and its variety, northern red oak, are considered together because of their similar characteristics and the occurrence of a number of intermediate forms. Of the two, northern red oak is more abundant and generally occupies the cooler, more moist sites. It dominates the moist north and east slopes and some level upland areas of the oak-hickory forests and is well represented as an associate of the maple-basswood forest. Northern red oak apparently is a larger, more vigorous and more rapidly growing tree than the red oak. However, these differences are not so great that the two cannot be treated as one for the purposes of this study.

Red oak is the most prominent constituent of the oak-hickory forests and more abundant than all of the other oak species combined, often forming practically pure, even-aged stands. White oak, black oak, bur oak, pin oak, scarlet oak, and shagbark hickory are commonly associated with it.

This species grows more rapidly than any of the other oaks. Dominant trees have an average of 10 to 13 annual rings to each inch of radius, but occasional trees grow much more rapidly. Codominant trees grow only about half as fast as the dominants, and when crowded severely or overtopped they soon lose vigor. Trees seldom withstand suppression for more than 10 to 15 years.

Reproduction is mainly from coppice shoots following clear cutting. Seedling reproduction occasionally starts but, because of the intolerance of this species, is unable to develop except in openings. Cutting methods must provide openings if seedling reproduction is to become established. Clear cutting in narrow strips, shelterwood, or group selection cuttings therefore should be most applicable to the oak forests. Coppice reproduction should not be relied upon in mature stands.

Red oak responds very favorably to thinnings. However, because of the tendency to form epicormic shoots, thinnings should open up the stand gradually.

Rotations of about 80 years in managed stands should suffice to produce high quality timber.

Clear length of all red oak trees averaged 28 feet, and bole length 35 feet. This is in agreement with other measurements of merchantable and clear lengths made for a number of sample plots, which show that merchantable stands average two 16.3 feet logs for dominant trees. Practically all trees come within the range of one to three logs. Clear lengths range from one-half to three logs, averaging close to one and one-half logs at 50 to 70 years. Clear lengths of three logs are uncommon and could be achieved under management only in very dense stands with long rotations and at a considerable sacrifice of diameter growth rate.

The growth under management of two to three log trees with clear lengths of one and a half to two logs would appear to fit in well with the growth possibilities of red oak.

Pin Oak

Pin oak is prominent on the drier sites, especially in the prairie-forest transition zone. It frequently occurs in pure stands, or commonly is mixed with bur oak or white oak. Growth characteristics of pin oak are very similar to those for black oak and scarlet oak, and some growth data for the latter two species were combined with data for pin oak. Growth statistics given for this species, therefore, apply to the other two also.

On very dry sites pin oak makes poor development, and locally may be known as scrub oak. On better situations, however, it grows rapidly and may have excellent form. In fact, the growth rate may compare favorably with that for red oak. Mature trees are from 10 to 18 inches D.B.H. and maximum diameters of 24 to 28 inches are attained. Dominant trees have an average of 10 to

12 annual rings per inch of radius and predominant trees may have from 6 to 8. Heights of 40 to 60 feet are reached, and occasional trees grow to 65 to 70 feet.

Apparently pin oak is not as long lived as the red oak, trees maturing at 80 to 100 years, and maximum ages seldom exceeding 120 years.

Seedling reproduction of this species is rare throughout most of the region. Present young stands are almost entirely of coppice origin. Occasional seedlings that start on the forest floor are intolerant and unable to persist without release.

There is a marked tendency for pin oak to form epicormic sprouts when suddenly released.

Bur Oak

Bur oak and its variety, the northern bur oak, are considered together as their silvical characteristics are very similar. Northern bur oak is the more abundant, and most of the data collected are from it. Bur oak proper is limited in distribution to the southeastern corner of the region. The common name, bur oak, is applied to both.

This species is widely distributed throughout southeastern Minnesota. It appears to be closely associated with, but not limited to, calcareous sites. It withstands a wide range of moisture and site conditions but is most typically a species of dry sites and severe exposure. Of all the oaks, bur oak is the most drouth resistant, and the principal species forming the prairie border stands and the isolated groves which are found scattered through much of the prairie region. It is found in mixture with various other oaks and in the big woods areas with the maple-basswood forest.

Growth is dependent upon site conditions. On severe, dry exposures trees may be no more than 10 to 20 feet tall, but on the best sites, splendid, rapidly growing specimens are found. When open grown, a large crown with prominent wide-spreading branches and a short bole are developed. Forest-grown trees ordinarily have good bole form, the best individuals having clear lengths of 30 to 40 feet. Mature bur oak trees on average upland sites are commonly from 12 to 18 inches D.B.H. but may attain much greater diameters. The largest tree measured was 42 inches D.B.H., 76 feet tall, and clear for 40 feet. Most mature trees are from 120 to 160 years, but maximum ages are over 200 years. Longevity appeared to be greater on the better sites.

Predominant and open growth trees have about 10 annual rings per inch of radius; average dominants have 13 to 15 rings per inch. Diameter growth on lower crown class trees is at the rate of from 20 to 40 rings per inch. Growth rate for trees of the different crown classes is remarkably uniform. On the basis of diameter growth rates, rotations of not less than 80 to 100 years are suggested for the production of commercial bur oak timbers.

Seedling reproduction is uncommon. The few seedlings found on the forest floor are unable to develop without release. As in the case of the other oak species, an open area is needed for successful establishment of seedling reproduction. Although bur oak coppices vigorously, most of the trees in existing stands appear to have originated as seedlings.

Black Willow

Black willow is found naturally only on wet sites. Flood plains and stream banks are its principal habitats, and in southeastern Minnesota it is most abundant on the broad flood plain of the Mississippi River where it is associated with cottonwood, silver maple, and river birch. It is able to effect establishment only in openings, usually on freshly deposited alluvium. Species of elm and ash succeed it. Black willow occurs in small even-aged stands or groups, with occasional trees found in mixed stands of the flood plain species.

Growth is extremely rapid, there being from 3 to 6 annual rings per inch of radius. Trees 20 to 30 years of age are usually 60 feet high, and heights of 70 to 80 are reached. Diameters of at least 24 inches are attained, but no trees were found over 50 years of age, indicating that this species may be very short lived. Trees grown in stands have excellent form with straight boles, good clear lengths, and narrow pyramidal crowns. Even open growth trees, as a rule, have good merchantable form. Rotations of only 40 to 60 years are adequate for the growth of large-sized trees.

Black willow is very intolerant and soon is eliminated by overtopping or intensive lateral crowding by crowns of other trees. It must be dominant to exist. Coppicing is vigorous but fails unless light conditions are favorable.

Basswood

Basswood is distributed generally throughout the region on moist, fertile sites. It is abundant in the big woods area and frequent in ravines and lower slopes, especially on northern aspects. Occasionally it is found on drier upland sites in association with oaks, particularly the northern red oak. Sugar maple, elm, ironwood, butternut, and green ash are other common associates. Basswood invariably occurs intermixed with other species and not in pure stands.

This species grows at a moderately rapid and uniform rate. Dominant trees have about 10 annual rings to each inch of radius, codominants 13 to 17, and intermediates 14 to 17. Due to their tolerance, trees of the intermediate crown class grow almost as rapidly as codominant trees. Mature trees usually range from 16 to 24 inches D.B.H., but maximum diameters exceed 30 inches. Heights range from 50 to 70 feet for mature trees.

Basswood is tolerant and seedlings are able to effect establishment and grow under oak stands. Seedling reproduction, however, is not abundant. Coppice shoots are probably much more effective than seedlings in maintaining the species. Coppice shoots develop from large standing trees and take the place of the older trees when they are destroyed. This ability to produce vigorous basal sprouts apparently is maintained throughout the entire life of the tree.

American Elm

The American elm is found throughout the forested portion of southeastern Minnesota. It is most abundant on river flood plain or valley sites and in the big woods area. On upland loess soils it is relatively uncommon. It occurs in mixed stands associated with black ash, green ash, and red maple as well as other flood plain species. On upland soils it is found as a member of the sugar maple–basswood community and occasionally with the oak-hickory forests.

Growth of dominant trees is rapid, an inch of radius having 7 to 10 annual rings, while codominants have 13 to 16 annual rings and intermediates from 16 to 20 rings for the same amount of growth. The tree develops to large size. Dominants often are 24 inches D.B.H. and occasionally as large as 48 inches. Heights range from 50 to 80 feet for mature trees. When open grown, the wide-spreading crown consists of a number of large ascending branches and the bole usually is short. Forest-grown dominants, as a rule, have good bole form.

Young trees are fairly tolerant, but later do not withstand severe crowding. Older trees require considerable growing space to develop successfully.

Reproduction is mainly by seed, but coppice develops well even from large stumps.

Slippery Elm

Slippery elm is distributed generally throughout the region. It is more abundant than the American elm on all except the flood plain sites, although it is found there also. It occurs in mixture with other species, especially sugar maple and basswood, but also with the oak-hickory type.

In growth and development it is very similar to American elm. Probably its growth rate is slightly more rapid. Reproduction is mostly by seed, and the seedlings are quite tolerant. They develop well in the open or under light shade and persist for a number of years under heavy shade. Next to aspen and birch, the slippery elm is reproducing more successfully than any other important species, and under a wide range of site conditions.

Rock Elm

The rock elm has a limited distribution in southeastern Minnesota, being confined generally to the proximity of stream banks, usually as scattered individuals or small groups. Basswood, sugar maple, butternut, hackberry, green ash, slippery elm, and American elm are its most common associates.

It is similar to the slippery and American elms, but with a narrower, more oblong, or rounded crown. Rock elm grows much more slowly than the other native elm species and does not attain such large diameters. Its longevity apparently is at least as great, with maximum ages reaching 200 to 300 years.

Rock elm is capable of growing under suppression for many years, and a large proportion of the trees in their early life have survived for 50 years or more in such a state. Suppressed trees have about 50 rings per inch of radius, intermediates 30 to 40, codominants 20 to 30, and dominants 10 to 20.

Reproduction appears to be almost entirely from seed although the species does coppice. Most seedlings begin growth in the shade under forest conditions. Occasionally they start in the open.

Bark Factors

Since the diameter growth data are based upon diameter inside bark, bark factors were determined to enable a ready calculation of diameters inside bark from diameters outside bark or vice versa.

D.B.H. and double bark thickness measurements were made on a number of trees, covering the common range of diameters

Table 12. Average Bark Factor for Double Bark Thickness at D.B.H. for the Important Tree Species of Southeastern Minnesota

Species	Basis—number of trees	Bark factor*
Ash, black	50	1.088
Ash, green	64	1.106
Aspen	77	1.101
Basswood	100	1.091
Birch, river	40	1.090
Birch, white	109	1.096
Butternut	92	1.108
Cherry, black	30	1.102
Cottonwood	61	1.105
Elm, American	28	1.096
Elm, rock	27	1.130
Elm, slippery	63	1.096
Hickory, bitternut	48	1.105
Hickory, shagbark	154	1.136
Maple, sugar	92	1.092
Maple, silver	90	1.070
Oak, bur	128	1.150
Oak, pin	140	1.104
Oak, red	295	1.115
Oak, white	211	1.097
Walnut, black	150	1.161
Willow, black	56	1.126

* Diameter inside bark multiplied by bark factor equals diameter outside bark.

for each of the important tree species. Bark factors represent the average relationship between diameter inside bark and diameter outside bark. These data are shown in table 12.

In most species double bark thickness equals close to 10 per cent of D.B.H. Black walnut, bur oak, shagbark hickory, and rock elm have bark thicker than the average of all species. Silver maple has the thinnest bark of any species sampled.

Silvicultural Recommendations

Pasturing

It was not necessary to carry on detailed studies to determine the effects of pasturing on the woodlands of southeastern Minnesota. The results are obvious to anyone observing the situation. Briefly, pasturing destroys existing tree reproduction and prevents establishment of further reproduction. It opens up the stand. The natural herbaceous cover of the forest floor is killed and replaced first by sedge cover and finally by bluegrass sod. Trampling of the soil hastens the death of larger trees. Any cutting further depletes the stand. Eventually the forest is transformed to a bluegrass pasture.

Because at least 85 per cent of the woodlands in southeastern Minnesota are pastured, a large portion of them will disappear within 25 years unless land use policies are modified to remedy this critical situation. Pasturing and sound woodland management therefore are entirely incompatible. Livestock should be removed from all woodland areas classified as being best and permanently suited only for forestry purposes, and from other areas where it is desired to grow forest tree crops.

Where more pasture is needed it would be far better to clear cut a portion of the woodlot and make it into a good pasture and retain the rest of the woodlot free of grazing, than to try to raise trees and cattle on the same ground.

Cutting

Since the oak-hickory stands are even-aged and since establishment and growth of oak seedling reproduction are possible only in openings or under conditions of comparatively light shading, cutting methods should provide such conditions.

Clear cutting in narrow strips or small blocks, shelterwood, or group selection cuttings appear to be the most applicable methods for high forest management.

For the production of fuel wood or other timber products on short rotations the coppice system with clear cutting in strip or block arrangements probably would be most effective. Evidence strongly indicates that coppice sprouts often develop as satisfactorily as seedlings. There is no apparent reason for discriminating against coppice reproduction of the oaks in any of the cutting methods. However, sprouts do not develop well from the stumps of large, old trees. If long rotations are used, it will be necessary to depend upon seedling reproduction.

The coppice with standards method also would be suitable silviculturally for the management of oak or oak-hickory forests.

Maple-basswood forests usually contain trees in a wide range of size classes. Reproduction normally is abundant and easily obtained. The selection system therefore is ideally adapted for application to these forests.

Rotations

Under management, rotations of 80 years will suffice for the production of quality sawlogs in the black oak group. Longer periods for the production of larger timbers also would be practical, especially in the case of red oak.

The more slowly growing shagbark hickory, white oak, and bur oak will require slightly more time than needed by the black oak group to yield timbers of similar quality. Rotations of from

80 to 100 years generally would be appropriate for these species. However, periods up to 200 years or more would be feasible because of the tendency to long life and the persistent growth of these species.

For the production of oak-hickory fuel wood by coppice methods, rotations of 40 to 50 years are recommended.

Other upland species, with the exception of aspen and paper birch, can be managed satisfactorily on the same rotation used for the oaks. Species of the flood plain forests as a rule require shorter periods. Only 40 to 60 years are needed for black willow and cottonwood, although the rotation for the latter in some cases might desirably be increased to 80 years. Silver maple, river birch, and other flood plain species normally require 60 to 80 years for the production of merchantable timbers. As a rule smaller sizes may be used for home use than for commercial purposes.

In the maple-basswood selection forests, the correlation between age and size of trees is low. Rotations therefore are difficult to determine, and cuttings should be made in accordance with the sizes of trees desired.

Thinning

Intensive competition slows down markedly the growth rate of the oak-hickory species. However, they respond very favorably to increased growing space. Thinnings are needed to regulate properly stand density and growth rate.

Inasmuch as the formative period for oak-hickory stands usually is from 30 to 40 years, thinnings during this time should be made carefully, frequently, and lightly. Thinning from below is recommended, allowing dominant trees a growing space ratio (average crown spread in feet/D.B.H. in inches) of 1.2 to 1.3 during the formative period. Heavier thinnings after 30 to 40 years should increase the growing space ratio to 1.4 to 1.6, where it should be maintained to the end of the rotation.

On average sites a stand basal area[3] of 80 to 100 square feet per acre should be achieved at 50 years of age. It is recommended that basal area thereafter be held constant at 80 to 100 square feet per acre by thinnings at 5- to 10-year intervals.

Particular attention should be given in the thinning process to obtain uniformity in the spacing of the final crop trees.

[3] Basal area equals the sum of the cross-sectional areas of all the trees on an acre taken at D.B.H.

Artificial Regeneration

The sparsity of seedling reproduction of oaks suggests that considerable difficulty may be encountered in getting seedling reproduction of these species. It is probable that artificial regeneration will be necessary in many instances if oak reproduction is to be obtained. Seeding with freshly gathered acorns in the fall or planting of one-year seedlings in early spring are the suggested methods of regeneration. If acorns are used it may be necessary to control the depredations of squirrels. Any openings without an available seed source, or bluegrass areas, probably would have to be seeded or planted, as oak reproduction in such places is very uncertain.

SUMMARY AND CONCLUSIONS

The forests of southeastern Minnesota were found to be of two principal associations, the oak-hickory and the maple-basswood. Physiographic factors, including soil, and past fires have been important in determining present distribution of the forests.

The oak-hickory forests are composed mainly of even-aged stands. Their ages show that over half of them originated during the two decades following settlement of the region. Cultivation of fields and building of roads, which prevented the annual or periodic fires, made possible the establishment of the new stands. This corroborates historical evidence to the effect that original oak-hickory forests in this region were largely of the savanna type.

Had it not been for early fires the oak forests would be more extensive and the forest frontier would extend farther into territory now dominated by the prairie.

Red oak (including northern red oak), white oak, bur oak, and pin oak were found to be the most important species of the oak-hickory forests. Shagbark hickory was important only in Houston County. Black oak and scarlet oak were of minor importance.

Red oak and white oak were found the most characteristic associates of the oak-hickory forests. Bur oak, pin oak, white oak, and red oak occurred in consociation form or in various mixtures along with shagbark hickory, black oak, and scarlet oak.

Oak-hickory forests were found to occupy the comparatively drier sites, maple-basswood the more moist sites.

Studies of the frequency of occurrence of species on different sites showed that the oaks could be classified in order of increasing moisture requirements as follows: (1) bur oak, (2) pin oak, (3) white oak, and (4) red oak. Black oak and scarlet oak were about coordinate with pin oak.

There was little evidence to indicate successional changes in upland oak stands. On the more moist situations, however, climax species of the maple-basswood forest were reproducing to a limited extent in oak-dominated stands.

Composition of subdominant vegetation in virgin oak communities was similar to that given by some authors for maple-basswood and other deciduous climax associations in north central and eastern United States. This is an indication, but not definite proof, that the climax maple-basswood association will evolve on at least the more moist oak-dominated forest areas.

Sample plot records showed oak seedling reproduction to be rare. Oak reproduction was almost entirely by coppice shoots. Ninety-two per cent of all new growth was from sprouts and only 8 per cent from seedlings. Aspen and birch were becoming increasingly important because of their abundant establishment on cutover areas.

Five significantly different physiographic sites were distinguished by their site index values. These are: (1) valley and cove, (2) moist slope, (3) level to rolling upland, (4) ridge, and (5) dry slope. Comparison with normal yield table site index values showed sites 1, 2, and 3 to be of average quality and sites 4 and 5 to be of poor quality.

A comparison of 14 selected oak stand values from southeastern Minnesota with normal yield table values showed that stands far below normal with respect to number of trees per acre may be practically normal with respect to basal area and far above normal in terms of mean tree diameter.

Curves were plotted to determine the diameter growth characteristics for the various crown classes of the 23 important tree species. Marked differences in growth rate were shown. Individual curve trends were remarkably smooth.

Pasturing threatens the eventual extinction of over 85 per cent of the woodlands in southeastern Minnesota.

Group selection, shelterwood, and clear cutting in narrow strips or small blocks are the silvicultural systems recommended for management of oak-hickory high forests. The selection system is recommended for maple-basswood forests.

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