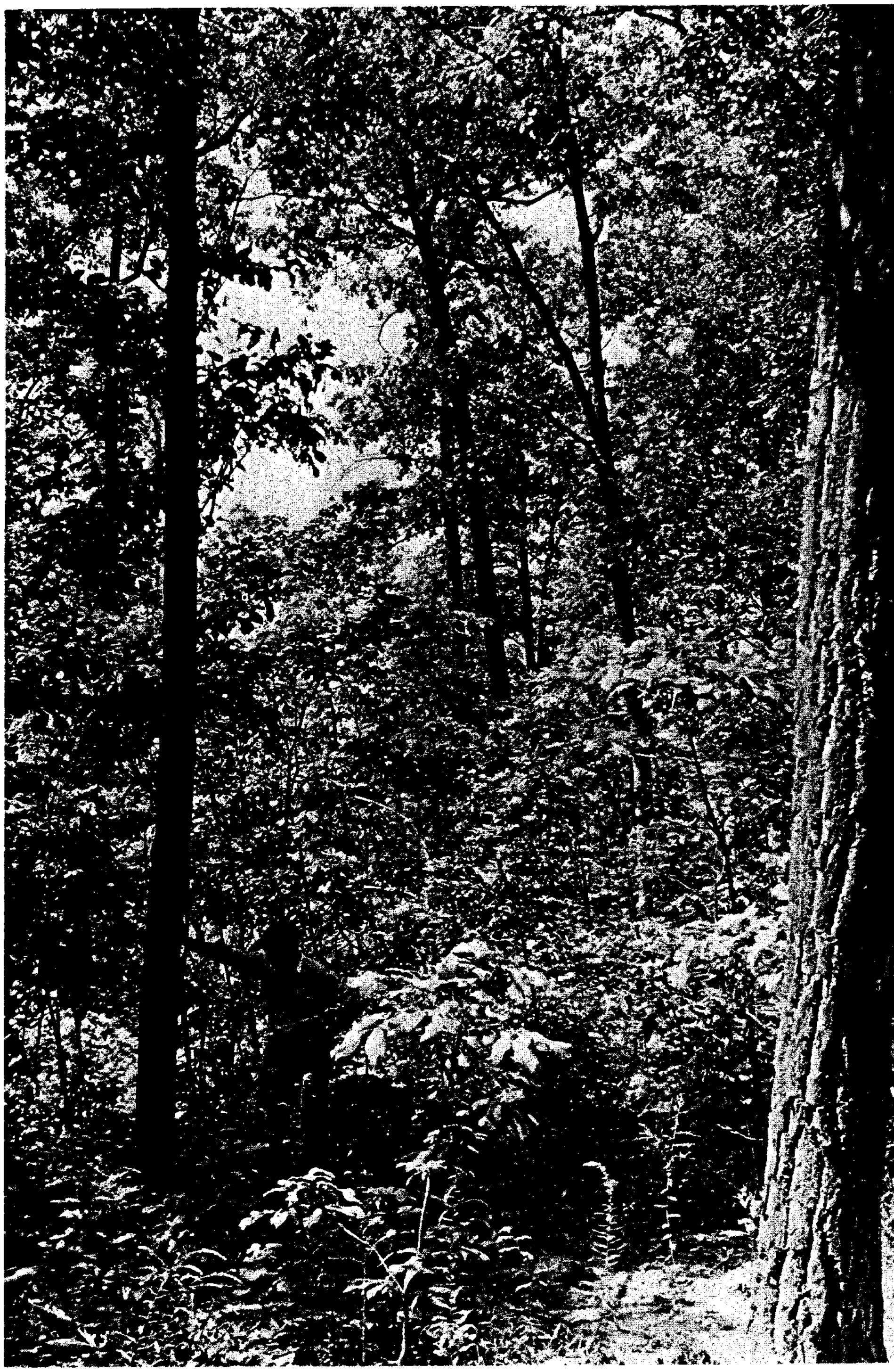
Reproduction of UPLAND HARDWOOD FORESTS *in the* CENTRAL STATES



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Forest Service
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of Agriculture

REPRODUCTION OF UPLAND HARDWOOD FORESTS IN THE CENTRAL STATES

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INTRODUCTION

Present upland hardwood stands in the central United States are a patchwork of species and conditions that reflect past stand treatment. Some stands that have developed under favorable circumstances are well stocked with high-value trees of the most desirable species. But many stands that have grown under less favorable circumstances because of such abuses as high-grading, "opportunistic" harvesting, overgrazing, or fire have few high-quality, vigorous trees of desirable species.

The reproduction that appears after a harvest cutting is often unsatisfactory in species composition, growth rate, or even survival. Simply avoiding stand abuses will not guarantee reproduction of fast-growing new stands of desirable species in upland hardwoods. To obtain the best species composition and fastest growth rate of reproduction after harvest cutting, forest managers need a more complete understanding of how the various upland hardwood species reproduce and develop after different types of harvest cuttings.

This handbook summarizes results of reproduction studies conducted in southern Illinois, southern Indiana, eastern Kentucky, and southeastern Ohio. Early results of some of these studies were published previously by Minckler and Jensen (1959), Minckler and Woerheide (1965), and Merz and Boyce (1958).

These studies provide data from more than 200 experimental plots covering a wide range of cutting methods, site qualities, and stand conditions. Although direct comparisons among the various study locations were not always possible, the studies all had a common objective: to find out what factors affect the establishment of reproduction and how all reproduction grows and develops when a stand is cut in a specific manner.

In general, these data and discussions apply within the physiographic areas designated in figure 1. East

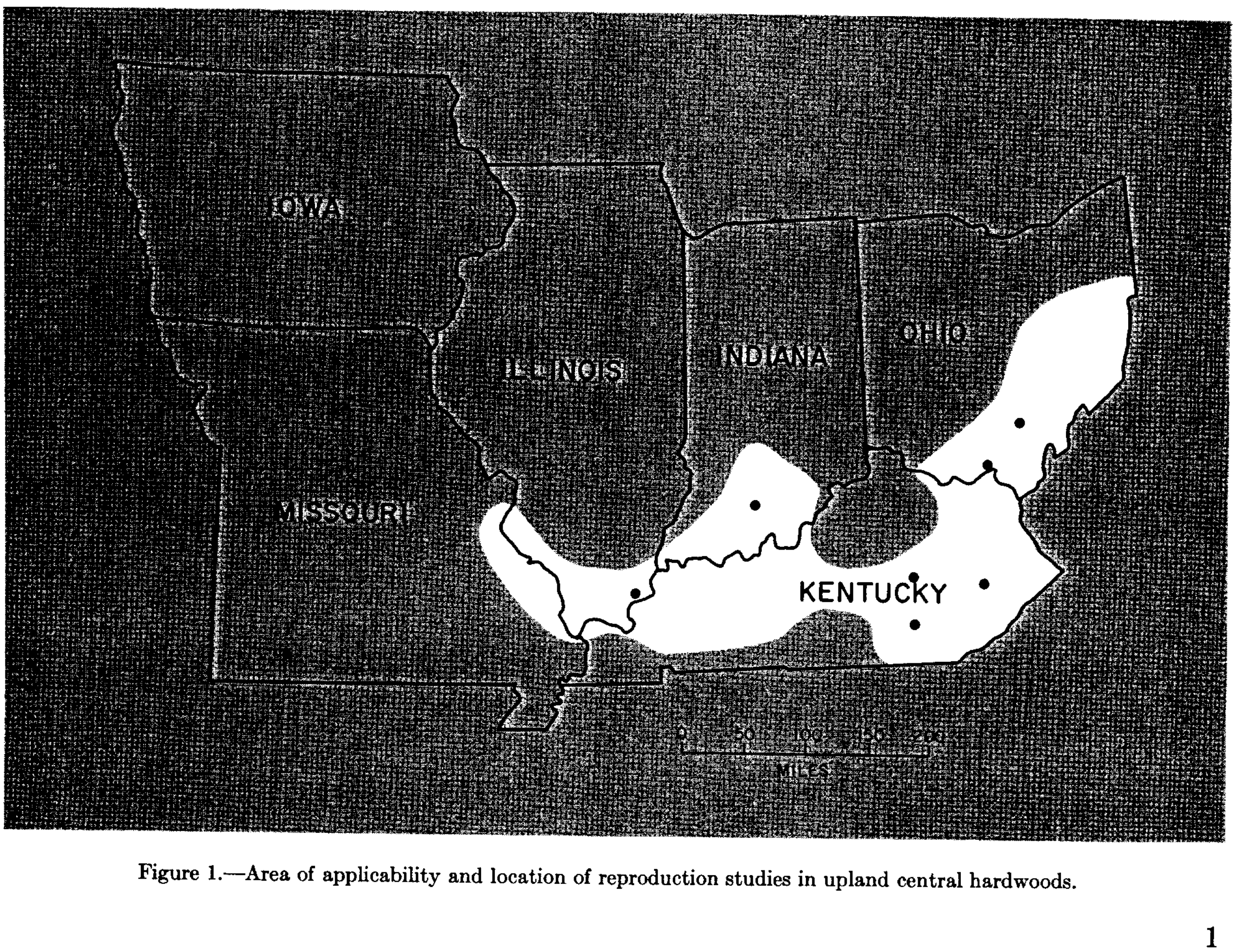

Figure 1.—Area of applicability and location of reproduction studies in upland central hardwoods.

of the Mississippi River, the northern boundary generally follows the southern limit of glaciation. The eastern hill country of Missouri is included because timber conditions there are similar to those further east. However, the glaciated areas in the northern part of the Central States, the prairie peninsula areas, the fertile limestone areas of Kentucky, and the Ozark region of Missouri are excluded because timber and soil conditions differ from those in the areas where these data were collected.

TIMBER TYPES

The upland central hardwood types contain mostly white, black, and scarlet oak;[1] but they also include several other species. On the drier sites, chestnut, chinkapin, or post oak may be numerous. Pignut hickory, blackgum, red maple, and—depending upon locality—occasional small groups of shortleaf, pitch, or Virginia pine may be present. On the moister sites, many species may occur. They include yellow-poplar, northern red oak, white ash, black cherry, black walnut, American beech, American basswood, sugar maple, slippery elm, Ohio buckeye, shagbark hickory, bitternut hickory, red maple, and blackgum.

Flowering dogwood, sassafras, and sourwood are the most numerous understory species in these types, but others may also be present. Locally abundant species include downy serviceberry and eastern hophornbeam on the drier sites, and eastern redbud, witch-hazel, hazelnut, and American hornbeam on the moister sites.

These upland timber types usually occur on residual soils derived from sandstone and shale, but are also found on shallow limestone soils and in areas covered by varying thicknesses of loess.

STUDY METHODS

Areas Studied

The studies were made on sites of both average and good quality. Average sites were generally located on middle and lower southeastern to southwestern slopes, upper northwestern to eastern slopes, and low ridges with well-drained soils. Such areas have a black oak site index[2] of 55 to 75. The good sites were generally found in coves and on lower northeastern to eastern slopes; such areas have a black oak site index of 75 to 95.

The timber stands used in these studies varied in composition, age, size of timber, and past treatment (table 1).[3] The even-aged stands (fig. 2)—which had originated after clearcutting or fire—were uniform and well stocked. The uneven-aged stands—which commonly resulted from past high-grading in which only the best timber was taken (fig. 3)—contained two or three age classes and varied in degree of stocking.

Cutting Methods

The cutting methods ranged from selection or light partial cuttings to complete clearcuttings (table 2). Aside from stimulating reproduction, the selection

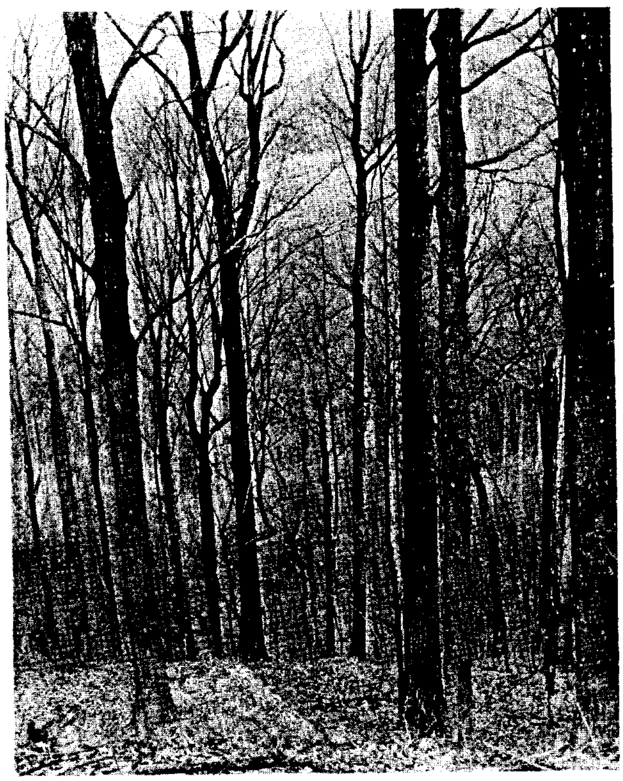

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Figure 3.—An uneven-aged stand on a good site in Kentucky.

[1] All common names are according to Little (1953). See appendix for scientific names.

[2] Average total height of dominant and codominant black oaks at age 50.

[3] All tables are in the Appendix, p. 21.

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Figure 2.—A mature even-aged stand on a good site in Ohio.

cuttings were aimed at improving the composition, quality, and diameter distribution of the residual stands. Trees that were removed were mature or cull, had poor quality, form, or vigor, or were crowding better trees. Some cuttings that were combined harvest and improvement cuttings were too heavy to be classed as true selection cuttings, so for convenience and lack of better terminology they are simply called partial cutting hereafter.

The shelterwood cuttings were done in two stages. The first was a combination preparatory and seed cutting that removed trees in the suppressed- and intermediate-crown classes and some of the poorer quality codominant or dominant trees. The trees that were left as a seed source were primarily oaks and other desirable species. This first cutting was aimed at stimulating seed production and getting new reproduction of desirable species established. The final cutting then removed the rest of the stand when the reproduction was well established.

In the complete clearcuttings, all merchantable trees were harvested and all unmerchantable trees killed. But in the commercial clearcutting, only trees that were merchantable for sawlogs were removed, and everything else was left. Residual stocking varied, of course, depending on the structure and stocking of the original stand.

Classification of Reproduction

Four categories of reproduction were recognized, based on how the stems originated and whether or not they were present at the time of cutting. They were: (1) New seedlings established after the harvest; (2) advance reproduction, which included all stems up to 2 inches in diameter at the ground established before the harvest; (3) new sprouts that developed after the harvest from advance reproduction less than 2 inches in diameter at the ground; and (4) stump sprouts that arose after the harvest from stumps over 2 inches in diameter at the ground.

RESEARCH RESULTS

Reproduction Before Cutting

Previous studies have shown that advance regeneration is important in reproducing certain upland central hardwoods. Merz and Boyce (1958) concluded that nearly 90 percent of the oaks present 2 years after harvest cutting in southeastern Ohio originated before the stands were cut. In southern Illinois, Minckler and Jensen (1959) classified over half of all stems present 4 years after harvest cutting as advance reproduction.

In later studies, wide variation was found in both numbers and composition of the advance reproduction (table 3). This was not unexpected, because these stands contain variable overstory species mixtures and occur over a wide range of site quality. Furthermore, the intensity, frequency, and type of previous commercial harvesting has varied widely, as has the amount of grazing and burning. All of these factors have influenced both the composition of the present overstories and the advance reproduction beneath them.

The amount of advance reproduction of a particular species was often poorly related to the amount of that species present in the overstory. In Ohio, the hickories usually accounted for less than 5 percent of the basal area of the overstory stands, yet the amount of hickory in the advance reproduction ranged from 5 to 30 percent. Up to 30 percent of the advance reproduction on many plots was either red maple or blackgum, but these species were rarely present in the overstory stands. Even the oaks showed a poor relationship between advance reproduction and the percentage of oaks in the overstory. Generally, if oaks were scarce in the overstory, oak advance reproduction was scarce; and if oaks were numerous in the overstory, advance oak reproduction was more abundant. But stands in Ohio that consistently had 80 percent or more of their overstory basal area in oaks also had oak advance reproduction that ranged from 20 to 80 percent of the total reproduction. Tryon and Carvell (1958) concluded that factors other than the amount of white and red oak in the overstory influence the number of seedlings of these species under oak stands in West Virginia.

The amount of oak advance reproduction appeared to be related to site quality. In Ohio, there was consistently more oak advance reproduction on average sites than on good sites. And in Illinois there were 1,800 stems per acre on average sites as compared with 1,000 stems per acre on good sites. This same relationship has been found in West Virginia, Michigan, and New Jersey (Weitzman and Trimble 1957; Arend and Gysel 1952; and Phillips 1963). In West Virginia, Carvell and Tryon (1961) found the amount of oak advance reproduction was directly related to the amount of sunlight reaching the forest floor. Their findings suggest that low light intensity on the forest floor beneath mature stands on good sites may be at least partially responsible for the scarcity of oak reproduction on these sites. On good sites, the overstory canopy is generally denser, and competition for light from shrubs and herbaceous vegetation is greater than on drier sites. Thus, even when new oak seedlings become established, they cannot survive very long, and the buildup of oaks in the understory is limited.

Although the number of stems of oak advance reproduction was greater on good sites than on average sites in Kentucky, the oaks made up the highest proportion of the total advance reproduction on both sites.

Reproduction After Cutting

Establishment

All cutting methods resulted in enough natural reproduction 2 years after cutting to produce stands with a satisfactory proportion of desirable species (table 4). Though there was much variation among plots and between study areas, cutting method did influence the composition of the reproduction.

Generally, clearcutting resulted in many more stems of yellow-poplar than partial cutting. After partial cutting, the reproduction was mostly oaks and more tolerant species. These results are similar to those reported from Ohio, Illinois, and West Virginia (Merz and Boyce 1958; Minckler and Jensen 1959; and Trimble and Hart 1961). Aside from these generalizations, no definite relationship between cutting method and species composition of the new stands could be detected.

Cutting method did affect the proportion of new sprouts and advance reproduction present after cutting (table 5). Except for yellow-poplar, which reproduced mostly from seed after all cuttings, most of the reproduction after partial cutting consisted of old stems of advance reproduction; while reproduction after clearcutting was largely new sprouts that came up from advance reproduction. This results from differences in the amount of area disturbed during logging. When an area is clearcut, a much higher proportion of it is disturbed; consequently, many more stems of old advance reproduction are cut, broken, or knocked over than when an area is partially cut. These damaged stems subsequently sprout, resulting in the higher proportions of new sprouts after clearcutting.

Cutting method had little effect on the proportion of stump sprouts in the reproduction. Stumps of all species will sprout, and some stump sprouts will always be present. However, 2 years after cutting, they generally make up a small proportion of the total reproduction of all species no matter how the stands were cut (table 5).

The silvical characteristics of the species also had an effect on the proportion of reproduction in each category. Regardless of the cutting method used, yellow-poplar reproduction was primarily seedlings;

but the oaks, hickories, blackgum, and dogwood resulted from advance reproduction. Black cherry, red maple, and sassafras reproduction was both of seedling origin and from advance reproduction.

Yellow-Poplar

Most of the yellow-poplar present in the reproduction originated from seed that had accumulated in the litter, rather than from the current seed crop. Where yellow-poplar seed-bearing trees are present in the overstory, a reservoir of seed will be stored in the litter and will germinate when favorable temperature, light, and seedbed conditions are created through cutting and logging. A study in Indiana and Illinois showed that yellow-poplar seed remained viable in the litter for at least 4 years (Clark and Boyce 1964). Later tests showed that seed germinated after being in the litter for as long as 8 years. This explains the presence of the large numbers of yellow-poplar seedlings usually present after clearcutting on good sites. Much of this stored seed will germinate after partial cuttings too, but most of these seedlings do not survive under even a light overstory.

Oaks and Hickories

About 90 percent of the oak and hickory stems present 2 years after cutting resulted from advance reproduction (table 5). Apparently these stems become established over a period of time under an overstory. Most stems do not remain true seedlings more than a few years because drought, frost, fire, rodents, mechanical agents, poor light, and moisture conditions (or a combination of these) kill the tops but not the roots. When this happens, one or more new sprouts usually develop from dormant buds near the root collar. Sometimes only part of the top dies back and a new sprout from somewhere on the lower part of the stem assumes dominance. In Illinois, a study of 1,000 oak stems less than 4.5 feet tall in the understory beneath mature stands showed that about half of them had died back to the ground at least once by the time the root system was 15 years old (fig. 4). The dying back and resprouting process may occur several times, forming the typical crooked, forked, flat-topped reproduction found in the understory (fig. 5).

After a harvest cutting, new sprouts develop when stems of advance reproduction are cut, broken off, knocked over, or held down by slash during logging, or when the old stem simply dies back to near ground level (figs. 6 to 8). Some old stems may persist while the new sprouts grow up and overtop them; others may persist without sprouting (figs. 9 and 10). The new sprouts are generally straight, have good form, and grow rapidly. Consequently, they are the best kind of oak and hickory reproduction in the new stand. The smaller number of new seedlings of these species that do become established after cutting grow slowly and seldom get into the dominant canopy of the new stand.

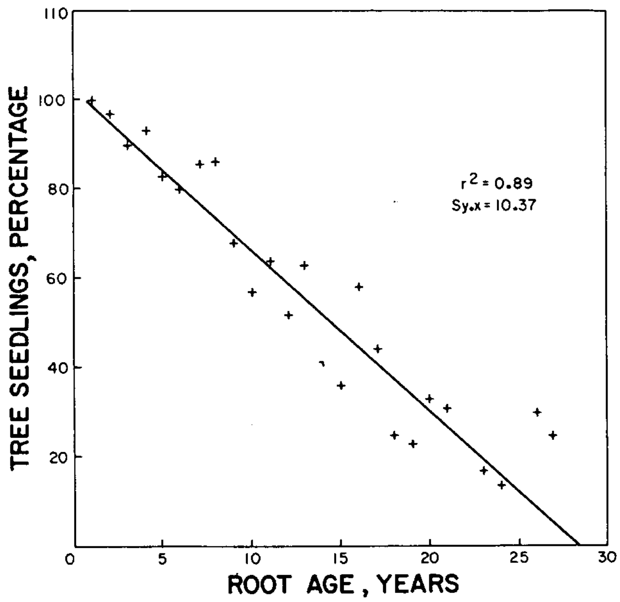

Figure 4.—Relationship between the root age of oak advance reproduction and the percentage of the total number of stems that have the same stem and root age.

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Figure 5.—A typical forked, flat-topped, crooked stem of oak advance reproduction.

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Figure 6.—A 1-year-old northern red oak seedling sprout. The old stem lying on ground in front of sprout was broken off during logging.

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Figure 7.—A 1-year-old northern red oak seedling sprout. The old stem was knocked over and held down by the top in lower left of photo.

Black Cherry

Seedbed, light, and moisture conditions for black cherry seed germination are not exacting (USDA Forest Service 1965). Consequently, the variation in the proportion of new seedlings (table 5) is probably due more to variation in the amount of available seed than to cutting method. Although not numerous, there were some black cherry seedlings on most plots, even though seed-bearing trees were scarce or absent in the overstory. Obviously, birds play a major role in the dissemination of black cherry seed. New cherry seedlings grow rapidly; consequently seedlings, advance reproduction, and new sprouts are all important in reproducing black cherry.

White Ash

The exact requirements for white ash regeneration have not been established (USDA Forest Service 1965), but the percentage of new white ash seedlings was greater after clearcutting than after partial cutting (table 5). White ash seed remains viable in the litter and duff for at least 2 years (Clark 1962; and Leak 1963). Thus, where white ash seed-bearing trees are present, there is usually a good seed supply. This, along with the full light and favorable moisture conditions created by clearcutting, probably accounts for the higher proportion of new white ash seedlings on these plots. However, the presence of white ash advance reproduction shows that some seed will germinate and the seedlings will survive under a closed canopy. More than half the white ash reproduction came from advance reproduction regardless of cutting method. Since new sprouts and stems of advance reproduction grow much faster than new seedlings, they are important in reproducing white ash.

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Figure 8.—A 2-year-old black oak seedling sprout. The old stem died during the first year after clearcutting.

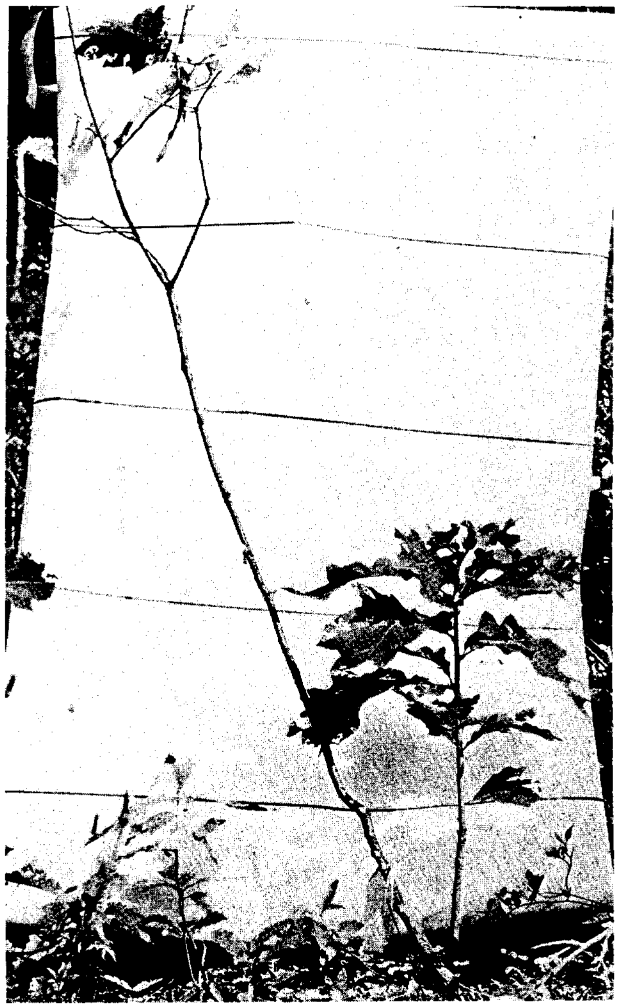

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Figure 9.—A 1-year-old northern red oak seedling sprout. The old stem is still alive but has poor vigor.

Red Maple

Red maple is generally an understory species in upland central hardwood stands. Occasionally it reaches sawtimber size, but quality is poor. Thus, it is considered an undesirable species, important primarily because it competes with more desirable species.

Most red maple reproduction present after cutting came from advance reproduction (table 5). Where a seed source was available, however, new seedlings also became established. They were most numerous on partially cut plots, and the highest proportion was found on plots that received the lightest cut. Partial cutting appears more favorable for establishing new red maple seedlings; because the seed germinates in early summer, soon after falling, it does not need much light to germinate, and a thin layer of leaf litter does not hinder germination (USDA Forest Service 1965). New red maple seedlings were scarce on the clearcut plots, probably because the current seed supply was eliminated on plots clearcut during the fall, winter, and spring. On plots clearcut during the summer, logging probably destroyed most of the newly germinating seedlings.

The new seedlings are not nearly as important as the new sprouts that come up after stems of advance

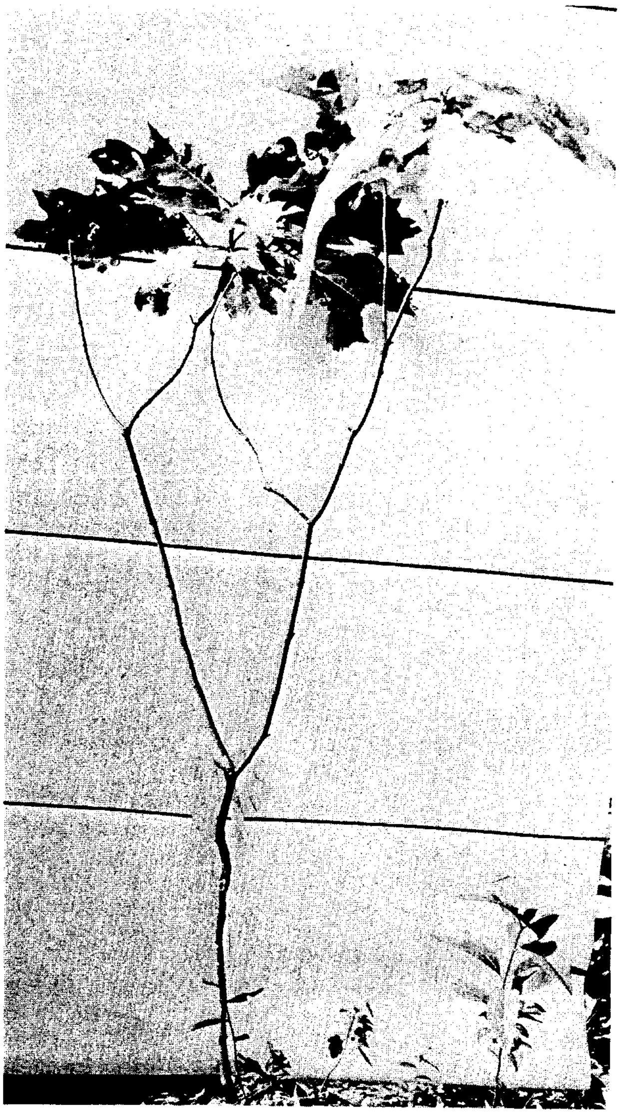

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Figure 10.—A stem of northern red oak advance reproduction that persisted without sprouting.

reproduction have been cut or broken off during logging. Red maple sprouts prolifically, the new sprouts grow vigorously, and stems of the more desirable species—particularly yellow-poplar seedlings—have difficulty competing with them.

Sassafras

After complete clearcutting, sassafras reproduction was primarily from root sprouts originating from sapling and pole-size trees present in the old stand. These sprouts grow rapidly, but the more desirable species can compete successfully with them except where they occur in dense sprout thickets. New sassafras seedlings were abundant after all types of cuttings, although the percentage of new seedlings was low under clearcutting because of the numerous root sprouts there. New sassafras seedlings are relatively unimportant because they do not grow fast enough to compete with other reproduction.

Stand Development

Early Mortality

The condition of the reproduction 2 years after harvest cutting represents only the first stage in the formation and development of new stands. Competition among the new stems or between the new stems and residual trees is severe and may drastically alter the density and composition of the final stand.

Cutting method appears to have an effect on the mortality of reproduction in the early years after cutting. In Indiana, mortality was lower 5 years after clearcutting than after shelterwood or selection cutting (table 6). In fact, there was a net increase on the clearcut plots, showing that some new stems originated 3 or more years after cutting. This increase was the result of increases in the number of black walnut, sugar maple, and slippery elm seedlings, which were small and probably will not survive. Observations indicate that unless a stem is established the first year after clearcutting, it is at a distinct disadvantage and will seldom grow into the dominant canopy of the new stand.

Part of the relatively high mortality on the shelterwood plots can be attributed to the destruction of reproduction when the residual overstory was removed. In this study, the second reproduction inventory was made right after the removal cutting was completed, and the reproduction had not recovered. With this exception, competition for light and moisture was probably responsible for most of the mortality on all plots.

At 5 years after cutting, competition was still intense, mortality was still high, and the character of the new stand was still changing rapidly.

Early Growth

The early growth of the new stands resulting from different cutting methods has differed according to the amount of the overstory that was removed. Growth differences among partial cuttings have not been as great as those between partial cuttings and clearcuttings.

In Ohio, there were more stems over 4.5 feet tall on the completely clearcut plot 7 years after cutting than on any of the other plots (table 7). At 10 years, the completely clearcut plot had almost four times as many stems larger than 0.6 inch in diameter at breast height as the plots treated with a medium partial cutting, and there were about twice as many stems on the completely clearcut plot larger than 2.5 inches in diameter at breast height as on any of the other plots. As would be expected, there was more basal area in every diameter class up through 4 inches on the completely clearcut plot than on any other plot (fig. 11).

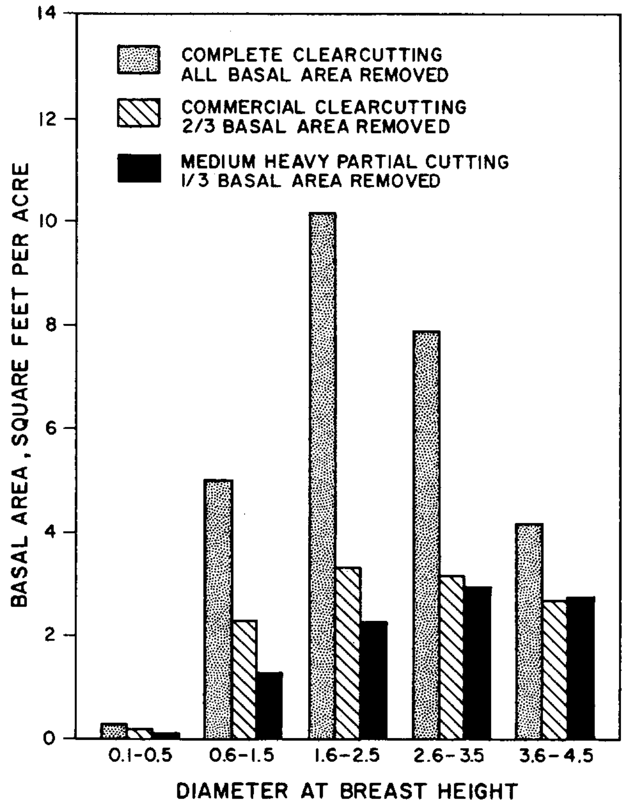

Figure 11.—Basal area of reproduction 10 years after harvest cutting in Ohio.

The big surge of reproduction growth came only after all the overstory of the original stand was removed, and cutting two-thirds of the basal area allowed only slightly better growth than cutting one-third. A study in Missouri also showed that the reproduction grew rapidly only after all of the original stand was removed (Brinkman and Liming 1961).

After Clearcutting

There was not much difference in growth rates among species during the first 4 or 5 years after clearcutting, so less desirable species often appeared prominent during this period (fig. 12). And where red maple sprouts occurred, they were frequently taller than any other stems, adding to the unfavorable impression. Between the fifth and tenth year, however, the oaks and yellow-poplar began to emerge and appear in the dominant and codominant classes. Their growth rate also came closer to that of red maple during this period. So, even though a clearcut area appears to contain many undesirable stems in a prominent position during the early years after cutting, more desirable stems usually become dominant by the time the stand reaches 12 to 15 years old.

On the good sites, new stands will contain a high proportion of dominant and codominant yellow-poplar while those on average-to-poor sites will contain mostly oaks (fig. 13). This observation is supported by examination of many other young stands and the results of older studies.

The oldest clearcutting experiments in upland central hardwood stands are 30 to 35 years old and on average sites. These plots now support fine, fully-stocked, pole-size stands composed mostly of oaks (fig. 14 and Bey 1964).

After Selection or Partial Cutting

Development of reproduction after selection or light partial cutting was markedly different from that after clearcutting. Although the seedlings and saplings had a surge of growth the first 3 or 4 years after a partial cutting, the understory growth slowed down drastically as the residual stand closed (fig. 15). All species, tolerant as well as intolerant, need increasing amounts of light as they increase in size in order to maintain rapid growth. This requirement, combined with the closing of the overhead canopy, naturally results in the slow development of reproduction after partial cuttings. However, tolerant species, although slow growing, continue to expand at the expense of the more intolerant species. Thirty-five years after one selection cutting, none of the reproduction had grown into pole-size trees, and the stand looked the same as it did 5 years after cutting (fig. 16).

After Shelterwood Cutting

The development of reproduction after shelterwood cutting was better than after selection or other partial cuttings. Growth was fairly good for 4 or 5 years after the preparatory and seed cutting; but from then until the final cutting, growth was slowed (fig. 17). The logging operation that removed the shelter destroyed much of the established reproduction. Although many of these stems resprouted, several years' growth had been lost. None of the shelterwood cuttings resulted in significant increases in the amount of reproduction of the oaks and other heavy seeded species.

Height Growth

Effect of Cutting Method

In Indiana, the dominant and codominant stems of all species in the reproduction averaged 4 to 6 feet taller 5 years after clearcutting than after shelterwood cutting and 6 to 10 feet taller than after selection cutting (table 8). Average height of the different species did not vary much on either the clearcut plots or the shelterwood plots. On the selection plots, however, height did vary; and the more tolerant and undesirable species, such as blackgum and dogwood, were taller than the desirable species. Although some stems of yellow-poplar and black walnut were present on the selection plots, neither species was present in the dominant or codominant reproduction.

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Figure 12.—Reproduction 5 years after clearcutting: *A*, On a good site; and *B*, on an average site. Height of all species was about equal at this time.

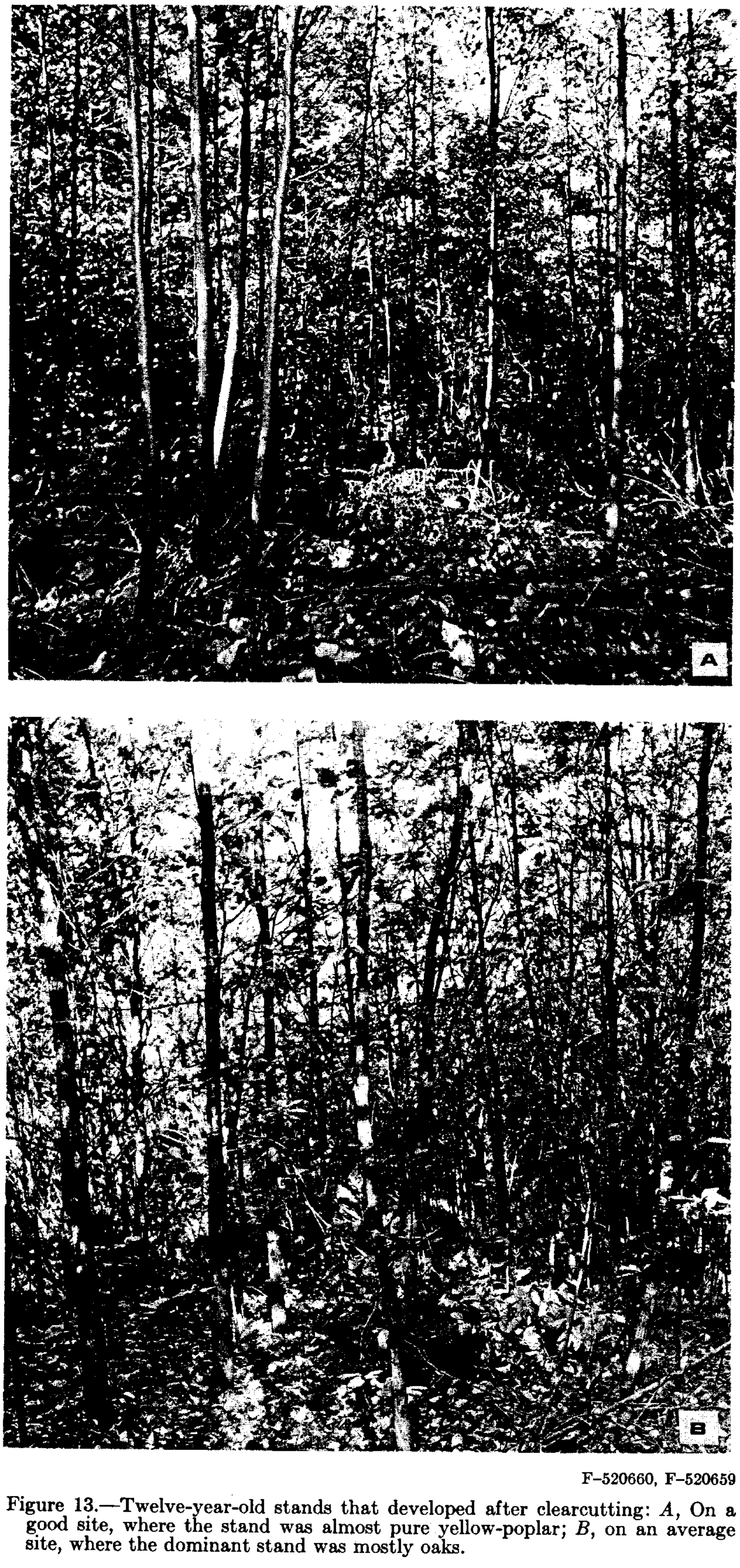

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Figure 13.—Twelve-year-old stands that developed after clearcutting: *A*, On a good site, where the stand was almost pure yellow-poplar; *B*, on an average site, where the dominant stand was mostly oaks.

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Figure 14.—A 35-year-old oak stand that followed clearcutting on an average site.

Kinds of Reproduction

Early height growth of the different kinds of reproduction differed greatly. In southern Illinois, new sprouts from advance reproduction grew much faster than either new seedlings or old advance reproduction after both clearcutting and partial cutting (fig. 18 and 19). Liming and Seizert (1943) and Paulsell (1963) have reported similar results in studies in Missouri. The new sprouts were more than twice as tall as the stems of old advance reproduction 6 years after cutting. The tops of some stems of advance reproduction died back the first year after cutting, and this resulted in a net reduction in average total height after one growing season. But in the second year, either live branches began to grow and assert dominance over the old tops, or new sprouts started to grow from the lower parts of the stems. From then on, annual growth was about half that of the new sprouts.

New oak seedlings grew very slowly and after 6 years were suppressed to the point where they did not have a chance to catch up with either of the other kinds of reproduction.

Consequently, most of the old advance reproduction is now intermediate or suppressed; only a few stems are in the dominant stand. The oak seedlings that became established after the cutting will never grow into the main stand; most, if not all, will probably die within a few years.

In the stand resulting from partial cutting, height growth of the new sprouts began to slow down after the second year. As the residual overstory continues to expand and the crowns close, the height growth of the new sprouts will slow down even more. The same thing will happen to the advance reproduction. As long as an overstory is maintained on these plots, growth will be slow.

Stump sprouts were not included in the Illinois study, but Kuenzel (1935) found that they grew

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Figure 15.—Reproduction in a small opening created by cutting one large tree: *A*, 2 years after cutting; and *B*, 10 years after cutting. Reproduction was more dense in (*B*) but had grown little in 8 years.

faster than any other kind of oak reproduction. Spaeth (1928) found that oak stump sprouts grew faster in diameter than seedlings or seedling sprouts up to about 10 inches; but beyond this, the diameter growth of all three kinds of reproduction was about equal.

Although stump sprouts make up a relatively small percentage of the total reproduction in the new stands, they are important because they grow so fast and compete with the other kinds of reproduction. However, stump sprouts are not necessarily undesirable components in the new stands. Stump sprouts of desirable species that originate at the ground line and from small stumps are evidently not very susceptible to rot. Many sprouts of this kind will undoubtedly develop into good quality trees.

Factors Affecting Establishment and Growth of Reproduction

Size of Opening

Within the limits studied, the size of the area clearcut did not affect the amount or composition of reproduction 2 years after cutting. In Ohio, openings ranging from 1/8 acre to 5 acres all had enough stems of timber species to form well-stocked stands (table 9). Two larger areas in Ohio (one 30 acres, the other 40 acres) were also well stocked with reproduction of timber species 2 years after cutting. The same results were found in Illinois, Indiana, and Kentucky in openings ranging from 1/20 acre to 4 acres.

However, opening size did affect growth of the reproduction. Four years after cutting, Smith[4] found that yellow-poplar stems in 1/2-acre openings were taller than those in either 1/4-acre or 1/10-acre openings. All openings, regardless of size, are bordered by a zone where reproduction growth is retarded (fig. 20). Small circular openings have a much higher percentage of their total area in this border zone than do large ones (fig. 21). Though the exact width of this zone has not been determined, it is likely to extend more than 10 feet but less than 30 feet from the boles of surrounding trees. Regardless of the exact width of this border zone, the percentage of area in it increases greatly for openings smaller than about 1/2 acre. Thus, for the best growth of the reproduction, the minimum size circular opening should not be less than 1/2 acre; 1 acre is probably more ideal. Openings of any other shape will have a higher percentage of their total area in the border zone. Thus, the minimum size square or rectangular opening should be not less than 1 acre.

[4] Smith, Henry W., Jr. Establishment of yellow poplar (*Liriodendron tulipifera* L.) in canopy openings. Ph.D. thesis, Yale Univ. School of Forestry, 1963.

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Figure 16.—Reproduction in partially cut plot in southern Indiana: *A*, 5 years after cutting; and *B*, 35 years after cutting. Note absence of any new pole-size trees.

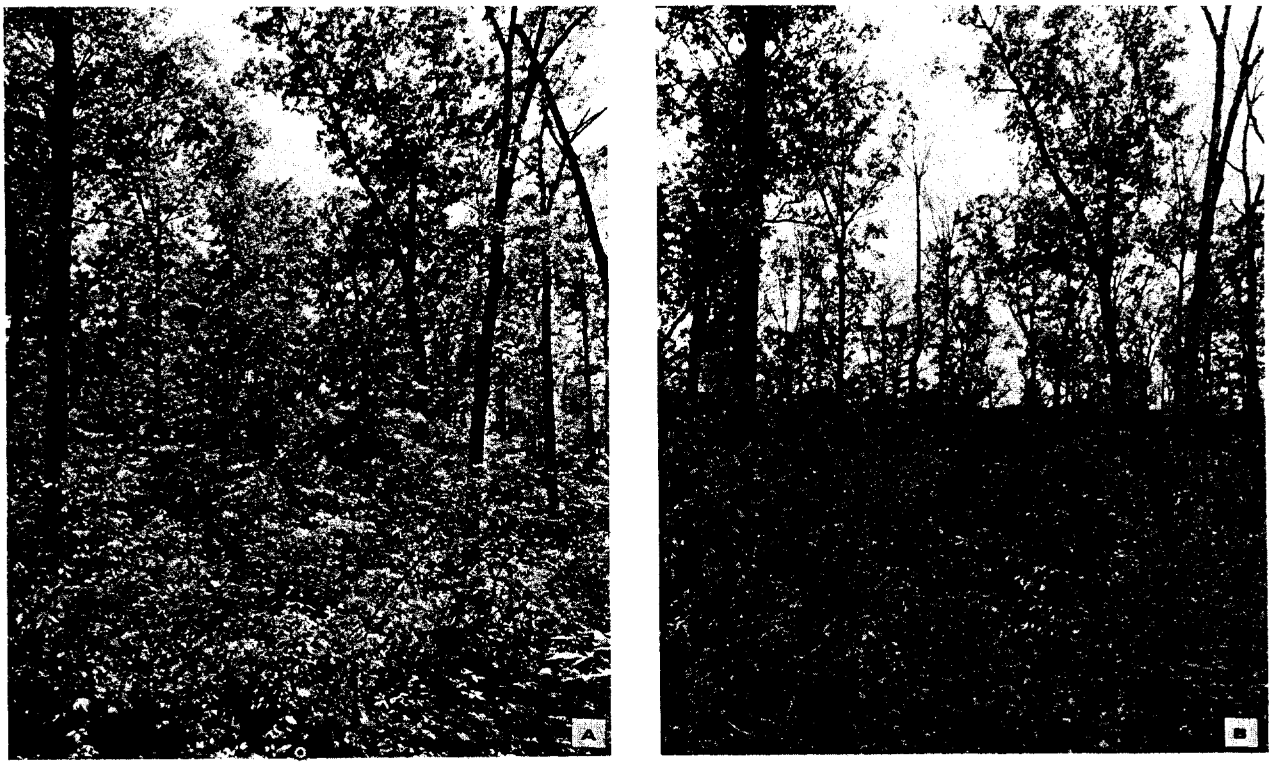

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Figure 17.—Reproduction under shelterwood: *A*, 5 years after cutting; and *B*, 9 years after cutting.

After 6 years, all three kinds of oak reproduction were taller after clearcutting than after partial cutting. The new sprouts on the clearcut plots were more than 5 feet taller than those on the partially cut plots, the old advance reproduction was 3.5 feet taller, and the new seedlings 0.5 foot taller. Kuenzel and McGuire (1942) found the same general relationships for chestnut oak reproduction in Indiana.

In the 6-year-old stand resulting from clearcutting, most of the dominant and codominant oaks were new sprouts from advance reproduction. Stems of old advance reproduction did not respond with increased

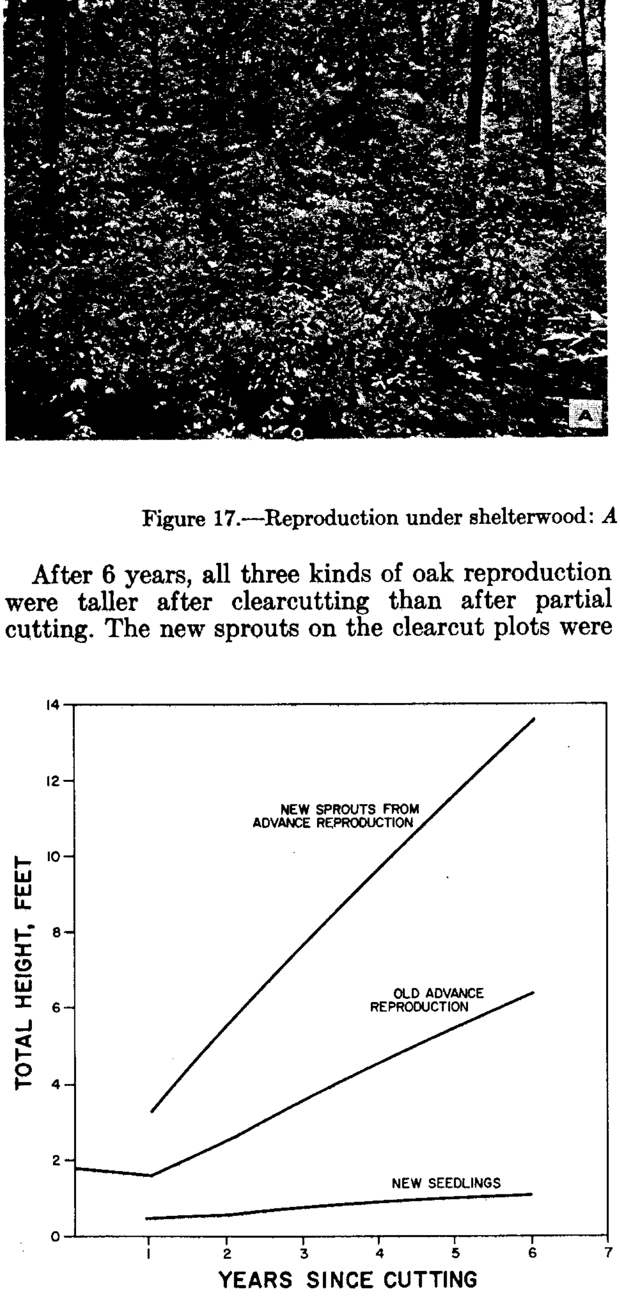

Figure 18.—Height growth of different kinds of oak reproduction after clearcutting in Illinois.

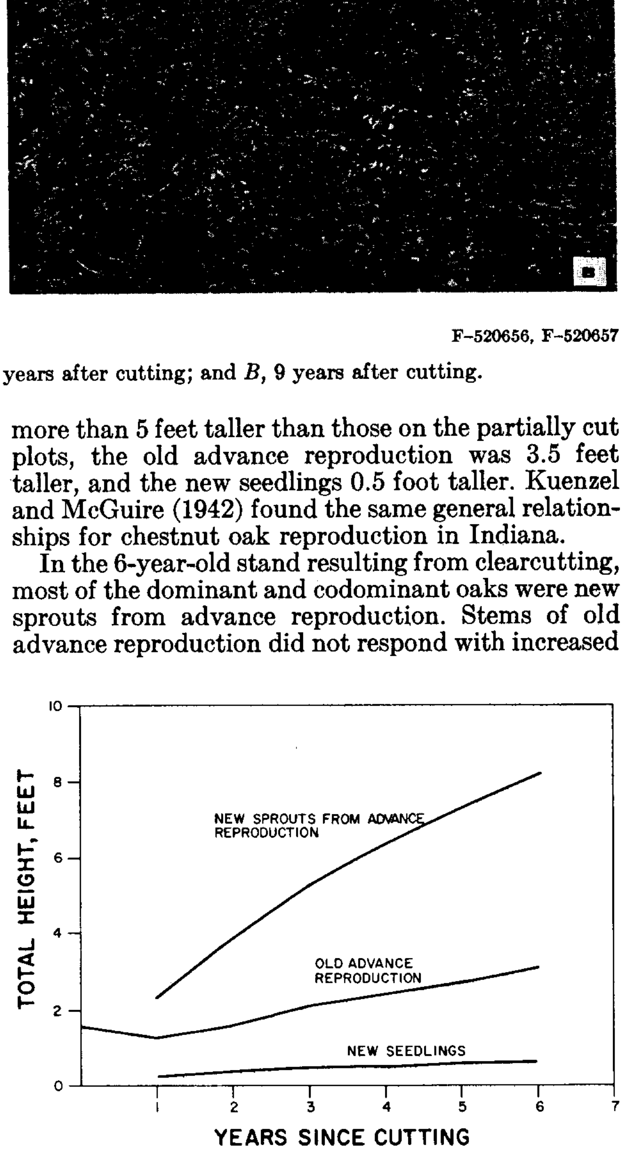

Figure 19.—Height growth of different kinds of oak reproduction after partial cutting in Illinois.

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Figure 20.—Five years after cutting, reproduction next to the old stand is much shorter than in the center of this ⅛-acre opening (right edge of photo).

growth the first year after clearcutting, and their subsequent growth was less than that of the new sprouts.

Site Quality

Most species of upland central hardwoods will grow on a wide range of sites, and the presence or absence of a particular species in the reproduction may be influenced by factors other than site quality. However, a few generalizations are possible.

There are generally more northern red and white oaks than chestnut and scarlet oaks on the good sites, and just the reverse on the average sites. Yellow-poplar is much more abundant on good sites, especially after clearcutting (table 10). Hemlock was found only on good sites in Kentucky. Ash, cherry, and walnut did not occur in the mature stands on enough plots to establish trends. Black oak occurred frequently on all sites. Aside from these generalizations, site quality *per se* had little influence on the amount or composition of 2-year-old reproduction.

Seedbed Conditions

It is well known that yellow-poplar seed germinates best in contact with mineral soil. However, a scarified seedbed of mineral soil does not appear to be a critical factor in reproducing yellow-poplar. Studies in Indiana showed that 17 percent of the ground surface was scarified in horse-logging clearcut plots, while 15 percent was scarified in the first cutting on shelterwood plots and only 4 percent on selection cutting plots. One year after cutting there were 4,000 yellow-poplar seedlings per acre on the clearcut plots, 4,800 per acre on the shelterwood plots, and 700 per acre on the selection plots. Although the seedling density was not as high as that obtained in other studies because of limited seed supply, yellow-poplar reproduction was adequate and distributed well enough to form excellent new stands on the clearcut and shelterwood plots.

Extreme treatments in Kentucky after clearcutting also promoted the establishment of yellow-poplar seedlings. Bulldozing scarified most of the plot

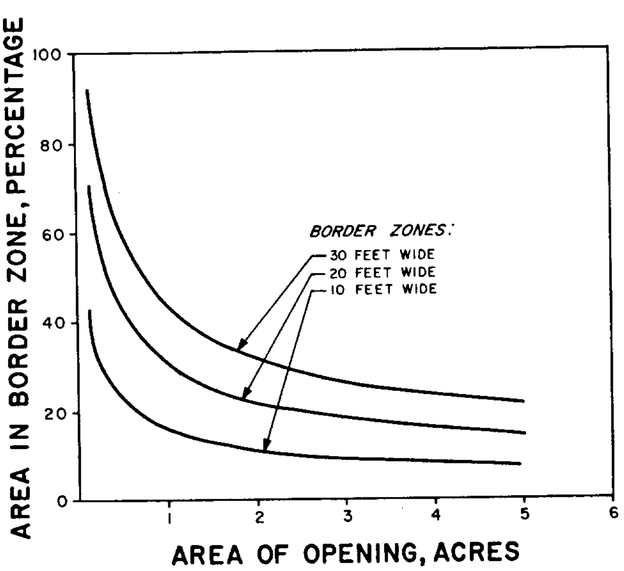

Figure 21.—Relationship between the total area of circular openings and the percentage of area of the opening contained in border zones 10 to 30 feet wide.

area, and there were four times as many yellow-poplar seedlings as on the check plots (table 11). However, in the check plots scarification due to logging was kept at a minimum; and results for these plots are conservative. Other cuttings with no logging restrictions have in every case produced an adequate stand of yellow-poplar where seed-bearing trees were on or near the plots. Thus in harvest cutting there is no real need for scarification beyond that created by logging.

Though treatments designed to encourage desirable reproduction did increase the amount of yellow-poplar in the new stands, such treatments did not result in increased oak reproduction, nor did they effectively reduce the number of undesirable trees. The treated plots had as many or more stems of undesirable species as the check plots (table 11). For real control of species composition, we must find more effective means of controlling the composition of the advance reproduction. Preharvest cutting treatments to encourage advance oak reproduction and eliminate undesirable species in the understory will probably be required.

Season of Logging

Season of logging was not critical in reproducing yellow-poplar. One study in Indiana showed that spring logging produced as many new seedlings per acre as fall logging. This is to be expected because most of the new seedlings came from seed already stored in the litter and not from the current year's crop.

In a seedbed scarification study in Indiana, seed lots of 1,000 yellow-poplar seeds were sown on plots scarified at different seasons of the year. Plots scarified in June, July, and August had fewer seedlings than plots scarified in May (fig. 22), because most of the seed on the summer-scarified plots did not germinate until the second growing season. Seedlings that germinated the second year were too small to compete with the rank vegetation that had developed the previous year on these good forest sites. Nevertheless, experimental cuttings in summer months have always produced enough yellow-poplar seedlings to form good stands if a seed source was previously present.

In an Ohio study, summer clearcutting produced an average of 6,000 yellow-poplar seedlings per acre while winter clearcutting produced 10,000. Even though summer logging produced fewer seedlings, the 6,000 thus produced were more than enough to restock the stand. There were numerous seed-bearing trees on and adjacent to these plots, and apparently a large amount of seed was stored in the litter. Where the seed supply is expected to be scarce, logging should probably take place in spring, fall, or winter to obtain maximum numbers of yellow-poplar.

White ash, another important species, has seed that germinates as well or better on unscarified as on scarified seedbeds. In our studies in Indiana, there were twice as many ash on unscarified ground as on disturbed ground.

Some effort has been made to increase the number of oak seedlings established through scarification treatments. Litter was shown to have an adverse effect on establishment of oaks in Iowa (Krajicek 1960). In a small test in Indiana, more white oak seedlings became established on shelterwood plots that were disked after a newly fallen seed crop than on plots that were not disked. However, 2 years later most of the white oak seedlings on all plots had died because of the competition from the dense stand of other trees and shrubs that developed.

Scholz (1955) concluded that neither disking nor hand-hoeing appeared to offer a practical solution to the problem of getting natural reproduction of northern red oak in Wisconsin, even though both treatments resulted in more seedlings per acre than the control. Cost of hand-hoeing and inefficient and unsafe operation of the disk on steep slopes were the reasons.

Effective cultural practices that favor establishment and development of oak seedlings as a direct result of treatment remain to be developed. To control either the number or species composition of oaks in the next stand, it will be necessary to get oak seedlings established through cultural treatments some years before the harvest cutting.

DISCUSSION AND CONCLUSIONS

The research undertaken shows that many upland central hardwood species will reproduce under a range of cutting methods. However, the amount of residual overstory has a direct effect upon survival and growth of the reproduction. Harvest cutting methods that result in new, even-aged stands or

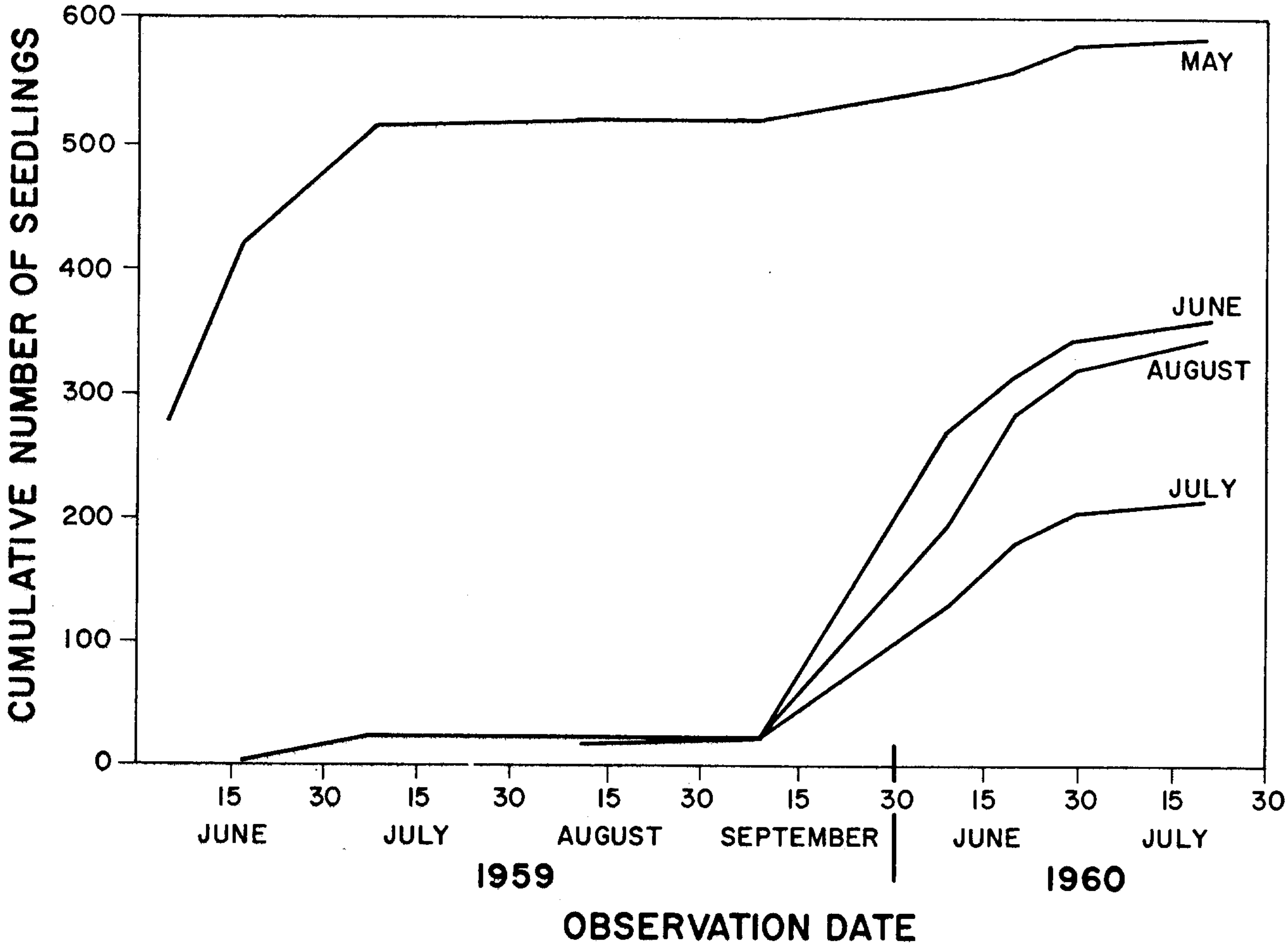

Figure 22.—Germination progress of yellow-poplar seed on seedbeds scarified in spring and summer months.

groups of trees best satisfy the silvical requirements of the upland hardwood species. Even so, the diversity of species and the range of conditions many will tolerate allow forest managers flexibility in choosing or modifying harvest cutting methods to satisfy owner and management objectives.

Where production of high-value timber products in a relatively short time is the major objective, clearcutting should be used for regeneration. This type of cutting has consistently resulted in the greatest numbers of the most desirable timber species and the fastest growth of all species. On the other hand, there are areas where esthetics or recreation are more important, and for these areas, group selection cutting may be the most desirable method.

The cutting method used will largely determine wildlife habitat conditions, and thus the wildlife species expected to inhabit or use a particular area. Under single-tree selection cutting, mast production will probably be near maximum, but production of browse and herbaceous vegetation will be low. Mast production will probably also be high where shelterwood cutting is used, at least until the final removal cut is made. Production of both browse and herbaceous vegetation will probably be higher than under single-tree selection cutting. Clearcutting and group selection cutting will provide a wide diversity of habitat. On recently cut areas, herbaceous vegetation and browse will be plentiful and intervening uncut areas will produce mast. The edge habitat needed by certain wildlife species also will be provided.

To satisfy management objectives or to coordinate multiple uses, cutting methods may have to be modified or used in combination. These modifications will result in sacrifice of values for some uses to enhance those for others. Whatever the objective, forest managers must decide what species are wanted in the new stand, and then use the cutting methods that will best meet the silvical requirements of those species.

Single Tree Selection

Single-tree selection cutting will probably leave harvest areas with optimum esthetic qualities. However, tolerant species such as blackgum, maples, beech, hickory, and dogwood can be expected to dominate the reproduction. The more valuable species such as the oaks, white ash, yellow-poplar, and black cherry may be present following a cut, and if conditions are right, a few may grow into the main stand. However, most of these will not persist very long, and yellow-poplar will not survive. Consequently, single-tree selection has little merit for timber production in upland central hardwoods.

Group Selection

Group selection cutting may meet esthetic or recreation objectives almost as well as single-tree selection. In addition, the reproduction and growth requirements of the more desirable timber species will be better satisfied and the timber production opportunities greater.

Silviculturally, there is little difference between group selection cutting and clearcutting. Although group selection cutting generally means creating small openings, the environmental conditions within the openings, particularly if they are at least ½ acre, are similar to those in larger clearcuttings. Openings smaller than ½ acre will work, but the smaller the opening, the more reproduction growth will be retarded by competition from the surrounding stand. The oaks, as well as the most tolerant species, will tolerate smaller openings than yellow-poplar and black cherry. However, growth may be slow in all but the center of the opening. The amount of reproduction of oak, hickory, and other heavy-seeded species present in the openings depends directly on the amount of advance reproduction before the cut.

Clearcutting

Clearcutting will be the most efficient method for timber production but its use requires advance reproduction of oaks, hickories, and to some extent white ash and black cherry. Advance reproduction of these species, while not abundant on every area studied, was generally adequate for restocking.

There are areas where advance reproduction may be scarce or lacking. In such cases, clearcutting should be delayed unless there is an excellent chance to reproduce desirable species such as yellow-poplar. On good sites, numerous yellow-poplar seedlings can be expected if an adequate seed source is present. And the reproduction of all species will grow rapidly over most of the clearcuttings if they are at least 1 acre in size. Larger cuttings have proportionately less area in a border zone where reproduction growth is retarded. Although these studies showed no silvicultural basis on which to recommend a maximum clearcutting size, consideration of other important forest uses or management objectives may well determine optimum clearcutting size.

Clearcutting has greater adverse effects on esthetics than any other harvest method. These effects can be reduced by varying the size, shape, and location of clearcuts to blend them into the landscape as naturally as possible. Large areas should *not* be clearcut at one time. Rather, openings should be kept relatively small, surrounded by uncut timber, and not enlarged until reproduction is well established. Felling unmerchantable remnants of the old stand instead of leaving them standing improves the appearance of clearcut areas.

Shelterwood

Shelterwood cutting offers a good way to increase oak and hickory in the new stand if advance reproduction is scarce or absent. Since few new oak and hickory seedlings became a part of the new stand after the shelterwood cuttings in these studies, some modifications are needed. The combined preparatory and seed cuttings in these studies were heavy cuts in previously unmanaged, mature stands. Advance reproduction was well established, and these preliminary cuts were heavy enough to permit it to develop into a dense understory. This understory hindered seedling establishment and suppressed the growth of new seedlings. A series of light cuts that gradually opens the old stand is better than one heavy cut.

After new oak and hickory seedlings are established, they must be allowed to develop into relatively large, sturdy stems before the final removal cut is made. The length of time required for this development is uncertain, but it may be as long as 20 years. During this period, it may be necessary to further reduce the overstory to keep the reproduction vigorous.

Under mature stands, where advance reproduction is well established and adequate for restocking, shelterwood cutting is not necessary. It can be used, however, to reduce the visual impact of harvest cutting and to prolong the period of mast and browse production.

When applying the shelterwood cutting method, some reproduction will be damaged each time a stand is entered. A small proportion may be killed, but most damaged stems will resprout and become a part of the new stand. Removal cuts must be timed to avoid excessive reduction of reproduction growth or possible elimination of such species as yellow-poplar.

SUMMARY

Studies of natural regeneration of upland hardwoods in southern Illinois, southern Indiana, eastern Kentucky, and southeastern Ohio covered a wide range of cutting methods, stand conditions, and site quality. Results represent an accumulation of data from more than 200 experimental plots.

Cutting method had no consistent effect on the total amount of reproduction established; no matter how a mature stand was cut, abundant tree reproduction followed. Yellow-poplar was the only species whose numbers varied by cutting method; it reproduced much more abundantly after clearcutting than after any other cutting method, and most of the yellow-poplar present in the new stand were new

seedlings. Most of the reproduction of species other than yellow-poplar was present as advance reproduction before cutting.

Reproduction present after any cutting method was composed of various amounts of old advance reproduction, new sprouts from advance reproduction, new seedlings, and stump sprouts. The abundance of these kinds of reproduction was influenced by cutting method. Clearcutting resulted in more seedlings and more new sprouts than any other cutting method. Reproduction that followed partial cuttings was mostly old advance reproduction.

Advance reproduction was particularly important for the oaks. None of the cutting methods produced many new oak seedlings, and most of the new seedlings that were established after cutting died. If oak advance reproduction was scarce, there were few oaks in the new stand, regardless of cutting method used.

This means that the oak component of the new stand is fixed when the harvest cutting is made; and to obtain adequate stocking of oaks in the new stand, careful attention should be given to the amount of oak advance reproduction under the old stand.

Yellow-poplar was the only species that reproduced almost entirely from seed that germinated after harvest cutting. Even so, it is not necessary to leave yellow-poplar seed trees because of the reservoir of seed that remains viable for up to 8 years in the litter and duff.

Although yellow-poplar seed germinates best on a mineral seedbed, we found that deliberate site preparation and ground scarification treatments to increase yellow-poplar reproduction were unnecessary if an adequate seed source was present. Extra scarification resulted in some increase in the numbers of yellow-poplar seedlings on some plots, but unscarified plots had enough yellow-poplar seedlings to form acceptable stands.

A residual overstory inhibited the growth rate of reproduction of all species, and in some cases eliminated intolerant species. Where adequate moisture and light were present, yellow-poplar and black cherry seedlings as well as new sprouts of oak, white ash, and black cherry were able to compete successfully with reproduction of red maple, blackgum, dogwood, and other undesirables. Reproduction of all species grew fastest after clearcutting.

Within the limits of our studies, we found no practical differences in numbers, distribution, or species composition of reproduction due to size of area clearcut. However, every opening has a border in which reproduction growth is reduced. The smaller the opening, the greater the percentage of area occupied by the border. Thus, there are silvicultural limits to the minimum size of opening for satisfactory reproduction growth. Openings should be at least 1 acre. We could find no silvicultural basis for recommending a maximum size for a clearcut area.

Although this research shows that many species of upland central hardwoods tolerate a range of conditions created by harvest cutting, most species are best suited to even-aged silviculture. Even so, all cutting methods tested or some modification of them may have a place in regenerating hardwoods to meet specific management objectives. The silvical requirements for successful establishment and acceptable growth of the species wanted in the next stand are important, and must be considered to determine when and how a harvest cutting method can be applied or modified. The application of any cutting method requires sound judgment along with careful planning and execution to produce new timber crops and to protect and improve water quality, wildlife populations, and esthetic values.

(More information on even-aged silviculture can be found in Roach & Gingrich's "Even-Aged Silviculture for Upland Central Hardwoods," AH 355, 1968.)

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APPENDIX

Common and Scientific Names

The common and scientific names of the species mentioned in this paper are:

American basswood	*Tilia americana* L.
American beech	*Fagus grandifolia* Ehrh.
American hornbeam	*Carpinus caroliniana* Walt.
Bitternut hickory	*Carya cordiformis* (Wangenh.) K. Koch
Blackgum	*Nyssa sylvatica* Marsh.
Black cherry	*Prunus serotina* Ehrh.
Black oak	*Quercus velutina* Lam.
Black walnut	*Juglans nigra* L.
Chestnut oak	*Quercus prinus* L.
Chinkapin oak	*Quercus muehlenbergii* (Engelm.)
Eastern hophornbeam	*Ostrya virginiana* (Mill.) K. Koch
Eastern redbud	*Cercis canadensis* L.
Flowering dogwood	*Cornus florida* L.
Hazelnut	*Corylus* L.
Northern red oak	*Quercus rubra* L.
Ohio buckeye	*Aesculus glabra* Willd.
Pignut hickory	*Carya glabra* (Mill.) Sweet
Pitch pine	*Pinus rigida* Mill.
Post oak	*Quercus stellata* var. *stellata*
Red maple	*Acer rubrum* L.
Sassafras	*Sassafras albidum* (Nutt. Nees)
Scarlet oak	*Quercus coccinea* Muenchh.
Serviceberry	*Amelanchier arborea* (Michx. f.) Fern
Shagbark hickory	*Carya ovata* (Mill.) K. Koch
Shortleaf pine	*Pinus echinata* Mill.
Slippery elm	*Ulmus rubra* Muhl.
Sourwood	*Oxydendrum arboreum* L.
Sugar maple	*Acer saccharum* Marsh.
Virginia pine	*Pinus virginiana* Mill.
White ash	*Fraxinus americana* L.
White oak	*Quercus alba* L.
Witch-hazel	*Hamamelis virginiana* L.
Yellow-poplar	*Liriodendron tulipifera* L.

Tables

TABLE 1.—*Description of timber stands cut*

Stand number	Location	Type of stand and age (years)	Site quality	Basal area per acre [1]	Volume per acre [2]		Major species in overstory in descending order of abundance
				Sq. ft.	*Cu. ft.*	*Bd. ft.*	
1	Illinois	Even-aged (70–80)	Average	65	—	4,700	White, black, northern, red and scarlet oaks; hickory; and blackgum.
2	Indiana	Uneven-aged (60–150)	Good	98	—	8,900	White, black and northern red oaks; sugar maple; white ash; beech; hickory; slippery elm; yellow-poplar; and scattered black walnut.
3	Kentucky	Uneven-aged (80–200+)	Average	79	—	5,300	Chestnut, scarlet, white, black and northern red oaks; hickory; blackgum; red and sugar maples.
4	Kentucky	Uneven-aged (60–200+)	Good	72	—	5,400	White oak; yellow-poplar; eastern hemlock; black, chestnut and northern red oaks; hickory; beech; white ash; red maple; and blackgum.
5	Kentucky	Uneven-aged (50–200+)	Good	63	—	5,000	Beech; hickory; white, black, northern red and chestnut oaks; eastern hemlock; yellow-poplar; cucumber magnolia; blackgum; red and sugar maples; and scattered black walnut.
6	Ohio	Even-aged (90–100)	Average	88	—	6,200	Scarlet, chestnut, black and white oaks; hickory; blackgum; and red maple.
7	Ohio	Even-aged (90–100)	Good	105	—	11,900	Black, white, chestnut and northern red oaks; hickory; blackgum; yellow-poplar; red maple; and scattered black cherry.
8	Ohio	Even-aged (60–70)	Average	100	3,060	—	Chestnut, scarlet, black, white and northern red oaks; hickory; blackgum; and red maple.
9	Ohio	Uneven-aged (60–150+)	Good	100	3,700	—	White, black, northern red and chestnut oaks; yellow-poplar; white ash; hickory; blackgum; red maple; and scattered black cherry and black walnut.

[1] In trees 4 inches d.b.h. and larger.
[2] Cubic volume is in trees 4 inches d.b.h. and larger.
Board foot volume is in trees 12 inches d.b.h. and larger, Int. 1/4 inch rule.

TABLE 2.—*Cutting methods used in reproduction studies of upland central hardwoods*

Location	Type of cutting	Stand number [1]	Description
Illinois	Heavy partial	1	Removed 50 percent of basal area and 60 percent of board-foot volume.
Illinois	Complete clearcut	1	Removed all trees over 4.5 feet tall.
Indiana	Selection	2	Removed 10 square feet of basal area and 1,000 board feet per acre in trees 12 inches d.b.h. and larger.
Indiana	Shelterwood	2	Removed 55 percent of basal area and 55 percent of board-foot volume. Removal cut 5 years later.
Indiana	Complete clearcut	2	Removed all trees over 2–4 inches d.b.h.
Kentucky	Selection	5	Removed 10 percent of basal area and 1,300 board feet per acre.
Kentucky	Heavy partial	5	Removed 55 percent of basal area and 2,600 board feet per acre.
Kentucky	Complete clearcut	3 & 4	Removed all trees over 2 inches d.b.h.
Ohio	Medium partial	8 & 9	Removed 35 percent of basal area and 35 percent of cubic-foot volume.
Ohio	Medium partial	6	Removed 35 percent of basal area and 20 percent of board-foot volume.
Ohio	Shelterwood	8 & 9	Removed 50 percent of basal area and 50 percent of cubic-foot volume. Removal cut 5 years later.
Ohio	Commercial clearcut	6	Removed 66 percent of basal area and 100 percent of board-foot volume.
Ohio	Complete clearcut	6 & 7	Removed all trees over 2–3 inches d.b.h.

[1] See Table 1.

TABLE 3.—*Advance reproduction per acre of upland central hardwoods on good and average sites, by species*[1]

Location	Red oak group[2]	White oak group[3]	Yellow-poplar	White ash	Black cherry	Black walnut	Hickory	Maple[4]	Slippery elm	Other trees[5]	Total trees	Woody brush[6]	Total stems
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Number*
						GOOD SITE							
Indiana	1	1	2	5	([7])	([7])	4	12	58	7	90	10	13,370
Kentucky	6	13	2	([7])	([7])	([7])	8	24	([7])	9	62	38	7,680
Ohio	17	8	3	1	1	0	7	11	2	2	52	48	7,860
						AVERAGE SITE							
Kentucky	12	10	3	1	0	([7])	12	18	0	13	69	31	4,860
Ohio	21	12	1	0	([7])	0	5	3	0	6	48	52	14,050

[1] Before logging in Indiana; immediately after logging in Kentucky and Ohio.
[2] Black, scarlet, and northern red oaks.
[3] White and chinkapin oaks in Indiana; white and chestnut oaks in Kentucky and Ohio.
[4] Sugar maple in Indiana; red maple in Kentucky and Ohio.
[5] Indiana: hackberry, American beech, and basswood.
Kentucky: blackgum on average sites; Eastern hemlock, American beech, and blackgum on good sites.
Ohio: blackgum.
[6] Dogwood, sassafras, redbud, American hornbeam, witch-hazel, hazelnut, and sourwood.
[7] Less than 1 percent.

TABLE 4.—*Natural reproduction per acre 2 years after harvest cutting in upland central hardwood stands in Indiana, Kentucky, and Ohio (in percentage of total stems)*

Type of Cutting	Red oak group[1]	White oak group[2]	Yellow-poplar	White ash	Black cherry	Black walnut	Hickory	Maple[3]	Other trees[4]	Total trees	Woody brush[5]	Total stems
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Number*
					INDIANA							
Selection	2	6	4	10	1	([6])	4	9	55	91	9	19,080
Shelterwood	([6])	5	21	18	1	1	3	4	34	87	13	21,930
Complete clearcut	1	2	26	7	1	1	4	5	22	69	31	15,780
					KENTUCKY							
Selection	7	7	1	2	([6])	([6])	6	16	6	45	55	12,420
Heavy partial	2	5	3	2	([6])	([6])	6	15	8	41	59	16,130
Complete clearcut	3	8	14	1	0	0	6	15	4	51	49	9,080
					OHIO							
Medium partial	6	13	12	7	1	0	5	10	3	57	43	16,830
Shelterwood	10	10	3	11	2	0	7	12	14	69	31	13,110
Complete clearcut	7	3	37	5	1	0	2	7	5	67	33	22,310

[1] Black, scarlet, and northern red oak at all locations.
[2] Indiana: white and chinkapin oaks.
Kentucky and Ohio: white and chestnut oaks.
[3] Indiana: sugar maple.
Kentucky and Ohio: red maple.
[4] Indiana: mostly slippery elm; but includes American beech, hackberry, basswood, and blackgum.
Kentucky: hemlock, blackgum, American beech, slippery elm, basswood, and cucumber magnolia.
Ohio: blackgum, slippery elm, American beech, and bigtooth aspen.
[5] Indiana: mostly sassafras, dogwood, and mulberry; but includes redbud, paw paw, and American hornbeam.
Kentucky: dogwood, sourwood, and sassafras.
Ohio: dogwood, sassafras, sourwood, witch-hazel, hazelnut, and American hornbeam.
[6] Less than 1 percent.

TABLE 5.—*Kinds of reproduction present 2 years after harvest cutting in upland central hardwood stands in Ohio*
(Percent)

Kind of reproduction	All oaks	Yellow-poplar	Ash	Black cherry	Hickory	Red maple	Black-gum	Dog-wood	Sassa-fras
				COMPLETE CLEARCUT					
New seedlings	1	98	43	33	2	4	1	0	21
Advance reproduction	19	1	5	6	30	21	28	22	2
New sprouts	76	0	51	61	56	74	68	71	76 [1]
Stump sprouts	4	1	1	0	12	1	3	7	1
				SHELTERWOOD					
New seedlings	1	100	35	17	2	11	14	0	41
Advance reproduction	65	0	34	66	77	67	72	68	9
New sprouts	27	0	30	17	21	20	14	32	50 [1]
Stump sprouts	7	0	1	0	0	2	0	0	0
				MEDIUM PARTIAL					
New seedlings	4	98	18	33	2	23	0	0	73
Advance reproduction	69	1	58	56	73	54	40	65	7
New sprouts	25	1	23	11	24	13	60	33	13 [1]
Stump sprouts	2	0	1	0	1	0	0	2	7

[1] Includes root sprouts.

TABLE 6.—*Number of stems of natural reproduction per acre 5 years after harvest cutting in Indiana and percent change from the number 2 years after cutting*

Species	Selection	Shelterwood	Clearcut	Selection	Shelterwood	Clearcut
	Number	*Number*	*Number*	*Percent*	*Percent*	*Percent*
Red oak group	160	30	110	−57	−57	−8
White oak group	570	210	330	−46	−81	−14
Yellow-poplar	10	1,620	2,890	−99	−64	−30
White ash	2,700	1,480	1,050	+43	−49	−4
Black cherry	100	50	130	−63	−74	−35
Black walnut	40	90	240	+33	−47	+100
Hickory	530	300	590	−24	−49	−16
Sugar maple	2,320	780	1,250	+27	−11	+41
Other trees	7,130	4,340	6,350	−33	−43	+80
Woody brush	1,400	1,680	3,390	−18	−41	−30
Total trees	13,560	8,900	12,940	−20	−53	+19

TABLE 7.—*Number of stems of natural reproduction per acre 2, 7, and 10 years after harvest cuttings of different intensities in Ohio*

Criterion	Type of cutting	Species: All oaks	Species: Yellow-poplar	Species: Other trees	Total
All stems 2 years after cutting	Medium heavy partial	9,310	1,180	2,290	12,780
	Commercial clearcut for sawtimber	5,140	3,020	1,600	9,760
	Complete clearcut	2,960	6,340	2,270	11,570
All stems taller than 4.5 feet after 7 years	Medium heavy partial	590	40	860	1,490
	Commercial clearcut for sawtimber	810	290	1,090	2,190
	Complete clearcut	590	550	1,980	3,120
All stems larger than 0.6 inches d.b.h. after 10 years	Medium heavy partial	200	20	390	610
	Commercial clearcut for sawtimber	370	100	500	970
	Complete clearcut	490	310	1,430	2,230
All stems 2.5 to 5.5 inches d.b.h. after 10 years	Medium heavy partial	53	6	55	114
	Commercial clearcut for sawtimber	71	4	46	121
	Complete clearcut	76	30	120	226

TABLE 8.—*Average height of dominant and codominant reproduction by species 5 years after harvest cutting in Indiana*

Species	Cutting method		
	Selection	Shelterwood	Complete Clearcut
		Feet	
Red oak group	2.1	2.0	8.5
White oak group	1.4	4.8	11.0
Yellow-poplar	(1)	6.6	12.0
White ash	2.9	4.0	11.5
Black cherry	1.3	7.0	11.3
Black walnut	(1)	4.7	10.5
Hickory	2.0	3.2	11.0
Sugar maple	3.9	4.5	14.2
Blackgum	4.6	6.0	11.6
Slippery elm	3.5	4.6	10.5
Dogwood	4.3	5.8	11.0
Sassafras	3.0	8.3	13.3
Redbud	4.7	6.7	10.4

[1] No dominant or codominant stems present in the reproduction.

TABLE 9.—*Number of stems of natural reproduction per acre 2 years after clearcutting openings of different sizes on good and average sites in Ohio*

Size of opening	Red oak group	White oak group	Yellow-poplar	White ash	Black cherry	Hickory	Red maple	Other trees	Woody brush	Total stems
					GOOD SITE					
Acres										
1/8	1,060	1,360	8,860	70	130	760	2,160	490	10,530	14,890
1/4	2,730	2,030	15,530	330	100	900	1,130	1,100	11,600	23,850
1/2	1,300	620	11,850	30	300	1,150	730	1,900	13,450	17,880
1	900	1,050	11,180	100	70	1,110	1,450	1,890	8,630	17,750
3	1,690	1,130	10,690	20	70	1,310	2,020	1,740	11,730	18,690
5	1,140	730	10,590	260	110	920	1,670	1,200	9,560	16,620
					AVERAGE SITE					
1/8	2,960	2,030	2,160	0	330	700	60	1,300	10,730	9,540
1/4	2,930	1,230	3,760	0	70	1,860	530	1,590	13,170	11,970
1/2	4,310	1,350	1,480	0	0	1,110	1,430	3,060	7,280	12,740
1	2,910	530	4,080	0	130	1,360	1,630	2,150	10,870	12,790
3	4,450	1,630	3,530	0	60	1,230	610	1,520	11,070	13,030
5	3,630	1,230	2,870	0	80	860	490	2,410	11,975	11,570

TABLE 10.—*Natural reproduction per acre 2 years after clearcutting on good and average sites in Kentucky and Ohio in percentage of total stems*

Site	Red oak group	White oak group	Yellow-poplar	White ash	Black cherry	Hickory	Red maple	Other trees	Total trees	Woody brush	Total stems
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Number*
					KENTUCKY						
Good site	2	8	19	(1)	0	4	18	6	57	43	11,060
Average site	4	8	7	1	0	8	8	1	37	63	7,770
					OHIO						
Good site	1	6	29	7	1	2	19	8	64	36	26,590
Average site	12	18	4	2	3	3	6	3	51	49	10,140

[1] Less than 1 percent.

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