Hardwood Regeneration Twenty Years After Three Distinct Diameter-limit Cuts in Upland Central Hardwoods[1]

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Abstract: The effects of diameter-limit cutting on the future species composition and development of 60-80 year-old upland oak stands were studied in southern Ohio. Four treatments, 11-inch diameter-limit cut, 14-inch diameter-limit cut with selective thinning, 14-inch diameter-limit cut with low thinning, and uncut control were evaluated on medium oak sites (black oak site index 60-75 ft) and good oak sites (black oak site index > 75 ft). Twenty 1.8 acre treatment areas were established, 2 complete replications of the 8 treatment combinations and one partial replication. One year after cutting, understory species counts were made for all trees $\leq$ 3.5 inches dbh on 20 milacre plots within each treatment area. Twenty years after cutting, regeneration $\geq$ 3.5 inches dbh was tallied on 150x150 foot plots centered in each of the treatment areas. Regeneration 0.6-3.5 inches dbh was inventoried using nine 0.01 acre subplots systematically located within each 150x150 foot plot.

Prior to cutting, oak and hickory accounted for 100 percent of the overstory canopy on medium oak sites, and 82 percent of the overstory canopy on good oak sites. One year after cutting all treatment-site combinations contained large populations of oak-hickory, red maple, and mixed-hardwood regeneration (stems $\leq$ 3.5 inches dbh), averaging more than 9000 stems per acre. Regeneration density was significantly higher on good than medium site. On good sites, diameter-limit cuts contained almost twice the stem density found on uncut areas. In general, oak-hickory densities were higher on the uncut areas than on the diameter-limit cuts while the densities of mixed hardwoods, red maples, and non-commercial species were higher on the diameter- limit cuts.

Twenty years after diameter-limit cutting regeneration on both medium and good sites was predominantly red maple and mixed-hardwoods. As expected, oak-hickory density was higher on medium than good sites, while mixed-hardwood density was higher on good sites. Red maple was abundant on all diameter-limit cuts on both sites, but was particularly successful on the heavier diameter-limit cuts on medium sites.

Results suggest that heavy diameter-limit cutting on a long cutting cycle may not be an appropriate harvesting method in management situations where maintaining a significant amount of oak in an oak-hickory stand is an important ownership objective. Similarly, heavy diameter limit cuts on long cutting cycles do not appear suitable as "preparatory cuts" for the purpose of stimulating suitable advanced oak regeneration prior to clearcutting.

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One-third of the 363 million acres of unreserved forest land in the eastern United States and 58 percent of Ohio's commercial forest land is classified as oak-hickory (Waddell et al. 1989, Griffith et al. 1992). Oaks are a highly desirable species component of this region. They are among the most economically valuable species and provide other benefits including important habitat needs for a wide variety of wildlife. Additionally, their fall colors make them an aesthetically desirable component in the landscape.

Obtaining adequate natural oak regeneration following timber harvesting, however, has often proven frustrating. Current knowledge suggests that any form of partial cutting discourages oak regeneration and encourages more tolerant species, such as red maple and other mesophytic hardwood species (Rudolph and Lemmien 1976, Heiligmann et al. 1985, Smith and Miller 1987, Hill and Dickmann 1988). Not infrequently, however, partial cuts involving diameter-limit guidelines have been employed in oak-hickory forests to maximize economic returns from timber sales. Forestry professionals generally regard such partial cuts based on diameter-limit guidelines to be improper for many ownership objectives, though few studies have actually documented long-term effects on stand composition and development (Heiligmann et al. 1985, Smith and Miller 1987).

The objective of this study was to examine the effects of three different diameter-limit cuts on the species composition of non-residual canopy trees and understory regeneration in oak-hickory stands 20 years after harvest and compare that composition with uncut stands. This should provide substantial insight into the possible future species composition of oak-hickory stands subjected to diameter-limit cutting.

METHODS

The study was established by the U.S. Forest Service in 60-65 year-old, even-aged, upland oak stands on the Mead Corporation Experimental Forest in southern Ohio. Topography was flat to locally steep, with slopes up to 50 percent. Predominant soils were Shelocta (fine-loamy, mixed, mesic hapludult), Wharton (fine-loamy, mixed, aquic hapludult), and Latham (clayey, mixed, mesic aquic hapludult) formed from residual shales, sandstones, and siltstones.

The study was established on two site classes - medium sites (black oak site index 60-75 feet at reference age 50 years) and good sites (black oak site index >75 feet at reference age 50 years). The overstory composition of the stands on medium sites prior to treatment (trees ≥ 9.6 inches dbh) was white oak (64 percent), other oaks (28 percent), and hickory (8 percent). The overstory composition of stands on good sites prior to treatment (trees ≥ 9.6 inches dbh) was white oak (60 percent), other oaks (9 percent), hickory (13 percent), yellow poplar (12 percent), and others (6 percent). Other stand characteristics prior to cutting are reported in Table 1. Prior to cutting, red maple was the most common understory species.

Treatments evaluated in this study were as follows:

11-Inch Diameter-Limit Cut - All trees ≥ 11 inches dbh were cut, reducing the cubic foot volume of the stand by one-half. This treatment will be abbreviated 11-DL.

14-Inch Diameter-Limit With Low Thinning - All trees ≥ 14 inches dbh were cut along with most of the trees in the 4-8 inch dbh class in order to reduce the stand cubic foot volume to half. This cutting was an attempt to incorporate a "shelterwood effect" into the diameter-limit cut. This treatment will be abbreviated 14-DL-LT.

14-Inch Diameter-Limit With Selective Thinning - All trees ≥ 14 inches dbh were cut and the density of the remaining stand was thinned to 60 percent stocking (Roach and Gingrich, 1968) favoring the retention of oak. This treatment will be abbreviated 14-DL-SEL.

Uncut - No trees were cut.

Stand characteristics following cutting on good and medium sites are reported in Table 1.

Table 1.—Stand characteristics by site before treatment and by site and treatment 1 year after treatment

Treatment	Density (stem/ac)	Basal area (ft^2/ac)	Stocking[a] (%)	DBH (in)
		Conditions Prior To Cut		
Good Sites	188	99	85	9.8
Medium Sites	212	100	89	9.3
		Good Quality Sites After Cutting		
14-DL-LT	59	42	34	11.4
11-DL	126	52	47	8.7
14-DL-SEL	151	68	62	9.1
UNCUT	191	94	82	9.5
		Medium Quality Sites After Cutting		
14-DL-LT	70	41	35	10.3
11-DL	166	58	55	8.0
14-DL-SEL	156	67	60	8.9
UNCUT	202	98	88	9.4

[a] Roach, B. A., and S. F. Gingrich (1968).

A two factor (cutting method, site quality) randomized block experimental design was used. The experiment contained two complete replications of all cutting methods and both site qualities. An additional 14-DL-LT treatment was established on a good site. Three additional 14-DL-SEL treatments were established, two on good sites and one on a medium site. The experiment included 20 treatment areas, each 1.8 acres in size.

The original and residual overstory composition, basal area, and average diameter were determined for each treatment area by complete sampling. Understory species counts by species group were made one year after the cutting for all stems $\leq$ 3.5 inches dbh on 20 milacre plots per treatment area (unpublished data, U.S. Forest Service). Originally, reproduction was categorized by type of reproduction (e.g. seedling, seedling sprout, advanced reproduction, stump sprout), but only one replication of these data on medium sites was saved. Species groups recognized were:

Oak-Hickory: *Quercus alba, Q. coccinea, Q. prinus, Q. rubra, Q. velutina, and Carya spp.*
Red Maple: *Acer rubrum.*
Mixed-Hardwoods: *Acer saccharum, Fagus grandifolia, Fraxinus americana, Juglans nigra, Liriodendron tulipifera, Nyssa sylvatica, Platanus occidentalis, Populus grandidentata, Prunus serotina, Tilia americana, and Ulmus spp.*
Non-Commercial: *Amelanchier spp., Carpinus caroliniana, Castanea dentata, Cercis canadensis, Cornus florida, Hamamelis virginiana, Lindera benzoin, Magnolia acuminata, Malus spp., Oxydendrum arboreum, Pinus echinata, Robinia pseudoacacia, Sassafras albidum, and Tsuga canadensis.*

Twenty years after cutting, tree and stand characteristics were determined within 150x150 foot plots centered in each of the 20 treatment areas. Each plot was surrounded by a 66 foot wide buffer strip which received the same treatment. All trees > 3.5 inches dbh were tallied by species, diameter, crown class, and whether or not the tree had been part of the residual overstory after cutting. Trees 0.6 to 3.5 inches dbh were inventoried by species and crown class using 9 0.01-acre circular subplots systematically located within each 150x150 foot plot. For analysis of 20-year data, all trees not part of the residual overstory were considered reproduction. Thus, reproduction included both advanced reproduction and reproduction which came in following the treatments.

Data were analyzed using analysis of variance with treatment and site quality as factors. Tukey's HSD test was used to test differences among cutting methods. Pearson correlations coefficients were used to evaluate correlations between original and residual stand parameters and regeneration densities 1 year and 20 years after treatment. Differences were judged significant at $p \leq 0.05$.

RESULTS

Regeneration One Year After Treatment

Regeneration density (stems ≤ 3.5 inches dbh) averaged more than 9000 stems per acre on all treatments one year after cutting (Table 2). This high density of regeneration was due to counting all stems ≤ 3.5 inches dbh, rather than those above a certain size threshold (e.g. 4.5 feet in height). Original data identifying the type of regeneration were available for only one replication of the treatments on medium sites. For this replication, first year regeneration on the diameter-limit cuts averaged 56 percent advanced regeneration, 32 percent seedling sprouts, 9 percent seedlings, 1 percent stump sprouts, and 2 percent undetermined. All of the regeneration in the uncut areas was classified as advanced regeneration. While there would be danger in generalizing from these data, the magnitude of the numbers suggest that, at least on the medium sites, advanced regeneration and seedling sprouts accounted for a relatively high proportion of the regeneration, while seedlings and stump sprouts were far less important.

Table 2.—Regeneration density (stems/ac) 1 year after cutting by treatment, species group, and site quality

Treatment	Oak-hickory	Red maple	Mixed-hardwoods	Non-commercial
		Good Quality Sites		
14-DL-LT	7,475	4,300	5,300	4,775
11-DL	2,850	1,700	8,425	7,875
14-DL-SEL	4,550	4,250	4,275	13,175
UNCUT	4,750	2,125	1,575	3,900
		Medium Quality Sites		
14-DL-LT	2,725	1,500	2,625	3,050
11-DL	5,375	2,450	500	2,050
14-DL-SEL	4,350	900	1,550	3,225
UNCUT	7,325	250	375	1,250

Species-group densities of regeneration one year after treatment were not correlated with original or residual stand density, basal area, or stocking. On medium sites there was significantly more red maple on the 11-DL than on the uncut areas. Other species-group densities did not differ significantly among treatments. Diameter-limit cuts, therefore, were pooled to determine if cutting affected regeneration densities relative to the uncut areas.

The effects of diameter-limit cutting on regeneration densities differed by site (Table 2), but all treatment/site combinations contained large populations of oak-hickory, red maple, and mixed-hardwood regeneration from which future canopy trees could develop. On good sites, diameter-limit cuts contained almost twice the stem density found on the uncut areas, 23,017 stems/ac versus 12,350 stems/ac. In contrast, on medium sites there was little difference in stem densities between the diameter-limit cuts and uncut areas, 10,100 stems/ac on the diameter-limit versus 9,200 stems/ac on the uncut. In general, oak-hickory densities were higher on the uncut areas than on the diameter-limit cuts while the densities of mixed-hardwoods, red maples, and non-commercial species were higher on the diameter limit cuts. Oak-hickory accounted for 59 percent of the regeneration on the uncut areas and 32 percent on the diameter-limit cuts.

Regeneration density was significantly higher on good than medium sites, 20,325 stems/ac and 9,875 stems/ac respectively. There were significantly more mixed-hardwood and red maple regeneration on good than on medium sites. Although oak-hickory density was not significantly different between sites, oak-hickory regeneration in the diameter-limit cuts accounted for 42 percent of the regeneration on medium sites compared with 22 percent on good sites.

Non-Residual Canopy Trees Twenty Years After Treatment

Twenty years after harvesting there were distinct differences between sites and treatments in the species composition of trees that had grown into the intermediate, codominant, or dominant crown positions. These trees are referred to hereafter as "non-residual canopy trees".

Uncut areas on good sites averaged 4 non-residual canopy trees per acre (3 red maple, 1 mixed-hardwoods) while diameter-limit cuts on good sites averaged 28 non-residual canopy trees (4 oak-hickory, 14 red maples, 10 mixed-hardwoods). On all diameter-limit cuts on good sites, non-residual canopy red maple and mixed-hardwoods were far more abundant than oak-hickory, with the red maple and mixed-hardwoods accounting for 85 percent of the species composition.

The species composition of non-residual canopy trees on medium sites differed in several ways from that on good sites (Figure 1). First, non-residual canopy trees were 9 times more abundant on uncut medium sites than on uncut good sites (37 versus 4 per acre). Second, oak-hickory constituted a substantially higher proportion (38 to 60 percent) of the non-residual canopy trees on all treatments except the 14-DL-LT. Third, the percent of red maple in the non-residual canopy trees generally increased as the post-treatment residual overstory density decreased. This was particularly evident with the two heaviest cuts, the 11-DL and 14-DL-LT, where red maple constituted 58 and 76 percent of non-residual canopy trees, respectively. Fourth, primarily as a result of the comparatively large number of red maple, the 14-DL-LT averaged more than 3 times non-residual canopy trees per acre as the other treatments, 103 versus 30. And fifth, very few mixed-hardwoods grew into the intermediate or higher crown positions on average sites during the 20 years following treatment.

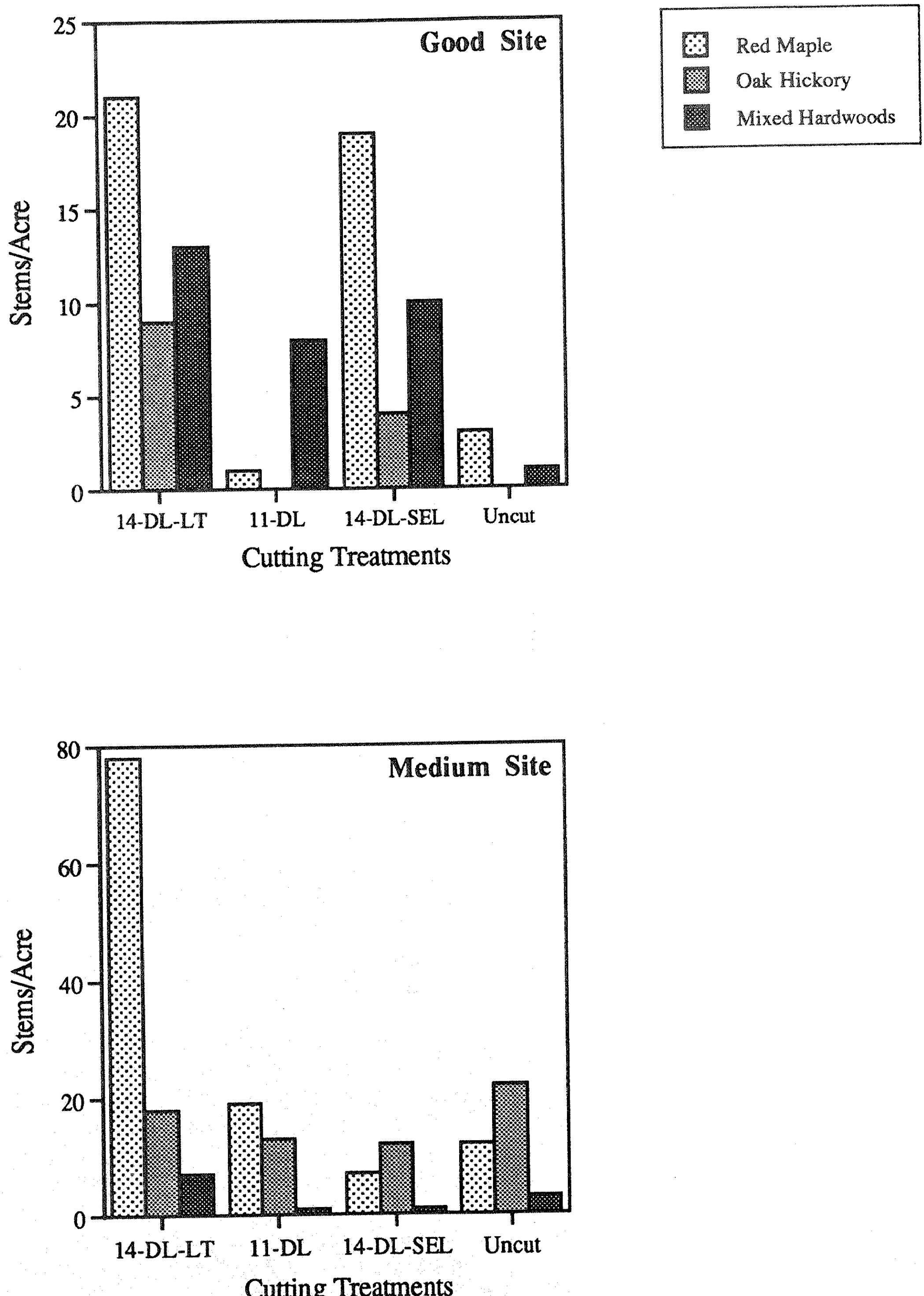

Figure 1.—Density of non-residual canopy trees 20 years after treatment.

Understory Tree Composition Twenty Years After Treatment

As with the non-residual canopy tree composition, there were distinct differences between sites and treatments in understory tree composition. For the most part, these differences paralleled those observed in the non-residual canopy trees.

On good sites, diameter-limit cuts averaged more than 2.5 times as many stems of commercial species per acre as uncut areas (Figure 2). Oak-hickory constituted a relatively small percentage of the understory composition on all treatments. The large increases in numbers of stems per acre observed on the diameter-limit cuts were due almost entirely to increases in the numbers of red maple and mixed-hardwoods. Mixed-hardwoods constituted an important component of the understory composition in the diameter-limit cuts on good sites, accounting for between 26 percent (14-DL-SEL) and 70 percent (11-DL) of the stems of commercial species.

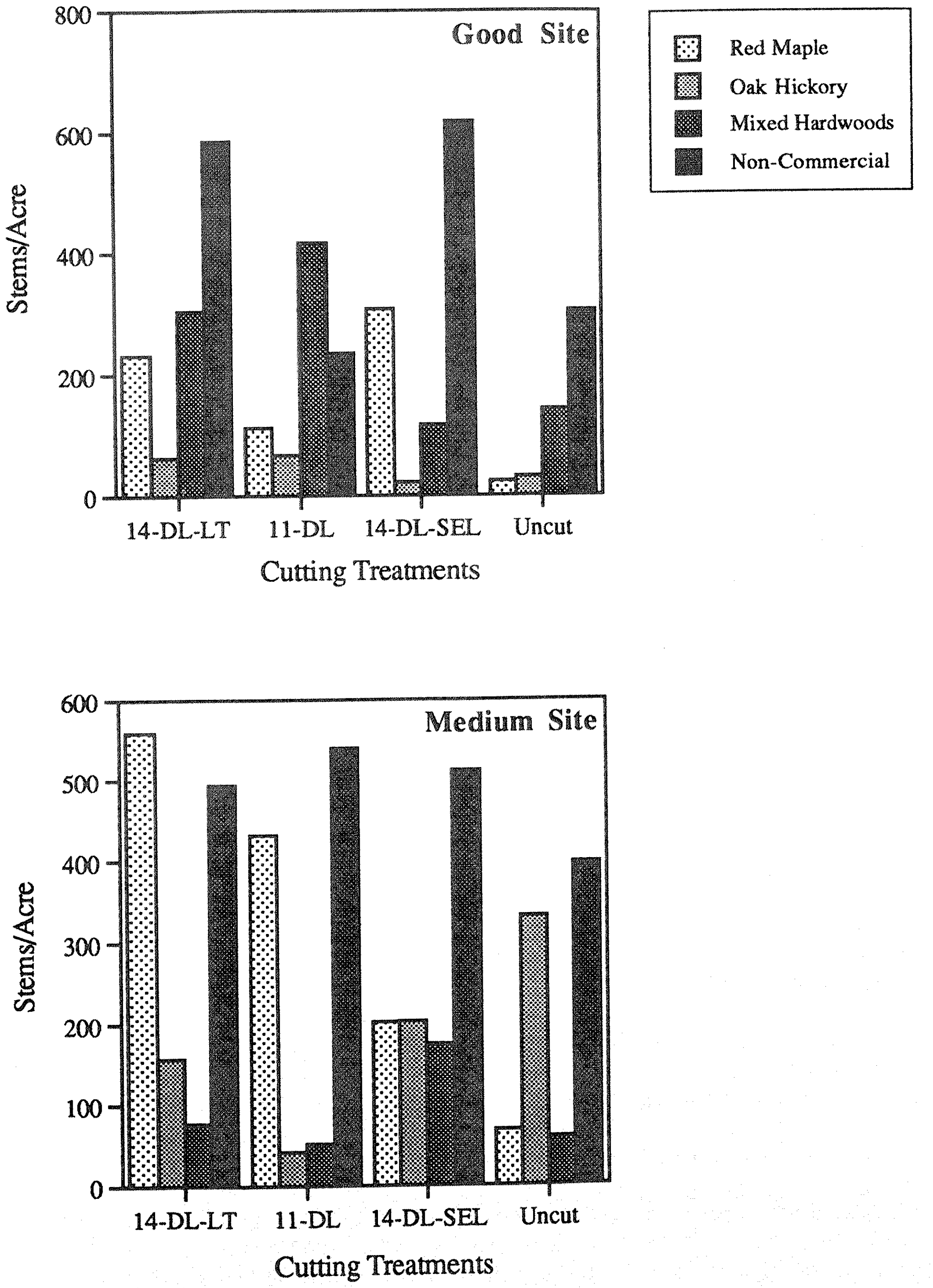

Figure 2.—Understory tree composition 20 years after treatment.

Again, the species composition on medium sites differed in several ways from that on good sites. Unquestionably, the most noticeable characteristic of the understory species composition was the direct relationship between red maple density and post-cut residual basal area. The lower the post-cut basal area, the higher the density of red maple. With the exception of the 11-DL treatment, oak-hickory understory density was much higher on medium sites than on good sites, averaging 150 and 203 stems per acre on the 14-DL-LT and 14-DL-SEL, respectively. Oak-hickory understory was highest, 332 stems per acre, on the uncut areas. In general, mixed-hardwood understory density was much lower on medium sites than on good sites.

DISCUSSION

Diameter-limit cutting in these even-aged upland central hardwood stands increased the amount, proportion, and importance (as expressed by crown position) of red maple and mixed-hardwoods relative to the uncut areas. In the diameter-limit cuts, red maple and mixed-hardwoods were the predominant species moving into the canopy, and were also the most abundant species in the understory.

Diameter-limit cuts, followed by 20 years without additional cutting, appear to have accelerated the succession of the relatively tolerant red maple replacing the less tolerant, slower growing oak-hickory, particularly on the medium sites. On medium sites oak-hickory regeneration fell to 3.6 percent of the first year count, on good sites it fell to 1.1 percent. By comparison, oak percentages on adjacent complete clearcuts were 11.8 percent for the medium sites and 3.9 percent on good sites (Ward and Heiligmann 1990). Partial cutting has been reported to encourage the establishment of more tolerant species in Illinois (Jokela and Sawtelle 1985), West Virginia (Smith and Miller 1987), and Michigan (Abrams and Scott 1989). On good sites, not only did the density of red maple reproduction increase, but also that of the relatively intolerant mixed-hardwoods, particularly yellow poplar. While mixed-hardwood regeneration was present throughout the diameter-limit cuts, it was particularly successful on good sites were the cut had been very heavy and appeared destined to becomepart of the overstory canopy. In diameter-limit cuts, the heavier the cut or the more irregular the distribution of cut trees, the more likely areas within the cut will approach the appearance and characteristics of a commercial or complete clearcut, conditions well suited to the faster growing, predominantly intolerant mixed-hardwoods, and to faster growing tolerants such as red maple. Undoubtedly competition from the greater number of understory stems present on the good site contributed to the significantly lower number of oak present on the good site 20 years later. Johnson and Jacobs (1981) reported that oak reproduction was inhibited by a heavy shrub layer which developed after a shelterwood cut in southwestern Wisconsin. Similarly, Martin and Hix (1988) examined a 26-year-old shelterwood and partly attributed the low proportion of red oak to competition from a high total regeneration density.

Throughout this study oak and hickory have been evaluated as the oak-hickory species group. Unfortunately, the data structure did not allow subdivision of the oak-hickory species group for the understory and non-residual canopy tree classes. For total regeneration (understory + non-residual canopy trees) hickory averaged 62 percent of the oak-hickory species group, oak averaged 38 percent. This percentage distribution probably represents well the understory regeneration which varied from 92 to 99 percent of the total regeneration, depending on the treatment. No assumptions can be made about the proportion of oak and hickory in the non-residual canopy trees. This fact, however, in no way negates the findings. Since the diameter-limit cuts proved relatively ineffective in regenerating the oak-hickory species group as a whole, they most certainly were ineffective in regenerating oak as part of that group.

If oak regeneration is an important management objective in an upland central hardwood stand, it would appear diameter limit cutting with long cutting cycles are not an appropriate harvesting method. Based on this study, such a harvesting strategy would increase the amount of red maple and mixed-hardwoods at the expense of the oak.

Partial cuts are sometimes used in upland central hardwoods in an attempt to stimulate advanced oak regeneration prior to clearcutting. In this study, the understory oak-hickory regeneration 20 years after diameter-limit harvesting averaged 92 stems/ac, 50 stems/acre on good quality sites and 134 stems/acre on medium quality sites. Recommendations suggest adequate advanced oak regeneration be somewhat more than 400 stems of suitable size per acre (Sander 1977). After 20 years, none of the diameter-limit cuts contained that much suitable advanced oak regeneration. The highest understory oak-hickory regeneration, 332 stems/ac, was present in the uncut areas on medium sites. Diameter-limit cuts on medium sites averaged 134 oak-hickory stems/ac. On good sites the uncut areas averaged 31 oak-hickory stems/ac and the diameter-limit cuts averaged 51 oak-hickory stems/ac.

MANAGEMENT IMPLICATIONS

There are unquestionably forest management situations where diameter-limit cutting is an appropriate harvesting method. Such a recommendation, however, requires careful evaluation of short- and long-term forest ownership objectives and individual stand characteristics. The results of this study suggest that if maintaining a significant amount of oak in an oak-hickory stand is an important ownership objective, heavy diameter-limit cutting on a long cutting cycle (20 years) is not an appropriate harvesting method. To the contrary, such a diameter-limit cutting will favor the establishment and growth of red maple and a variety of mostly intolerant mixed-hardwoods that successfully compete in the larger openings created by the harvest. Similarly, heavy diameter-limit cuts on long cutting cycles do not appear suitable as "preparatory cuts" prior to clearcutting for the purpose of stimulating suitable advanced oak regeneration. Such cuts, instead, favor the development of red maple and mixed-hardwood advanced regeneration.

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