HARDWOOD REGENERATIVE RESPONSE TO CLEARCUTTING AND EDGE EFFECTS IN AN OAK DOMINATED FOREST OF CENTRAL INDIANA[1/]

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Abstract.--In 1981, eleven treatment blocks were installed in an upland oak forest in central Indiana to investigate long term effects of even-aged silvicultural systems on small isolated woodlands of the Tipton Till Plain Region. In July, 1981 the first block was clearcut, and 26.3 m^2 ha^{-1} of basal area was removed. Oak species accounted for 63% of the stems removed and 88% of the basal area. Five year results indicate that while greater than 700 stems ha^{-1} of red and white oak species were found in the clearcut, these stems were dominated across all height and diameter classes by less desirable competing species. Based on these results, an additional release will be necessary to promote the oak component of the future canopy.

Keywords: upland oak, clearcut, competition

INTRODUCTION

Problems encountered by foresters in the regeneration of economically valuable oak species are well documented throughout the central hardwoods region (e.g., Merritt 1979, Watt 1979, Sander 1979). These and other authors cite a long list of attributes for oak species (in terms of seed production, germinating capacity and seedling vigor in relation to climatic fluctuations) as well as methodologies of providing for and nurturing oak reproduction. Successes have been few on good sites, and still little is known about optimal macro and microsite requirements of these species which favor establishment and vigorous growth to economic maturity.

The hypothesis held by many that most of the old-growth oak stands throughout the region were initiated as a result of major disturbance (e.g., forest clearing for row crop agriculture and fire sweeping through slash and as a tool for clearing) seems reasonable given average ages found for many of these stands (e.g., Jokela and Sawtelle 1985). Certainly, disturbance has been documented as a major component in the life histories of species in other regions as well as a primary force determining composition, abundance and distribution (Oliver 1981, White 1979). Hence, the possibility that oak species possess vital attributes (Noble and Slayter 1980) that are attuned to a particular disturbance regime, or a complex of disturbance regimes, cannot be discounted when considering appropriate silvicultural techniques or management strategies to favor these species.

Since the early part of this century, when legal controls were installed to prevent indiscriminate cutting and wildfire, we have seen a gradual shift in dominance throughout the region from mid-successional oak species to late-seral, shade tolerant species like sugar maple (Newman and Ebinger 1985, Nigh et al. 1985, Parker et al. 1985). Of concern to many, along with this apparent trend, is the possibility of a coinciding decrease in species diversity at the macroscale and genetic diversity within populations due to the dissected nature of the landscape (Forman and Godron 1981, Forman 1986, Harris 1984). These concerns are not unfounded as studies continue to show a general decline in oak species dominance over large regions (McGee 1984, Harcombe and Marks 1983). It is clear that an ongoing research effort is necessary to understand the complexities and paradoxes surrounding the silvical requirements of oak

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species in relation to site and environmental variables.

The objective of this research was to study the response of hardwood species, particularly oak species (in terms of composition, abundance and distribution), to patch clearcutting of the southwest corner of a mature oak stand and subsequent effects on edge composition of the residual stand. The long-term goal is to investigate the use of even-aged silvicultural systems on small isolated woodlands in the Till Plain Region of Indiana.

STUDY AREA

The Miller-Purdue Agricultural Center is located in Grant County, Indiana, east and north of the approximate geographic center of the Tipton Till Plain (fig. 1). The Tipton Till Plain region, which extends from western Ohio to eastern Illinois (Schneider 1966), was predominately forested until clearing for row crop agriculture began in the early 1800's. Forests that remain today generally occur as isolated woodlots (<20 ha in area) surrounded by cropland or as corridors along stream margins. Most of these forests have been exposed to varying intensities of cutting, grazing by domestic livestock and fire (Den Uyl 1947, Indiana Dept. Natural Resources 1981). Soils of the area are derived from glacial till and outwash of the Wisconsin glaciation and are fairly uniform in depth over bedrock except at rare outcroppings along stream margins (Lindsey et al. 1969, Franzmeier and Sinclair 1982).

The total forested area of the Miller-Purdue Agricultural Center is approximately 58 ha and is divided into four compartments. Compartment 2 (the study area) encompasses just over 13 ha and is dominated in the overstory by large Quercus alba, Quercus rubra and Carya spp. with scattered individuals of Quercus macrocarpa, Acer saccharum and Fraxinus americana. The compartment is isolated from other compartments by surrounding cropland. Dominant soils are Blount silt loam (SI = 65 for red and white oak) and Morley silt loam (SI = 80 for red and white oak), ranging from well drained to somewhat poorly drained and formed in loess over calcareous glacial till (Beers 1961, Fischer 1986).

This property has been protected from livestock and managed by the Dept. of Forestry and Natural Resources, Purdue University, since 1938. Prior to acquisition by Purdue the woodlands were grazed by sheep, and Compartments 1 and 2 were periodically swept by wildfire up to 1945. Dominant oak trees in Compartment 2 were found to be 130-150 years old, and it is assumed other dominants in the overstory reflect similar ages.

In 1981, Compartment 2 was divided into eleven blocks measuring 60 x 160 m to be treated on a 5 year interval. The block on the southwest corner was selected for the initial clearcut treatment in order to promote drier conditions, resulting from the southwest aspect, within the clearcut area and in the adjacent uncut edge. This block was clearcut and 154 merchantable sawtimber stems were removed in July, 1981 (table 1). Forty-nine percent of the stems removed (≥15 cm dbh) were Quercus alba individuals accounting for 63% of the basal area (16.6 m^2 ha^{-1}), with Quercus rubra accounting for 10% of the stems removed and just under 13% of the basal area (derived from Fix 1980). Quercus macrocarpa and Quercus velutina accounted for 4.5% of the timber removed with a combined basal area of 3.2 m^2 ha^{-1}. Other overstory species removed during the cut included Acer saccharum (10% of stems removed and 6.5% of the basal area), Carya spp. (11% of stems removed and 2.5% of the basal area) and scattered individuals of Fraxinus americana, Prunus serotina, and Juglans nigra. Overall basal area (all species combined) removed was 26.31 m^2 ha^{-1}.

After the clearcut was completed, all residual stems (≥5 cm dbh) were cut, and tops were removed for fuelwood. Residual slash was left on the site with no further treatment to the area.

In the early spring of 1986, 40 circular sample plots (3.6 m radii = 40.7 m^2) were systematically located in the treated and untreated areas of Compartment 2. Three rows of 8 plots were placed in the clearcut, and two rows of 8 plots were placed in the adjacent uncut forest edge and interior. For each plot, measurements were taken on: 1) height (m) of all woody stems occupying the regeneration layer (0.3-1.3 m), 2) height (m) and diameter (cm) of all saplings and poles occupying the midstory (≥1.4-11.3 m) and 3) diameter (cm) of all stems occupying the overstory (≥11.4 m). Each stem was recorded by plot number, species, number of stems by clump or noted as an individual, height (m) by strata and diameter (cm) for midstory and overstory individuals.

Data were summarized by species, species combinations and all species combined by regeneration layer, midstory and overstory. Fortran IV programs were written by the authors to combine plots and average measured variables into Series (labeled S in figures) for direct gradient analysis at distance intervals. Species diversity for each height strata was calculated as:

$$H' = - \Sigma_i P_i \ln P_i$$

where: P_i = relative abundance of the ith out of S species.

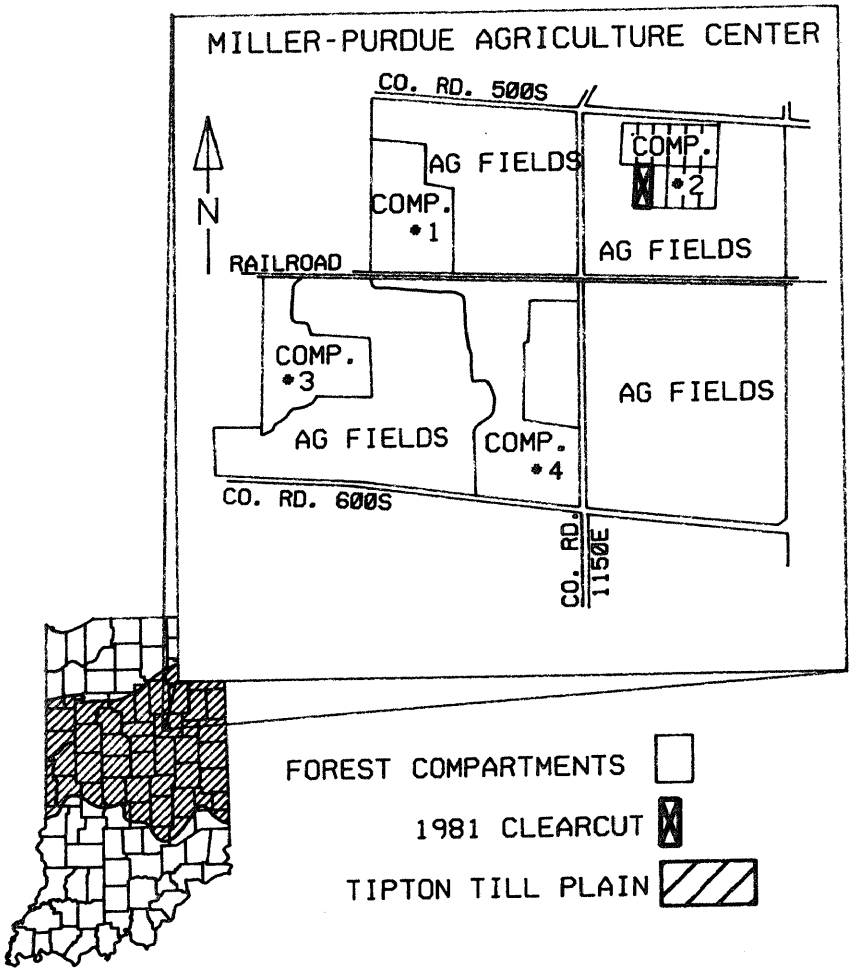

Figure 1.--Miller-Purdue Agricultural Center (projection) and its location on the Tipton Till Plain of central Indiana. Compartment 2 (study area) is shown in the northeast quarter of the property. The 1981 clearcut (blackened block) is shown in Compartment 2 along with 10 other future treatment blocks.

This measure takes into account both the number of species present and the relative distribution of individuals among species (Grieg-Smith 1983). Data were analyzed using standard linear parametric methods as described by Neter et al. (1985), SPSS subroutines (Nie et al. 1975), Purdue University Computing Center's Cyber 205 virtual memory vector machine and the Vax Intergraph 11-750 IGDS Application Software.

RESULTS AND DISCUSSION

Diversity and Composition

Twenty-eight woody species were found over the entire study area (tables 2 and 3). Of these, 20 midstory species and 22 regeneration layer species were found in the clearcut. Only 12 species were found for either height strata in the forest edge and interior, all of which are tree species. Greater species numbers in the clearcut reflect greater presence of mostly shrubby species (e.g., Rhus glabra, Sambucus canadensis and Salix spp.) (tables 2 and 3). Figure 2 illustrates the change in species richness (number of species) and species diversity (H') from the outer margin of the clearcut to the forest interior at 20 m distance intervals. The greatest number of species in the regeneration layer and the midstory was found on the outer margin of the clearcut which borders a tilled agricultural field. Species numbers for both height strata declined from that point to a low within the forest edge.

Differences in mean diversity for the regeneration layer, midstory and both strata combined between the clearcut and the uncut residual stand were tested using Student's t distribution (Neter et al. 1985). All three tests revealed significant differences in diversity between the treatment and control ($.01 < p < .05$ for regeneration, $.001 < p < .01$

Table 1.--Number of stems, approximate basal area (m^2) of cut stems, and basal area per hectare (m^2 ha^{-1}) by species for all stems (6 inches dbh and greater) removed from the study area at Miller-Purdue Agricultural Center during July, 1981 (derived from Fix 1980).

Species	Number of Stems Cut	BA (m^2)	BA (m^2 ha^{-1})
Quercus alba	75	2.70	16.58
Quercus rubra	15	0.54	3.30
Quercus macrocarpa	5	0.41	2.54
Acer saccharum	16	0.28	1.73
Quercus velutina	2	0.11	0.65
Carya spp.	17	0.11	0.65
Fraxinus americana	7	0.06	0.35
Prunus serotina	7	0.03	0.19
Juglans nigra	1	0.02	0.12
Other species[1/]	9	0.03	0.20
Total	154	4.29	26.31

[1/] Other species include: *Populus* spp., *Ulmus* spp. and *Crataegus* spp.

Table 2.--Density (# stems ha^{-1}), percentage of stems in clumps and relative density for regeneration layer[1/] woody species by relative edge position at Miller-Purdue Agricultural Center.

	CLEARCUT			FOREST EDGE			FOREST INTERIOR		
Species	DEN	%	REL DEN	DEN	%	REL DEN	DEN	%	REL DEN
Acer negundo	6.1		0.1						
Acer saccharum	1928.0	53.8	21.7	472.8	11.7	32.8	730.7	13.5	41.5
Carya cordiformis	264.0	25.6	3.0	18.4		1.3	79.8		4.5
Carya glabra							24.6		1.4
Carya ovata	399.1	50.8	4.5	24.6		1.7	24.6		1.4
Celtis occidentalis	6.1		0.1						
Cornus florida									
Cornus racemosa	767.5	53.6	8.6						
Crataegus spp.	165.8	55.6	1.9				12.3		0.7
Fraxinus americana	1307.9	46.0	14.7	245.6	27.5	17.0	270.2	29.6	15.3
Juglans nigra	6.1		0.1						
Liriodendron tulipifera	6.1		0.1						
Ostrya virginiana									
Prunus americana									
Prunus serotina	343.9	28.6	3.9	24.6	75.0	1.7	98.2	62.5	5.6
Quercus alba	12.3		0.1				12.3		0.7
Quercus macrocarpa	128.9	61.9	1.5	12.3		0.9			
Quercus palustris	6.1		0.1						
Quercus rubra	190.4	45.2	2.1	110.5	5.6	7.7	73.7		4.2
Quercus velutina	12.3		0.1						
Rhus glabra	98.2	12.5	1.1						
Salix spp.	18.4		0.2						
Sambucus canadensis									
Tilia americana				12.3	100.0	0.9	12.3	100.0	0.7
Ulmus americana	607.9	76.8	6.9	411.4	31.3	28.5	331.6	42.6	18.8
Ulmus rubra	2585.0	40.6	29.1	110.5	38.9	7.7	92.1	46.7	5.2
Viburnum prunifolium	18.4	33.3	0.2						
Zanthoxylum americanum	12.3		0.1						
All species	8891.0	47.4	100.0	1443.0	23.0	100.0	1762.2	24.7	100.0

[1/] Regeneration = All stems greater than 0.3 m and less than 1.4 m in height.

Table 3.--Density (# stems ha^{-1}), percentage of stems in clumps and basal area (m^2 ha^{-1}) for midstory[1/] woody species by relative edge position at Miller-Purdue Agricultural Center.

Species	CLEARCUT			FOREST EDGE			FOREST INTERIOR		
	DEN	%	BA	DEN	%	BA	DEN	%	BA
Acer negundo									
Acer saccharum	2842.9	61.8	0.34	822.8	11.9	0.33	718.4	4.3	0.37
Carya cordiformis	577.2	59.6	0.12	12.3		x	6.1		x
Carya glabra							6.1		x
Carya ovata	227.2	91.9	0.04	12.3		0.01	6.1		0.01
Celtis occidentalis	6.1		x						
Cornus florida				6.1		x	6.1		x
Cornus racemosa	786.0	50.0	0.03	18.4		x			
Crataegus spp.	55.3	77.8	x				6.1		x
Fraxinus americana	1252.6	48.0	0.17	282.5	23.9	0.06	171.9	3.6	0.04
Juglans nigra									
Liriodendron tulipifera									
Ostrya virginiana							6.1		x
Prunus americana	6.1		x						
Prunus serotina	356.1	39.7	0.03	18.4		0.04	49.1	25.0	0.02
Quercus alba	18.4		x						
Quercus macrocarpa	55.3	77.8	0.01	24.6	50.0	x			
Quercus palustris	6.1	x							
Quercus rubra	319.3	55.8	0.05	49.1	12.5	0.02	61.4		0.05
Quercus velutina	6.1		x						
Rhus glabra	18.4		x						
Salix spp.	6.1		x						
Sambucus canadensis	6.1		x						
Tilia americana				18.4	100.0	0.03			
Ulmus americana	1228.0	77.0	0.41	368.4	16.7	0.30	178.1	20.7	0.21
Ulmus rubra	3199.0	61.2	0.59	55.3	11.1	0.04	36.8	16.7	0.06
Viburnum prunifolium	6.1	100.0	x						
Zanthoxylum americanum									
All species	10,978.7	60.3	1.80	1688.6	16.0	0.84	1252.6	7.4	0.78

[1/] Midstory = All stems greater than or equal to 1.4 m and less than 11.4 m in height.
x = Indicates a value less than 0.01 m^2 ha^{-1}.

for midstory, and $.01 < p < .05$ both combined). The greatest difference was found in the midstory (range = 1.47 to 1.13), with the range in the regeneration layer from 1.59 to 1.29 for the clearcut and residual stand respectively. Greater diversity in the clearcut vs. the uncut residual stand would be expected given the availability of suitable sites for colonization at the time of treatment. In addition, prior to treatment in 1981, the western edge of the clearcut was the historical forest edge, bordering on the tilled agricultural field. Several studies have shown increased numbers of species are found within forest edges relative to interior positions (e.g., Wales 1972).

The sloped line showing a gradient in diversity for the regeneration layer in figure 2 is within the range of variability as no significant difference could be found for this stratum over the gradient ($.05 < p < .10$). One-way analysis of variance for the midstory, however, revealed a strong significant difference over the west to east gradient ($.001 < p < .01$). Scheffe's Multiple Comparisons Test revealed that diversity for the midstory is greatest on the westernmost margin of the clearcut (mean diversity = 1.60) and lowest 30 m into the interior from the forest edge (mean diversity = 1.05). No difference could be found between mean diversity at these two points and mean diversity over the other three distance intervals.

Paired t-tests revealed no significant differences in mean diversity between the regeneration layer and midstory stems at 10 meters, 30 meters, 50 meters, or 70 meters along the gradient into the edge. At 90 meters along the gradient (30 meters into the interior), however, mean diversity for these strata was significantly different ($.01 < p < .05$). In the interior, the regeneration layer is much more diverse than the sapling and small pole class (1.32 vs. 1.05). The difference in diversity at this point is attributable to an increase in equitability (i.e., a more even distribution of stems among species) in the regeneration layer

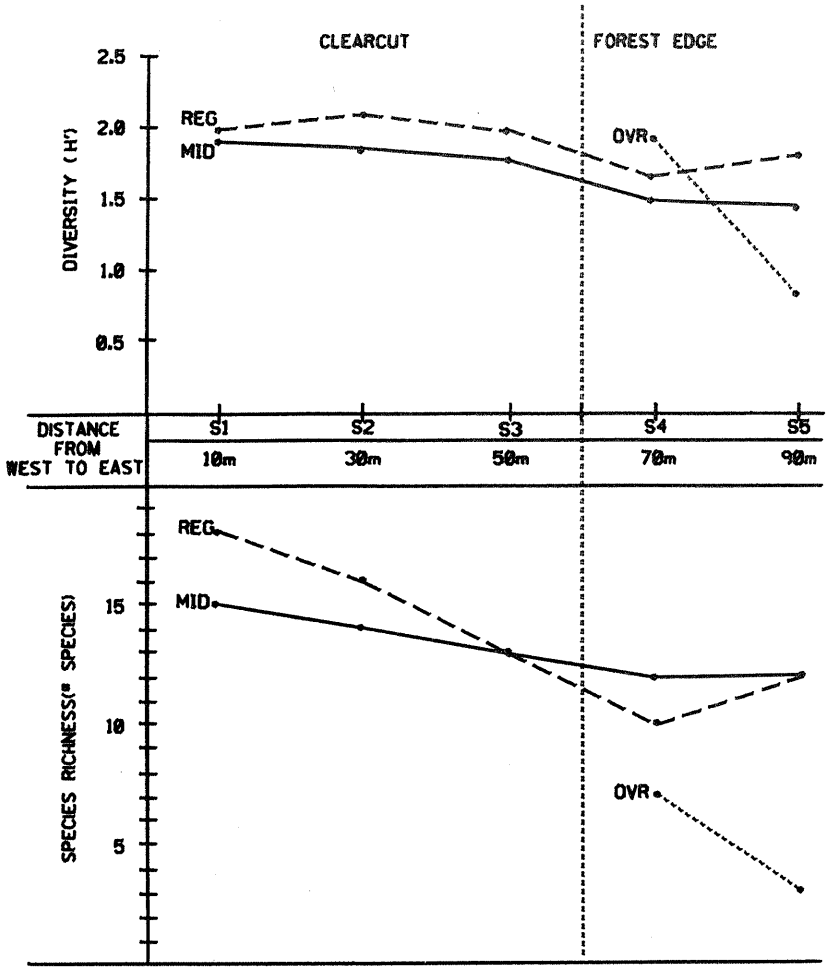

Figure 2.--Species diversity (H') and species richness for overstory, midstory and regeneration layer, all species combined, on a west to east distance gradient from the clearcut to the interior on the west edge of Compartment 2 at Miller-Purdue Agricultural Center.

even though there is no difference in the number of species found in either stratum at this point (fig. 2).

Most species increased in density following the clearcut for both the regeneration and midstory strata (tables 2 and 3). Much of this increase is due to multi-stemmed sprouts from established root systems. Little increase is believed due to seed germination.

The most abundant species in the clearcut tended to be those which are also most abundant in the understory of the adjacent forest. The five most abundant tree species were Ulmus rubra, Acer saccharum, Fraxinus americana, Ulmus americana and Carya spp. Quercus alba, which was the most abundant tree removed, was present in the clearcut in very low numbers.

Several species, not found in the adjacent forest plots, were sampled in low numbers in the clearcut. These were mostly shrub species such as Viburnum prunifolium, Rhus glabra and Sambucus canadensis.

Height and Diameter Distributions

Figure 3 illustrates the height (m) distribution of the four dominant midstory species occupying the clearcut as compared to the distribution of Quercus rubra stems. It is readily apparent that five years after the clearcut, Quercus rubra is in a subordinate position in terms of height growth. The alternating juxtaposition over all height classes up to 4.5 m for Ulmus rubra and Acer saccharum underscores the dominance of these two species in terms of relative numbers of stems

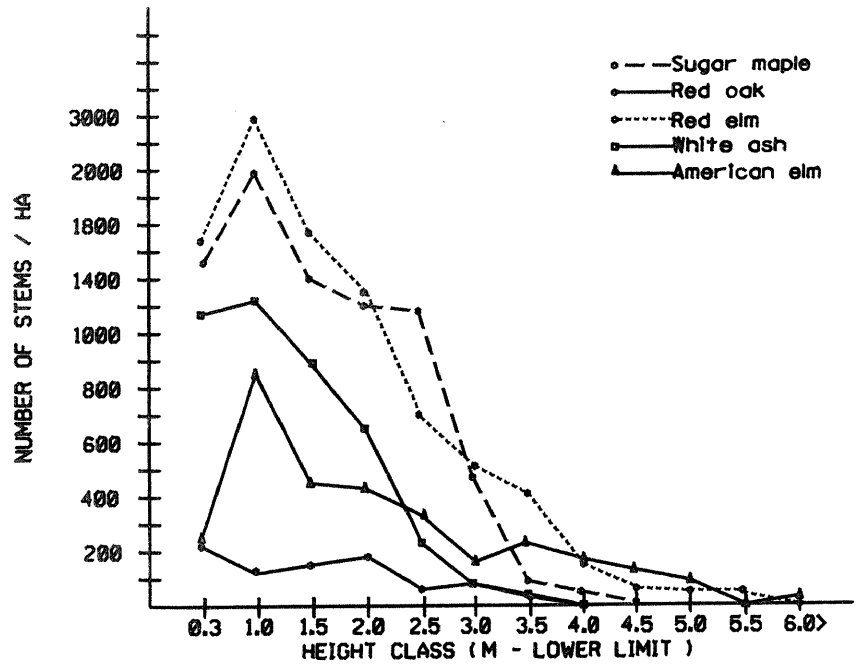

Figure 3.--Height distribution by 0.5 m height classes for selected species occupying the five year old clearcut on the west edge of Compartment 2 at Miller-Purdue Agricultural Center.

and five year height growth. Ulmus americana exhibits dominance in only the upper height classes, being ranked 4th in the regeneration layer behind Fraxinus americana. Quercus rubra is dominated across all height classes by the other four species.

Average height for Ulmus rubra midstory individuals in the clearcut was 2.4 m, increasing to 2.8 m in the forest edge and 4.6 m for interior stems. Acer saccharum displayed a similar pattern over the gradient with average height in the clearcut at 2.3 m, 3.0 m in the edge and 3.3 m in the interior. Both Ulmus americana and Fraxinus americana showed increases in mean height for midstory stems in the interior. Quercus rubra individuals in the clearcut averaged 2.2 m in height, increasing to 2.9 m in the forest edge and 4.3 m in the interior. The few midstory Quercus alba individuals found in the clearcut averaged 1.5 m in height with no sapling sized individuals of this species found in the edge or the interior. Quercus macrocarpa was more successful with mean clearcut height of 2.3 m, declining to 2.0 m in the edge and, like Quercus alba, no sapling sized individuals of this species were found in the interior.

Diameters for these species, as expected, reflect the pattern for height distribution found in the clearcut (fig. 4). In the upper diameter classes, Ulmus spp. dominate with a few Ulmus americana individuals being found in the 6.0 cm class and above. Again, Quercus rubra is dominated across all classes by the greater diameters of competing species. Average dbh for this species in the clearcut was 1.2 cm, increasing slightly to 1.3 cm in the 5 year old edge and increasing in the interior to 2.8 cm. With the exception of Quercus alba and Quercus macrocarpa, average diameter increased over the gradient into the interior. Ulmus rubra increased from 1.2 cm to 3.4 cm over the gradient while Fraxinus americana increased relatively little (0.3 cm). Average diameters for Acer saccharum showed an increase of only 0.7 cm over the range, and Ulmus americana increased by 1.3 cm.

Although no pre-harvest data were taken on average stand diameter for unmerchantable midstory stems, it may be assumed that conditions 30 m into the interior of the residual stand have not changed significantly over the five year period. Due to the great increase in solar radiation penetrating the 5 year old edge, however, it may be assumed that many, if not most, previously suppressed stems experienced some degree of release in the sapling and small pole classes. This has yet to be tested, however. Comparing average stand diameter in the clearcut for the seven species of interest (Acer saccharum, Ulmus rubra, Ulmus americana, Quercus rubra, Quercus alba, and Quercus macrocarpa) with average midstory stand diameter 30 m into the interior, we find a difference of only 1.3 cm (range = 1.2 cm to 2.5 cm).

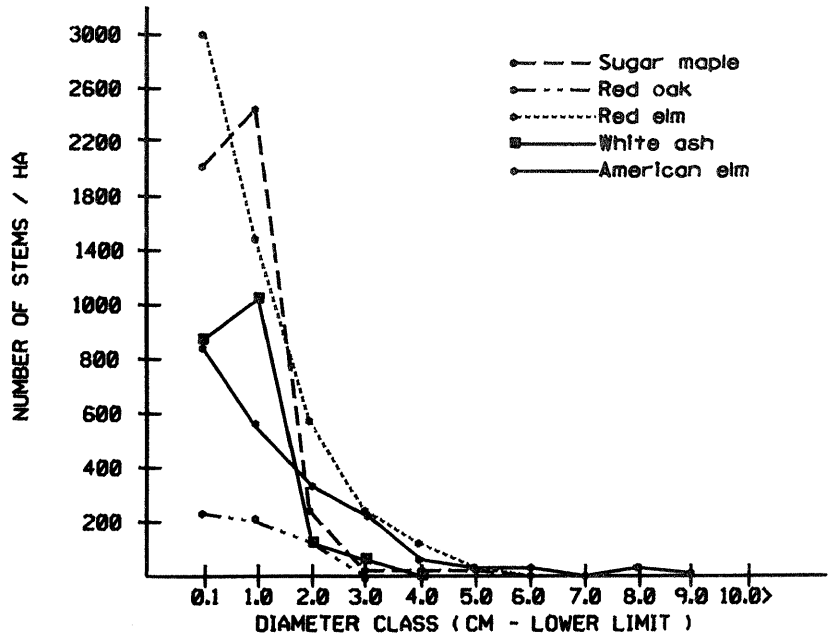

Figure 4.--Diameter distribution by 1.0 cm diameter classes for selected species occupying the five year old clearcut on the west edge of Compartment 2 at Miller-Purdue Agricultural Center.

Student's t-tests for all species combined revealed significant differences in the mean height of the regeneration layer between the cut stand (treatment) and uncut stand (control) (table 4). Greater mean height for small sprouts and newly established seedlings would be expected under the high light conditions of the clearcut as compared with the uncut residual stand even with increased lateral light penetration into the west edge. The greatest proportion of this growth, however, is most likely attributable to the vigorous growth normally associated with stump sprouts over seedling sprouts. In addition, regeneration layer stems on the interior of the uncut stand would be expected to be, on the average, much older than stems of the same strata in the clearcut and be in a state of suppression awaiting release as has been shown for Acer saccharum (Canham 1985).

Significant differences were also obtained for mean height, mean diameter and mean basal area between midstory stems in the clearcut vs. the uncut residual stand (table 4). Greater height, diameter and basal areas (all species combined) were found in the uncut residual stand vs. the clearcut. This would be expected as all stems >5 cm dbh were cut over the clearcut area at the time of treatment.

Since treatment, Ulmus spp. have attained greater height and gained dominance in the clearcut in the 6.0 m height class, which is just over 50% of the width of the total midstory interval (up to 11.3 m). Residual midstory stems in the edge and interior have, over time, attained heights equal to the entire midstory class width producing greater mean values. Of course, this would also apply to average diameters for residual midstory stems and, hence, basal areas. No attempt was made to document class movement over the five year period, but it is assumed little movement from midstory to overstory status was made by residuals on the interior.

It is surprising to find so little a difference in mean diameter and mean height between the clearcut and residual stand after only five years (0.69 cm-dbh and 0.76 m-height). Increased variability in the uncut residual stand, as evidenced by inflated standard errors (table 4), reflects the greater number of stems occupying the upper strata of the midstory, although these stems represent fewer species than that found in the clearcut. On average, then, a major proportion of the average diameter and height of the midstory stand has been recovered in the clearcut after only five years.

In an attempt to elucidate the complex interaction between average measured variables and edge effects, one-way analysis of variance, utilizing Scheffe's Multiple Comparison Test (Neter et al. 1985, Nie et al. 1975), was performed over the west to east distance gradient (from clearcut to interior) and a south to north distance gradient (table 4). The north margin of the clearcut also borders on the edge of the residual stand of Compartment 2. For these tests, treatments were considered to be

Table 4.--Mean height (m) of the regeneration layer[1/], and mean diameter (cm), mean height and mean basal area (m^2) of stems measured in the midstory[2/] for all species combined by treatment and distance gradients at Miller-Purdue Agricultural Center.

TREATMENT	REGENERATION MEAN HT	(SE)	MIDSTORY MEAN DBH	(SE)	MEAN HT	(SE)	MEAN BA	(SE)
Cut	0.96	(0.007)**	1.17	(0.02)**	2.31	(0.02)**	0.0002	× **
Uncut	0.79	(0.012)	1.86	(0.09)	3.07	(0.08)	0.0006	(0.0001)
Distance Gradient (m) West to East from Clearcut to Interior								
10.0	0.97	(0.010)	1.12	(0.03)	2.29	(0.03)	0.0001	×
30.0	0.98	(0.013)	1.16	(0.04)	2.34	(0.04)	0.0002	×
50.0	0.92	(0.015)	1.25	(0.04)	2.33	(0.04)	0.0002	×
70.0	0.82	(0.018)	1.73	(0.11)	2.90	(0.10)	0.0005	(0.0001)
90.0	0.77	(0.017)	2.03	(0.14)	3.31	(0.13)	0.0006	(0.0001)
Distance Gradient (m) South to North								
10.0	0.90	(0.019)	1.50	(0.07)	2.66	(0.06)	0.0003	×
30.0	0.91	(0.021)	1.42	(0.07)	2.61	(0.06)	0.0003	×
50.0	0.94	(0.020)	1.56	(0.08)	2.74	(0.07)	0.0004	×
70.0	0.95	(0.018)	1.40	(0.10)	2.55	(0.10)	0.0003	(0.0001)
90.0	0.94	(0.019)	1.45	(0.11)	2.64	(0.12)	0.0004	(0.0001)
110.0	0.91	(0.016)	1.12	(0.04)	2.24	(0.04)	0.0002	×
130.0	0.92	(0.016)	1.05	(0.04)	2.24	(0.04)	0.0001	×
150.0	0.89	(0.167)	1.12	(0.07)	2.27	(0.06)	0.0002	×

1/ Regeneration = All stems greater than 0.3 m and less than 1.4 m in height.
2/ Midstory = All stems 1.4 m and greater and less than 11.4 m in height.
* = Indicates a significant difference at the .05 level.
** = Indicates a significant difference at the .01 level.
× = Indicates a value less than 0.0001.

relative edge position with 5 levels of treatment 1 (west to east gradient) and 8 levels of treatment 2 (south to north gradient). In neither test were differences in mean values for the regeneration layer or the midstory significant, although trends in the data are apparent. Two-way analysis was performed utilizing distance over both gradients as treatments. The results of this test produced significant interaction terms ($p < .01$ for midstory, $p < .05$ for regeneration), the nature of which are unknown. It is suspected, however, that the interaction involves a combination of both edaphic factors and edge effects and is not simply a linear combination of distance intervals. No data were taken over the course of the study (e.g., texture and moisture availability of the soil, rooting depth, ph or nutrient availability) which could be correlated with this interaction.

The trends shown in table 4 over both gradients reveal more about the complex nature of edge effects on height and diameter than the simple t-tests would suggest. The inverse relationship between declining mean height for the regeneration layer and increasing mean values for the midstory over the west to east distance gradient becomes apparent in table 4. For all measured and computed variables, standard errors increase from the outer margin of the clearcut into the forest interior, with a sharper increase in the variability of midstory variables upon entry into the forest edge. In general, variability within the regeneration layer is less than that for the midstory with the exception of 150 m into the clearcut on the south to north distance gradient. At this point, proximal to the forest edge on the north margin of the clearcut, variability in the regeneration layer is more than twice that of the midstory. This may be due to an interactive edge effect from both the south facing and west facing edges bordering the clearcut, or due to site variation.

Linear correlation analysis, between height and diameter of midstory stems and basal area and height of midstory stems, was performed for

all species combined and species grouped by reported shade tolerances (table 5). No functional relationship between the variables is implied in this analysis and is used only as a measure of the degree to which these variables vary together over the gradient from the outer margin of the clearcut to the forest interior. For both the shade tolerant species group and the shade intolerant species group, there is a reduction in the degree of linearity between height and diameter at a point 50 m into the clearcut and adjacent to the west facing forest edge. This trend is not as apparent for all species combined or for the shade midtolerant species. The reduction in linearity between basal area and height is apparent at this location over all species groups. Although all r^2 values were statistically significant at the .05 level over the gradient, this reduction indicates greater variability between the two variables at this location. This suggests not only an edge effect on height and diameter growth of stems located adjacent to the uncut residual stand, but possibly an effect due to side shading from the west by adjacent stems in the clearcut.

Table 5.--Linear correlation analysis utilizing the Coefficient of Determination (r^2) between height (m), diameter (dbh in cm) and basal area (m^2 ha^{-1}) for all midstory[1/] species combined, and species grouped by shade tolerance, on a distance gradient (m) from clearcut edge to forest interior at Miller-Purdue Agricultural Center.

Distance Gradient (m) West to East	HT by DBH	BA by HT	n
	All Species Combined		
10.0	0.84	0.67	824
30.0	0.86	0.66	490
50.0	0.84	0.57	474
70.0	0.86	0.73	275
90.0	0.89	0.73	204
Distance (m)	Shade Tolerant Potential Canopy Trees		
10.0	0.87	0.81	150
30.0	0.82	0.62	151
50.0	0.79	0.45	162
70.0	0.93	0.84	137
90.0	0.92	0.77	117
Distance (m)	Shade Mid-Tolerant Potential Canopy Trees		
10.0	0.87	0.71	498
30.0	0.89	0.70	218
50.0	0.85	0.59	275
70.0	0.87	0.73	127
90.0	0.90	0.76	73
Distance (m)	Shade Intolerant Potential Canopy Trees		
10.0	0.77	0.59	132
30.0	0.87	0.78	35
50.0	0.52	0.34	23
70.0	0.94	0.82	7
90.0	0.87	0.93	11

[1/] Midstory = All stems greater than or equal to 1.4 m and less than 11.4 m in height.

Note: All r^2 values were statistically significant at the .05 level.

CONCLUSION

Studies continue to show the difficulties in obtaining adequate oak reproduction after clearcutting on good sites (e.g., Hilt 1985). In those cases where oak reproduction is in sufficient numbers in the resulting stand, either from seedling or stump sprouts, the competition from other less desirable hardwood species is so great that doubts are cast as to the ability of oak species to eventually dominate the stand without treating the competing stems. Our study of hardwood regenerative response to clearcutting at the Miller-Purdue Agricultural Center in central Indiana concurs with these findings. Greater than 700 stems per hectare of red and white oak species were found in the clearcut area. This would most likely be sufficient to eventually produce an oak dominated canopy in the absence of other competing species. Given that these stems are dominated across all height and diameter classes at the end of five years, however, additional release may be necessary to increase oak in the future canopy.

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