EXPERT REVIEWED

Natural Oak Regeneration Following Clearcutting on the Hoosier National Forest

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Introduction

Problem Statement

Oak *(Quercus spp.)* forests moved into the Central Hardwood Forest Region (CHFR) approximately 7,000 years ago (Davis, 1981), where they dominated the forested landscape through pre-settlement times (Abrams and McCay, 1996; Dyer, 2001). Their ability to supply high-quality timber, abundant wildlife food, and various other non-timber forest products allowed oaks to become the most important aggregation of hardwoods found in North America (Harlow et al., 1996). Seventeen species of oaks are native to Indiana. Oak species comprised over a third of the 348 million board feet (bd ft) of logs milled in Indiana in 2000 (Bratkovich et al., 2004).

Current oak forests in the CHFR are commonly even-aged, secondary forests. These stands and their predecessors were exposed to regular occurrence of natural and anthropogenic disturbances and fire until the early 1900's. Fires were often low intensity burns that effectively reduced understory densities of less fire-resistant species, thus benefiting growth and regeneration of more fire-hardy species such as oaks.

Unfortunately, by the middle of the twentieth century, forest managers began to notice a decreasing oak component in stands that had once been dominated by oak (Carvell and Tryon, 1961). This decrease was attributed to shifting anthropogenic influences (less intensive silvicultural systems, fire suppression, etc.). The desire to preserve oak ecosystems prompted numerous investigations into silvicultural systems best suited to the perpetuation of oak-dominated stands. Even-aged silviculture was soon deemed a suitable method for oak regeneration (Roach and Gingrich, 1968), and clearcutting was adopted as the primary method of oak forest regeneration on the Hoosier National Forest of Indiana and throughout much of the CHFR.

The clearcutting method involves removal of all stems in a stand with one cutting, allowing for natural regeneration from existing seedlings and saplings, stump sprouts, and seed. This method of harvest is often favored due to its ease of implementation, and economic benefits (Smith et al., 1997). Clearcuts are also valuable in the CHFR due to their creation of extremely dense young stands with wide species diversity. These juvenile stands provide ideal habitat and food sources for many species of wildlife across the region.

Following 40 to 50 years of clearcutting in the CHFR, several studies have still observed oak replacement by less desirable hardwood species. This transformation is altering wildlife habitat and food sources and decreasing a valuable timber source. While numerous studies have monitored stand composition following clearcutting of oak dominated stands, a majority have been constrained by examining sites across a limited landscape over a relatively short period of time (Standiford and Fischer, 1980; Heiligman et al., 1985; Arthur et al., 1997; Wright et al., 1998; Ward and Stephens, 1999; Shostak et al., 2002). However, when sites are revisited throughout their growth period, they exhibit noticeable changes in stand structure and species composition (Ward and Stephens, 1999). Research on sites up to 28 years following clearcutting showed that high-quality mesic sites are most often dominated by faster growing maple (*Acer* spp.), yellow poplar *(Liriodendron*

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tulipifera), white ash *(Fraxinus americana)* and various other less desirable species, while only more xeric sites regenerate with oak (Heiligman et al., 1985; Hilt, 1985; Fischer et al., 1987; Wright et al., 1998; Shostak et al., 2002).

Research Needs

Attempting to understand the effects of management on oak dominated forest requires an understanding of natural and anthropogenic influences at work within the system. Although many factors have yet to be identified in the research to date, we need to better understand trends evident in the declining oak component of these ecosystems. An examination of multiple stands encompassing a wide range of environmental conditions under a single silvicultural system may help to understand factors involved in oak decline within the parameters of that system.

This study proposes that effects of even-aged silviculture on oak regeneration may be best understood by observing harvested stands across a wide variety of landscapes within a region over an extended period of time. By observing stand structure of previously measured 22 to 35 year old sites, we will be able to gain a better understanding of processes contributing to the decreased oak component of clearcut sites in the CHFR. The objectives of this study were to develop a set of permanent plots in previously clearcut stands across the Hoosier National Forest to be used to assess species composition changes over time. This paper presents data from these plots and analysis designed to show how ecological conditions and site characteristics interact to influence future stand conditions.

Methods

Study Sites

In 1986/87, the regeneration response of 74 upland hardwood clearcuts in the Hoosier National Forest, many of which contained a significant oak component, were reported by Fischer et al., (1987). The stands originated from clearcuts initiated between 1969 and 1982, which ranged in size from approximately 5 to 50 acres. The stands captured a wide variety of site characteristics (i.e., aspect, topography, and slope) and were spread throughout the National Forest with 34 sites in the Southern Tell City Ranger District and 40 in the Brownstown Ranger District (Figure 1). These stands have remained unmanaged since harvest, providing insight into natural progression following even-aged regeneration. Stand composition was reassessed over a three-year period. Current stand parameters were compared to pre-harvest stand composition, and stand composition reported from a study conducted by Fischer et al., (1987). The results presented here represent findings from 32 of the 34 sites located in the Tell City Ranger District (two stands are now under private ownership and could not be assessed) (Table 1 and Figure 2).

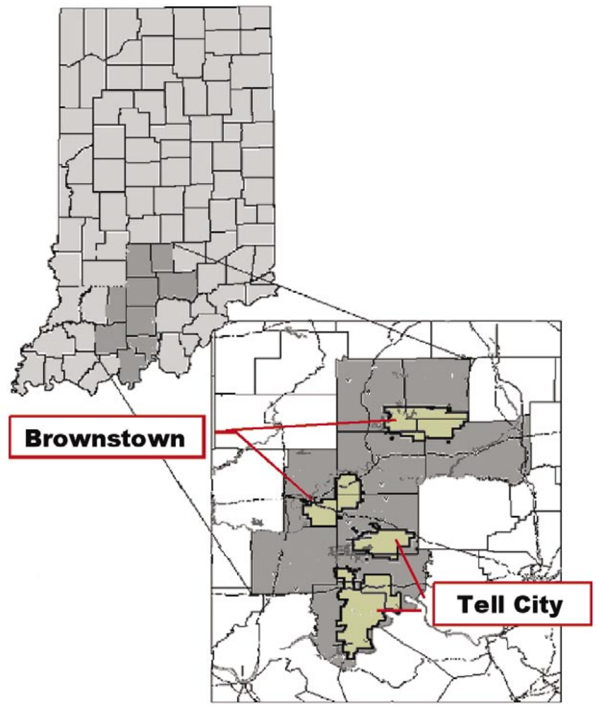

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Figure 1. *Ranger districts of the Hoosier National Forest.*

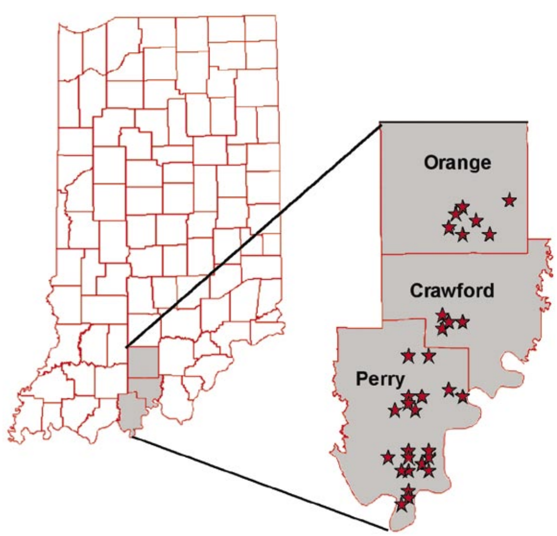

Figure 2. *Location of the 32 sampled stands in the Tell City Ranger District of the Hoosier National Forest (stars represent approximate stand locations).*

Table 1. *Attributes of the 32 stands sampled in the Tell City Ranger District of the Hoosier National Forest.*[1]

Stand	Age	Area (acres)	# of Plots	# of Species	Stem density (TPA)	Mean canopy ht. (feet)	Vine density (Vines / ac.)	BA / acre (sq. ft.)
1	23	14.8	15	26	606	71	129	68
2	33	40.0	37	34	606	72	64	89
3	25	12.4	13	29	785	62	136	59
4	35	10.9	11	27	559	78	65	92
5	26	5.4	6	25	895	67	205	68
6	27	21.3	21	26	817	54	97	65
7	28	14.9	13	28	885	61	142	85
8	28	14.3	14	32	698	53	146	82
9	27	6.9	7	23	583	60	150	82
10	34	49.9	47	30	638	83	23	114
11	22	9.0	8	28	614	55	255	65
12	22	22.8	22	39	1075	47	278	65
13	25	13.4	13	24	622	62	72	89
14	23	25.6	24	32	1043	44	68	66
15	29	23.1	23	36	1006	53	133	80
16	29	23.2	24	31	855	60	70	82
17	30	12.2	11	22	743	63	35	86
18	24	13.4	14	26	646	55	63	89
19	32	27.8	27	30	744	67	91	97
20	25	23.5	23	40	1021	47	242	70
21	23	18.8	17	34	652	45	206	67
22	24	42.8	38	35	996	50	89	83
23	24	8.2	8	36	893	45	186	67
24	24	11.0	10	30	735	53	88	72
25	35	15.8	16	25	689	67	68	98
26	27	10.9	11	29	898	66	205	76
27	24	22.7	23	32	1525	54	120	77
28	32	23.5	24	30	660	78	41	102
29	33	8.4	9	28	804	77	32	93
30	31	16.1	16	27	771	60	37	90
31	31	21.5	18	22	530	80	44	101
32	31	10.1	9	27	1018	67	134	98

[1] Data is from 2004 sampling period.

Field Measurements

Previously measured stands were located and boundaries defined using a global positioning system (GPS) with < 10 feet accuracy, allowing for an accurate assessment of the harvested area's size and location. A 209 × 209 foot grid was generated over the stand and sampling plots were established at grid intersections, for a resultant sampling intensity of 1 plot per acre (Figure 3). A 2-foot piece of rebar was permanently installed at plot centers and plot locations were logged (latitude, longitude, and elevation) using GPS to facilitate future stand measurements (Figure 4).

A circular 0.01 acre regeneration plot and a concentric 0.10 acre tree tally plot were established at each plot center (Figure 5). This sampling regime is similar to

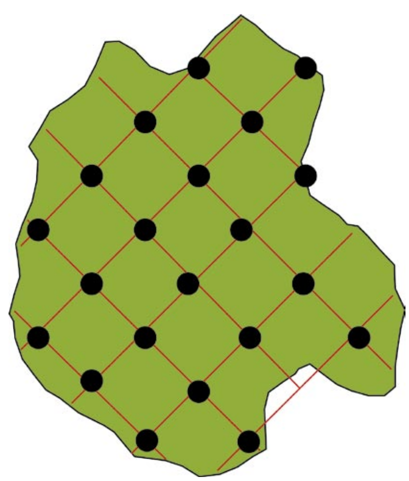

Figure 3*. Example stand outline and grid overlay for plot establishment.*

that of Fischer et al., (1987), who sampled using one 0.01 acre plot per acre. Due to changing stand dynamics (self thinning resulting in fewer trees per acre), it was necessary to increase the tree tally plot size used by Fischer et al., (1987). Aspect, slope percent, landscape position, and average canopy height were determined

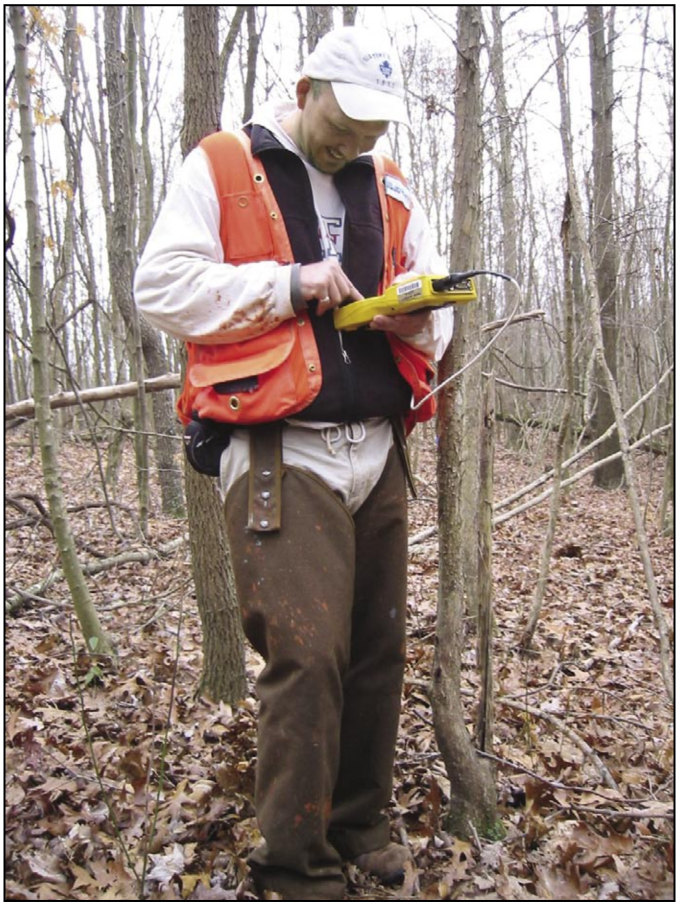

Figure 4. *GPS and data recorder used for plot establishment and data collection.*

Figure 5. *Example of 0.10 acre tree tally plot layout.*

at plot centers. Regeneration sampling consisted of recording all trees < 1.0 inch diameter at breast height (DBH) by species. Individual tree data in the 0.10 ac plot included species, DBH, crown classification (suppressed, intermediate, or dominant), estimates of merchantable volume, and estimation of origin (sprout vs. seed) for all trees with a DBH > 1.0 inch. If a measured tree hosted any grapevines, all were tallied and vine diameter recorded.

Results

Stand summaries

Thirty-two of harvested stands in the Tell City Ranger District of the Hoosier National Forest were measured between fall 2003 and fall 2004. Stands ranged 5.4 to 49.9 acres in size and 22 to 35 years in age (Table 1). A total of 572 permanent plots were established and approximately 46,500 trees of 59 different species were measured. When averaged across all sampled stands, 29 different tree species comprised a mean stand density of 792 trees per acre (TPA) (Table 2) with a mean DBH of 3.6 inches and a mean basal area of 84 square feet per acre (Figure 6).

Figure 6. *Winter (top) and fall (bottom) stand conditions of a typical sampled clearcut.*

Table 2. Mean species per acre values by crown class and origin for 32 sampled stands in the Tell City Ranger District during 2004 measurement period.

Species	Dominant		Intermediate		Suppressed		Total
	Seed	Sprout	Seed	Sprout	Seed	Sprout	
White Ash	13	5	23	3	11	1	56
Bl. Cherry	34	4	14	1	1	0	54
Black Oak	6	1	3	0	1	0	11
Bl. Walnut	1	0	0	0	0	0	1
Y. Poplar	50	8	9	2	3	0	72
Chest. Oak	4	4	2	1	1	0	12
Chinq. Oak	1	0	2	0	1	0	4
N. Red Oak	8	4	5	1	2	0	20
Scarlet Oak	2	1	1	0	0	0	4
White Oak	9	5	9	2	6	0	31
Sub Total	**128**	**32**	**68**	**10**	**26**	**1**	**265**
Am. Beech	1	0	7	1	15	2	26
Aspen	3	0	0	0	0	0	3
Buckeye	0	0	0	0	1	0	1
Am. Elm	1	0	2	0	2	0	5
Red Elm	9	2	10	1	5	0	27
Other Elm	1	0	2	0	3	0	6
Bl. Gum	1	0	5	3	8	3	20
Sweet Gum	1	0	1	0	0	0	2
Bitt Hick.	1	0	1	0	0	0	2
Pignut Hick.	2	1	4	1	3	0	11
Shag. Hick.	1	0	1	0	1	0	3
Black Locust	2	0	1	0	0	0	3
Red Maple	6	7	8	7	4	3	35
Sugar Maple	14	9	44	41	53	42	203
Mulberry	0	0	1	0	0	0	1
Persimmon	1	0	1	0	0	0	2
Sassafras	11	2	20	2	2	0	37
Sycamore	2	1	1	0	0	0	4
Sub Total	**57**	**22**	**109**	**56**	**97**	**50**	**391**
Ailanthus	1	0	0	0	0	0	1
Blue Beech	0	0	4	3	8	6	21
Red Bud	1	1	13	5	5	1	26
Red Cedar	0	0	1	0	1	0	2
Dogwood	0	0	6	4	15	8	33
Ironwood	1	1	18	13	15	0	48
Sumac	1	0	3	0	0	0	4
Pawpaw	0	0	0	0	1	0	1
Sub Total	**4**	**2**	**45**	**25**	**45**	**15**	**136**
Total	**189**	**56**	**222**	**91**	**168**	**66**	**792**

Diameter distribution of the sampled stands illustrates that a majority of the trees are in the 1 to 4 inch size class (Figure 7) and indicates that the stands are undergoing stem exclusion (Smith et al., 1997), typical for even-aged stands of this age. As these stands continue to mature, decreases in the number of stems and a change in species composition and crown dominance is likely to occur. However, stand development has progressed to a point where numerous large, potentially high-quality stems are found in most plots (Figure 8). It is reasonable to assume that these larger dominant trees will close the canopy, limiting growth of subtending trees. Therefore, to predict future stand conditions, it is appropriate to consider the species composition of trees in the dominant class.

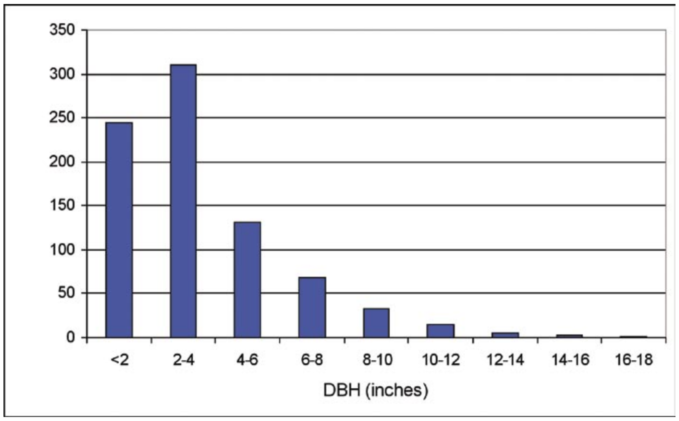

Figure 7. *Diameter distribution of all trees measured in 32 sampled stands of the Tell City Ranger District in 2004 (792 TPA, 3.6 inches mean DBH).*

Figure 8. *Large diameter dominant trees (from left to right, black cherry, sugar maple, northern red oak).*

Oak Composition

Oaks comprise approximately 10 percent (84 TPA) of all trees within sampled stands, and approximately 23 percent (43 TPA) of all dominant trees. Oak species had a greater mean DBH (5.0 inches) compared to the overall stand average of 3.6 inches (Figures 7 and 9). The greater stature of oaks is likely due to the silvics of the species as well as to the high proportion of dominant oaks that originated from coppice regeneration (Figure 10). Approximately 34 percent of all dominant oaks originated from stump sprouts, while a smaller proportion of other dominant trees were of stump sprout origin (Figure 11). It is reasonable to assume that the stored nutrient and carbohydrate reserves within root systems of sprouting oaks helped facilitate rapid growth to a dominant position.

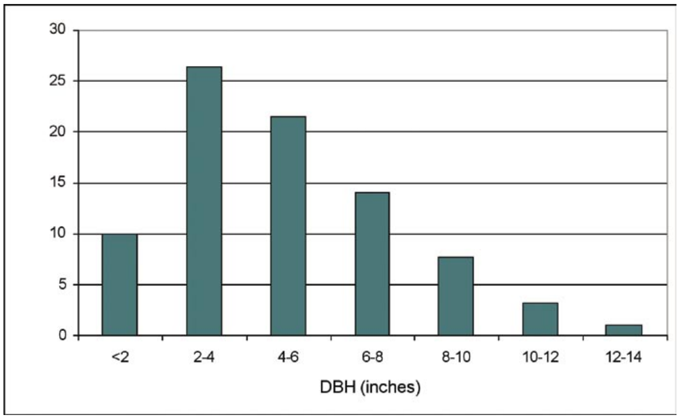

Figure 9. *Diameter distribution of all oaks measured in 32 sampled stands of the Tell City Ranger District in 2004 (84 TPA, 5.0 inches mean DBH).*

***Figure 10**. Chestnut oak (Quercus prinus) originated from seed (left) and from stump sprouts (right).*

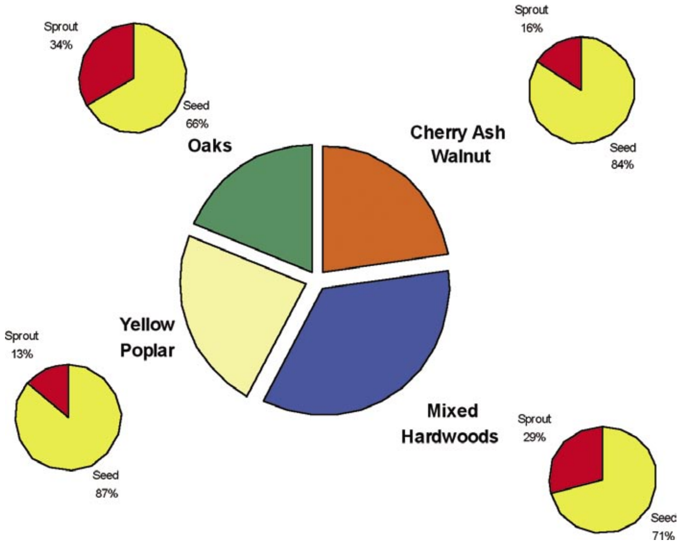

__Figure 11.__ Relative proportions of origin by species type for all dominant trees sampled in the 32 stands of the Tell City Ranger District for the 2004 measurement period.

Pre-harvest estimates of oak composition were obtained from reported timber volumes removed. It is assumed that all timber removed was from dominant and co-dominant trees, and that all dominant and co-dominant trees were harvested. Timber volume was converted to TPA assuming an average of 150 bd ft / tree. Based on these assumptions, pre-harvested stands maintained an average of 30 oaks per acre (60 percent) in the dominant size class.

Measurements in 1987 showed that there were approximately 120 oaks per acre in the dominant class; yet only 7 percent of all dominant trees were oak species. In 1987, 31 percent, 19 percent and 50 percent of oaks were in the dominant, intermediate, and suppressed classes, respectively. Since that time oaks have successfully competed with other species and become a more dominant species type with 55 percent in the dominant class and only 13 percent suppressed (Figure 12).

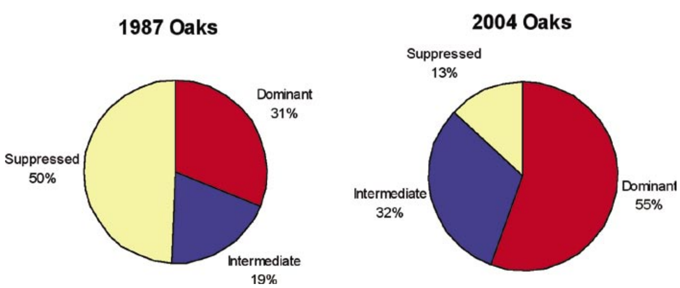

__Figure 12.__ Canopy class distribution of all oak species in the 32 sampled stands of the Tell City Ranger District for 1987 and 2004 measurement periods.

While current composition percentages of dominant oaks are not yet equal to pre-harvest levels, a greater density (TPA) of dominant oaks exist in approximately 70 percent of sampled stands (see Table 3 on next page). This paradox is due to higher overall densities of current stands, as compared to pre-harvest levels. If oaks continue to move to more dominant positions in the canopy strata, they may eventually out-compete other species and regain pre-harvest composition levels.

Site Effects

While up to 70 percent of dominant trees in some stands are oaks, other stands scarcely support any oaks in their dominant class (see Table 3 on next page). This illustrates the importance of site specific silivicultural management, demonstrating that one management strategy will not have equal effects across all sites. To gain a better understanding of the influence of site conditions on even-aged regeneration, plots were separated by aspect. To present data in an easily discernible manner, aspects were placed into four different categories based upon the Beers et al., (1966) aspect transformation (Figure 13). Aspect strongly affects site quality through sun exposure and therefore soil moisture regimes. Forest growth is greater on northern and eastern slopes as a result of increased moisture availability. Aspect code four is therefore assumed to be the most mesic and productive and one the most xeric and thus least productive.

Aspect Codes*			
1	2	3	4
---Azimuth degrees---			
185 to 265	135 to 185	85 to 135	5 to 85
	265 to 315	315 to 5	

*Adapted from Beers et al (1966)

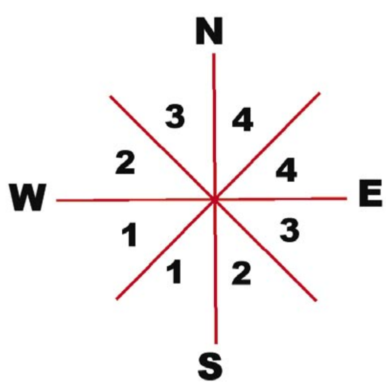

__Figure 13.__ Aspect transformation codes used to determine site effects.

Table 3. Stand composition of dominant oaks prior to harvest, and during 1987 and 2004 samplings for 32 sampled stands in the Tell City Ranger District (Highlighted stands currently exceed pre-harvest dominant oak densities).

Stand	Pre-Harvest*		1987**		2004	
	------------------------------------Dominant oaks---------------------------------------					
	TPA	of dominant trees	TPA	of dominant trees	TPA	of dominant trees
1	3	32%	49	2%	37	6%
2	9	51%	52	6%	11	27%
3	23	82%	156	6%	32	17%
4	46	77%	76	11%	51	33%
5	13	19%	55	2%	50	21%
6	19	88%	238	12%	76	32%
7	13	79%	169	11%	61	25%
8	45	87%	176	11%	111	70%
9	53	79%	29	4%	11	5%
10	26	74%	157	19%	73	44%
11	43	52%	0	0%	1	1%
12	24	54%	85	3%	64	23%
13	75	72%	95	4%	16	7%
14	62	96%	197	9%	80	28%
15	21	58%	184	12%	89	48%
16	40	58%	43	3%	33	17%
17	14	69%	77	6%	34	17%
18	85	92%	480	25%	65	38%
19	12	50%	66	9%	45	24%
20	10	32%	289	11%	51	25%
21	36	57%	48	2%	19	10%
22	62	82%	64	3%	31	13%
23	42	78%	200	7%	57	27%
24	69	88%	300	16%	54	46%
25	17	43%	43	6%	38	28%
26	1	13%	40	3%	21	9%
27	14	35%	179	4%	44	13%
28	18	49%	40	5%	2	16%
29	12	36%	48	4%	22	2%
30	30	69%	134	9%	51	33%
31	13	67%	10	1%	9	4%
32	19	51%	52	4%	49	25%
Stand Avg.	**30**	**61%**	**120**	**7%**	**43**	**23%**

* Pre-havest composition estimated from timber volume removed and assuming 150 bd.ft. per tree
** 1987 composition adapted from Fischer et al (1987)

The 1987 measurement showed slight differences in oak dominance relative to aspect code (Figure 14). Oaks comprised approximately 10 percent of all dominant trees for aspect codes one through three and slightly less than 10 percent for aspect code four. Differences between aspects have become more evident following the 2004 measurements. Oaks have made the most significant gains on the more xeric sites, now comprising almost 30 percent of dominant trees. While dominant oak gains are still apparent over time on mesic sites, they appear to be inhibited by an increased yellow poplar (Liriodendron tulipifera) component. Figure 14 also shows a consistent loss of the mixed hardwood component across all aspects. This is likely due to the longevity and silvics of associated species. For instance, species such as dogwood *(Cornus florida)* and eastern

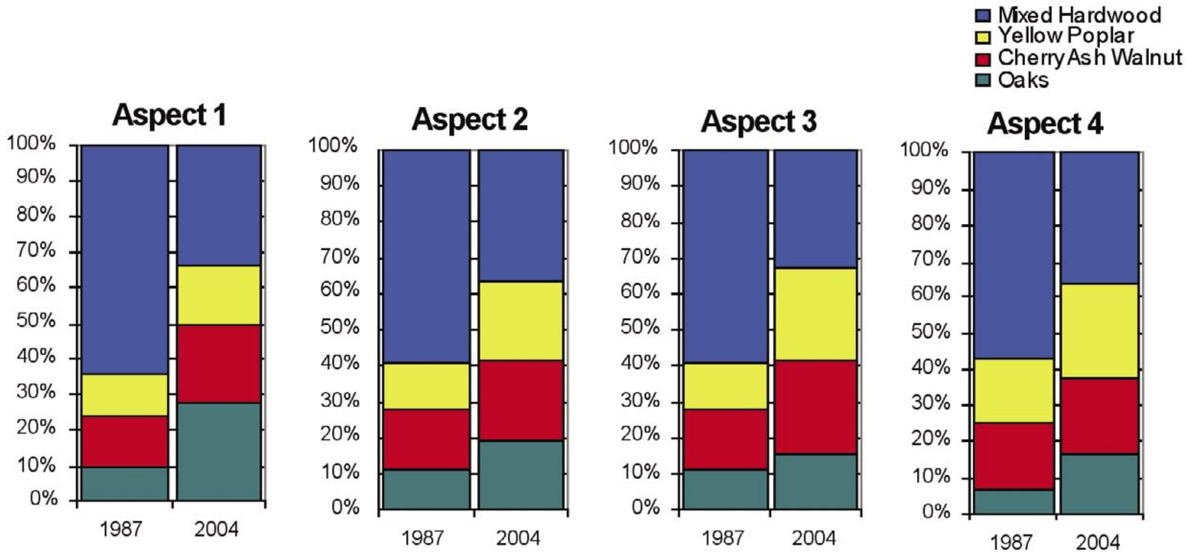

Figure 14. *Dominant species composition by aspect and measurement period for 32 sampled stands in the Tell City Ranger District.*

hophornbeam *(Ostrya virginiana)* that established themselves in dominant positions immediately following harvest are now being overtopped by larger species.

Concerns

Grapevines commonly affect stand performance in the CHFR through crown suppression, increased wind damage potential, and competition for light, water, and nutrients (Trimble and Tyron, 1974). Due to the shade intolerance of grapevines, this problem is most prevalent following clearcut harvesting (Trimble and Tyron, 1974). An average of 105 grapevines per acre was observed across all sampled stands, with > 25 percent of all dominant trees supporting at least one vine (Figure 15). Smith (1989) recommends that when managing for timber the maximum tolerable amount of trees hosting grapevines is 6 percent.

Figure 15. *Example of an area with heavy vine densities causing suppression of hardwoods in background.*

Almost half of all grapevines were located in black cherry *(Prunus serotina)*, sugar maple *(Acer saccharum)*, or yellow poplar, and 45 percent of all black cherries contained at least one grapevine.

Another interesting observed phenomenon was an extraordinarily high number of dead yellow poplars in a dominant canopy position (Figure 16). Approximately 25 percent of all yellow poplar were killed due to stress induced by a severe drought in 1999. Yellow poplars

Figure 16*. Example of drought induced death in a formerly dominant yellow poplar.*

were tallied as incurring mortality due to drought if a tree formerly in the dominant position was dead with no other obvious sign of damage. A decreasing yellow poplar component was also noted by Moser et al., (2004), who attributed this to severe drought. No other species were noticeably affected by drought-induced stress at the time of measurement.

Conclusions and Recommendations

This study indicates that even-aged management of oak stands may not be as detrimental to oak perpetuation as several studies have noted. Preliminary results show that oaks have successfully regenerated to pre-harvest levels in approximately 70 percent of sampled stands. A previous study on these sites indicated a significantly reduced oak component shortly after harvest (Fischer et al., 1987). Current data shows that successional changes over another 17 years have allowed oaks to move through the canopy strata and establish dominant oak densities greater than pre-harvest levels. This delayed response of oak to gain a dominant position in the canopy is in agreement with Sander and Graney's (1992) findings. While dominant oak composition is still less than pre-harvest estimates, this is largely due to the present stand development stage which contains numerous smaller trees of shade intolerant species that will most likely die off. As this occurs, stands will likely resume a structure and composition more closely mimicking their previous character (Figure 17).

Figure 17. *Example of a mature oak stand adjacent to a regenerating clearcut in the Tell City Ranger district of the Hoosier National Forest.*

While overall results show successful regeneration of oaks, not all stands exhibited equal effects from harvest. Several stands maintained significantly less oaks than pre-harvest levels, indicating the need to manage forests on a site specific level. Site aspect proved to be a reasonable partial indicator of future stand conditions. More mesic northern and eastern sites exhibited increased competition between oaks and yellow poplar, and therefore a reduced oak component, while southern and western slopes demonstrated larger increases in oak between the previous and current measurement periods. This finding is in agreement with Jenkins and Parker (1998), who found an increased oak component on more xeric locations in 16-27 year old stands in the Hoosier National Forest.

Predicting mature stand conditions based on the current status of a stand and natural progression is often difficult and imprecise. However, intermediate silvicultural operations allow a land manager to control and shape future stand structure and composition. The overall status of sampled stands makes these stands prime candidates for operations such as a thinning aimed at crop tree release. The stands are currently carrying a high density of small, non-commercially valuable trees. Elimination of these less desirable competing species would greatly enhance survival of crop trees such as oak in the mature forest canopy. These operations could also serve as a means to remove the heavy vine component described in these stands. Vine removal would likely decrease the likelihood of large blow-down events and prevent form defects due to canopy suppression.

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