DEFERRED ROTATION HARVESTS IN CENTRAL APPALACHIA: 20- AND 25-YEAR RESULTS

Melissa Thomas-Van Gundy and Thomas M. Schuler[1]

Abstract.—In deferment harvest, two distinct age classes are created and the residual trees remain after establishment of the second cohort. The 20- or 25-year preliminary results from four deferment areas are described. For each area, volume and growth in the residual trees and new cohort, and structure and composition of the new cohort are presented. We also address whether the deferment harvest accomplished regeneration goals of establishing species that range from shade intolerant to tolerant.

INTRODUCTION

In the early 1980s concerns regarding the efficacy of regeneration practices promoted as alternatives to clearcutting prompted the initiation of this study. The practice under study, a hybrid between even-aged and uneven-aged silvicultural systems, is often referred to as deferment harvesting. In this system, two distinct age classes are created and residual trees remain after the second cohort is established. Study areas were established on the Fernow Experimental Forest and Monongahela National Forest in West Virginia to evaluate this system. Early results addressed concerns regarding composition of regeneration and growth of residual trees, but long-term results are necessary to fully understand this relatively new silvicultural system for the eastern United States (Smith and others 1989, Miller and Schuler 1995, Smith and others 1994, Miller 1996, Miller and others 1997).

Reasons for using deferment harvesting range from improved aesthetics (Smith and others 1989), to maintaining species diversity in regeneration (Miller and Kochenderfer 1998), and reducing negative impacts to wildlife (Miller and others 1995). While the improvement in aesthetics was not strongly supported by visual quality surveys (Pings and Hollenhorst 1993), songbirds appeared to benefit from the vertical structure created (Miller and others 1995).

Earlier results from the study have been reported. Five-year results concluded that the number and composition of stems were no different from those expected after a clearcut (Smith and others 1989). In 1995, 10-year results of residual tree growth and regeneration were combined with songbird count data (Miller and others 1995). Most residual trees in the deferred harvest areas showed greater diameter at breast height (d.b.h.) growth than trees of the same species in control stands (Miller and others 1995).

Survival, grade reduction, and regeneration results from deferment harvests on the Monongahela and Fernow were summarized by Miller and others (1997). The authors concluded that 89 percent of residual trees survived and initial grade was maintained on 76 to 100 percent of these trees depending on species. Also, d.b.h. growth of the residual trees increased for most species 2 to 5 years post-harvest. Regeneration after harvest was a mix of desirable commercial species and was similar to regeneration through clearcutting.

[1]Research Foresters (MT-VG and TMS), Northern Research Station, USDA Forest Service, PO Box 404, Parsons, WV 26287. MT-VG is corresponding author: to contact, call (304)478-200 or email at mthomasvangundy@fs.fed.us.

Twenty-year post-harvest regeneration inventories showed that residual trees influenced growth and composition of regeneration in their immediate vicinity (Miller and others 2004, Miller and others 2006). Basal area of the regeneration increased with increasing distance from the reserve trees; basal area of shade-intolerant species more than doubled along the gradient.

OBJECTIVES

It has been 20 to 25 years since the creation of the deferment harvesting study on the Fernow and Monongahela. Reported here are the preliminary 20- or 25-year results from four of the six original areas. For each study area, two main topics are presented: volume in the residual trees and new cohort, and structure and composition of the new cohort.

STUDY AREAS

Study areas are on the Fernow Experimental Forest and the Monongahela National Forest in north-central West Virginia on the Allegheny Plateau province. Stands were unmanaged second-growth of mixed hardwoods before harvest with northern red oak (*Quercus rubra* L.) site indices ranging from 70 to 80 (base age 50). Age of initial stands was between 75 and 80 years at harvest. On all areas, annual average precipitation is about 59 inches and is distributed throughout the year. Average soil depth exceeds 3 feet (Miller and others 2004).

Results are reported for the Fish Trough, Shavers Fork, Riffle Creek, and Red House study areas. For Fish Trough and Shavers Fork, results reported here are 25 years after harvest; for Riffle Creek and Red House, results are 20 years post-harvest.

The Fish Trough area includes two sub-compartments (5.8 acres and 7.3 acres) established in 1981 on the Fernow Experimental Forest. The sub-compartments have similar site indices (80 for northern red oak), but differ in aspect. The sub-compartments were combined for reporting following an earlier assessment of no meaningful differences between the two areas. Harvest took place in the fall/winter of 1980-1981. Yellow-poplar (*Lirodendron tulipifera* L.) was the main species chosen for residual trees.

The Shavers Fork study area is 10.2 acres on the Monongahela with a northern red oak site index of 80. Yellow-poplar made up the majority of the residual trees. The area was harvested from May to August 1981.

The Riffle Creek study area was established in 1979 on the Monongahela and is approximately 14.8 acres with a northern red oak site index of 70. The area was logged during the spring of 1981. Red and white (*Q. alba* L.) oaks were favored as leave trees.

Established in 1985, the Red House study area is 8.9 acres on the Monongahela with a northern red oak site index of 80. Logging was completed in March 1985. Yellow-poplar, northern red oak, and black cherry (*Prunus serotina* Ehrh.) were featured leave trees. The dense striped maple (*Acer pennsylvanicum* L.) understory on about half (4.5 acres) of the study area was treated with herbicide before logging.

METHODS

Data collection methods for these study sites were reported earlier (Smith and others 1989, Miller and Schuler 1995). All study sites included the same data collection methods for regeneration, growth plots, and deferment trees.

Permanent regeneration plots were established on a 1 by 1, 1 by 2, or 1.5 by 1.5 chain grid in all areas to serve as plot centers for both small (<1.0 inch d.b.h.) and large (1.0 to 4.9 inches d.b.h.) regeneration; numbers of plots per study area vary from 47 to 60. All large woody stems, 1.0 to 4.9 inches d.b.h. were measured on 0.01-acre plots. Trees larger than 4.9 inches d.b.h. were recorded in large regeneration plots if they occurred in the area before the reestablishment of overstory growth plots. Our regeneration results include only stems 1.0 inch d.b.h. and larger. These regeneration surveys are used to describe stand composition and structure both before and after harvest.

Four 0.5-acre overstory growth plots were established in each study area with permanent center points before harvest and then again 20 years after harvesting. All trees 1.0 inch d.b.h. and greater were measured to the nearest 0.1 inch. These growth plots were used to describe vegetation both before and after harvest. On all study sites, all trees 1.0 inch d.b.h. and larger (except for the deferment trees) were cut during logging and site preparation.

Volume estimations were calculated from either growth plots or deferment trees alone. Cubic-feet volume was calculated for trees 5.0 inches d.b.h. and greater to a 4.0-inch top. Board-foot volume (International ¼ inch rule) was calculated for trees 11.0 inches d.b.h. and greater to an 8.0-inch top. Local volume Tables were used for both estimates.

Prelogging data for each residual tree consisted of: species, d.b.h., crown class, butt log grade, total height, crown width, clear bole length, merchantable height, epicormics by 8-foot sections, and general remarks. We do not address crown, bole, or grade characteristics in this paper. All deferment trees were permanently identified.

In this preliminary analysis, we examined diameter growth by site using standard analysis of variance procedures. We also used the Tukey-Kramer adjustment, which controls the experiment-wise error rate, for means comparison when statistical differences were identified ($\alpha = 0.05$ for all tests). Further analysis is planned to test for differences in species, species•site and species•time interactions.

RESULTS

Volume Growth—Residuals and Ingrowth

There were 174 residual trees, about 13 per acre (Table 1) at the Fish Trough site following harvesting. At age 25, 161 deferment trees remained, about 12 per acre. Net change (based on growth plot data) from year 1 to year 25 is an increase in total cubic foot volume of 1,580 and an increase of 4,549 board feet per acre (Fig. 1). Annual volume growth was approximately 182 board feet per acre or 63 cubic feet per acre. Stand volume was 21,787 board feet per acre before harvest; at age 25, stand volume has recovered to about 45 percent of the initial volume. Cubic-foot volume has grown to approximately 64 percent of the initial stand volume.

In the Shavers Fork study area, a total of 134 deferment trees (about 13 per acre) were selected (Table 1). The board-foot volume per acre for the deferment trees averaged 3,833 per acre and cubic-foot volume averaged 558 per acre immediately after harvest (based on measurements of residual trees). Net change (from growth plot data) from year 1 to year 25 is an increase of 1,675 cubic feet per acre and 4,687 board feet per acre (Fig. 1). Stand volume was about 14,483 board feet per acre before harvest. Board-foot volume at age 25 is about 58 percent of the preharvest average per acre. Cubic-foot volume has grown to

Table 1.—Summarized stand data for pre-treatment and most recent surveys. Preharvest and post-harvest data come from the 0.5-acre growth plots; preharvest data for the deferment trees alone come from individual tree measurements of all deferment trees.

	Trees per acre			Volume/acre (5" d.b.h. +)		Basal area (ft^2/acre)		
Year	5.0"-10.9"	11"+	Total	Cubic ft.	Board ft	5.0"-10.9"	11"+	Total
				Fish Trough				
Preharvest	53	78	131	3,603	21,787	18.0	119.0	137.0
Preharvest (deferment trees)	0	13	13	667	4,786	0.0	24.0	24.0
1981 - year 1	0	15	15	722	5,290	0.0	26.0	26.0
2007 - year 25	174	20	194	2,302	9,838	46.0	52.0	98.0
				Shavers Fork				
Preharvest	91	60	151	2,698	14,483	27.0	82.0	109.0
Preharvest (deferment trees)	0	13	13	558	3,833	0.0	20.0	20.0
1982 - year 1	0	11	11	506	3,696	0.0	18.0	18.0
2007 - year 25	172	13	184	2,182	8,383	49.0	44.0	93.0
				Riffle Creek				
Preharvest	98	72	170	3,357	15,245	34.0	100.0	134.0
Preharvest deferment trees	1	11	12	478	2,612	0.7	16.7	17.4
1980 - year 1	1	11	13	537	2,999	0.6	19.0	20.0
2004 - year 20	85	13	98	1,528	6,709	19.0	42.0	61.0
				Red House				
Preharvest	70	128	198	4,833	28,218	25.0	162.0	197.0
Preharvest deferment trees	0	19	20	830	5,802	0.0	30.0	30.5
1985 - year 1	1	19	19	734	5,104	0.0	27.0	27.0
2004 - year 20	165	19	183	1,925	9,257	36.0	46.5	83.0

approximately 81 percent of the initial stand volume. Annual growth is approximately 187 board feet per acre or 67 cubic feet per acre.

For the Riffle Creek study area, leave trees averaged about 13 trees per acre (Table 1). Board-foot volume of the deferment trees averaged 2,612 per acre; cubic-foot volume averaged 478 cubic feet per acre. After logging, 184 trees were left on the study site. From year 1 to year 20, net growth (based on growth plot data) was 991 cubic feet of volume per acre and 3,710 board feet of volume per acre (Fig. 1). Annual growth was 161 board feet per acre and 43 cubic feet per acre. Board-foot volume at age 23 was about 44 percent of the pre-harvest total while cubic-foot volume was about 46 percent of total.

In the Red House study area, 174 deferment trees were chosen (about 20 per acre) and six were lost in logging, leaving about 19 per acre (Table 1). Volume in deferment trees averaged 5,547 board feet per acre in 1985 immediately post-logging. Net change from year 1 to year 20 was the addition of 1,191 cubic feet per acre and 4,153 board feet per acre. Annual board-foot volume growth was approximately 208 per acre and cubic foot volume growth was about 60 per acre (Fig. 1). Board-foot volume at age 20 is about 33 percent of the preharvest volume while cubic-foot volume is about 40 percent of the preharvest amount.

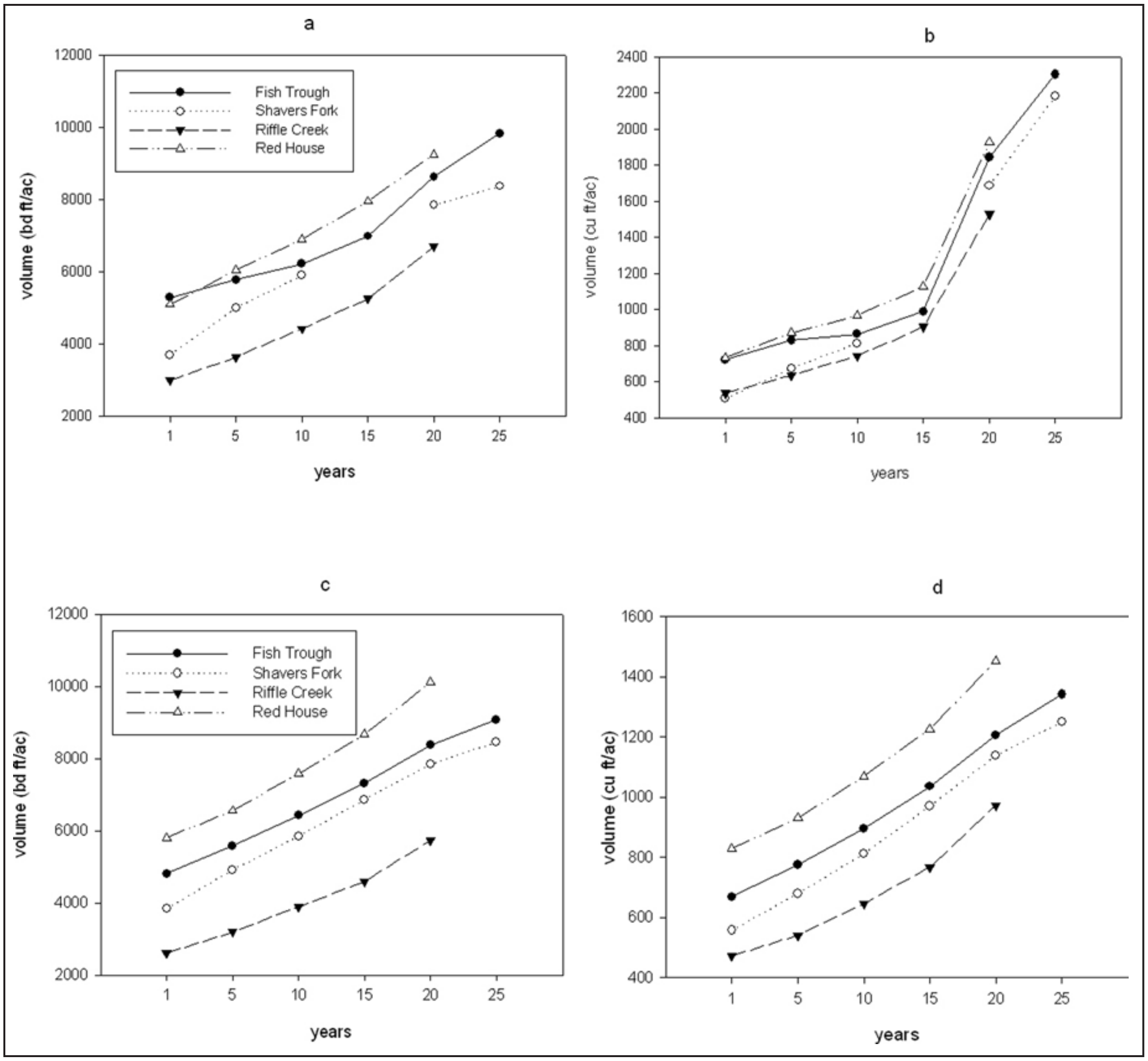

Figure 1.—Volume for each study area from post-logging to present; a) board foot volume from growth plots; b) cubic-foot volume from growth plots; c) board-foot volume from residual trees only; d) cubic-foot volume from residual trees only.

For the Fish Trough, Riffle Creek, and Red House areas cubic foot volume exhibits a distinct increase between 15 and 20 years post-harvest (Fig. 1). This increase marks the ingrowth of the new cohort from less than 5 inches d.b.h. to the pole-sized class. Similar ingrowth probably occurred around the same time on the Shavers Fork study area, but 15-year growth plot data are not available.

Diameter Growth of Residuals

Analysis of variance results indicated the diameter growth of residual trees differed by site for all measurement periods ($P < 0.05$ in each case). Shavers Fork consistently exhibited greater growth throughout the past two decades and was significantly different from the other three locations (Table 2), averaging more than 4 inches of d.b.h. growth per decade with all species combined. For the other locations, differences by site declined over time. Five years after treatment, each site exhibited a unique response in terms of diameter growth. However, after 20 years, only the Shavers Fork location was statistically discernable. Diameter growth ranged from 3.5 to 3.2 inches per decade after 20 years at Fish Trough, Riffle Creek, and Red House (Table 2). Diameter growth for central Appalachian species in unmanaged stands

Table 2.—Average annual diameter growth rates (inches/year) of deferment trees by site and measurement period. The Tukey-Kramer adjustment for means comparison was used to identify differences by site (α = 0.05) within 5-year measurement periods (mean differences indicated by lowercase letters).

Site	5 Years	10 years	15 years	20 years	25 years
Shavers Fork	0.51 a	0.43 a	0.41 a	0.42 a	0.37 a
Fish Trough	0.35 b	0.34 b	0.33 b	0.35 b	0.33 b
Riffle Creek	0.29 c	0.31 c	0.32 b	0.32 b	
Red House	0.24 d	0.30 c	0.30 c	0.32 b	
Combined	0.34	0.33	0.33	0.35	

Table 3.—Average annual diameter growth rates (inches/year) of deferment trees by location for selected species. Shavers Fork, Red House, and Riffle Creek were combined due to similarities in growth rates.

Species	5 Years	10 years	15 years	20 years	25 years
			Fish Trough, Red House, and Riffle Creek		
White oak	0.26	0.28	0.28	0.28	--
Northern red oak	0.32	0.37	0.39	0.41	0.47
Yellow-poplar	0.31	0.32	0.31	0.33	0.33
Black cherry	0.21	0.21	0.21	0.22	0.24
Sugar maple	0.32	0.31	0.31	0.32	0.26
			Shavers Fork		
White oak	0.47	0.44	0.44	0.43	0.38
Northern red oak	0.48	0.48	0.48	0.50	0.45
Yellow-poplar	0.53	0.41	0.39	0.40	0.35
Black cherry	0.46	0.41	0.40	0.39	0.35

is expected to be about 2 inches per decade for northern red oak, yellow-poplar, and black cherry, and somewhat less for white oak (Miller and others 1995).

Diameter growth differences by site could not be solely attributed to differences in the species composition of the residual trees. At Fish Trough, Shavers Fork, and Red House, the majority of residual trees were yellow-poplar, at 63, 57, and 64 percent, respectively. At these three sites, northern red oak was the second most abundant species of residual tree, at 12, 23, and 28 percent, respectively. At the Riffle Creek study area, northern red oak and white oak combined represented 75 percent of the residual trees, with yellow-poplar making up just 10 percent of the total.

Given the significant differences in diameter growth by site, we grouped Fish Trough, Red House, and Riffle Creek for a species assessment of growth rates, while Shavers Fork was kept separate (Table 3). We selected white and northern red oak, yellow-poplar, black cherry, and sugar maple for further analysis and reporting because of their commercial value and overall importance in the region, although sugar maple was not present as a deferment tree at Shavers Fork.

Growth rates were greatest for northern red oak for most measurement cycles. The Fish Trough, Red House, and Riffle Creek combined results show an increasing growth rate for northern red oak at each

5-year period that exceeded 4.5 inches per decade at the last measurement period. Shavers Fork northern red oak has maintained d.b.h. growth rates greater than 4 inches per decade for the past 25 years, which equates to adding about 10 inches of stem diameter in the last 25 years.

In contrast, yellow-poplar at Shavers Fork has slowed in diameter growth at each measurement cycle after an initially vigorous response (0.53 inches per year during the first 5 years). At the other three locations, yellow-poplar has maintained a steady growth rate of just over 3 inches per decade. Black cherry diameter growth responded favorably at the Shavers Fork location 5 years after treatment (0.46 inches per year), but growth has slowed at each subsequent measurement cycle. For the combined locations, black cherry growth rate was near the expected norm for unmanaged stands of about 2 inches per decade. Our results indicate black cherry is not always capable of responding vigorously to additional growing space associated with deferment harvesting. Shagbark hickory (*Carya ovata*, (P. Mill) K. Koch), chestnut oak (*Q. prinus* L.), and white ash (*Fraxinus americana* L.) also had 20-year post-treatment average annual d.b.h. growth rates of less than 0.25 inches per year.

Stand Structure and species Composition

Currently much of the regeneration established from the two-age harvest is represented by 6- to 10-inch d.b.h. stems. The growth plot data were summarized by area at year 20 or 25 to show stems per acre and crown position for commercial species by diameter class (Table 4).

In the Fish Trough and Shavers Fork areas, pole-sized regeneration is mainly dominant/co-dominant yellow-poplar. In the Riffle Creek area, yellow-poplar and northern red oak share dominance of the pole-sized regeneration. Riffle Creek has the lowest site index (70) of the four areas, while still relatively high; oaks appear to have an advantage on this site. Yellow-poplar was also dominant in the Red House area; however, unlike the other areas, black cherry stems were also competitive. Pole-sized pin cherry is still present in all study sites although they are a minor component.

Sugar maple, oaks, and black cherry were chosen to track from pre-harvest through the 20- or 25-year development of the second cohort (regeneration from 0.01-acre plots and pole-size stems from 0.5-acre growth plots) (Table 5). Sugar maple made up much of the large regeneration at the time of harvest, and is the main shade-tolerant species found in the large regeneration layer in most areas. White and chestnut oak were tracked in the Riffle Creek area along with northern red oak; on other areas, northern red oak was the only oak present as large regeneration.

On the Fish Trough site, northern red oak and black cherry large regeneration did not appear in the plots until 1991, 10 years post-harvest. Both species have persisted to the present as small saplings, and a minor percentage have moved into the pole-sized class at 20 years post-harvest. There has been a decline in stem density in the 1 to 4.9 inch d.b.h. class as the stand reached the stem exclusion stage between 15 and 20 years of age.

At the Shavers Fork site, there were two stems per acre (large regeneration) of northern red oak before harvest, increasing to 44 per acre 10 years after harvest, or about 4.5 percent of the total regeneration of commercial species (Table 5 does not include total). At 20 years post-harvest, northern red oak stems show movement into the pole-size class, but total only three per acre. Also at 20 years post-harvest, yellow-poplar, black cherry, and sugar maple regeneration moved into the pole-size class. Total commercial regeneration has declined since 15 years post-harvest as competition increased and stems moved into larger d.b.h. classes.

Table 4.–20- or 25-year stand structure—commercial species. D/C = dominant/codominant crown class, I/O = intermediate/overtopped crown class. Data are from the 0.5-acre growth plots.

	Stems per acre						
	6-10"		12-16"		18-24"		
Species	D/C	I/O	D/C	I/O	D/C	I/O	Total
			Fish Trough				
Birch	19	2	0	0	0	0	21
Northern red oak	1	0	0	0	0	0	1
Yellow-poplar	69	25	6	0	9	0	109
Black cherry	4	1	0	0	1	0	6
Sugar maple	3	4	0	0	0	0	7
Red maple	0	1	0	0	0	0	1
Basswood	29	13	0	0	5	0	47
White ash	1	0	0	0	1	0	2
other	8	4	0	0	2	0	14
Total	134	50	6	0	18	0	208
			Shavers Fork				
Birch	15	5	0	0	0	0	20
Northern red oak	2	1	0	0	4	0	7
Yellow-poplar	85	33	2	0	8	1	128
Black cherry	2	0	1	0	0	0	3
Sugar maple	2	1	0	0	0	0	3
Red maple	7	1	0	0	0	1	9
Basswood	2	3	0	0	0	3	8
other	13	10	0	0	0	1	24
Total	129	54	3	0	12	6	204
			Riffle Creek				
Birch	6	0	0	0	0	0	6
White oak	1	0	0	0	7	0	8
Chestnut oak	8	1	0	0	0	0	9
Northern red oak	16	0	0	0	9	0	25
Yellow-poplar	18	3	1	0	1	0	23
Black cherry	6	1	0	0	0	0	6
Sugar maple	2	1	1	0	1	0	5
Red maple	14	6	0	0	2	0	22
other	4	1	1	0	0	0	6
Total	75	13	3	0	19	0	110
			Red House				
Birch	10	0	0	0	0	0	10
Northern red oak	1	0	0	0	2	0	3
Yellow-poplar	86	6	0	0	13	0	105
Black cherry	46	2	1	0	6	0	55
Red maple	1	1	0	0	0	0	2
Basswood	1	0	0	0	0	0	1
White ash	0	0	1	0	0	0	1
Total	145	9	2	0	21	0	177

Table 5.—Stems per acre of selected species from preharvest to latest measurement. Data for stems less than 6 inches d.b.h. are from 0.01-acre regeneration plots and the 6-10 inches d.b.h. stems from 0.5-acre growth plots. Table displays data for selected species, not total found in study areas.

		oaks	black cherry	yellow-poplar	beech	sugar maple	oaks	black cherry	yellow-poplar	beech	sugar maple
		Fish Trough					Shavers Fork				
Preharvest	<6"	0	0	0	75	142	2	0	6	232	52
	6"	0	0	0	4	14	1	1	5	11	9
	8"	0	1	0	1	6	0	1	10	3	5
	10"	0	0	1	1	3	0	0	10	2	1
5 yrs	<6"	0	0	32	10	47	14	2	352	4	16
	6"	0	0	0	0	0	0	0	0	0	0
	8"	0	0	0	0	0	0	0	0	0	0
	10"	0	0	0	0	0	0	0	0	0	0
10 yrs	<6"	22	27	252	60	278	44	8	434	94	54
	6"	0	0	0	0	0	0	0	0	0	0
	8"	0	0	0	0	0	0	0	0	0	0
	10"	0	0	0	0	0	0	0	0	0	0
20 yrs	<6"	17	20	102	70	297	32	6	218	170	74
	6"	0	3	53	0	3	2	1	66	0	1
	8"	0	1	27	0	0	1	1	30	0	0
	10"	0	0	7	0	0	0	1	4	0	0
25 yrs	<6"	10	12	37	72	287	20	2	144	190	90
	6"	1	3	45	0	6	2	1	50	0	2
	8"	0	2	31	0	1	1	0	48	0	0
	10"	0	0	16	0	0	0	1	20	0	0
Preharvest		Riffle Creek					Red House				
	<6"	6	0	0	175	62	2	0	0	93	54
	6"	6	0	0	3	8	2	1	1	4	9
	8"	10	0	1	1	3	2	4	3	0	2
	10"	20	1	1	0	3	1	8	11	0	1
5 yrs	<6"	89	19	43	15	11	2	153	200	0	0
	6"	0	0	0	0	0	0	0	0	0	0
	8"	0	0	0	0	0	0	0	0	0	0
	10"	0	0	0	0	0	0	0	0	0	0
10 yrs	<6"	243	55	87	179	89	34	283	689	11	17
	6"	0	0	0	0	0	0	0	0	0	0
	8"	0	0	0	0	0	0	0	0	0	0
	10"	0	0	0	0	0	0	0	0	0	0
20 yrs	<6"	168	17	38	387	160	19	123	255	17	15
	6"	21	4	8	0	3	1	40	61	0	0
	8"	4	2	8	0	0	0	7	28	0	0
	10"	0	0	4	0	0	0	1	2	0	0

In the Riffle Creek area, there were six oak stems per acre in the large regeneration layer before harvest. At age 10 there were more oak stems than beech, sugar maple, or yellow-poplar when considered separately. At age 15, oaks contributed 283 stems per acre or about 20 percent of the total commercial species regeneration. Between years 15 and 20, the numbers of oaks declined to 168 per acre (13 percent). Beech stems have increased in number since harvest and now total 387 stems per acre (31 percent). As in the other areas, growth of stems into the pole-sized class is detected 20 years post-harvest. Unlike the other areas, oaks are competitive with yellow-poplar.

At the Red House site, yellow-poplar has dominated the regeneration since 10 years after harvest. There have been very few oak stems in this stand throughout the study period. A dense layer of striped maple limited advanced regeneration of commercial species preharvest. Movement of stems into the pole-sized class is noted at 20 years post-harvest.

DISCUSSION

Volumes in the study areas continue to increase as the new cohort develops and residual trees continue to increase in volume. Increased cubic-foot volume indicates that stand structure includes many smaller, pole-sized stems per acre than were in the initial stand. As shown in the growth of board-foot volume, vigorous growth of residual trees has, in some areas, recovered to 50 percent or more of the preharvest volume.

Regeneration in the new stand has reached pole size and is diverse. Yellow-poplar dominated the regeneration and the pole-sized stem classes in all but one area. This outcome is consistent with even-aged regeneration methods on similar high site indices in the Appalachians (Smith and others 1976, Loftis 1983, Beck and Hooper 1986, Loftis 1989, Brashears and others 2004). Black cherry has regenerated in the deferment harvests and could benefit from early release.

Shade-tolerant beech and sugar maple dominated the advanced regeneration in the areas before harvest. Current dominance by yellow-poplar reflects the open conditions created by the deferment harvest and possibly the seed source provided by the abundant yellow-poplar leave trees on most sties. Regeneration in the areas came from many sources: sprouts (basswood, oak); stored seed (black birch); advanced regeneration (sugar maple, beech); and new seed from surrounding forest and residual trees.

In previous assessments, deferment harvests resulted in an abundance of black birch hindering regeneration of other more desirable commercial species (Miller and Schuler 1995). Twenty-plus years after harvesting, we find black birch remains a significant component of the new cohort (Table 4). However, in the pole-sized stratum, birch is less abundant than other commercial species. In the Shavers Fork area, birch regeneration has declined in relation to other commercial species, but it has remained about the same at Fish Trough and increased at Riffle Creek. Birch makes up about 30 percent of the large reproduction in the Red House area. Birch is also present as pole-sized stems in all study areas, mainly in the dominant/codominant class.

On most of the study areas, pin cherry is a component of the pole-sized regeneration and often has the largest d.b.h. in the stand. Pin cherry is relatively short-lived, but can interfere with regeneration of more desirable species.

Miller and others (2004, 2006) discuss impacts the residual trees had on regeneration in these areas. Shade from the older cohort has limited development and species diversity under the crowns of the residual trees. Even with the documented impacts to regeneration from the residual trees, deferment harvesting as conducted may still meet many landowner objectives. Slower growth under the crown of and immediately adjacent to each residual tree may be acceptable given continued growth of high valued residuals, continued mast production, and continued presence of mature trees of species with regeneration difficulties under any silvicultural system. As documented here, species composition of the new cohort is diverse, with a large component of shade-intolerant species such as yellow-poplar. The high numbers of young (i.e., small d.b.h.) stems per acre in the areas at 20 or 25 years post-harvest indicate that there are still options in the stands to control species composition and growth through tending of the new cohort.

The low amount of oak regeneration and its gradual relegation to overtopped status, the influence of the residual overstory, and the abundance of low-quality competitors such as birch and pin cherry all point to the need for early precommercial thinning or crop tree release (Miller 2000, Schuler 2006). This analysis, as well as previous work, shows the need to capture the diversity in regeneration before desirable species and stems are irrevocably subordinated or lost altogether. Based on the 20- and 25-year results and previous analysis of these areas, this precommercial step should take place before age 20.

Given the absence of advanced oak regeneration before harvest, it is not surprising that young oaks are struggling to maintain a competitive position. Moreover, these areas were not dominated by northern red oak in the overstory before harvest and most regeneration methods would have led to a decline in oak abundance. Retention of some oak in the overstory can also be seen as "insurance" for the future as oaks continue to be a source for regeneration, provide hard mast for wildlife, and add diversity to the stand.

Expected growth rates and life expectancies are two criteria for selecting deferment trees. For example, black cherry did not always respond to release in this study and has a relatively short life expectancy. As such, black cherry would not be a good species to retain in a deferment harvest. In contrast, northern red oak does seem to maintain elevated growth rates after deferment harvesting for at least 25 years and has a life expectancy that can span a second rotation in a deferment harvest. Management objectives of deferment harvesting will more likely be achieved if species characteristics regarding growth, quality, and persistence are fully considered.

Deferment harvesting has become one of the most commonly applied new silvicultural techniques on both public and private lands in the central Appalachians in the last two decades. Growth of residual trees, abundance of regeneration, and structural characteristics that enhance wildlife habitat for both game and nongame species have all contributed to the interest and use of deferment harvesting. Forest managers using deferment harvesting on productive sites should consider crop tree release of the new cohort 15 to 20 years following the initial harvest. Partial reduction of declining or an over-abundant overstory during a crop tree release may be feasible, or even enhance, such an operation. Future work in this area should address these issues and also more fully investigate deferment harvesting on lower quality sites. Oak regeneration on some medium or lower quality sites with this technique appears promising.

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