Two-Age Silviculture—An Innovative Tool for Enhancing Species Diversity and Vertical Structure in Appalachian Hardwoods

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Abstract.—Silvicultural practices that promote a two-age stand structure provide an opportunity to maintain diversity of woody species and vertical structure for extended periods of time in Appalachian hardwoods. Data from four two-age stands initiated by deferment cutting in West Virginia are summarized for the first 10 to 15 years after treatment. Results indicated that 15 commercial hardwood species regenerated successfully and that height growth of the new cohort provides a predictable change in vertical structure over time. Growth, quality, and vigor of residual trees after treatment varied by species and initial condition. Diversity in vertical structure seems to improve habitat suitability for some wildlife species. Songbird counts were compared for 2 consecutive years, beginning at least 10 years after treatment, in even-age and two-age stands. For two-age stands, songbird density estimates were higher in both study years, whereas nesting survival was lower the first year compared to that in even-age stands. Preliminary implications of two-age regeneration methods for meeting forest health objectives and future research needs are discussed.

INTRODUCTION

Increased emphasis on managing forest ecosystems to maintain forest health and to produce multiple benefits calls for innovative silvicultural practices. For example, clearcutting in the Appalachians promotes reproduction of both shade-tolerant and shade-intolerant commercial hardwoods and attracts a diversity of wildlife species, including songbirds. However, clearcutting continues to draw public criticism for perceived negative impacts on aesthetics. Two-age reproduction methods have been proposed and applied as a viable alternative to clearcutting, but forest managers need key information to fully evaluate the impact of such practices on forest health. How do residual trees develop? What is the composition and quality of reproduction? What is the impact of a two-age stand structure on other forest ecosystem components such as songbirds?

The application of two-age regeneration methods to manage eastern hardwoods for multiple benefits is growing rapidly. From 1979 to 1983, deferment cutting was applied in mature hardwood stands on the Monongahela National Forest and Fernow Experimental Forest in West Virginia to study the effects of two-age stand structures on residual tree development and natural regeneration. Silvicultural systems that promote a two-age stand structure have since been initiated on other national forests, state forests, industrial forests, and to a lesser degree on nonindustrial private forests in many eastern states. Two-age methods were used to achieve two management goals: 1) to regenerate a variety of hardwood species, particularly those that are shade-intolerant, and 2) to

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mitigate the perceived negative visual impacts of clearcutting.

Immediately after logging, two-age stands resemble those following a seed-tree cut (figure 1). Such practices leave 15 to 20 codominant residual trees/acre, and perhaps some flowering shrubs, mast trees, and den trees for aesthetics and wildlife; and all other stems are cut. Residual basal area averages 20 to 30 ft^2/acre, depending on stand age and site quality. By contrast to seed-tree methods, residual trees in two-age stands are retained for many years, perhaps as long as a typical even-age rotation. In the central Appalachians, forest managers usually plan to apply two-age regeneration methods every 40 to 80 years.

Similar to natural regeneration in clearcut stands, natural regeneration resulting from two-age regeneration methods includes a variety of both shade-tolerant and shade-intolerant commercial hardwoods (Miller and Schuler 1995). Unlike clearcutting, however, the presence of residual overstory trees in the two-age stands improves aesthetics (Pings and Hollenhorst 1993) and maintains a more diverse vertical stand structure that may benefit certain wildlife species. As the new cohort of seedlings develops beneath the large overstory residuals, the stand exhibits two distinct height strata. These strata provide a diverse habitat and provide for songbirds that forage in high-canopy trees (Wood and Nichols 1995), as well as those that require a brushy cover characteristic of a young even-age stand (DeGraaf and others 1991).

This report summarizes three aspects of stand development 10 years after two-age regeneration

Figure 1.—A two-age central Appalachian hardwood stand 5 years after a regeneration harvest; residual trees are 85 years old.

harvests were applied in four central Appalachian hardwood stands: 1) growth, quality, and vigor of residual overstory trees, 2) composition, distribution, and quality of natural reproduction, and 3) species richness, density estimates, and nest survival of songbirds in the study areas. The implications of two-age regeneration methods for meeting forest health objectives are discussed. Finally, research needed to refine two-age methods as a useful silvicultural tool for enhancing forest health is suggested.

STUDY AREAS

Study areas are located in north-central West Virginia. The topography consists of low valleys dissected by northeast-southwest ridges. Elevations range from 1,800 to 3,600 feet above sea level. In general, soils are medium textured and well drained, derived from sandstone shale with occasional limestone influence. The average soil depth exceeds 3 feet. Annual precipitation averages 59 inches and is well distributed throughout the year. The growing season averages 145 frost-free days.

The initial stands were unmanaged second-growth Appalachian hardwoods with an average age of 75 years that became established after heavy logging in the early 1900's. Periodic fire was common throughout the local area as the stands became established. Chestnut blight also killed some large trees during the 1930's and resulted in some patchy reproduction before and during World War II. Forest types included cove hardwoods, Allegheny hardwoods, and oak-hickory. Stand size ranged from 10 to 15 acres for the two-age treatments and from 10 to 28 acres for the clearcuts used to study songbirds.

METHODS

Deferment cutting, a two-age regeneration method, was applied in four central Appalachian hardwood stands by retaining 12 to 15 codominant trees per acre and cutting all other stems 1.0 inch diameter breast height (d.b.h.) and larger (Smith and Miller 1991). Sawtimber trees were skidded tree-length in three stands using a wheeled skidder and in one stand using a truck-crane cable system. All other cut trees were left on the site. Each harvest operation was completed by a three-person logging crew, instructed to take special care to avoid damage to the few residual trees.

Residual trees were marked to achieve an average residual stocking of 20 ft^2/acre. In general, trees with the greatest potential value as high-quality sawtimber and veneer products were chosen using the following criteria:

- Species—northern red oak, black cherry, yellow-poplar
- Crown class—dominant or codominant
- Vigor—no evidence of epicormic branches or other sign of stress
- Risk—no disease, low forks, shallow roots, or other risk factors
- Quality—current or potential high-quality butt log
- Spacing—residual trees well distributed throughout the stand

Data for residual trees and reproduction surveys were recorded before and after treatment, followed by remeasurements 2, 5, and 10 years later. Species, d.b.h., crown class, crown width, total height, merchantable height (to the nearest 8-foot half log), butt-log grade, and number of epicormic branches were recorded for each residual tree. Live epicormic branches at least 1 foot long were counted by 8-foot bole sections to the top of the second 16-foot log. Residual trees also were examined to assess logging damage, and the length and width of sapwood wounds were recorded.

Tree reproduction data were obtained from 172 permanent sample points located along systematic grids in each stand. At each point, small reproduction (1.0 foot tall to 0.99 inch d.b.h.) was tallied within a 1/1000-acre circular plot, and large reproduction (1.0 inch d.b.h. and larger) was tallied within a 1/100-acre circular plot. Species, d.b.h., stem origin, quality, and crown class were recorded for each tree observed on a plot. Trees with the potential to become sawtimber crop trees in the future were classified as good. Trees with low forks, crooked or leaning stems, weak crowns, or other evidence of low vigor were classified as poor.

Songbird data were collected on six clearcut and six two-age stands that were treated 9 to 14 years before initiation of the bird study. Four of the two-age stands provided data on the development of residual trees and woody reproduction. Songbird counts were conducted at permanent points using the variable circular plot method (Reynolds and others 1980) within and on the periphery of each treated stand. Density estimates were determined from bird counts recorded at each sample point 5 times during May and June 1993 and 1994. Nest survival was calculated from 141 nests monitored during the same period. Nest status was checked every 3 to 4 days to determine incubation, nestling stage, fledgling stage, and to quantify predation and parasitism. Songbird density estimates were compared using analysis of variance, and nest survival was compared with the z-statistic. Wood and Nichols (1995) provide detailed descriptions of all field and statistical methods used.

RESULTS

Overstory species composition before two-age treatment included yellow-poplar, northern red oak, chestnut oak, hickory, black cherry, white oak, basswood, white ash, American beech, red maple, and sugar maple. Initial basal area averaged 127 ft^2/acre and merchantable volume averaged 15.9 Mbf/acre (Table 1). The two-age regeneration harvests removed 84 percent of the basal area and 78 percent of the board-foot volume. Basal area in the residual stands averaged 20.2 ft^2/acre in 13.8 high-quality, codominant trees/acre, while residual volume averaged 3.5 Mbf/acre. Species composition in the residual stands was dominated by northern red oak, yellow-poplar, black cherry, and white oak. During the 10-year period after treatment, residual stand basal area increased 0.6 ft^2/acre/year to an average of 26.6 ft^2/acre. Net volume growth was 140 bf/acre/year, with volume averaging 4.9 Mbf/acre after the study period.

Individual Tree Growth

In general, residual trees after deferment cutting exhibited faster diameter growth compared to control trees in similar uncut stands over the 10-year study period, though analysis of variance indicated that growth response varied by individual species (fig. 2). Growth response did not vary by study area. Deferment trees were free-to-grow with an average crown growing space of 20 feet to adjacent residual tree crowns after treatment (Miller and Schuler 1995). Control trees are located in stands that were similar to treated stands before two-age regeneration cuts were applied. Control trees also were codominant, but they had crown

Table 1.—Summary data for central Appalachian hardwood stands before and 10 years after a two-age regeneration harvest.

	Number of trees		Basal area		Volume			Average d.b.h.	
Stand	5.0–10.9[a]	11.0+	5.0–10.9	11.0+	5.0–10.9	11.0+	11.0+	5.0–10.9	11.0+
	------ No./acre ------		------ Ft^2/acre ------		------ Ft^3/acre ------		------ Bf/acre[b] ------	------ Inches ------	
				SI 70—26.9 acres					
Initial	111.3	73.7	36.4	94.5	641	2,378	14,187	7.7	15.3
Cut	110.0	61.2	35.7	77.2	627	1,937	11,511	7.7	15.2
Residual	1.3	12.5	0.7	17.3	14	441	2,676	9.9	15.9
After 10 years	0.0	11.9	0.0	22.4	0	581	3,706	0.0	18.6
				SI 80—23.3 acres[c]					
Initial	75.9	68.3	24.2	99.2	452	2,671	17,824	7.6	16.3
Cut	75.6	54.9	24.1	76.5	448	2,050	13,362	7.6	16.0
Residual	0.3	13.4	0.1	22.7	4	621	4,462	9.6	17.6
After 10 years	0.0	13.0	0.0	31.4	0	880	6,359	0.0	21.0

[a]*Inches d.b.h.*

[b]*International 1/4-inch rule.*

[c]*Data combined for two stands on each site index.*

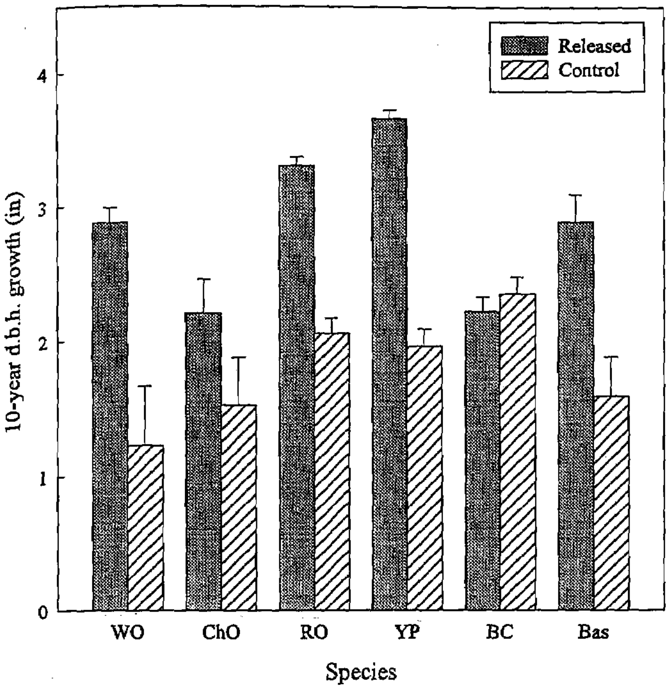

Figure 2.—Mean 10-year d.b.h. growth of residual trees released by a two-age cut compared to unreleased control trees; one standard error is shown above each bar.

competition on all sides during the study period. Growth of control trees and residual trees in two-age stands was compared using a *t*-statistic for independent samples. For black cherry, average d.b.h. growth of untreated controls exceeded that of released trees, though the difference was not statistically significant ($P = 0.301$). For all other species tested, released trees had greater average d.b.h. growth than the control trees.

D.b.h. growth of released trees was 45 to 134 percent greater than controls, led by white oak, yellow-poplar, basswood, and red oak. White oak, chestnut oak, red oak, and basswood grew faster the second 5 years compared to the first 5 years after treatment. For yellow-poplar, deferment trees grew faster during the first 5 years after treatment, though growth during the second 5 years continued to exceed that of controls.

Survival and Quality Development of Residual Trees

Within the four study areas, 667 trees were selected as residuals. After 10 years, 89 percent of the residual trees had survived. Six trees (1 percent) were destroyed or removed due to inadvertent damage during logging. After logging, 22 trees (3 percent) died after 2 years, and an additional 38 trees (6 percent) died between the 2nd and the 5th year. Mortality after the 5th year was greatly reduced; only an additional 7 trees (1 percent) died by the end of the 10th year. Mortality was greatest for black cherry (more than 20 percent), least for yellow-poplar (less than 5 percent). For white oak, chestnut oak, red oak, and basswood mortality was 12, 14, 9, and 18 percent, respectively.

Epicormic branching increased for all species within 2 years after treatment. Between year 2 and 10 there was no significant increase in the number of epicormic branches on the butt 16-foot log sections (Miller 1995). Epicormics continued to increase on the second 16-foot-log section for black cherry, red oak, and yellow-poplar between years 2 and 10. The net effect on quality was that 12 percent of the residual trees exhibited reduced butt-log grade due to new epicormic branches during the study period (Table 2). Of the few grade reductions observed, white oak, northern red oak, and black cherry were most susceptible, while less than 1 percent of the yellow-poplar trees had lower grades due to epicormic branching.

Logging operations resulted in bark wounds (exposed sapwood) on about one-third of the residual trees. For wounded trees that survived the 10-year study period, 16 percent had wounds less than 50 in^2, and 16 percent had larger wounds. Most of the wounds were located on the lower portions of the bole and were caused by skidding logs too close to residual trees. More than 95 percent of the logging wounds that were less than 50 in^2 callused over and were closed within 10 years after logging. The rate of healing over a 10-year period indicates that larger wounds up to 200 in^2 will close within 15 to 20 years after logging (Smith and others 1994).

Quality and Development of Reproduction

Before deferment cutting, small reproduction (1.0 foot tall to 0.99 inches d.b.h.) averaged 3,019 stems/acre, with 50 percent in shade-tolerant species (maples and American beech), 37 percent in

Table 2.—Average number of epicormic branches and change in butt-log grade for residual trees 10 years after deferment cutting.

Species	Number of trees	Initial d.b.h.	Number of epicormics		Change in butt-log grade			Grade loss due to epicormics
			Initial	10-years	Reduced	None	Improved	
		Inches			Number of trees (pct)			
White oak	59	14.4	0.64a[a]	2.61a	16(27)	22(37)	21(36)	14(24)
Chestnut oak	12	14.4	0.00b	0.00b	1(8)	2(17)	9(75)	0(0)
Red oak	200	16.7	0.03b	1.62b	25(12)	103(52)	72(36)	24(12)
Yellow-poplar	190	17.8	0.01b	0.26b	9(5)	137(72)	44(23)	2(1)
Black cherry	66	14.2	0.00b	2.58a	14(21)	24(36)	28(42)	15(23)
Basswood	18	15.1	0.11b	2.89a	3(17)	6(33)	9(50)	3(17)
All species	545	16.2	0.09	1.37	68(12)	294(54)	183(34)	64(12)

[a]*Values in columns followed by the same letter are not significantly different (p>0.01) using Tukey-Kramer HSD.*

shade-intolerant species (black cherry and yellow-poplar), and 13 percent in intermediate-shade-tolerant species (oaks and white ash). More than 80 percent of the survey plots had at least one commercial hardwood species, and more than 60 percent of the survey plots contained sugar maple or American beech.

Two years after harvest, small reproduction in the study areas averaged 9,100 commercial stems/acre composed of 60 percent seedling-origin and 40 percent sprout-origin stems. Also, there were more than 14,000 noncommercial woody stems/acre. At least one commercial stem occurred in more than 95 percent of the survey plots. Five years after harvest, the canopy of the new age class developing beneath the residual overstory had not closed. Large woody reproduction (1.0 inch d.b.h. and larger) at 5 years included more than 300 commercial and 100 noncommercial stems/acre.

After 10 years, the canopy of the new age class developing beneath the residual trees was nearly closed, and codominant trees averaged 35 feet tall. Large reproduction included 991 commercial stems/acre, with 450 codominant stems/acre classified as good—exhibiting the potential to become high-quality crop trees in the future (Miller and Schuler 1995). On excellent growing sites, northern red oak reproduction was sparse, averaging only 10 potential crop trees/acre (Table 3). Other codominant, commercial reproduction included a variety of both shade-tolerant and shade-intolerant species distributed over 74 percent of the stand area.

Table 3.—Summary of reproduction of commercial species 10 years after a two-age regeneration harvest.

Species	Total	Codominant	Good, Codominants
	No. stems/acre		
		SI70	
Black cherry	392	316	220
Beech	110	59	35
Red maple	105	63	47
Red oak	86	54	45
Black birch	77	54	52
Sugar maple	50	26	13
Chestnut oak	48	32	22
Yellow-poplar	44	21	16
Other	87	48	38
Total	999	673	488
		SI 80	
Yellow-poplar	383	206	190
Sugar maple	136	49	40
Black birch	85	50	46
Beech	65	20	10
Red maple	45	19	12
Basswood	36	9	9
Red oak	31	11	10
White ash	29	10	6
Other	172	91	84
Total	982	465	407

Density Estimates and Nest Survival of Songbirds

Forest-interior species had similar density estimates (F=0.65, P=0.63) in the two treatments (two-age = 207 birds/40 ha, clearcut = 190 birds/40 ha). By contrast, interior-edge (359 vs. 320 birds/40 ha) and edge (83 vs. 12 birds/40 ha) species were more abundant in the two-age treatment ($P < 0.001$). Thus, overall songbird density estimates were significantly higher ($F=19.08$, $P < 0.001$) in the two-age treatment (649 vs. 522 birds/40 ha). Species composition was similar in these two treatments; however, some species were observed in only one treatment. Ten species that occurred in the two-age stands were absent from the even-age stands: least flycatcher, cerulean warbler, Canada warbler, Kentucky warbler, winter wren, yellowthroat, mourning warbler, purple finch, American goldfinch, and brown thrasher. Four species observed in even-age stands were absent from the two-age stands: blackburnian warbler, worm-eating warbler, black-billed cuckoo, and great crested flycatcher.

Nest survival trends differed during the 2 years of study. In 1993, nest survival was lower ($P < 0.05$) in the two-age treatment (36.4 percent) than in the even-age treatment (59.3 percent). In 1994, survival was higher in the two-age stands, 59.4 percent compared to 47.1 percent in the even-age stands; however, the difference was not significant ($P > 0.10$). Predation by mammals was the most common cause of nest failure in all treatments. Only three nests failed due to cowbird parasitism.

DISCUSSION

Stand information reported here is from a relatively narrow range of two-age management alternatives. Residual basal area ranged from 17 to 25 ft^2/acre, with all residual stocking in codominant, mature trees. In each treatment area, all trees 1.0 inch d.b.h. and larger, except for the selected overstory residuals, were cut. No saplings or poles were left after harvest, though in practice this is certainly an option. In the central Appalachians, residual basal area in two-age stands could probably be as great as 60 ft^2/acre if all residual trees are near sawtimber rotation age and located in a codominant crown position. However, if younger trees are retained, maximum residual basal area will be reduced to allow for crown expansion as the overstory trees mature.

Two-age regeneration harvests should be applied no more frequently than one-half the recommended sawtimber rotation for local conditions. In the central Appalachians, economic sawtimber rotations are 90, 80, and 70 years for northern red oak SI 60, 70, and 80, respectively. As a result, two-age harvests could be applied as frequently as every 40 to 50 years. A concern with relatively frequent harvests is that many large poles and small sawtimber need to be cut at short intervals to provide adequate light for regeneration of a new age class. At age 40, even-aged stands in the region contain 75 to 100 codominant stems per acre, with an average d.b.h. of only 12 to 14 inches (Smith and Miller 1987). To maintain a two-age stand structure, 20 to 30 of the best codominant trees will be retained to reach maturity, while the remaining trees will be cut. A disadvantage of short cutting intervals is that many cut trees will be removed at a time when their potential growth and value increase are at a maximum.

The benefits of two-age silviculture are consistent with general forest health concepts (Kolb and others 1994). Selecting superior phenotypes for residual trees has the potential to maintain vigor and resistance to pathogens and insects in present and future generations. Natural regeneration includes a variety of species, early and late successional species, shade-tolerant and shade-intolerant species. This enhanced diversity of woody species provides a resilience to host-specific insects and reduces the impact of insects and pathogens that thrive in monocultures (Gottschalk 1993). From a utilitarian view, merchantable products can be removed periodically, and stands have the capability to renew themselves, thus meeting management objectives for sustained yield of wood products. From the ecosystems view, diversity of woody species, vertical structure, and, in this study, songbird density were enhanced. Moreover, with appropriate planning of two-age regeneration harvests over a landscape, a diversity of seral stages and stand structures can be maintained to enhance wildlife habitat. For example, while American beech reproduction in clearcuts would not produce mast for many years, trees old enough to produce mast could be retained in two-age stands, thus maintaining an important benefit of older seral stages.

As two-age regeneration methods are employed to meet forest management objectives, additional research is needed to better understand the implications of this innovative practice. It is important to define linkages among abiotic and biotic ecosystem components that may be affected by maintaining two vertical strata of woody vegetation over extended periods of time. For example, a supplement to the songbird study will include a survey of insect populations to determine the relationships between vertical stand structure and insect populations that are important food sources for many species of songbirds observed in the treatment areas. Research also is needed to define habitat potential for other wildlife species and to define the susceptibility of residual trees to attacks by insects and pathogens over much longer time periods. Two-age methods show promise for application in the central Appalachian hardwood region. With additional information from long-term observations, this practice and its many potential variations may provide forest managers with an ecosystem management tool for the future.

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