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The Regeneration of Central Appalachian Hardwoods With Emphasis on the Effects of Site Quality and Harvesting Practice

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ABSTRACT

This report is an attempt to integrate and summarize research results from studies made mostly in West Virginia and to show the relationship of site quality and cutting practices to hardwood reproduction, with special emphasis on species composition. Reproduction has been found satisfactory in numbers and distribution after both clearcutting and selection cutting, but the species composition differs greatly; shade-tolerant species predominate after selection cutting, but generally a good proportion of the regeneration that follows clearcutting will be composed of intolerant species — depending somewhat on the density of advance reproduction and the abundance and species composition of stump sprouts. Site quality influences the species composition of reproduction after cutting, and the effect is greater with clearcutting than with selection cutting. After clearcutting, on the excellent sites we can expect a good representation of yellow-poplar and black cherry; and on the fair sites we can expect a variable number of oak stems. After selection cutting, we get beech and sweet birch on both sites with sugar maple predominant on the excellent site and red maple better represented on the fair site. When group selection or patch cutting is the reproduction method, and where the objective is a good species mix including some intolerants, results of research suggest that openings should be at least ½ acre and preferably 1 acre. Some factors other than site quality and cutting practice that affect the nature of regeneration are: species composition of the overstory, season of cutting, density of low vegetation, presence of grapevines, and damage by spring frosts.

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INTRODUCTION

THIS IS A REPORT of results from research and observations made mostly on the Fernow Experimental Forest near Parsons in northern West Virginia. Many of the data were generated by long-range research—in some instances as long as 20 years. Where appropriate, data from other areas are used to expand or substantiate results from Fernow studies. In the main, this is a summary and integration of information already published piecemeal in a number of other sources.

In evaluating the information presented here, the reader should keep in mind that deer browsing on the Fernow or in most of West Virginia is not a serious deterrent to obtaining satisfactory reproduction, as it is in many hardwood forest areas. On the Fernow, only about 3 to 4 percent of the woody stems are browsed each year; and the deer herd probably does not exceed 15 animals to the square mile (*Cromer and Smith* 1968). Moreover, because of the dispersion of cutting operations, deer browsing is not concentrated.

DESCRIPTION OF THE FERNOW EXPERIMENTAL FOREST

The Fernow Experimental Forest, a 3,640-acre tract on the Monongahela National Forest, is an outdoor laboratory for studies in managing mountainous forest land. The forest stands here are second-growth hardwoods dating from around 1905, when heavy cuttings were made, with a varying admixture of old-growth stems. In topography, history of cutting, climate, and variety of species, the Fernow Forest is representative of much of the timberland in West Virginia and adjacent states.

Almost all Fernow soils are well-drained, medium-textured loams and silt loams. Most are derived from sandstone and shale, but some excellent sites are underlain by limestone. Average soil depth is about 3 feet. Based on site index, almost all areas on the Fernow can be rated as fair, good, or excellent. These designations correspond to oak site indexes 60, 70, and 80 feet plus.

In this hardwood forest, upland oaks are the most common species group. Northern red oak, which is found on all sites, is most abundant. Chestnut oak and white oak are the next most abundant oaks. These two species, although seldom found on the excellent sites, are more common than red oak on the fair sites. Scarlet and some black oak can also be found on fair sites.

Sugar maples are numerous on all but the fair sites, and beech covers the site range but is most frequent on the good sites. Yellow-poplar makes up a large part of excellent and good site stands, along with black cherry, white ash, hickory, and basswood. Scattered trees found in mixture on the better sites include yellow birch, cucumbertree, butternut, and elm.

Red maple, black locust, sweet birch, and—to a lesser extent—Fraser magnolia are consistent but generally minor components of the forest on all sites. However, these species are more common on the good and fair sites. Black gum, sassafras, and sourwood are fair-site trees of little commercial importance.

Among the scrubby tree species are flowering dogwood, pin cherry, striped maple, eastern hophornbeam, and downy serviceberry.

GENERAL CONSIDERATIONS

Most of the study results summarized here were obtained on areas that ranged in size from 2 to 80 acres. The major variables whose relationships to reproduction are reported are site quality and cutting practice.

Site quality was expressed for each area on the basis of average oak site index *(Schnur 1937)* taken from grids of site-measurement points. Although site quality is a continuous variable, it is not subject to precise measurement; and it is usually expressed for convenience as a discrete variable (generally by 10-foot site-index classes), thus weakening the true expression of its real relationship to reproduction.

Cutting practices were expressed in the context of harvesting systems such as clearcutting, individual-tree selection cutting, and diameter-limit cutting.

In Appalacian hardwood stands, the quality of the site is strongly expressed in the species that predominate in stands originating from the same type of cutting. For example, yellow-poplar is abundant after clearcutting on excellent sites, but it is rarely found on poor sites. And chestnut oak, while abundant on poor and fair sites, is sparse on excellent sites. It is generally considered that the more demanding species in terms of moisture and nutrients are better competitors on good sites but compete less successfully with the less-demanding species on sites of low moisture or nutrient status.

The influence of cutting practice is strongly expressed through its effect on the amount of light that reaches the forest floor and the understory vegetation. Because different species of trees react differently to different light intensities, the degree of overhead canopy removal has a strong effect on the species that germinate, develop, and grow. The key to evaluating light effects is the inherent shade tolerance of the species involved. The term as used here refers to the ability of the plant to survive under deep shade. As examples of different species tolerance, sugar maple is considered to be very tolerant, and black locust is rated as very intolerant. The tolerance of a given species is known to vary. Baker *(1950)* said that young trees are more tolerant than old trees; trees growing on moist, rich soils seem to be more tolerant than the average of the species; and tolerance seems to be greater in the southern part of the range of a tree.

A number of other variables whose influences have only weakly or indirectly been measured—if measured at all—also affect the establishment and development of reproduction, and some of these are discussed.

THE NATURE OF REPRODUCTION

What is the Nature of Advance Reproduction Before Cutting?

Because advance reproduction may have the potential to form a large part of the new stand after cutting, it is important that we have good information about it. Depending on the objectives of management and on the characteristics of this advance reproduction, we may elect to rely on it for the next crop, or we may decide to destroy all or selected components of it so that more desirable stems may take its place.

For over 20 years, we have been examining advance reproduction under undisturbed middle-aged hardwood stands on excellent, good, and fair sites on the Fernow Experimental Forest. In addition, we made a reproduction survey in conjunction with an oak site study, which covered undisturbed sawtimber stands in north-central West Virginia and western Maryland *(Weitzman and Trimble 1957)*.

Abundance and Distribution

Before cutting, all previously unmanaged stands on the Fernow Experimental Forest contained advance reproduction (tables 1 and 2). Considerable variation existed between stands in number of both large (1.0 inch to 5.0 inch dbh) and small (1 foot tall to 1.0 inch dbh) reproduction stems. Tight uniform stands had sparse reproduction, but stands

Table 1.—*Reproduction before logging—commercial species*
[From Trimble and Hart 1961]

Site quality	Original[a] basal area per acre	Area[b]	Stems per acre (average)	Mil-acres stocked	Five most abundant species by percent of total stems: 1	2	3	4	5
	Sq. ft.	*Acres*	*No.*	*Pct.*					
					SMALL REPRODUCTION[c]				
Excellent	126	143	1,300	59	Sugar maple 42%	Beech 32%	Sassafras 8%	Red maple 4%	E. hophornbeam 3%
Good	109	317	2,100	72	Sugar maple 52%	Beech 25%	Sassafras 8%	Hickory 4%	Red maple 3%
Fair	117	88	3,400	79	Sassafras 33%	Chestnut oak 19%	Sugar maple 14%	Red oak 9%	Red maple 8%
					LARGE REPRODUCTION[d]				
Excellent	126	143	410	—	Sugar maple 31%	Beech 28%	Sweet birch 13%	Red maple 10%	White ash 4%
Good	109	317	410	—	Sugar maple 40%	Beech 21%	Sweet birch 12%	Red maple 7%	Red oak 4%
Fair	117	88	430	—	Red maple 26%	Sugar maple 12%	Red oak 11%	Beech 9%	Chestnut oak 9%

[a]In trees over 5.0 inches dbh.
[b]These are total acreage figures for the respective categories. Each is a summation of several cutting areas.
[c]Stems ranging from 1 foot tall to 1.0 inch dbh, measured on milacre plots.
[d]Stems ranging from 1.0 to 5.0 inches dbh, measured on 1/100-acre plots.

Table 2.—*Reproduction before logging—commercial species*
[1972 data]

Site quality	Original[a] basal area per acre	Area[b]	Stems per acre (average)	Mil-acres stocked	Five most abundant species by percent of total stems: 1	2	3	4	5
	Sq. ft.	*Acres*	*No.*	*Pct.*					
					SMALL REPRODUCTION[c]				
Excellent	141	35	1,600	38	Sugar maple 69%	E. hophornbeam 10%	Beech 9%	Basswood 6%	Fraser magnolia 3%
Good	112	34	4,000	74	Sugar maple 67%	White ash 7%	Hickory 5%	Red maple 4%	Red oak 3%
Fair	107	29	2,100	85	Sassafras 34%	Chestnut oak 20%	Red maple 14%	Red oak 9%	Sugar maple 6%
					LARGE PRODUCTION[d]				
Excellent	141	35	148	—	Sugar maple 69%	Beech 18%	E. hophornbeam 7%	Red maple 3%	Basswood 2%
Good	112	34	307	—	Sugar maple 54%	Red maple 17%	Hickory 6%	Beech 3%+	White oak Red oak Each 3%−
Fair	107	29	333	—	Red maple 34%	Sourwood 13%	Sugar maple 9%	Sweet birch 8%	Beech 7%

[a]In trees over 5.0 inches dbh.
[b]These are total acreage figures for the respective categories. Each is a summation of several cutting areas.
[c]Stems ranging from 1 foot tall to 1.0 inch dbh, measured on milacre plots.
[d]Stems ranging from 1.0 to 5.0 inches dbh, measured on 1/100-acre plots.

whose canopies were broken up by heavy losses of the chestnut component or older residual trees had more reproduction. This relationship conforms to the findings of Bowersox and Ward *(1972)* who, on the basis of a study on intermediate sites in Pennsylvania, concluded that basal area density was negatively correlated with the development of acceptable advance reproduction and that stand age was positively correlated.

Small stems were considerably more numerous than large stems; in most stands several thousand small stems per acre contrasted to several hundred large stems per acre.

In general, an inverse relationship seemed to exist between the abundance of reproduction and site quality. This can probably be attributed to lower overstory densities on the poorer sites.

The percentage of sampled milacres that were stocked with at least one stem of commercial species was used as a measure of distribution of stocking. Distribution was measured only for the small reproduction class. As with abundance, it was better on sites of lower quality. On the excellent sites, average milacre stocking (tables 1 and 2) was 38 to 59 percent; on the good sites, it was 72 to 74 percent; and on the fair sites, it was 79 to 85 percent.

Species Composition

Most of the reproduction in both small and large classes, consisted of species that rated very tolerant and tolerant (table 3): sugar maple, beech, eastern hophornbeam, and red maple. Some species, particularly on the fair

Table 3.—*Tolerance ratings*[a]

Species	Tolerance rating				
	Very tolerant	Tolerant	Intermediate	Intolerant	Very intolerant
Eastern hophornbeam	X				
American beech	X				
Sugar maple	X				
Flowering dogwood	X				
Red maple		X			
Basswood		X			
Black gum		X			
Sweet birch		X[b]			
Fraser magnolia			X[d]		
Cucumbertree			X[d]		
White ash			X		
Basswood			X[b]		
Black gum			X[b]		
Yellow birch			X		
Sweet birch			X		
White oak			X		
Northern red oak			X		
Black oak			X		
Chestnut oak			X[c]		
Slippery elm			X[b]		
Hickories			X[b]		
Downy serviceberry			X[b]		
Sourwood			X[b]		
Scarlet oak				X[c]	
Butternut				X	
Hickories				X	
Yellow-poplar				X	
Sassafras				X[d]	
Black cherry				X	
Bigtooth aspen					X
Black locust					X
Pin cherry					X[b]

[a]From Baker *(1950)* unless otherwise noted.
[b]Local observation.
[c]Silvics of Forest Trees of the United States *(USDA 1965)*.
[d]Great uncertainty *(from Baker)*.

sites, rated borderline between tolerant and intermediate or rated intermediate: basswood, sweet birch, hickory, white ash, chestnut oak, red oak, and Fraser magnolia. One species, sassafras, a rated intolerant that is quite tolerant when young, was plentiful in the smaller size classes, but died out before it reached an inch dbh.

Under a closed canopy, most of the stems that reach large reproduction size on the excellent and good sites are of the very tolerant and tolerant species (tables 1 and 2). As site quality declines, more species of intermediate tolerance, most important the oaks, survive to grow beyond the 1.0-inch dbh threshold.

This relationship confirms the findings of Weitzman and Trimble *(1957)* in a survey of well-stocked stands containing a minimum of 32 percent of oaks in the overstory. They found that natural oak reproduction, like the distribution of oak trees, is more prevalent on the medium to poor sites. This provides a clue to the sites on which oak may be able to maintain itself. In the stands they sampled, oak formed a decreasing proportion of the total reproduction as site quality improved. At about site index 65, oak reproduction dropped from first place. On site index 80, only 3 percent of the total established reproduction was oak.

Weitzman and Trimble *(1957)* reported that:

- At site index 60, 26 percent of established reproduction was oak and at site index 40, the percent rose to 47.

- On better sites, competition from faster-growing or more tolerant species makes conditons less conducive to the establishment of the oaks.

- A breakdown of oak reproduction by species . . . indicates that some oak reproduction occurs over a wide range of site quality; with red oak absent on the areas of lowest site index (40) and scarlet oak absent from the better sites (site index 70 and 80).

How is the New Stand that Follows Cutting Related to Advance Reproduction?

After Partial Cutting

Advance reproduction under unmanaged sawtimber stands is composed largely of tolerant species, particularly on the better sites. These species will germinate, hang on, and then grow when released. After selection cutting, many stems of sugar maple, red maple, and beech will develop into good candidates for crop trees *(Trimble 1965 and 1968)*.

On lower-quality sites, which have more open canopies, some stems of intermediates, such as most of the oaks and sweet birch, will persist for years; and a few of them may develop into merchantable trees after heavy partial cutting.

After Clearcutting

Little work has been done to define the type of advance reproduction that survives clearcutting and develops to form a portion of the new stand. We know that many larger advance reproduction stems either survive the cutting and grow, or, if broken off, produce sprouts that develop and grow. In oak, at least, these sprouts grow much faster than comparable undamaged reproduction *(Sander 1966)*. About two-thirds of large advance reproduction stems are broken off in clearcutting *(Trimble and Rosier 1972)*.

We know from observations that an undetermined number of advance reproduction stems die in the first few years after sudden exposure. We know that some larger advance reproduction stems enter the dominant crown class of the new stand—although too high a proportion of them are branched and limby *(Trimble 1972)*. We suspect—based on considerable observation—that small stems (less than 2 to 4 feet tall) of suppressed reproduction of oak and sugar maple—and probably other species—cannot compete successfully with the flush of new plant growth that follows clearcutting.

From work done in the Central States, we know that on oak sites, the new stand will contain oak in proportion to the advance oak reproduction on the area before the harvest cut *(Clark and Watt 1971)*. And we know, based on work done by Sander *(1972)*, also in the Central States, that the bulk of oak reproduction that makes acceptable growth after clearcutting comes from advance stems over 4.5 feet tall. On the other hand, some rated intolerants, such as black cherry and sassafras, are quite tolerant when young; and after clearcutting, small stems of these species can compete successfully for a place in the new stand.

How Does Degree of Overstory Removal Affect Reproduction?

Species by Site Quality

The degree of overstory removal has a definite effect on the species composition of the new stand. And this effect is variable according to site quality. Moreover, the numerical order of species will change with time from cutting.

In a publication on diameter-limit cutting *(Trimble 1971)*, a summation was made from data from a number of areas on the effect of degree of canopy removal on tolerant versus intolerant reproduction. The two extremes of canopy removal were clearcutting and selection cutting; diameter-limit cutting, in amount of residual basal area, fell between them but nearer to selection cutting than to clearcutting. The heavier the removal, the higher the proportion of reproduction that is of intolerant species. This is illustrated by the 7- to 20-year observations (table 4) on large reproduction. Intolerants made up 37 percent of these stems after clearcutting, 18 percent after diameter-limit cutting, and only 5 percent after selection cutting. Reproduction of tolerant species was in a reverse order: 27 percent for clearcutting, 62 percent for diameter-limit, and 78 percent for selection cutting.

Under selection cutting, in the immediate years after a harvest, there is a tendency for the seeds of some intolerant species to germinate and for the seedlings to grow for a while but then to die out. The life-long intolerants, like yellow-poplar, die soon; those species that are fairly tolerant when young, such as white ash and black cherry, persist longer but as they lose their early tolerance with increasing age and as the upper canopy closes, they too succumb. Thus it is misleading in predicting future stand composition to weigh too heavily reproduction counts of small stems.

The long-range reproduction trend is clear following light to medium selection cutting: maple, beech, hophornbeam, and sweet birch will predominate in the new stand *(Trimble 1965 and 1970)*. Sugar maple and beech will probably be most numerous on the excellent and good sites, and red maple and beech will dominate the fair sites. Sweet birch will be well represented on all areas.

From data for clearcut compartments on the good and excellent sites, we can expect to get a good representation of black cherry and yellow-poplar seedlings if viable seed is present. The actual proportions depend to a large extent on the amount of competitive advance reproduction—which is composed largely of

Table 4.—*Effect of cutting practice on the proportions of tolerant versus intolerant reproduction*

Type of cutting	No. of areas	Total acreage	Site index (for oak)		Number of 1- to 5-inch stems in—		Stump sprouts as a proportion of total reproduction
			Range	Average	Intolerant species[a]	Tolerant species[b]	
	No.	*Acres*	*Ft.*	*Ft.*	*Weighted pct.*	*Weighted pct.*	*Pct.*
Clearcut	9	110	61-77	70	37	27	58
Diameter-limit	5	151	59-75	69	18	62	18
Selection	7	198	59-82	71	5	78	18

[a]Includes the following very intolerant, intolerant, and intermediate species: red oak, yellow-poplar, black cherry, white ash, black locust, sassafras.
[b]Includes the following very tolerant and tolerant species: beech, sugar maple, red maple.

Table 5.—*Ranking of 1- to 5-inch stems of reproduction 7 years after clearcutting five most numerous species.*
[Numbers in parentheses are numbers of stems per acre]

Ranking	Excellent site (S.I. 80 for oak)	Good site (S.I. 70 for oak)	Fair site (S.I. 60 for oak)
1	Sugar maple (91)	Black locust (124)	Red maple (186)
2	Basswood (49)	Sugar maple (111)	Sassafras (176)
3	Eastern hophornbeam (43)	Red maple (107)	Chestnut oak (103)
4	Black locust (38)	Sassafras (97)	Red oak (84)
5	Black cherry (27)	Yellow-poplar (75)	Sourwood (49)

tolerant species—and on the age of the stand when cut. Clearcut young stands produce a lot of fast-growing, space-occupying stump sprouts.

On fair sites, yellow-poplar and black cherry appear infrequently; the most abundant intolerant is sassafras. We can usually expect a lot of red maple and oak stump sprouts. And if advance reproduction of oak is present—which it usually is—we can expect a good representation of oak seedlings and, more likely, seedling sprouts.

The reproduction tally on these clearcut areas indicates that species composition was strongly influenced by site quality, but a wide variety of species of all tolerance classes was represented on all sites and all study areas—a greater variety than found under selection cutting where a few tolerant species predominate. On two excellent sites, each about 35 acres, one of which had been cut three times by the selection system and the other had been harvested 12 years previously by clearcutting, tallies were made of 1 to 5 inch stems.

Twenty commercial species were tallied on the clearcut areas and 17 on the selection cut area. However, when the number of species containing 5 percent or more of the total number of stems were compared, the clearcut area had 7; but the selection cut area had only 3.

At 7 years on the clearcut compartment, the larger free-to-grow stems (table 5) were composed mostly of species that had at least one of the following characteristics: (1) great sprouting vigor (red maple, oak, and basswood); (2) shade tolerance, permitting a start under the old stand (sugar maple); (3) unusually fast early growth (black cherry, eastern hophornbeam, and sweet birch); and (4) a tendency to root sucker (black locust and sassafras).

Under a clearcutting system, the proportional relationship between tolerants and intolerants in the new stand is far from consistent because of the presence in varying numbers of tolerant advance reproduction and of stump sprouts, which together can make up an appreciable part of new stands after clearcutting.

On good and excellent sites under intensive even-aged management, advance reproduction will create something of a problem. Present indications are that a thick understory of tolerant species will develop in such stands as a result of thinnings and that this situation will have to be countered if a new stand of intolerants is sought after the clearcut harvest. If this advance reproduction is not over 15 feet tall, it can be controlled by an understory foliar spray a couple of years before the harvest cut *(Smith and Trimble 1970)*.

In sites of lower quality, where the desired species will probably be oak, the effect of properly designed late thinnings may be to encourage an understory of advanced oak reproduction and thus favorably influence the composition of the next stand.

Table 6.—*Ranking of 1- to 5-inch stems of reproduction 12 years after clearcutting, 5 most numerous species.*
[Numbers in parentheses are numbers of stems per acre]

Ranking	Excellent site (S.I. 80 for oak)
1	Sweet birch (550)
2	Sugar maple (246)
3	Yellow-poplar (221)
4	Black cherry (145)
5	Eastern hophornbeam (114)

The change in species composition with time from cutting cannot be defined accurately until more time has passed. Some switching in numerical order may take place after clearcutting, which is illustrated by a comparison of 12-year data (table 6) to 7-year data (table 5) for the excellent site clearcuts (data are not yet available for the good and fair sites). The big difference is the increasing proportion of sweet birch and yellow-poplar in the large reproduction class at 12 years as compared to 7 years.

We have good information on the growth and development of tolerant reproduction (sugar maple) under selection cutting *(Trimble 1965 and 1968)*, but comparable information following clearcutting is lacking. Several studies now under way should tell us how different species grow and develop over time after clearcutting on sites of different quality levels. When this information becomes available—in about 5 years—we will be better able to predict regeneration development.

Abundance and Distribution

On the Fernow Experimental Forest, clearcutting has resulted always in an abundant, well distributed stand of reproduction. This has been true on all sites. Species composition has sometimes left something to be desired, but abundance and distribution can be rated as satisfactory, as shown by tables 7 and 8 *(Trimble 1972, Trimble and Hart 1961)*. Selection cutting, too, has produced a satisfactory number and distribution of understory stems (table 8), although they are composed mostly of a few tolerant species.

The Fernow data indicate that 7 to 10 years after cutting we can expect 5,000 to 10,000 stems of small reproduction and 300 to 800 stems of large reproduction per acre of commercial species under all types of commercial harvesting, with the actual number of stems roughly proportional to the degree of canopy removal. We can expect faster growth rates after heavy canopy removal; this is illustrated by the greater numbers of large reproduction after clearcutting (table 8).

We can expect good distribution of reproduction; more than 85 percent of the milacres should be stocked with small reproduction of commercial species under both selection cutting and clearcutting. For large reproduction, we found that 80 percent or more of all 1/100-acre plots were stocked with commercial species.

Table 7.—*Reproduction of commercial species after 7 growing seasons from clearcutting*

Compartment number	Small reproduction (1 foot tall to 1 inch dbh)		Large reproduction (1 to 5 inches dbh)	
	Total stems per acre	Proportion of 1/1000-acre plots stocked	Total stems per acre	Proportion of 1/100-acre plots stocked
	No.	*Pct.*	*No.*	*Pct.*
	EXCELLENT SITE			
32	7,400	96	420	80
33	15,755	98	378	84
43	9,067	93	289	91
Average	10,741	96	362	85
	GOOD SITE			
36	6,223	91	926	96
37	4,333	91	790	100
39	7,400	96	907	100
Average	5,985	93	874	99
	FAIR SITE			
34	8,955	98	579	89
35	8,156	96	898	100
38	7,434	98	844	100
Average	8,181	97	774	96

Table 8.—*Commercial species: reproduction 5 and 10 years after logging in a well-stocked sawtimber stand on an excellent site, by intensity of cut.*

Intensity of cut	Basal area cut	Original basal area per acre[a]	Small reproduction Per acre	Small reproduction Distribution[b]	Large reproduction Per acre
	Pct.	*Sq. ft.*	*No.*	*Pct.*	*No.*
5-YEAR MEASUREMENTS					
Clearcut	87	103.0	10,130	100	450
Diameter-limit	58	98.2	10,060	81	340
Extensive selection cut	48	103.0	8,130	87	290
Intensive selection cut	46	105.8	7,500	88	210
10-YEAR MEASUREMENTS					
Clearcut	—	—	5,820	92	760
Diameter-limit	—	—	5,850	88	490
Extensive selection cut	—	—	9,690	100	500
Intensive selection cut	—	—	8,330	98	330
Check plot	0	124.1	880[c]	48	410

[a]In trees over 5.0 inches dbh includes live culls.
[b]Percentage of milacres stocked with at least one stem.
[c]No natural openings in this small plot.

No conclusive relationships were apparent between site quality and abundance or distribution of reproduction.

What Are Some Observed Effects of Other Variables on Reproduction?

Size of Opening

The effects of size of opening on reproduction have been reported by Smith *(1963)*, Minckler and Woerheide *(1965)*, and Sander and Clark *(1971)*. Trimble and Tryon *(1969)* reported on a study made on the Fernow Experimental Forest.

The objectives of these studies varied somewhat in detail; but in general, they were aimed at determining the relationship of size of opening and height of border trees to the abundance and height growth of reproduction, giving special attention to intolerant species.

Smith *(1963)* studied the height growth of 3-year-old yellow-poplar seedlings in openings in a hardwood stand on a high-quality site in Tennessee. Growth in portions of openings 1/10 acre, ¼ acre, and ½ acre in size was reported. In the two smallest plots, the seedlings were tallest in the center; and height decreased toward the edge of the opening, showing a definite edge effect. In the ½-acre plot, the height was poorest at the border, showing a definite edge effect. Also height growth was somewhat reduced at the center.

Minckler and Woerheide *(1965)* reported on growth of naturally established hardwoods in openings having diameters of ¼, ½, ¾, 1, 1½, and 2 times the height of surrounding trees. Fewer tall stems occurred in the two smallest openings than in the larger ones, and no difference was evident in height growth in openings larger than the ¾ size opening. Also, trees in the central and northern portions were taller than in the rest of the opening.

Sander and Clark *(1971)*, studying openings from ⅛ acre to 5 acres in size in Ohio, found that after 2 years all had enough stems of timber species to form well-stocked stands.

Tryon and Trimble *(1969)*, working in middle-aged hardwood stands, found that the surrounding stand had little or no effect on height growth of reproduction in openings until the plots were as small as ¼ acre. In plots larger than ¼ acre, the border zone of shorter trees was confined largely to the area under the branches of the overstory trees on the edge of the plot. This held true even for intolerant species such as yellow-poplar. The openings had been cut 14 years when the reproduction was measured. The opening dimensions were measured from the trunks—not the crowns—of border trees.

It would seem that where a good species mix at stand maturity is the objective, including some desirable intolerants, openings should be at least ½ acre in size and preferably 1 acre.

These suggestions apply to openings that are more or less round; they would not be valid for narrow strips of the same open area.

Species Composition of the Overstory

The relationship between the species composition of the overstory and the species composition of the reproduction is a tangled skein; but it does seem to be determined in part by some general principles, which operate subject to many modifying influences.

Whether or not a strong relationship exists between the species composition of the old stand and that of the new stand seems to depend largely on whether or not the method of harvest cutting that is used to establish the new stand was the method used to establish the overstory. Following selection cutting with selection cutting can be expected to reproduce a new species mix that is essentially similar to the old stand. Following clearcutting with clearcutting can be expected to do the same thing. However, following clearcutting with selection cutting and following selection cutting with clearcutting can be expected to produce stands composed of species mixes that differ considerably from the old overstories.

Although we cannot substantiate all of the above relationships with Fernow data, we do have considerable information bearing on two of the situations: following clearcutting with selection cutting, and following clearcutting with clearcutting.

In the first instance, selection cutting in areas previously clearcut and occupied by sawtimber stands composed in large part of intolerants is, without exception, reproducing new stands composed almost entirely of tolerants. This is true on both good and better sites *(Trimble 1965)* and on fair sites.

On nine even-aged compartments (covering a site range from 60 to 80 oak site index) that were clearcut, we compared species composition of the 7-year reproduction to the species composition of the old stand *(Trimble 1972)*. With some exceptions, the predominant reproduction was correlated to the most numerous species in the old stand, although the numerical order was somewhat different.

An outstanding exception concerns red oak on excellent sites. Red oak was one of the most numerous sawtimber-size trees in the old stand, but constituted only a very small proportion of the reproduction. Several species were more prominent in the new stand than in the old. These were sweet birch, sassafras, hophornbeam, black locust, and yellow-poplar. With the exception of yellow-poplar, these species are relatively short-lived, and most of them can be expected to drop out before rotation age. Although they occurred infrequently in the old stand when it was cut, these same short-lived species may have been numerous when the stand was 7 years old.

We feel that leaving seed trees has little effect on either the abundance or species composition of the new even-aged stand. Many of the stems present in the new stand are advance reproduction under the old stand. Many new stems are stump sprouts. No doubt many new seedlings come from dormant seed in the duff (yellow-poplar—*Sander and Clark 1971;* black cherry—*Wendel 1972;* white ash—*Clark 1962, Leak 1963)*, and many result from the current year's seed crop at the time the stands are harvested.

Season of Cutting

Investigating and reporting the effects of season of logging on the establishment and growth of reproduction has been limited largely to one species—yellow-poplar. From a study made on the Fernow Experimental Forest, Trimble and Tryon *(1969)* concluded:

> The results of this study indicate that survival and height growth of yellow-poplar seedlings, in competition with other vegetation that develops simultaneously in newly clearcut areas, are dependent on time of germination. A high proportion of those seedlings that appeared before mid-June competed well with the flush of new vegetation. Most seedlings that came up after 1 July lost out in the race for growing space.

The practical implication of these findings is that the old stand should be logged between the end of the growing season (preferably after yellow-poplar seeds ripen) and 1 May of the following year to favor yellow-poplar reproduction. This would promote maximum germination and some development of yellow-poplar seedlings early in the growing season before strong competition from other plants develops. Logging in the spring and early summer results in late summer seedlings, which do not survive well; and competing vegetation is able to get a head start on seedlings originating the following year.

This restriction on time of logging becomes less important in areas where the yellow-poplar seed source is extremely plentiful and where site conditions are ideal for this species. However, where the situation is not so favorable for yellow-poplar, control of time of logging might provide the needed advantage.

Sander and Clark *(1971)* came to about the same conclusions from yellow-poplar reproduction studies made in the Central States.

Considering the differences among forest species in seeding characteristics and early development, it is likely that future studies will turn up important effects of season of logging on reproduction establishment for other species.

Density of Low Vegetation

The effect of competition from low vegetation on tree reproduction has not been measured on the Fernow Experimental Forest; but, based on observations, some generalizations are possible.

Several charactertistic types of shrubby and herbaceous cover hinder the establishment and development of reproduction under both selection cutting and clearcutting. On good and better sites, the tolerant, long-lived rhododendron growing in dense thickets hinders the establishment of seedling reproduction unless its density is reduced through cutting or chemical treatment. It resprouts after cutting; but regrowth is so slow that seedlings can get started and grow beyond its shade, at least after clearcutting. Mountain laurel, found on the poorer sites, has somewhat the same effect as rhododendron; but it is less abundant. In moist swales under sawtimber stands on high quality sites, a dense cover of such herbaceous growth as nettles, touch-me-not, and black snakeroot often carpets the ground. This heavy herbaceous layer apparently retards the early development of reproduction—especially such intolerants as yellow-poplar. In the situations where it is profuse, this type of cover seems to persist indefinitely after selection cutting and for a number of years after clearcutting.

Tyron and Carvell *(personal communication March 1973)* have noted that in some areas of the central Appalachians, patches of fern growing under tree canopies apparently prevents the establishment of even the most tolerant reproduction.

After clearcutting, but not selection cutting, a heavy cover of blackberry plants develops on all sites. Although seedlings do come through this blanket, it is our opinion that it delays their height growth from the second to about the fifth year and that its shade discriminates against the intolerant species. Moreover, because of its persistent foliage and weak stem, it flattens out under snowfall, which bends over, breaks, and deforms many seedlings in the process.

Grapevines

Wild grapevines are a threat to young hardwood stands after clearcutting on good and excellent sites in many areas of the central Appalachians. They are also a threat following any type of partial cutting, such as group selection, that creates large holes in the canopy. Because this long-lived vigorous vine is fairly shade intolerant, it does not pose as serious a threat under an individual tree selection system. In selection cutting, it can be controlled by severing the stems. Results of studies currently under way on the Fernow Experimental Forest indicate that this vine does not occur frequently on fair and poorer sites.

Grapevines reproduce by seed and by sprouting. Seeds can lie dormant many years in the forest floor and then germinate. It is the sprouts that are the real problem. Sprouts from grapevine stumps cut off at the time of clearcut harvest grow 5 to 15 feet the first year, mounting quickly into any young tree in the vicinity.

Grapevines damage young trees by breaking limbs and tops, twisting and bending over the main stem, augmenting ice and snow damage, and submerging the tree foliage in large grape leaves, thus interfering with photosynthesis. In some young even-aged hardwood stands, grapevines are adversely affecting a majority of the stems in the stand.

Satisfactory measures for controlling grapevines have not as yet been worked out for even-aged systems, but several studies are under way.

Susceptibility to Spring Frosts

Differences in susceptibility among species to damage by spring frosts may have an effect on species composition of stands in certain areas. This phenomenon has been investigated and reported on by Tryon and True *(1964)*. Some of their work was done on the Fernow Experimental Forest. With permission, their publication is quoted in the following:

> Frosts occur frequently in the Appalachian region, and spring frosts which occur after growth has started are especially damaging to forest trees. Such frosts deform stems, reduce growth rate, and may kill the smaller reproduction. Although frost injury is widespread and recurs each year, the damage is often unnoticed or is observed months later without its true cause being recognized.
>
> The Appalachian region's irregular topography provides many pockets for the accumulation of cold, heavy air. Such conditions are ideal for heavy spring frosts. Many of the susceptible species . . . or . . . such as yellow-poplar, frequent rich cove and bottomland soils where these frosts are common, severe, and very damaging.
>
> Trees of all sizes may be damaged, but the reproduction and saplings are usually most severely injured. The period of establishment is therefore critical.

The investigators prepared a frost-susceptibility rating tabulation based on frost damage during the springs of 1961 and 1963. They examined tree species in 12 localities in northern and east-central West Virginia and rated the degree of damage by late frosts to the newly formed leaves and shoots:

Highly susceptible[a]	*Moderately susceptible*	*Less susceptible*	*Least susceptible*
Sassafras	Fraser magnolia	Smooth alder	Slippery elm[b]
American sycamore	White ash[c]	Serviceberry	Willow[b]
Black locust	American chestnut	Witch-hazel	Flowering dogwood[b]
American beech	White oak	Striped maple	Hawthorn
Cucumbertree	Scarlet oak	Fire cherry	American basswood
Yellow-poplar	Chestnut oak	Red maple	Sugar maple
Hickory spp.	Northern red oak		Black cherry
Black walnut	Yellow birch[c]		
Butternut[a]	Black birch[b]		

[a]The most susceptible species are at the top, and the least susceptible are at the bottom within each susceptibility class.
[b]Based on few observations.
[c]Considerable variation in degree of damage.

Again quoting Tryon and True:

> It is evident that considerable variation exists in susceptibility to late frosts among these hardwoods, including the more valuable species. Within the limits of the study, black cherry was definitely most resistant to late frost damage, and was followed by sugar maple and American basswood which were slightly less resistant. Yellow-poplar, black walnut, and American beech were among the species most susceptible to frost damage, with the oaks being slightly less susceptible. Considerable tree-to-tree variation in frost susceptibility was found for white ash and yellow birch.

The investigators recommend that when stands are being regenerated in locations where frost pockets occur, resistant species should be favored. They recommend also that, in such areas, regeneration by sprouts be discouraged because their observations indicated that young sprouts are more heavily damaged by frosts than are seedlings.

SUMMARY AND DISCUSSION

Reproduction trends were related in this report primarily to site quality and to type of timber harvest—selection cutting versus clearcutting. But other factors affect reproduction, and some of these were discussed.

In general, advance reproduction composed mostly of the more tolerant species exists in fair numbers and is fairly well distributed under unmanaged sawtimber stands. Composition varies some with site quality, but on excellent, good, and fair sites, sugar maple, red maple, and beech are predominant, with oak often numerous on the fair sites.

Reproduction has been found satisfactory in numbers and distribution after both clearcutting and individual tree selection cutting, but the species composition differs greatly; tolerants predominate following selection cutting but generally a good representation of intolerants, as well as tolerants, can be expected after clearcutting—depending somewhat on the density of advance reproduction and the abundance of stump sprouts.

Site quality makes a difference in the species composition of reproduction after cutting, and the difference is greater for clearcutting than for selection cutting. After clearcutting on the excellent sites, we can expect a good representation of yellow-poplar and black cherry; and on the fair sites, we can expect a variable number of oak stems. After selection cutting, we get beech and sweet birch on both sites with sugar maple in the number one spot on the excellent site and red maple better represented on the fair site.

When group selection or patch cutting is the reproduction method and where the objective is a good species mix, including some intolerants, results of research suggest that openings should be at least ½ acre in size and preferably 1 acre.

A relationship usually exists between the species composition of the old stand and the reproduction where the cutting method is the same one as used in establishing the overstory. For example, stands established by clearcutting when clearcut again reproduce more or less the same species. However, when selection cutting follows clearcutting, a drastic change may take place in species composition; and such species as red oak, yellow-poplar, and black cherry may be replaced by the maples and beech.

Season of logging has some effect on the germination and development of yellow-poplar reproduction. There may be some advantage to logging between about 1 September and 1 May to favor this species.

Several characteristic types of low vegetation, such as rhododendron and blackberry thickets, retard the development of reproduction.

Wild grapevines pose a threat to young even-aged hardwood stands on the better sites. Following individual tree selection cutting and on sites of low quality, this vine is less of a problem.

What do the results of these reproduction studies mean in terms of forest practices? Do they indicate that we know enough to tailor our cutting methods by site class to get specific stand composition?

Within limits and subject to certain qualifications, we can predict and influence stand composition in most situations in the Central Appalachians. If we practice individual tree selection cutting on our better sites, we can expect to get stands composed largely of maples and beech. The two highly valued trees, yellow-poplar and black cherry, will be scarce indeed; a loss of timber value, esthetic qualities, and—in black cherry—a heavy blow to game. If we practice even-aged silviculture with clearcutting harvests, we will reproduce these two species and a great number of other species also, including the maples and beech. We will, in effect, retain the same kinds of forests on our high-site areas that are so universally admired today by sightseers and hunters.

Our oak stands on the lower quality sites are today also typically even-aged. These oak stands are not only valuable for wood products, but they are essential to such game species as squirrels and turkey. Under individual selection cutting, they will be succeeded by the more tolerant species such as red maple, beech, black gum, and sweet birch. The oaks are intermediate to intolerant; and although they will germinate and grow for a while in shade, they need canopy removal to develop.

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APPENDIX

Common and scientific names of species referred to in this study:

TREES

Alder, smooth	*Alnus serrulata* (Ait. Willd.)
Ash, white	*Fraxinus americana* L.
Aspen, bigtooth	*Populus grandidentata* Michx.
Basswood	*Tilia americana* L.
Beech, American	*Fagus grandifolia* Ehrh.
Birch, yellow	*Betula alleghaniensis* Britton
Birch, sweet (black)	*Betula lenta* L.
Butternut	*Juglans cinerea* L.
Chestnut, American	*Castanea dentata* (Marsh.) Borkh.
Cherry, black	*Prunus serotina* Ehrh.
Cherry, pin (fire)	*Prunus pensylvanica* L. f.
Cucumbertree	*Magnolia acuminata* L.
Dogwood, flowering	*Cornus florida* L.
Elm, slippery	*Ulmus rubra* Muhl.
Gum, black	*Nyssa sylvatica* Marsh.
Hickory	*Carya* spp.
Hophornbeam, eastern	*Ostrya virginiana* (Mill.) K. Koch
Locust, black	*Robinia pseudoacacia* L.
Magnolia, Fraser	*Magnolia fraseri* Walt.
Maple, red	*Acer rubrum* L.
Maple, striped	*Acer pensylvanicum* L.
Maple, sugar	*Acer saccharum* Marsh.
Oak, black	*Quercus velutina* Lam.
Oak, chestnut	*Quercus prinus* L.
Oak, northern red	*Quercus rubra* L.
Oak, scarlet	*Quercus coccinea* Muenchh.
Oak, white	*Quercus alba* L.
Rhododendron	*Rhododendron maximum* L.
Sassafras	*Sassafras albidum* (Nutt.) Nees.
Serviceberry, downy	*Amelanchier arborea* (Michx. f.) Fern.
Sourwood	*Oxydendrum arboreum* (L.) DC
Sycamore, American	*Platanus occidentalis* L.
Yellow-poplar	*Liriodendron tulipifera* L.
Walnut, black	*Juglans nigra* L.
Willow	*Salix* spp.

SHRUBS AND VINES

Blackberry	*Rubus* spp.
Black snakeroot	*Cimicifuga racemose* (L.) Nutt.
Grapevine	*Vitis* spp.
Hawthorn	*Crataegus* spp.
Mountain laurel	*Kalmia latifolia* L.
Nettles	*Laportea canadensis* (L.) Wedd.
Touch-me-not	*Impatiens* spp.
Witch hazel	*Hamamelis virginia* L.

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