Chapter 5
Structure and Species Composition of Upland Hardwood Communities After Regeneration Treatments Across Environmental Gradients

David L. Loftis, Callie J. Schweitzer, and Tara L. Keyser

Abstract Early successional habitats can be created with a broad array of silvicultural techniques that remove all or most canopy trees in one to several cuttings and small to large patch sizes. Composition and early structural development of the resulting vegetation can be variable. Arborescent species composition is a function of regeneration sources already present and those that arrive during or after the cutting. The suite of species available for regeneration of a site, large or small, is a cumulative effect of disturbances and varies across multiple environmental gradients that include moisture, elevation (temperature), and soil chemistry.

5.1 Introduction

Regeneration activities in managed forests create forest stages with characteristics of early successional habitats such as low dense vegetation and openness overhead (Greenberg et al., Chap. 1). Where management is used to achieve multiple objectives (e.g., wood products and both young, open habitats and older, closed-canopy habitats for a range of wildlife species), regenerated areas provide transient early successional habitats during the early years of stand development. Oliver and Larson (1990) proposed a classification of stages of stand development that applies well to arborescent

D.L. Loftis (✉) • T.L. Keyser
USDA Forest Service, Southern Research Station, Bent Creek Experimental Forest, 1577 Brevard Road, Asheville, NC 28806, USA
e-mail: davidloftis@bellsouth.net; tkeyser@fs.fed.us

C.J. Schweitzer
USDA Forest Service, Southern Research Station, Bent Creek Experimental Forest, P.O. Box 1568, Normal, AL 35762, USA
e-mail: cschweitzer@fs.fed.us

C.H. Greenberg et al. (eds.), *Sustaining Young Forest Communities*, Managing Forest Ecosystems 21, DOI 10.1007/978-94-007-1620-9_5,

vegetation development following regeneration cuts that remove all or most of the overstory in one cut or several cuts within a decade or two. The stand initiation stage is the period of the early growth of individuals that existed in the understory prior to cutting (advance reproduction), stump and root sprouts from harvested trees, and seedlings that become established after cutting. Within a few years, growth of regenerating individuals and expansion of their crowns results in canopy closure, after which establishment of new seedlings ceases and many stems in a subordinate crown position die. This process marks the beginning of the stem exclusion stage, and typically occurs at about 10 years after cutting in hardwood forests of the Central Hardwood Region (Johnson et al. 2009; Nyland 1996). The stem exclusion stage can last many years and is followed by the understory reinitiation stage in which herbaceous, shrubs and tree regeneration become more prominent in the understory. The old-growth or complex stage (Johnson et al. 2009) follows, characterized by interspersion of the closed canopy environment, with canopy gaps created by overstory mortality. Where gaps are large enough to prevent crown closure by lateral crown growth of surrounding trees, the stand initiation stage may be triggered at the gap scale (Peet 1992). In hardwood forests of the Central Hardwood Region, early succesional habitats are provided in the stand initiation stage and the first few years of the stem exclusion stage, generally up to 15 years after the cutting that initiates regeneration.

5.2 Regeneration Methods

Tree harvests that replace an existing stand of trees with new age-classes (cohorts) are classified as regeneration methods. In the USA, these methods are usually classified by the number of cohorts created and maintained (even-aged, two-aged, and uneven-aged (3 or more)) and further distinguished by the timing and pattern of removal of the existing stand (SAF 1998). The following discussion deals with natural regeneration methods, or methods that rely on naturally occurring, rather than artificially-introduced regeneration sources.

5.2.1 The Clearcutting Method: Structure

Clearcutting is an even-aged method. The new cohort develops in the very open microenvironment created when all existing trees are cut. In the first 2–3 years after cutting, during the stand initiation stage, tens of thousands of stems per hectare become established from seedlings and saplings that existed on the site at the time of the cutting (i.e., advance reproduction), or from stump and root sprouts of harvested trees (Table 5.1). This response occurs over a wide geographic area, and, notably, over a broad range of site quality (as evaluated by the authors cited). As stands approach age 10, a distinct canopy begins to develop, and stands begin the transition to the stem exclusion stage. Stem density remains high as thousands of stems per

Table 5.1 Changes in stem density following clearcutting in upland hardwood forests of the Central Hardwood Region

Location	Years after harvest	Stems/ha	Size cut-off	Site index (m)[a]	Reference
Indiana	2	39,055	All	22.9–29.0	Sander and Clark (1971)
Kentucky	2	22,473	All	16.8–22.9	Sander and Clark (1971)
Ohio	2	55,217	All	16.8–22.9	Sander and Clark (1971)
Ohio	2	28,462	All	22.9–29.0	Merz and Boyce (1958)
Ohio	2	28,942	All	16.8–22.9	Merz and Boyce (1958)
North Carolina	2	45,851	All	27.4	Beck and Hooper (1986)
North Carolina	3	25,211	All	22.9	McGee (1967)
North Carolina	4	19,498	>1.4 m in height	27.4	Loftis (1978)
Kentucky	5	15,215	≥2 cm groundline diameter	Good	Arthur et al. (1997)
West Virginia	7	27,479	>0.3 m in height	24.4	Trimble (1973)
West Virginia	7	16,976	>0.3 m in height	21.3	Trimble (1973)
West Virginia	7	22,163	>0.3 m in height	18.3	Trimble (1973)
Alabama	8	24,245	>0.3 m in height	25.9	Schweitzer (*in prep.*)
Alabama	8	26,648	>0.3 m in height	18.3	Schweitzer (*in prep.*)
Ohio	10	5,519	>1.5 cm dbh	16.8–29.0	Sander and Clark (1971)
North Carolina	10	5,437	>1.4 m in height	27.4	Beck and Hooper (1986)
Kentucky	11	6,505	>2 cm dbh	Good	Arthur et al. (1997)
North Carolina	15	4,041	>1.4 m in height	27.4	Beck and Hooper (1986)

[a]Site index (SI) is the height (m) of a tree at 50 years of age and is used as an indicator of site quality

hectare compete for growing space and self-thinning begins. Again, at this age, there is no apparent relationship between stem density and site quality. Over the next few years, reduction in stand density through self-thinning and increasing canopy height (Beck and Hooper 1986) reduce the cover value for wildlife species such as Ruffed Grouse (*Bonasa umbellus*) (Dessecker and McAuley 2001).

5.2.2 The Shelterwood Method: Structure

In the shelterwood method, trees retained after an initial cut moderate the regeneration microenvironment. These overstory trees, or overwood, typically are removed in one or more removal cuts within a decade or two of the initial cut. In one variant of the shelterwood method, an overstory sparse enough to allow for the long term development of the new cohort is retained and results in a two-aged stand.

Shelterwood cuts can be separated into two structural and composition categories. In the first category, residual overstory density is low enough after the initial cut that regeneration density and species composition are similar to those after clearcutting (i.e., there is no differential species response to the environmental conditions created by the residual overstory density). In the second category environmental conditions created by a higher level of residual canopy density after the initial cut do result in differential species response of regeneration sources present at the time of the cut. Subsequent removal cuts in these shelterwoods will result in structural development similar to shelterwoods in the first category and to clearcuts, but with altered species composition due to the changes in the size structure and composition of the regeneration sources (see discussion of species composition below).

Regeneration development in the first category of shelterwood cuts and following the removal cuts in the second category of shelterwood cuts follows the same pattern as in clearcuts (Table 5.2). Very high initial stem densities diminish over time as the canopy of the new age-class closes. As a result, along with the early successional habitats provided by the substantial reduction in overstory trees, the shelterwood cut retains some remnant structure from the stand being harvested. It would be possible, for example, to harvest using a shelterwood method, providing both early successional habitats, and retention of some mature oak (*Quercus* spp.) trees to sustain some acorn production to benefit wildlife species that eat acorns (Greenberg et al., Chap. 8) that would not be possible with the clearcutting method. One might also retain trees that have cavities to benefit wildlife for either a few years in the case of conventional shelterwoods or for much longer periods of time in the case of two-aged stands.

5.2.3 Selection Methods: Structure

Uneven-aged methods create and maintain three or more cohorts using the single-tree and group selection methods. In the single-tree selection method, individual trees are removed periodically and more-or-less throughout the stand to provide

Table 5.2 Changes in stem density following the shelterwood method in upland hardwood forests of the Central Hardwood Region

Location	Years after cutting	Residual basal area (m^2/ha)	Stems ha^{-1}	Size cut-off	Oak site index (m)[a]	Citation
Indiana	2	10.1	54,276	All	22.9–29.0	Sander and Clark (1971)
Ohio	2	11.5	32,447	All	16.8–22.8	Sander and Clark (1971)
West Virginia	2	3.9	12,478[b]	0.3 m tall–2.3 cm dbh	21.3	Miller and Schuler (1995)
West Virginia	2	4.1	28,927[b]	0.3 m tall–2.3 cm dbh	21.3	Miller and Schuler (1995)
West Virginia	2	5.7	15,755[b]	0.3 m tall–2.3 cm dbh	24.4	Miller and Schuler (1995)
West Virginia	2	4.6	30,343[b]	0.3 m tall–2.3 cm dbh	24.4	Miller and Schuler (1995)
North Carolina	3	15.1	57,589	All	22.9	Loftis (1983a)
North Carolina	3	7.6	61,102	All	22.9	Loftis (1983a)
North Carolina	5	11.5	14,181	>1.4 m tall	24.4	Loftis (1983a)
West Virginia	2–5	<9.0	11,217	>0.3 m tall–2.3 cm dbh	24.4	Johnson et al. (1998)
West Virginia	2–5	<9.0	4,898	>0.3 m tall–2.3 cm dbh	21.3	Johnson et al. (1998)
Virginia	2–5	<9.0	1,516	>0.3 m tall–2.3 cm dbh	18.3	Johnson et al. (1998)
Alabama	8	5.7	12,372	>1.4 m tall	25.9	Schweitzer (*in prep*)
Alabama	8	11.5	12,236	>1.4 m tall	25.9	Schweitzer (*in prep*)
West Virginia	10	3.9	2,628[b]	>2.5 cm dbh	21.3	Miller and Schuler (1995)
West Virginia	10	4.1	2,309[b]	>2.5 cm dbh	21.3	Miller and Schuler (1995)
West Virginia	10	5.7	2,475[b]	>2.5 cm dbh	24.4	Miller and Schuler (1995)
West Virginia	10	4.6	2,405[b]	>2.5 cm dbh	24.4	Miller and Schuler (1995)
North Carolina	10	5.7	9,616	>1.4 m tall	25.9	Loftis (1983a)
North Carolina	17	15.1	1,441	Dominant/codominant	22.9	Loftis (1983a)
North Carolina	17	7.6	1,040	Dominant/codominant	22.9	Loftis (1983a)
West Virginia	17–22	5.3	794	Dominant/codominant	21–24	Miller et al. (2006)

[a]Site index (SI) is the height (m) of an oak tree at 50 years of age and is used as an indicator of site quality
[b]Commercial species only

Table 5.3 Stem density (stems/ha) following group selection in upland hardwood forests across the Central Hardwood Region

Location	Years after cutting	Opening size (ha)	Stems per ha	Size cut-off	Site index[a] (m)	Citation
Ohio	2	0.1	59,029	All	23–29	Sander and Clark (1971)
Ohio	2	0.2	44,253	All	23–29	Sander and Clark (1971)
Ohio	2	0.3	43,931	All	23–29	Sander and Clark (1971)
Ohio	2	0.1	29,626	All	17–22	Sander and Clark (1971)
Ohio	2	0.2	31,532	All	17–22	Sander and Clark (1971)
Ohio	2	0.3	31,655	All	17–22	Sander and Clark (1971)
Indiana[b]	6–10	0.07–0.23	10,300	≥2.5 cm dbh	N/A	Weigel and Parker (1997)
North Carolina	10	0.1–0.2	10,065	≥0.5 cm dbh	24	W.H. McNab (unpublished)
Indiana[a]	11–15	0.07–0.23	12,000	≥2.5 cm dbh	N/A	Weigel and Parker (1997)

[a]Site index (SI) is the height (m) of a tree at 50 years of age and is used as an indicator of site quality
[b]Estimated from graphical values

growing space for regeneration while still maintaining a relatively dense stand of trees. The relatively continuous canopy characteristic of single-tree selection and lack of canopy openness do not provide characteristic early successional habitats (Nyland 1996).

Group selection involves periodic removal of groups of trees, creating openings that might range between 0.1 and 0.4 ha, and results in a mosaic of relatively small patches of regeneration throughout the stand. As with the clearcutting and shelterwood methods, group selection provides the high stem density and overstory openness characteristic of early successional habitats (Table 5.3). In patch sizes from 0.1 to 0.4 ha (which meets the technical definition of group selection for eastern hardwoods (SAF 1998)), data generally do not suggest a strong relationship between stem density and patch size. In group selection, the condition of high density of small stems and overstory openness characteristic of early successional habitats is interspersed with more mature, closed-stand conditions. Further, within any given stand the aggregate amount of early successional habitats is less, by design, than in even-aged methods.

From a structural standpoint, clearcutting, shelterwood and group selection methods can all provide the low, dense vegetation and overstory openness characteristic of early successional habitats. In shelterwood methods with low residual basal areas after the initial cut, stem densities, although quite variable from stand to stand, show no relationship to the residual overstory basal area for the period of time the overwood remains intact. These stem densities are similar to those observed in clearcuts.

In group selection, stem densities show no strong relationship to patch size in the range of 0.1–0.4 ha and are similar those in the clearcutting and shelterwood methods. There is some evidence to suggest, however, that stem densities are related to site quality. Minkler's (1989) group selection study that compares north and south slopes, Sander and Clark's (1971) group selection data for good and fair sites, and Johnson et al.'s (1998) study of two-aged stands comparing stands on mesic sites and intermediate sites in West Virginia and more xeric sites in the Ridge and Valley Province of Virginia suggest higher stem densities on more productive sites. In contrast, graphical data provided by Weigel and Parker (1997) following group selection show no difference in stem density between openings created on northern and southern aspects with >10,000 stems per hectare >2.5 cm in diameter at breast height (dbh) observed regardless of aspect, and data from the Cumberland Plateau (Schweitzer, unpublished) show no difference in stem density between clearcuts on the mesic escarpment and the xeric top of the plateau.

Structural differences among the clearcutting, shelterwood and group selection methods are related in one way or another to retention, or lack of retention, of trees as stands are being regenerated. Many variations of the shelterwood method provide not only the same quality and scale of early successional habitats as the clearcutting method, but also the structural and compositional functions provided by residual overstory trees. The residual trees may be retained for a relatively short period of time – 5–15 years – or for an extended period of time at very low densities.

Group selection, over time, provides a mosaic of small patches in different stages of stand development. The relatively small patch size of group selection openings (0.1–0.4 ha) provides adequate early successional habitat for some animals but may not by sufficiently large for others (Dessecker and McAuley 2001; Shifley and Thompson, Chap. 6). The effect of differing spatial distributions of patches and road corridors that provide connectivity among them may be a fruitful area for research.

5.3 Species Composition of Regeneration

While some might argue that the structure of regeneration is the more important factor in early successional habitats, arborescent species composition of naturally regenerated stands has been a major focus of research in the Central Hardwood Region.

The past century's rich body of literature on secondary succession provides constructs for understanding species composition of regeneration following the application the various methods discussed above. One of the most interesting ideas related to timber harvest comes from Clements (1916):

> In all cases of burning or clearing the intensity or thoroughness of the process determines whether the result will be a change of vegetation or the initiation of a sere. The latter occurs only when the destruction of the vegetation is complete, or so nearly complete that the pioneers dominate the area. Lumbering consequently does not initiate succession except when it is followed by fire or other process which removes the undergrowth.
>
> Frederick E. Clements

Clements's observation raises the question of whether the use of successional terminology associated with seral stages (i.e., early succession, mid-succession, late succession) is appropriate for characterizing the compositional development of arborescent vegetation after timber harvest. His statements also highlight the role of propagules present in a stand prior to disturbance and that persist through disturbance in influencing the potential of the next stand. Other ecologists have also recognized the importance of propagules (or regeneration sources) present prior to disturbance. An extension of Egler's (1954) concept of Initial Floristics to forest management suggests that species composition after significant overstory removal is a function of regeneration sources that survive the disturbance plus new individuals that arrive during or after the disturbance (Kimmins 1997). In the vital attributes approach of Noble and Slatyer (1980) (Cattelino et al. 1979), the first vital attribute of a species is whether it persists through disturbance or arrives after disturbance. Other vital attributes of species deal with environmental conditions necessary for establishment and growth rates of regeneration sources. The silviculture literature has long recognized the multiple sources of hardwood regeneration. In hardwood silviculture application of natural regeneration methods typically attempts to utilize or enhance advance regeneration to influence stand composition.

An example of the importance of advance reproduction and influence of site quality (or position of a site along environmental gradients) in determining outcomes is oak regeneration, (see Johnson et al. 2009 for a complete discussion of regeneration and other topics in oak ecology and silviculture, as well as an extensive bibliography). It has long been known that oak regeneration depends on advance reproduction and sprouts from harvested trees in most upland hardwood forests (Leffelman and Hawley 1925; Liming and Johnson 1944; Sander and Clark 1971; Sander 1971; Loftis 1983b; Sander et al. 1984; Beck 1988; Johnson 1989). Further research established that success of oak advance reproduction is related to stem size at the time of canopy removal. In other words, the probability of an individual stem becoming dominant or codominant (dominance probability) in the new cohort that develops after substantial overstory removal increases with increasing groundline diameter or height of the advance reproduction (Sander 1971; Sander et al. 1984; Loftis 1990a). This research also established that the dominance probability for an advance oak stem of a given size decreased with increasing site quality, or more generally, from xeric to mesic sites. This inverse relationship is a function of increasing competition from other, faster-growing tree species with increasing site quality. The dominance probability for stump sprouts is also related to stem size (i.e., dbh). However, for stump sprouts, dominance probabilities decrease with increasing stem size, largely because the probability of sprouting decreases with increasing stem size (Johnson 1977; Weigel and Johnson 1998).

Johnson (1977) also notes that on more xeric sites with a more open canopy, oak seedlings that establish after good acorn (seed) crops tend to survive and accumulate over time beneath the canopy. On more mesic sites, disturbance, whether natural or silvicultural, is required for survival and growth of newly established oak seedlings (Loftis 1983b).

Based on these relationships, it is not surprising that successful oak regeneration is a common outcome of the regeneration methods listed above on xeric sites. Advance reproduction is relatively abundant after release, and competitive with regeneration sources of other species that occur on xeric sites. Stump sprouts (which are generally more abundant from stumps of smaller oak trees) provide an additional source of oak regeneration. The establishment of new oak stands after regeneration cuts is a likely outcome in the Western Dry Region of the Central Hardwood Region (see McNab, Chap. 2, Fig. 2.1) on all but the most mesic sites (on a relative scale)(Johnson et al. 2009). This outcome, however, is more restricted as one moves eastward to the Transition Dry Mesic and Central and Eastern Mesic subregions (Fig. 2.1), where a larger portion of the forested landscape would be classified as intermediate or mesic on the moisture gradient. Establishment of new oak stands or cohorts is still a common outcome after regeneration harvests, but is restricted to the more xeric end of the moisture gradient.

More species occur on intermediate and mesic sites than on xeric sites. In the Cumberlands and Southern Appalachians, stands on intermediate and submesic sites frequently have 20 or more arborescent species. A few of these, notably yellow-poplar (*Liriodendron tulipifera*), can regenerate and compete successfully from new seedlings established after harvest. Most species, however, depend on advance reproduction and stump sprouts as the source of future dominant and codominant stems (Johnson 1989; Beck 1988; Loftis 1989). Oaks often dominate the overstory of stands on intermediate sites and can be prominent on mesic sites. The application of regeneration harvests, however, frequently results in stands or even quite small openings (group selection) dominated by yellow-poplar (McGee 1975; McGee and Hooper 1975; Beck and Hooper 1986; Loftis 1983a, b, 1985, 1989; Beck 1988). Only where large oak advance reproduction is present prior to harvest does oak compete successfully after harvest with yellow-poplar (Loftis 1983a, b, 1990a). Dey (1991) found that pre-harvest size was also an important determinant of post-harvest growth for other advanced growth dependent species; like oak, these species must be present as large advance reproduction prior to disturbance to increase their likelihood of being represented in the new stand. It is likely that variation in species composition of regenerating stands is largely due to variation in the amount and size distribution of advance reproduction of all species present at the time of substantial overstory removal (Loftis 1989). For example, results from shelterwood cuts on the escarpment of the Cumberland Plateau illustrate the variability in regeneration outcomes on mesic sites (Schweitzer in prep; Table 5.4). In Table 5.4 yellow-poplar, which is commonly considered an "early successional species" is abundant in clearcuts, the 25% retention shelterwoods and 50% retention shelterwoods. Note, however, that white ash (*Fraxinus americana*) and sugar maple (*Acer saccharum*), both of which depend on advance reproduction and are usually associated with later stages of succession, are also abundant after application of all three methods (Table 5.4).

Table 5.4 Number of stems ha^{-1} >1.4 m in height and <15.2 cm diameter at breast height 8 years following a clearcut, a shelterwood with 50% basal area retention, and a shelterwood with 25% basal area retention on the Cumberland Plateau, Tennessee, USA (Schweitzer *in prep.*)

Species	Treatment clearcut	25% retention	50% retention
Fraxinus americana	2,140	764	1,082
Acer saccharum	1,282	1,046	1,470
Liriodendron tulipifera	3,175	964	1,529

As suggested in Sect. 5.1, there appears to be a level of basal area retention (category 1 shelterwoods) below which differences in species composition are due to differences in composition and size structure of advance reproduction prior to harvest rather than the basal area retained after harvest. This level appears to be about 50% of the pre-harvest basal area in the Southern Appalachians and the Cumberland Plateau. That is, species composition outcomes are essentially the same in cuts ranging from 0% basal area retained to 50% basal area retained, and is a function of composition and size structure of advance reproduction at the time of the initial harvest. This response assumes that overwood is removed in 5–15 years after the initial cut. Other areas within the Central Hardwood Region differ in the residual stocking level at which this response occurs.

If the amount and size distribution of advance reproduction of all species is important in determining species composition following a regeneration harvest, one must consider the factors that influence the variation. Variation in regeneration outcomes from stand to stand is a function not only of site quality, which determines the suite of species that grow on sites, but also the cumulative effect of disturbances and other events (e.g. seed production) that occur in the last few decades leading up to the regeneration harvest. We have shown experimentally that treatments that modestly alter the light environment on intermediate and mesic sites can substantially alter the size distribution of oaks and many other species that depend on advance reproduction (Loftis 1990b) (Table 5.5). Natural (and stochastic) disturbances such as ice (McNab et. al. 2006) and wind (Berg and Van Lear 2004) result in a range of light environments in stands subjected to these disturbances (see White et al., Chap. 3). Silvicultural treatments can be implemented in the decade (or more) prior to substantial overstory removal associated with a regeneration harvest to alter development of advance reproduction and, therefore, species composition after a regeneration harvest.

5.4 Summary

Early successional habitats—low dense vegetation and openness overhead—can be created using several regeneration methods. The clearcutting method, variations of the shelterwood method that leave mid- to low levels of residual trees and provide for timely removal cuts, and the group selection method all provide for early successional habitats. In all cases, structural changes associated with growth and self-thinning limit early successional habitats to about the first 15 years of stand or

Table 5.5 Density (trees ha^{-1}) of species by height class in control and treated plots (20–30% basal area reduction) in 1980 and 1995 (15 years post-treatment)

	Control		Treated	
	1980	1996	1980	1996
Liriodendron tulipifera				
<0.3 m	906	4,775	818	170
≥0.3 and <1.4 m	247	329	31	0
≥1.4 m	55	0	0	0
Betula lenta				
<0.3 m	55	165	0	124
≥0.3 and <1.4 m	192	137	0	463
≥1.4 m	0	55	15	494
Quercus-Carya[a]				
<0.3 m	6,010	4,967	895	942
≥0.3 and <1.4 m	1,125	1,290	509	1,204
≥1.4 m	55	165	124	679
Fraxinus americana/Tilia americana[a]				
<0.3 m	27	0	602	46
≥0.3 and <1.4 m	27	0	15	232
≥1.4 m	0	0	0	77
Acer rubrum[a]				
<0.3 m	19,431	29,997	20,161	3,041
≥ 0.3 and <1.4 m	274	274	602	1,328
≥1.4 m	55	0	15	340
Cornus florida[a]				
<0.3 m	631	82	247	0
≥0.3 and <1.4 m	439	110	324	31
≥1.4 m	110	82	15	93
Other[a, b]				
<0.3 m	1,811	2,113	1,853	679
≥0.3 and <1.4 m	659	796	1,050	710
≥1.4 m	27	384	31	247

[a]Heavily dependent on advance reproduction and stump sprouts
[b]Includes *Magnolia* spp., *Pinus strobus*, *Ostrya virginiana*, *Oxydendrum arboreum*, *Nyssa sylvatica*, *Halesia tetraptera*, *Carpinus caroliniana*, and *Sassafras albidum*

cohort development. Although there is some indication that density does vary with site quality (xeric to mesic), the vegetation, by any measure, is dense. The shelterwood and group selection methods, which retain mature trees in stands for varying periods of time, provide early successional habitats with the possibility of greater structural complexity.

Species composition resulting from the regeneration methods discussed is affected by the amount and size of advance reproduction present at the time of a regeneration harvest that removes a substantial part of the overstory. The amount and size of advance reproduction present at the time of a harvest is influenced by disturbance (including silviculture) and other events that occur prior to harvest.

Literature Cited

Arthur MA, Muller RN, Costello S (1997) Species composition in a Central Hardwood Forest in Kentucky 11 years after clear-cutting. Am Midl Nat 137:274–281

Beck DE (1988) Regenerating cove hardwood stands. In: Smith CH, Perkey AW, Kidd WE Jr (eds) Guidelines for regenerating Appalachian hardwood stands, vol 88-03. Soc Amer For Pub, Morgantown, pp 156–166

Beck DE, Hooper RM (1986) Development of a southern Appalachian hardwood stand after clearcutting. S J Appl For 10:168–172

Berg EC, Van Lear DH (2004) Yellow-poplar and oak seedlings density responses to wind-generated gaps. In: Connor KF (ed) Proceedings of the 12th biennial southern silvicultural research conference. Gen Tech Rep SRS-73, USDA Forest Service Southern Research Station, Asheville, pp 254–259

Cattelino PJ, Noble IR, Slatyer RO, Kessell SR (1979) Predicting the multiple pathways of succession. Environ Manage 3:41–50

Clements F (1916) Plant succession: an analysis of the development of vegetation, vol 242. Carnegie Inst Wash. Pub, Washington, DC

Dessecker DR, McAuley DG (2001) Importance of early successional habitat to ruffed grouse and American woodcock. Wildl Soc Bull 29:456–465

Dey DC (1991) A comprehensive Ozark regenerator. Dissertation, University of Missouri, Columbia

Egler FE (1954) Vegetation science concepts I. Initial floristic composition factor old field vegetation management. Vegetatio 4:412–417

Johnson PS (1977) Predicting oak sprouting and sprout development in the Missouri Ozarks. Res Pap NC-149, USDA Forest Service North Central Forest Experiment Station, St Paul

Johnson PS (1989) Principles of natural regeneration. In: Hutchinson JG (ed) Central hardwood notes. USDA Forest Service, North Central Forest Experiment Station, St Paul, pp 301–305

Johnson JE, Miller GW, Baumgras JE, West CD (1998) Assessment of residual stand quality and regeneration following shelterwood cutting in Central Appalachian hardwoods. N J Appl For 15:203–210

Johnson PS, Shifley SR, Roberts R (2009) The ecology and silviculture of oaks. CABI, London

Kimmins JP (1997) Forest ecology: a foundation for sustainable management. Prentice Hall, Upper Saddle River

Leffelman LJ, Hawley RC (1925) The treatment of advance growth arising as a result of thinnings and shelterwood cuttings. Yale University Sch For Bull 15, New Haven

Liming FG, Johnson JP (1944) Reproduction in oak-hickory forest stands of the Missouri Ozarks. J For 42:175–180

Loftis DL (1978) Preharvest herbicide control of undesirable vegetation in southern Appalachian hardwoods. S J Appl For 2:51–54

Loftis DL (1983a) Regenerating Southern Appalachian mixed hardwood stands with the shelterwood method. S J Appl For 7:212–217

Loftis DL (1983b) Regenerating red oak on productive sites in the Southern Appalachians: a research approach. Gen Tech Rep SE-24, USDA Forest Service, Southeastern Forest Experiment Station, Asheville, pp 144–150

Loftis DL (1985) Preharvest herbicide treatment improves regeneration in Southern Appalachian hardwoods. S J Appl For 9:177–180

Loftis DL (1989) Species composition of regeneration after clearcutting Southern Appalachian hardwoods. In Miller JH (ed) Proceedings of the fifth biennial southern silvicultural research conference. Gen Tech Rep SO-74, USDA Forest Service, Southern Forest Experiment Station, New Orleans, pp 253–257

Loftis DL (1990a) Predicting post-harvest performance of advance red oak reproduction in the Southern Appalachians. For Sci 36:908–916

Loftis DL (1990b) A shelterwood method for regenerating red oak in the southern Appalachians. For Sci 36:917–929

McGee CE (1967) Regeneration in southern Appalachian oak stands. Res Note, SE-72 USDA Forest Service, Southeastern Forest Experiment Station, Asheville

McGee CE (1975) Regeneration alternatives in mixed oak stands. Res Pap SE-125 USDA Forest Service, Southeastern Forest Experiment Station, Asheville

McGee CE, Hooper RM (1975) Regeneration trends 10 years after clearcutting of an Appalachian hardwood stand. Res Note SE-227, USDA Forest Service, Southeastern Forest Experiment Station, Asheville

McNab WH, Roof T, Lewis JF, Loftis DL (2006) Evaluation of landsat imagery for detecting ice storm damage to oak forests in eastern Kentucky. In: Buckley DS, Clatterbuck WK (eds) Proceedings of the 15th central hardwood forest conference. Gen Tech Rep SRS-101, USDA Forest Service Southern Research Station, Asheville, pp 128–138

Merz RW, Boyce SG (1958) Reproduction of upland hardwood in southeastern Ohio. Tech Pap 155, Central States Forest Experiment Station, Columbus

Miller GW, Schuler TM (1995) Development and quality of reproduction in two-aged central Appalachian hardwoods – 10 year results. In: Gottschalk KW, Fosbroke SLC (eds) Proceedings of the 10th central hardwood forest conference. Gen Tech Rep NE-197, USDA Forest Service, Northeast Forest Experiment Station, Radnor, pp 364–374

Miller GW, Kochenderfer JN, Fekedulegn DB (2006) Influence of individual reserve trees on nearby reproduction in two-aged Appalachian hardwood stands. For Ecol Manage 224: 241–251

Minkler LS (1989) Intensive group selection in central hardwoods. In: Rink G, Budelski CA (eds) Proceedings of the seventh central hardwood forest conference. Gen Tech Rep NC-132, USDA Forest Service, North Central Forest Experiment Station, St. Paul, pp 35–39

Noble IR, Slatyer RO (1980) The use of vital attributes to predict successional changes in plant communities subject to recurrent disturbances. Vegetatio 43:5–21

Nyland RD (1996) Silviculture: concepts and applications. McGraw-Hill, New York

Oliver CD, Larson BC (1990) Forest stand dynamics. McGraw-Hill, New York

Peet RK (1992) Community structure and ecosystem function. In: Glenn-Lewin DC, Peet RK, Veblen TT (eds) Plant succession: theory and prediction. Chapman-Hall, London

Sander IL (1971) Height growth of new oak sprouts depends on size of advance reproduction. J For 69:809–811

Sander IL, Clark FB (1971) Reproduction of upland hardwood forests in the Central States. In: Agri Handbook 405, USDA Forest Service, Washington, DC

Sander IL, Johnson PS, Rogers R (1984) Evaluating oak advance reproduction in the Missouri Ozarks. Res Pap NC-251, USDA Forest Service, North Central Forest Experiment Station, St. Paul

Society of American Foresters (1998) In: Helms JA (ed) The dictionary of forestry. Society of American Foresters, Bethesda

Trimble GR (1973) The regeneration of central Appalachian hardwoods with emphasis on the effects of site quality and harvesting practice. USDA Forest Service, Northeastern Forest Experiment Station, Upper Darby

Weigel DR, Johnson, PS (1998) Stump sprouting probabilities for Indiana oaks. Tech Brief NC-7, USDA Forest Service North Central Forest Experiment Station, St. Paul

Weigel DR, Parker GR (1997) Tree regeneration response to the group selection method in southern Indiana. N J Appl For 14:90–94