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Ecological Silviculture for Oak Ecosystems of the Central Hardwoods Region, USA

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16.1 Introduction

This chapter focuses on the largely oak (*Quercus*)-dominated forest, woodland, and savanna ecosystems that characterize the Central Hardwoods Region. These ecosystems occur across much of the eastern United States, including five ecoregion provinces (Figure 16.1) [1, 2].

The Central Hardwoods Region contains productive agricultural land and a high proportion of the population of the United States. Approximately 75% of the forest land is privately owned [3], exceeding 90% in many states. Fragmentation continues to decrease the size of privately owned forests and woodlands with average area ranging from less than 8 ha in Ohio, Pennsylvania, and New York to 12–16 ha in Missouri, Illinois, and Virginia [4].

Ownership patterns strongly influence management. Passive management favored by nonindustrial private forest owners has led oak-hickory (*Carya*) ecosystems to succeed in more mesic mixed hardwood forests region-wide [5]. High grading is also common and has degraded forest quality. Where active, planned management occurs, even-aged regeneration methods (e.g. clear-cutting, shelterwood) are most commonly applied using rotations of 70–120 years. On poor sites in the southwestern-most Central Hardwoods where oak competitors are of less concern, uneven-aged methods (e.g. selection) can successfully regenerate oak.

Applying knowledge of natural disturbance and historical range of variability to management of these ecosystems is challenging, considering the substantial change that has already occurred (e.g. loss of American chestnut, land conversion, fire suppression) and the way multiple disturbances of varying type, frequency, and severity interact [6]. Yet, there is interest in silvicultural approaches that better reflect the dynamics and structure associated with a natural model (i.e. ecological silviculture), particularly given private landowner concerns over maintaining mature canopy and habitat, often at the expense of successful regeneration [7]. Incorporating ecological principles into oak silviculture has been discussed previously [3, 6, 8, 9], and the growing use of prescribed burning reflects a understanding of the role disturbance played in maintaining oak species historically. However, the application of ecological silviculture remains limited. This chapter provides a general framework for designing ecological silvicultural systems that can be applied in oak ecosystems across the Central Hardwoods Region.

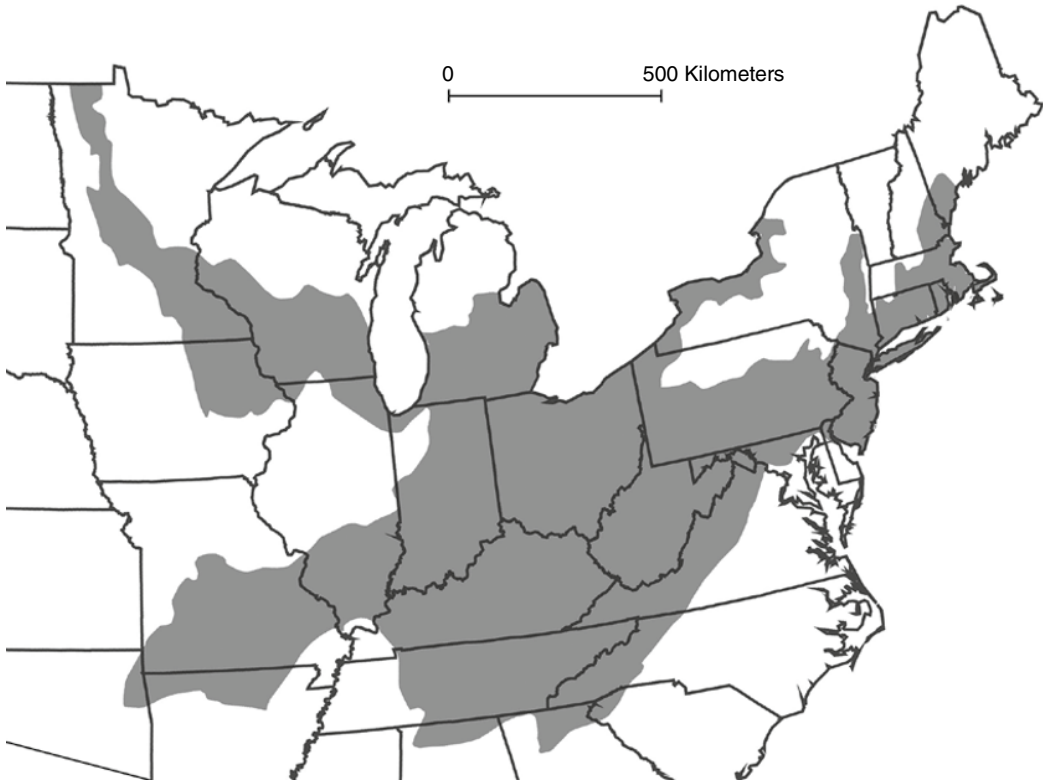


Figure 16.1 Central Hardwoods Region of the United States. *Source:* Adapted from Hanberry et al. [1].

16.2 Characteristics of Central Hardwood Forests and Woodlands

16.2.1 Composition and Structure

While the Central Hardwoods region contains a wide range of environmental conditions and over 100 native tree species, oak, and hickory species are most common (Table 16.1), and the forest type is broadly classified as oak hickory [12]. Oak ecosystems can be organized into three general types with distinctive structures and compositions: savannas, woodlands, and forests (Figure 16.2). These communities develop in predictable patterns across landscapes in association with specific soils, topography, and disturbance patterns. In reality, structure and composition of each occur along a continuum [17].

Savannas have the lowest tree density [16] with widely spaced or small clusters of trees each with a dominant crown class, large diameter, and spreading crown indicative of open growth (Figure 16.2). Associated species flourish in the higher temperatures and light levels present in open conditions. While the structure can appear simple, multiple cohorts may be present [18].

Woodlands have widely spaced trees with spreading crowns, but sufficient tree-to-tree competition to encourage crown differentiation (development of crown classes). There may be multiple cohorts present. Many herbaceous species flower and produce seed during the summer, a result of past disturbances that reduced stand density sufficiently to support a light-demanding understory.

Table 16.1 Silvical characteristics for common species in Central Hardwoods ecosystems [10, 11].

Species	Shade tolerance	Mast frequency (years)	Maximum longevity (years)	Fire response
Bitternut hickory (<i>Carya cordiformis</i> (Wangenh.) K. Koch)	Intolerant (to intermediate in bottomlands)	3–5	200	Easily wounded and top killed; sprouts and suckers following fire
Black oak (<i>Quercus velutina</i> Lam.)	Intermediate	2–3	250	Susceptible to wounding and decay; stump sprouts
Bur oak (<i>Q. macrocarpa</i> Michx.)	Intermediate	2–3	400	Mature trees resistant; stump sprouts
Mockernut hickory (<i>C. tomentosa</i> (Poir.) Nutt.)	Intolerant (varies from tolerant to intolerant)	2–3	300	Easily top-killed; stump sprouts
Northern red oak (<i>Q. rubra</i> L.)	Intermediate	2–5	400	Susceptible to wounding and decay; stump sprouts
Pignut hickory (<i>C. glabra</i> Mill.)	Intolerant (Northeast) to tolerant (Southeast)	1–2	325	Somewhat resistant, seedlings typically top-killed; stump sprouts
Post oak (<i>Q. stellata</i> Wangenh.)	Intolerant	2–3	400	Frequently top-killed; smaller trees readily stump sprout
Shagbark hickory (<i>C. ovata</i> (Mill.) K. Koch)	Intermediate	1–3	350	Stump sprouts; root suckers more common as parent trees age
White oak (<i>Q. alba</i> L.)	Intermediate	4–10	600	Stump sprouts
Scarlet oak (<i>Q. coccinea</i> Muenchh.)	Very intolerant	3–5	250	Very susceptible to fire damage and mortality; stump sprouts
Chestnut oak (<i>Q. montana</i> Willd.)	Intermediate	4–5	400	Stump sprouts
Red maple (<i>Acer rubrum</i> L.)	Tolerant	1–2	150	Easily top-killed, stump sprouts
Black cherry (<i>Prunus serotina</i> Ehrh.)	Intolerant	1–5	250	Easily top-killed, stump sprouts

Forests have higher tree densities and closed, multitiered canopies. On dry sites, white oak and hickory can occur in the midstory and understory whereas maples (*Acer*), beech (*Fagus*), and shade-tolerant shrubs frequently dominate the woody understory community on mesic sites. Multiple cohorts are usually present. Spring ephemerals are important herbaecous indicators; they flower and produce seed prior to spring leaf out by trees and suggest a recent absence of fire.

16.2.2 Natural Disturbance

Low-intensity, frequent fire is a dominant disturbance in oak savannas, woodlands, and forests [19]. Historically, most fire in the Central Hardwoods Region was set by humans [20].

Central Hardwoods Oak Ecosystems			
Overstory	Bur oak, post oak, white oak, chinkapin oak, blackjack oak	Bur oak, black oak, post oak, white oak, black hickory, mockernut hickory, shagbark hickory	Northern red oak, white oak, bitternut hickory, mockernut hickory, pignut hickory, shagbark hickory, sugar maple
Subcanopy	Eastern redbud, slippery elm, ironwood, paw paw, musclemwood	Fragrant sumac, green briar, Carolina buckthorn, virginia creeper, summer grape, <i>vaccinium</i> spp.	American hazelnut, wild plum, rough-leaf dogwood
Ground flora	Big bluestem, switchgrass, Indian grass, sideoats grama	Bristly sunflower, nodding fescue, panic grasses, river oats, sedges, asters, milkweed, horsemint, beard-tongue, dittany	May apple, bloodroot, wild geranium, phlox, false Solomon's seal, Dutchman's breaches, trilliums, trout lily, wild comfrey
Structure	Structure equivalent to 10–30% stocking, 1–3 cohorts; Widely spaced or small clusters of trees each with a dominant crown class, large diameter, and spreading crown indicative of open growth	Structure equivalent to 30–75% stocking, 1–3 cohorts; Widely spaced trees with a simple structure including dominant, codominant, and some intermediate trees with spreading crowns. Bell-shaped diameter distributions are common. Open understory.	Structure equivalent to >75% stocking, 1–4 cohorts; Closely spaced trees with a multi-tiered canopy; a reverse-J diameter or irregular diameter distribution is common, semi-open understory

Figure 16.2 Representative plant species and structural conditions associated with the three, general oak-dominated ecosystems that occur in the Central Hardwoods Region: (A) savanna; (B) woodland; (C) forest [13–15]. Species composition varies across the large region. Densities that characterize each ecosystem type have been presented in terms of stocking [16] (see Figure 16.3). *Source:* Photos: USDA Forest Service.

Lightning is also a source of ignition, but it does not occur frequently enough to generate the fire return intervals reconstructed across the region [21]. Fire frequency largely drives community type with mean return intervals ranging from 10–20 years in forests to 1–5 years in savannas. The variability in recovery periods following fire interacts with mean fire interval to influence composition and structure [22]. For instance, variable recovery periods between fires in an ecosystem with short mean fire intervals favor the germination and establishment of oak, whereas regular fires with consistent, equally short recovery periods and the same mean interval encourage dominance by grasses, as found in prairies and savannas. Historically, large, stand-replacing fires occurred infrequently with return intervals of 100–500 years [23], varying across the region [20, 24]. Other important disturbances include wind, insect and disease outbreaks, drought, ice damage, and grazing and browsing [25]. Each of these disturbance types, particularly in combination, contributes to greater heterogeneity in oak ecosystem structure at both stand and landscape scales than created by traditional, timber-focused silvicultural systems.

16.3 Natural Developmental Model

The natural development model for oak-dominated ecosystems is summarized in Table 16.2. This model begins with one (or more) moderate- to high-intensity disturbances that release oak advance regeneration and retain some live and deadwood legacies. It proceeds through young, mature, and old stages of development. Throughout, repeated, moderate-intensity surface fires under a sparse

Table 16.2 A developmental model for oak-dominated savannas, woodlands, and forests.

Stage	Attribute	Cause or Consequence
Disturbance and Legacy Creation	Live tree and deadwood legacies retained; aggregated (savanna or woodland) to dispersed (forest)	Near stand-replacing to partial-canopy disturbance
Preforest stage	Oak and hickory sprout dominated (woodlands or forests) with herb/shrub/grass occurring (savanna); absent to lasting <5 years (woodland, forest) to 15 years (savanna)	Hardwood sprouting shortens this process where sprouts are exceptionally abundant
Young stage	Recruitment and development of oak sprouts in mixtures of hickories; thinning from reintroduction of fire (savanna, woodland) or self-thinning from competition (forest)	Recruitment into overstory may take up to 50 years; stems of sprout origin may be locally abundant; density is reduced due to competition-induced mortality and/or to low-intensity surface fire and browsing
Mature stage	Oaks with wide crowns dominate the overstory; dead wood increases in abundance; greater species diversity occurs in the understory and ground layer (savanna, woodland) or in the seedling layer (forest)	Surface fire creates canopy openings commensurate with intensity; low-intensity fires retain closed canopies of dominant trees (closed woodland) and high-intensity fires create partial openings (open woodland); oak and hickory seedling sprouts accumulate in the understory during fire-free periods (forest)
Old stage	Dominated by oaks with wide crowns with two or more ages classes present; deadwood abundant; patchy canopy with abundant snags; diverse species composition in the ground layer (savanna, woodland); some presence of more mesic, shade-tolerant tree species (forest)	Overstory structure becomes more complex due to tree mortality; low-intensity fire continues to facilitate establishment and early growth of oak stump sprouts (savanna, woodland); less frequent fire (forest)

(savanna) or open canopy (open woodland) or low-intensity surface fires under a closed canopy (closed woodland, forest) are required to maintain characteristic understory species. Fires also encourage development of oak advance regeneration. Stages are described at the stand scale; horizontal complexity across stands results from inherent variability in soil properties such as depth, nutrient, and water supply, and microtopography as well as the influence of legacy trees on the understory microenvironment.

16.3.1 Disturbance and Legacy Creation

Canopy disturbances are needed to increase light availability and release oak advance regeneration. Due to variations in fire frequency and regularity, recruitment of regeneration in oak ecosystems is generally episodic rather than continuous, occurring during fire-free intervals in each community type [22]. Mature legacy trees serve a minor role in stand regeneration; rather, new cohorts typically recruit from advanced regeneration. The spatial distribution of legacy trees following disturbance varies, depending on topography and soil conditions. Legacy trees tend to occur in aggregated patterns near and along streams or other natural fire breaks and in a more dispersed pattern where natural fire breaks are absent.

16.3.2 Preforest Stage

The structure and composition of the preforest stage vary widely across the region and within a landscape depending on disturbance type, disturbance severity, and site characteristics. To varying degrees, shrubs, forbs, graminoids, vines, and vegetative sprouts from top-killed oak and hickory advance regeneration can dominate the preforest stage [26]. Regardless of specific circumstances, the herbaceous and woody understory is well developed [26], and the greater abundance of fruit, quality browse, small prey, and other foods benefit wildlife [27]. The length of this stage varies between savannas, woodlands, and forests. Frequent fire can maintain elements of the preforest stage for extended periods in savannas and woodlands, but eventually, a fire-free period is necessary to allow recruitment. In forests, the preforest stage can last as few as 10 years if ample advance regeneration leads to fast recruitment [28].

16.3.3 Young Stage

In all three ecosystems, the Young Stage may last as many as 50 years as the newest cohort grows enough to resist top-kill by fire and recruits to the canopy. In forests and woodlands, the understory diminishes as the canopy approaches closure and competition leads to crown differentiation and self-thinning (forests). This can occur across an entire stand or in small patches within a stand [29]. On dry and nutrient poor (e.g. the Ozark Highlands) and/or frequently disturbed sites, oaks and hickories emerge as the dominant species, eventually overtopping other tree species less tolerant of stressful conditions.

16.3.4 Mature Stage

The mature stage in savannas and woodlands, both open forest ecosystems [13], is characterized by an abundance of large-diameter, fire-tolerant oaks. Forests in this stage have a closed canopy with an abundance of black oak, white oak, and northern red oak (Figure 16.2). During this stage, the species composition and structure depend on fire frequency and severity. Low-intensity, infrequent surface fires top kill only some of the trees <12 cm dbh, leaving the canopy closed in forests and diverse. High-intensity or frequent surface fires top kill greater numbers of trees <12 cm dbh and can shift composition over time, removing all but the most fire-tolerant oaks (e.g. bur oak [*Q. macrocarpa* Michx.] or post oak [*Q. stellata* Wangenh.]) in stands with partial openings and an overall lower stocking [30]. During fire-free periods, the small-diameter oaks and hickories top-killed by fire resprout, and a rich ground flora develops comprising spring ephemerals that flower and set seed in the spring prior to leaf out (forests) or legumes, forbs, and C3 grasses that flower or set seed in the summer (woodland). In savannas, openings created and maintained by fire lead to abundant, light-demanding C4 grasses.

16.3.5 Old Stage

The old stage begins when 20–30% or more of the overstory exceeds an age of at least 90 years, depending on the region (ranging from >90 years in Minnesota to >150 years in the central Appalachians) [3, 22]. Old savannas, woodlands, and forests exhibit greater structural complexity than earlier stages as well as abundant deadwood. Infrequent, but moderate-intensity fire provides fuel for low-intensity surface fires that move quickly, remove herbaceous biomass, and top-kill accumulating oak sprouts. In woodlands, white oaks and hickories become

dominant in the stand as shorter-lived oaks (e.g. black oak [*Quercus velutina* Lam.]) die, which provide snags and downed wood. Resulting canopy gaps favor the accumulation of seedling sprouts in isolated patches; these are kept in check by infrequent low-intensity surface fire. In oak forests, white oaks and northern red oaks typically dominate alongside hickories, red maple, and other species more or less abundant depending on location (e.g. sassafras [*Sassafras albidum* (Nutt.) Nees], hackberry [*Celtis occidentalis* L.]), and understory shrubs. Canopy heterogeneity develops as shorter-lived tree species die and gap-scale disturbances occur, allowing the development of a distinct midstory and understory. Variability in the light environment creates heterogeneity in the understory plant community. Downed wood volumes frequently exceed $35.9 \text{ m}^3 \text{ ha}^{-1}$ and vary across the region [31–34]. Older trees that have experienced wind, ice, or other damage develop features such as cavities that provide habitat and contribute to greater structural complexity. The section that follows illustrates how knowledge of the natural model can be applied to management of these ecosystems through an ecological silviculture system.

16.4 Ecological Silvicultural Systems for Central Hardwoods Ecosystems

16.4.1 Disturbance and Legacy Creation

Variable retention harvesting (VRH, similar to shelterwood with reserves or clear-cut with reserves) or an irregular shelterwood method can be applied in a way that models natural disturbance and maintains or restores key ecosystem attributes and functions in oak ecosystems (Table 16.3). Regeneration harvests enhance structural complexity by creating biological legacies as well as space for a new cohort.

If the desired future condition includes a multi-cohort age structure, continuous cover irregular shelterwood [35] can be used to create openings (gaps) across a stand such that one-third or less of the stand is harvested in any entry (Figure 16.4). The size of the openings necessary for successfully regenerating oak (generally $0.08\text{--}0.2 \text{ ha}$) [3] varies with tree height and slope as well as region, climate, and site quality. Larger gaps may be necessary to provide oak and hickory enough light to compete successfully with shade-tolerant species, particularly on richer soils and where prescribed fire is less frequently applied. Reducing stocking in the matrix to less than 75% and maintaining the midstory, as needed, will also increase light availability in gaps (Figure 16.3). Alternatively, VRH can be applied to achieve a two-cohort structure (Figure 16.4). The level and spatial distribution of retention should be informed by the natural disturbance regime as well as stand and site objectives.

Many historical woodlands and savannas now resemble forests, following decades of fire suppression and exclusion. VRH is recommended for creating legacies and initiating the preforest stage [9, 36]. To achieve woodland structure, postharvest stocking should not exceed 30% (Figure 16.3). Assuming overstory trees are of merchantable size and age ($>40 \text{ cm DBH}$), retention should include $50\text{--}75 \text{ trees ha}^{-1}$. Retained, live tree legacies can be arranged in clumps (aggregates), dispersed across a stand, or some combination of both (Figure 16.4). As with woodlands, VRH can be used to initiate the preforest stage in savannas, but with fewer live trees retained.

Across all three Central Hardwoods ecosystems, existing snags and large downed dead wood should be retained to the extent possible. It may also be desirable to supplement large dead wood pools at the time of harvesting, i.e. use harvesting equipment or girdling to create dead wood.

Table 16.3 An ecological silvicultural system for oak-dominated savannas, woodlands, and forests.

Stage	Years	Outcome			Potential silvicultural actions		
		Forest	Woodland	Savanna	Forest	Woodland	Savanna
Disturbance/ Legacy Creation	0	Retention of legacy trees and deadwood; initiation of preforest stage			First establishment cutting for irregular shelterwood; harvest 30% of stand area in gaps >0.2 ha; residual stocking in remainder of stand <75%; alternatively, apply variable retention harvest (VRH, clear-cut with reserves)	VRH; dispersed and aggregated retention (stocking 20–30%)	VRH; dispersed retention (stocking 20–30%)
Preforest stage	1–10	Promote ground flora in all ecosystems, particularly woodlands and savannas. Establish new cohort (primarily released advance regeneration) and reduce understory competition from mesophytic tree species			Post-sale slashing operations (where there is no pine component); lopping slash and removing it from the vicinity of legacy trees to reduce severity of future prescribed fires	If natural regeneration is understocked, supplement with seedlings	
					Plant shortleaf pine or pitch pine seedlings where these species are a desired component		
Young stage	10–40	Recruit new cohort			Conduct post-sale slashing operations if delayed to favor pine regeneration	Moderate-intensity ground fire applied shortly after harvest to reduce competition by mesophytic tree species	
	40	Retention of legacy trees and deadwood; initiation of patch-scale preforest stage	Promote ground flora, increase tree growth, and enhance crown expansion		Fire-free recruitment period; free thinning of youngest cohort (crop-tree release)	If natural regeneration is understocked, supplement with seedlings	
	40–50				Establishment cutting; harvest 30% of stand area in gaps >0.5 acres, thin remainder of stand to <75% stocking	Thin to maintain stocking <60%; periodic prescribed fire; treat invasive species as needed	Thin to maintain stocking <30%; periodic prescribed fire; treat invasive species as needed
	50–80	Establish new cohort and enhance structural heterogeneity			Where pine component is desired, conduct delayed post-sale slashing operations; moderate-intensity ground fire applied shortly years after harvest to reduce competition by mesophytic tree species; where natural regeneration is understocked, plant seedlings	Fire-free recruitment period; free thinning of youngest cohort (e.g. crop-tree release)	
		Recruit new cohort					

Mature stage	80	Retention of legacy trees and deadwood; initiation of patch-scale preforest stage	Promote ground flora, increase tree growth, and enhance crown expansion	Establishment cutting; harvest 30% of stand area in gaps >0.5 acre, thin remainder of stand to <75% stocking; OR VRH can be applied to initiate the preforest stage across the stand	Thin to maintain stocking <60%; periodic prescribed fire; treat invasive species as needed	Thin to maintain stocking <30%; periodic prescribed fire; treat invasive species as needed
	80–90	Establish new cohort, enhance structural heterogeneity		Where pine component is desired, conduct delayed post-sale slashing operations; Moderate-intensity ground fire applied five to seven years after harvest to reduce competition by mesophytic tree species; where natural regeneration is understocked, plant seedlings		
	90–120	Recruit new cohort		Fire-free recruitment period; free thinning of youngest cohort (e.g. crop-tree release)		
Old stage	120+	Can initiate preforest stage in patches. Enhance structural heterogeneity, including addition of deadwood. Increase tree growth and encourage crown expansion. Discourage potential mesophytic species in the understory. Promote ground flora in woodland and savanna.		Establishment cutting; harvest 30% of stand area in new gaps >0.5 acre with 1 retained tree; residual stocking in remainder of stand <75%	Thin to maintain stocking <60%; periodic prescribed fire; treat invasive species as needed	Thin to maintain stocking <30%; periodic prescribed fire; treat invasive species as needed
		Establish new cohort		Where pine component is desired, conduct delayed post-sale slashing operations; moderate-intensity ground fire applied shortly years after harvest to reduce competition by mesophytic tree species		
		Recruit new cohort		Fire-free recruitment period; free thinning of youngest cohort (crotree release)		

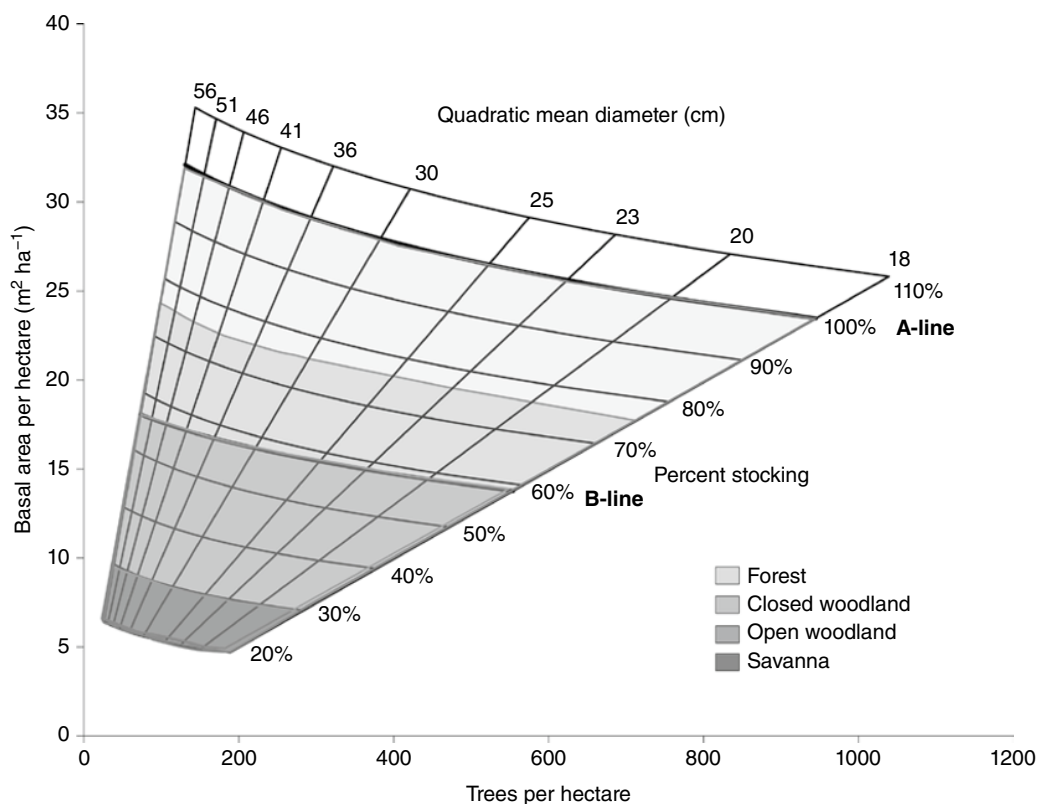


Figure 16.3 Stocking guide [16] that illustrates thresholds for managing savannas and woodlands compared to forests. Woodlands can be further divided into those with closed (lighter grey shading) or open (darker grey shading) canopies [3].

16.4.2 Preforest Stage

Across all three ecosystem types, moderate-intensity surface fire should be applied shortly after harvest to reduce competition from shrubs and mesophytic tree species. Timing depends on fuel loading and advance regeneration. Assuming oak advance regeneration is present, seedlings will be most likely to resprout following fire if the root collar diameter exceeds 0.6 cm [37]. If advance regeneration is not adequately stocked, periodic fire can be applied to reduce competition and leaf litter in anticipation of a future mast year, particularly on richer sites. If artificial regeneration is required, delay planting as necessary to allow an appropriate period of dominance by herbaceous species and shrubs.

16.4.3 Young Stage

During this stage, treatments appropriate for forests differ from those recommended for managing woodlands and savannas. Frequent, low-intensity fires are needed to maintain the understory in woodlands and savannas. Thinning during this stage should maintain stocking at less than 60% for woodlands and less than 30% for savannas, enhancing spatial variability, encouraging overstory tree growth, and allowing ample light to reach the understory.

Fire is excluded during most of the young stage in forests to allow established regeneration to recruit to the canopy. Once the most recently recruited cohort has developed fire-resistant bark,

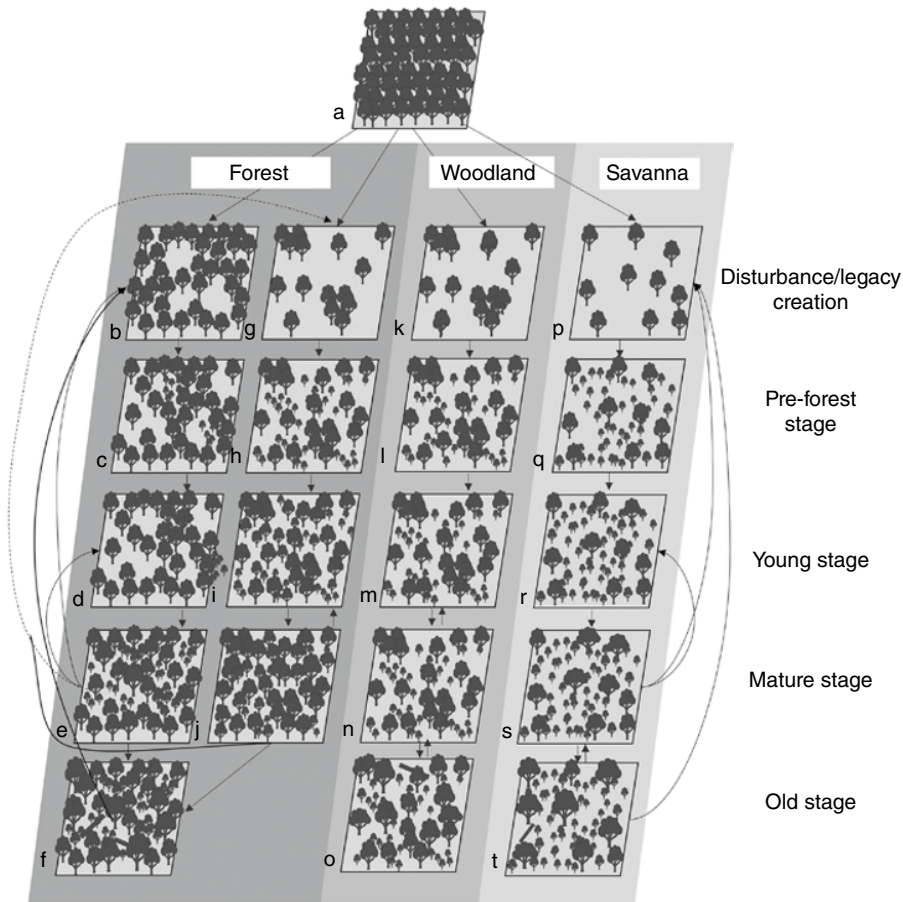


Figure 16.4 Stages of development for Central Hardwoods forests managed with a continuous cover irregular shelterwood system (b–f) and forests (g–j), woodlands (k–o), and savannas (p–t) managed with VRH. The presentation of a single, forest-like starting point (a) across ecosystem types assumes an absence of recent disturbance as is common across the region. Arrows indicate different potential pathways. The dashed line illustrates the option to move mature forest stands initially managed within an irregular shelterwood system back to an earlier developmental stage using VRH.

prescribed burns can be reintroduced to maintain the understory flora, reduce competition, and encourage advanced regeneration. A second establishment cutting will make space for a new cohort in patches across the stand as well as create new legacies. Thinning will encourage diameter growth and crown expansion. This can be accomplished through a thinning from below, but free thinning methods such as crop-tree release are better suited for encouraging growth of specific trees for either ecological or timber objectives, so long as stocking is also maintained. Once a new cohort is established, fire should be excluded for a period to allow regeneration to grow until it develops fire resistance (and recruits to the canopy).

16.4.4 Mature Stage

At this stage, two to three cohorts should be present and well-established. Silvicultural actions may appear similar between the young and mature stages, but the overall structure will differ as legacy

trees continue to grow, develop cavities and similar features, and die (contributing to dead wood pools). Management can direct further development via one of multiple pathways. Forests, woodlands, and savannas can be maintained in the mature stage indefinitely with prescribed fire and periodic, partial harvests as described above. Alternatively, the application of VRH can return all three ecosystem types to the preforest stage (Figure 16.4). Lastly, forests, woodlands, and savannas can be allowed to advance to the old stage. While dead wood abundance typically increases after harvest, it begins to decline again within 20 years due to decay and an absence of continued recruitment [38]. Creating or maintaining snags during the mature stage will ensure a continuous supply of large dead wood.

16.4.5 Old Stage

Given the disturbance-dependent and dynamic nature of these ecosystems, strictly defining the old stage and developing an associated silvicultural approach presents a challenge. Except on the poorest, driest sites, oak, and hickory species require periodic fire to recruit to the canopy, and an absence of disturbance leads to compositional change.

Silviculture in old-stage stands is most likely to advance non-timber objectives [3]. Gap-scale disturbances (e.g. fire, mild to moderate wind, insects) will create openings that may recruit or release younger cohorts [29]. Partial harvest, as described above with repeated establishment cuttings in a continuous cover irregular shelterwood system, can also be continued. Prescribed fire can be applied to maintain advanced regeneration if dominance by oak and hickory species is desired. Other actions may include invasive species removal, free thinning to create additional structural heterogeneity and supplement dead wood pools, and treating the understory to reduce competition. Some presence of mesic, shade-tolerant tree species is expected at this stage in oak forests, so treatments will depend on site characteristics and desired future conditions.

16.5 Climate Change Considerations

Projected changes in future climate, as well as emerging pests, pathogens, and invasive species, will interact with the legacy of extensive changes to disturbance regimes, composition, and structure that have already occurred across the Central Hardwoods Region. The region is large and highly variable, so climate change projections vary, and acquiring up-to-date information about specific locations is key to effective climate adaptation management. Broadly, annual precipitation is expected to increase across the region [39, 40], but higher temperatures, longer-growing seasons, and greater seasonal variation in precipitation may increase water stress [41] and shift composition toward more southern and/or xeric species [42].

Despite these expected changes, oak and hickory species of the Central Hardwoods Region are well-adapted to disturbance and stressful conditions [8], traits that may buffer impacts from projected climate change. Managing oak ecosystems in a changing climate has been addressed in greater detail elsewhere [3, 40], and we provide broad guidelines below.

As proposed for other ecosystems in this text, a practical framework for adaptation includes resistance, resilience, and transition strategies [43, 44]. Resistance tactics for maintaining current species composition and structure largely center on thinning treatments that reduce tree-to-tree competition and prioritize release of species that are particularly valued for products, habitat, or

other qualities. By increasing resource availability, thinning lessens vulnerability to disease, insects, and other stressors, at least in the short term.

The resilience strategy focuses on allowing some change within the range of historical variability and an eventual return to prior composition and structure (or at least function). Tactics for encouraging resilience also include thinning to reduce competition but with greater emphasis on encouraging more future-adapted native species, increasing age- and structural diversity through the application of two- or multi-cohort silvicultural systems like those described in this chapter, and maintenance of the understory with fire or other tools to minimize establishment of invasive species and ensure regeneration potential. Many of the most common species (e.g. bur oak, white oak, mockernut hickory, post oak, and northern red oak) are considered less vulnerable to climate change [3] and might be encouraged.

The transition strategy embraces the likelihood of future change and modifies forest structure as suggested for resistance (lower stocking) and resilience (two or more cohorts), as well as species composition, to facilitate adaptation. In addition to thinning and applying uneven-aged silvicultural systems, potential tactics include enrichment planting with stock selected to increase the genetic diversity of species already present, such as through seed sources from zones that currently resemble projected future conditions for a given area. Assisted range expansion, planting species projected to have suitable habitat but not currently present, may also assist with transition, particularly in the northern part of the Central Hardwoods Region.

16.6 Summary

Ecological silviculture for oak ecosystems differs from traditional timber-focused approaches that prioritize timber production, efficiency, and wood quality.

Keypoints

- 1) Open forest ecosystems (e.g. savannas and woodlands) are important components of the Central Hardwoods Region, both culturally and ecologically, having been maintained largely through prescribed fires applied by indigenous peoples. They should be managed accordingly with greater focus on ground flora than tree recruitment.
- 2) Regeneration harvesting should prioritize biological legacies and the maintenance of a healthy and diverse understory, creating structures that reflect the dynamic and disturbance-dependent nature of these ecosystems.
- 3) The preforest stage provides valuable early successional habitat that can be enriched and encouraged through fire while also encouraging desired oak and hickory regeneration. In woodlands and savannas, characteristics of this stage are maintained throughout development.
- 4) Application of treatments should reflect the best available knowledge of the natural and historic disturbance regime. Specifically, such knowledge should inform recovery periods (between prescribed fires and/or harvest entries) and disturbance severity (e.g. severity of surface fire, proportion of canopy removed, abundance of dead wood created).
- 5) Diversity and variability in structure, timing (e.g. recovery periods), and community composition in the understory (if not trees) are prioritized in these ecological silvicultural systems to promote native biodiversity and maintain adaptive capacity.

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