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Ecological Silviculture for Southern Appalachian Hardwood Forests

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8.1 The Southern Appalachian Mixed-Oak Forests

The forests of the southern Appalachians, defined here as the Central Blue Ridge Mountains, Southern Blue Ridge Mountains, and the Metasedimentary Mountains, stretch from northeast Georgia to southwestern Virginia, USA (Figure 8.1). The complex topography and humid temperate climate create growing conditions for a rich variety of forested plant communities. Forest types occur in ecological zones classified by elevation, aspect, and geology that create patterns of temperature, moisture, and productivity [1].

Forestland is the dominant cover type within the region, comprising 77% or ~2.9 million ha, and is held by a mix of ownerships including private (55%), federal (40%), and state and local (5%) entities. Within the region, 13 forest-type groups are identified, with 75% of forestland classified as oak/hickory (*Quercus/Carya*) (Figure 8.2a, ~2.2 million ha) and the next most abundant forest type (9%), being oak/pine (*Quercus/Pinus*). Most forests were harvested in the early twentieth century, with less than 1% of oak/hickory forestland >140 years (Figure 8.2b). Federal lands have been managed for multiple uses and private landowners increasingly value managing their properties for ecosystem services beyond timber production.

Forest management in the southern Appalachians is centered on regenerating a suite of oak species, including white oak (*Quercus alba* L.), chestnut oak (*Quercus montana* Willd.), northern red oak (*Quercus rubra* L.), scarlet oak (*Quercus coccinea* Muenchh.), and black oak (*Quercus velutina* Lam.), with the relative species dominance dependent on-site quality. Coupled with restoration efforts to regenerate and conserve oak species are objectives associated with the sustainable production of high-value hardwood sawtimber and other non-timber-related goods and services, such as understory plant diversity, wildlife populations, and wildlife habitat diversity.

The diversity of hardwood species is important for timber products within the local and regional economy and leads to complex timber values, markets, and therefore, management. Management systems for commercial hardwoods vary across ownerships, with high-grading and commercial clearcutting commonly applied to privately owned forestland and a broader suite of true silvicultural systems, including various even-aged, two-aged, and uneven-aged

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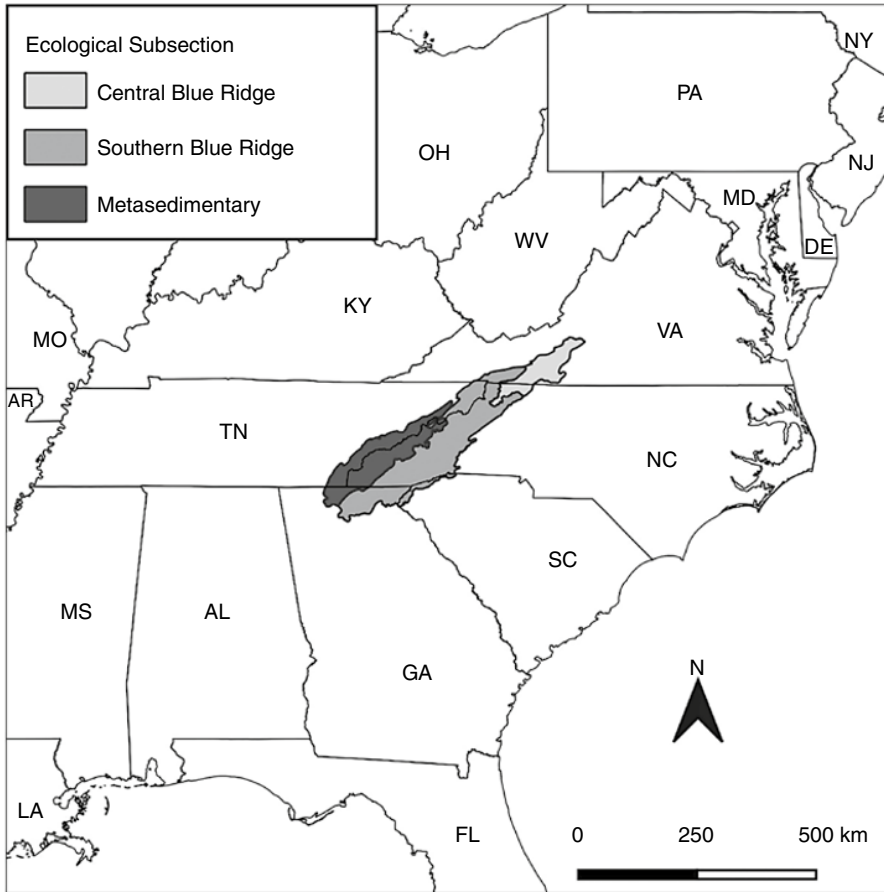


Figure 8.1 Location of Ecological Subsections forming the southern Appalachians.

regeneration methods on public lands. Commercial thinning and improvement cuts are uncommon in upland hardwoods due to inconsistent demand for pulpwood and high operational costs throughout the region.

8.2 Contemporary Forests of the Southern Appalachians

Current forests of the region are a legacy of land use practices from as far back as the 1800s. Europeans colonized the area using subsistence agriculture that involved frequent fire to clear forestland and stimulate forage production. Surrounding areas were harvested for fuel and construction materials, and over time land management practices increased in scale and frequency. Clearing practices intensified as industrialization expanded. By the early 1900s, over 50% of the forestland in the southern Appalachians was owned by private companies, and forests were cleared or severely high-graded for timber. Cutover and degraded forestland were eventually abandoned, along with traditional forest farming practices, and a portion of this land was incorporated into the National Forest System.

The introduction of chestnut blight (*Cryphonectria parasitica* (Murrill) Barr) to North America in 1904 functionally eliminated American chestnut (*Castanea dentata* (Marsh.) Borkh.) from this forest by the 1930s [2]. Before its decline, American chestnut comprised 36% of the basal area and

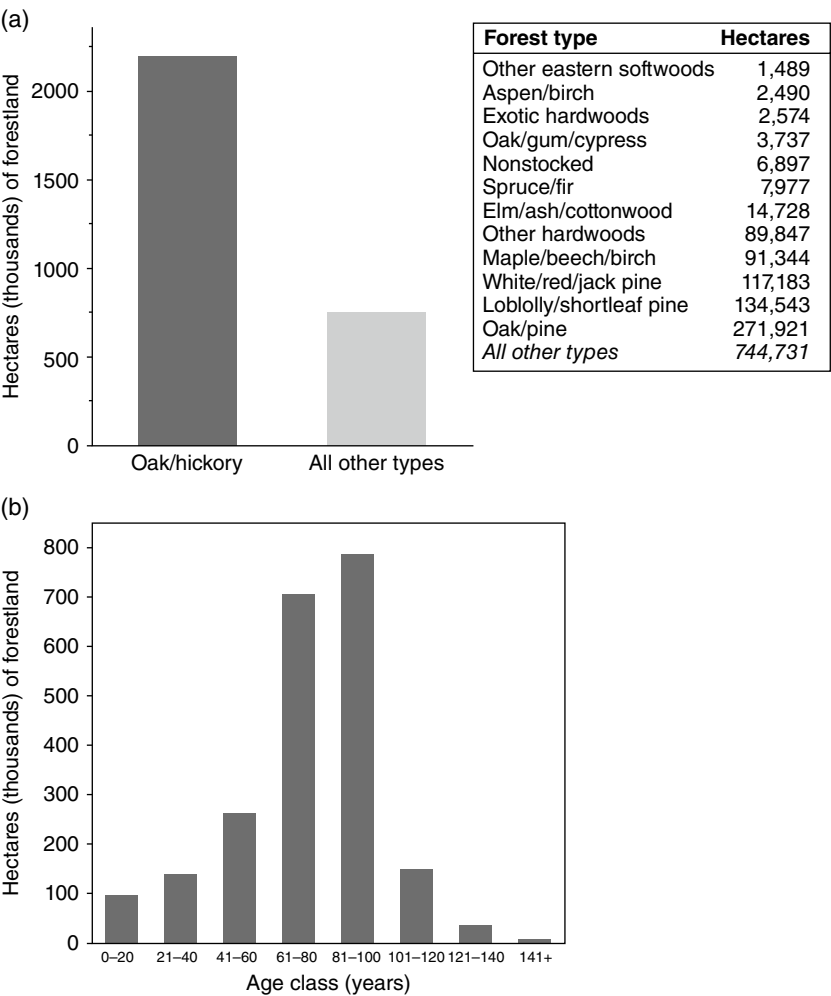


Figure 8.2 Distribution of forestland in the southern Appalachians by forest type group (a) and age class distribution of the most abundant forest type, oak-hickory (b).

22% of the density of the second-growth forests in the Blue Ridge Mountains [3]. The loss of American chestnut from the canopy released codominant and subordinate oak and hickory, which persisted through the period of frequent anthropogenic disturbance, thus allowing oak and hickory to recruit into dominant canopy positions where they remain in the contemporary landscape.

Anthropogenic fire was common throughout the eighteenth and nineteenth centuries [4]. Active fire suppression began in the mid-twentieth century which, coupled with a wetter climate and lack of other anthropogenic disturbances, allowed a suite of shade-tolerant and mesophytic hardwood species, including red maple (*Acer rubrum* L.), American beech (*Fagus grandifolia* Ehrh.), and blackgum (*Nyssa sylvatica* Marsh.), to dominate the midstory layer. This strata reduces light levels, limits air movement, and increases humidity, thus resulting in cooler and moister conditions in the understory than likely found in ecosystems historically influenced by frequent fire [5].

This history has led to contemporary landscapes dominated by forests where oak and hickory are canopy dominants but are not recruiting following disturbance events and mortality. This pattern is illustrated in tree establishment and growth release periods from a 200-year-old mixed oak stand in Pisgah National Forest [6] (Figure 8.3). Peaks in tree establishment during a transition in

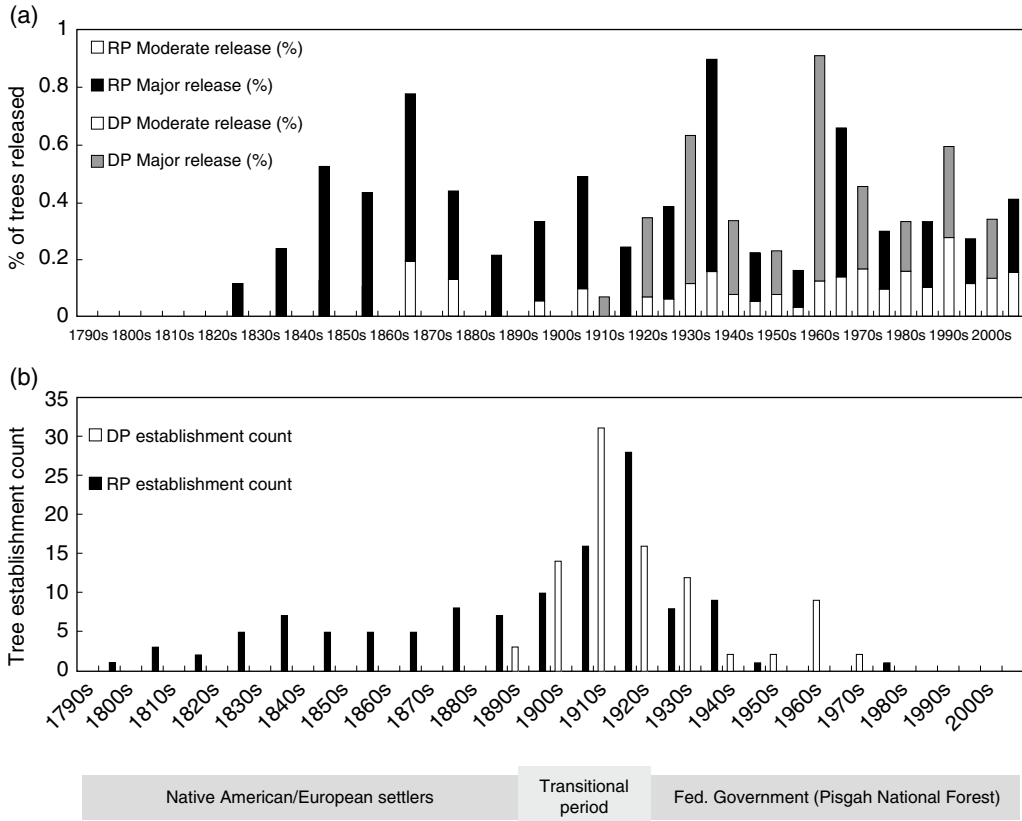


Figure 8.3 Growth release events (a) and establishment (b) of dominant species groups. Frequent burning and harvesting of this area before federal protection favored oaks and hickory (ring-porous species, RP). In contrast, after federal protection in 1914, the forest developed with less intensive management activities that reduced opportunities for oak and hickory but created conditions conducive to the establishment of more mesic species, including yellow-poplar and red maple (diffuse-porous species, DP). *Source:* Reproduced from Grover et al. [6].

ownership (1910–1930) highlight the effects of shifting forest land-use practices. These patterns are consistent across the region, resulting in a landscape of even-aged forests lacking species such as oak and hickory in the lower canopy strata compared to the mosaic of developmental stages, particularly the complex, multi-aged stands that once dominated the region [7].

8.3 Structure, Composition, and Development of the Southern Appalachian Mixed-Oak Ecosystem

8.3.1 Structure and Composition

The natural disturbance regime of mixed-oak forests is characterized by frequent, small-scale disturbances punctuated by intermediate disturbances of moderate extent and frequency. Much of the knowledge on natural dynamics of mixed-oak forests comes from the work available from cove forests, which are unique systems occurring in sheltered topographic positions on concave slopes that promote moist conditions. Canopy gap sizes vary from 25 to >1000 m², with most gaps <200 m² in size [8, 9]. Intermediate intensity disturbances create gaps ranging from single-tree-sized up to

10 ha [10], affecting forests at stand, watershed, and landscape levels. Stand reconstructions [8] suggest canopy gaps in old-growth cove forests form at an average rate of 1% per year on an area basis and are primarily caused by single-tree mortality, with an average rotation of 100 years. Age- or competition-related mortality is similar to mortality due to exogenous (e.g. drought, wind, insects/disease) disturbance events [11]. A recent study tracking tree populations 21 years after wind microbursts in second-growth mixed-oak forests corroborated that these patterns extend beyond cove forests. Mortality from small-scale disturbance (*background*) averaged 0.8% of stems dying per year compared to 39% cumulative mortality 21 years following a high-severity wind disturbance event [12].

Species assemblages in upland hardwood forests are complex, with over 90 arborecent species native to the southern Appalachians. Stands of moderate to high productivity contain a mixture of oak, along with numerous other genera and species also with intermediate shade tolerance (e.g. *Fraxinus americana* L., *Tilia heterophylla* Vent., and *Magnolia* spp.). These species have persistent reproductive strategies that rely on the presence of advance reproduction prior to and persisting through the disturbance. More mesophytic species with varying levels of shade tolerance also co-occur in these mixtures, especially as site productivity increases. The reproductive strategies of many such species, for example, rapid initial height-growth of yellow-poplar (*Liriodendron tulipifera* L.) from seed that can persist in litter for four to seven years, differ greatly from the persistence strategy common among the shade-midtolerant species.

Successful regeneration for persistent-strategy species, especially oak, is a multistep process that includes seed production, seedling establishment, and recruitment into the competitive sapling layer (i.e. large advance reproduction) [13]. Since oaks are generally mid-tolerant of shade (Figure 8.4), moderate overstory or mid-story disturbance is required for development of competitive advance reproduction (i.e. oak saplings >1.4 m tall) [14]. This oak understory is more likely to recruit to the overstory after release, thus sustaining oak as a dominant canopy tree species. Lack

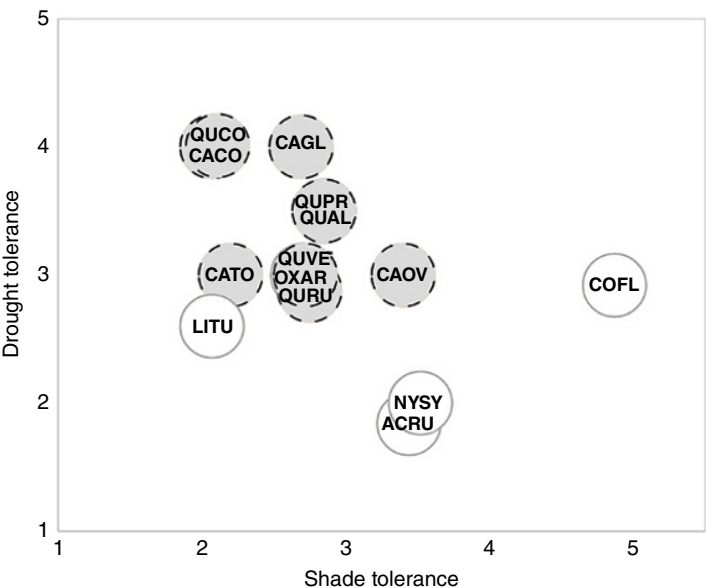


Figure 8.4 Sorting of common species as a function of their tolerance for shade and drought using rankings from Niinemets and Valladares [38]. *Quercus* and *Carya* species appear in green (upper left), while mesophytic species are hollow-fill (except OXAR, *Oxydendrum arboretum* (L.) DC.). ACRU, *Acer rubrum*; CACO, *Carya cordiformis*; CAGL, *C. glabra*; CAOV, *C. ovata*; CATO, *C. tomentosa*; COFL, *Cornus florida*; LITU, *Liriodendron tulipifera*; NYSS, *Nyssa sylvatica*; QUAL, *Quercus alba*; QUCO, *Q. coccinea*; QUGL, *Q. glabra*; QUPR, *Q. prinus*; QURU, *Q. rubra*; QUVE, *Q. velutina*. Source: Adapted from Niinemets and Valladares [38].

of disturbance prevents oaks from developing competitive advance reproduction and allows more shade-tolerant species to replace oak and eventually dominate the overstory canopy on moderate to good quality sites (e.g. [15]). If the canopy is opened without competitive advance oak regeneration, shade-intolerant competitors, such as seed-origin yellow-poplar, sweet birch (*Betula lenta* L.), and black cherry (*Prunus serotina* Ehrh.), quickly outcompete small, less competitive oak and hickory seedlings [14, 16] resulting in oak regeneration failure.

The interior of canopy gaps in contemporary forests is often dominated by yellow-poplar [17] and sweet birch [18], while advance reproduction of a variety of species near gap edges substantially increases in density, survivorship, and growth [19]. In oak forests of the Cumberland Plateau, oak seedlings exhibited greater growth extending 20 m from the edge of large created gaps [20], and light availability was elevated up to 12 m outside gaps [21]. Edge environments and their influence differ based on the origin type, shape, position on the landscape, or orientation.

8.3.2 Natural Development Model

A natural development model for oak-hickory forests (Table 8.1) describes the succession of the forest from disturbance through old forest stages. Following a large disturbance, multiple life-forms compete for resources and quickly fill in the understory and midstory layers of the

Table 8.1 Attributes of developmental stages in southern Appalachian oak-hickory forest ecosystems.

Stage or event	Attribute	Cause or Consequence
Disturbance and legacy creation	Spatially heterogeneous live and dead tree legacies, seedling and sapling layer representing diversity of regeneration mechanisms; small to moderate openings in matrix of second-growth even-aged forest	Results from recurring low-severity disturbances and less frequent, mesoscale events
Preforest	Advance regeneration, woody sprouts, vines, and herbs form a dense midstory and groundlayer within two years following disturbance	Rapid site capture through sprouting, seedling establishment from soil seedbanks or windblown seed, and release of advance regeneration when present
Young forest	Oak success depends on its initial crown position or persistence relative to other species	Crown closure is complete by 20 years after disturbance with well-defined crown classes in place. Self-thinning may cause approximately 80% mortality on average sites. Competitive sorting occurs with the composition of the stand at this stage being indicative of the future canopy
Mature forest	Diverse forest structure and age-class; large dead trees accumulate	Windthrow and breakage of canopy dominants allow for recruitment of new cohorts. Midtolerants recruit in large gaps following frequent burning, otherwise, intolerants or tolerants outcompete
Old forest	Dominated by mid-tolerant oak-hickory species in the overstory, with a lesser, but significant shade-tolerant and intolerant components	Long-term, frequent gap disturbance and fire result in diversity of live-tree size and age structures; complex deadwood conditions; multiple treefall gaps and mesoscale wind events create heterogeneity and foster tree diversity

developing forest. Fire at even low intensity during this early stage will give a competitive advantage to oaks, promoting seedling development by reducing fire-intolerant competitors. A moderate-severity disturbance occurring within decades after the large disturbance opens the canopy again and recruits the advance regeneration of oak and hickory that have accumulated. In the absence of fire, crown closure occurs within 20 years of the disturbance and the oak seedling bank fails to develop.

It is important to note that introduced pathogens and insects have significantly influenced stand dynamics and the developmental model. Mortality events in oak forests caused by pests and pathogens are often triggered by an inciting factor, most often drought in this region, causing stress and declines in growth. Periodic droughts have occurred historically, but enhanced hydroclimate variability has led to increased plant water stress and widespread tree mortality in recent decades [22] driven by decreases in precipitation and increases in temperature throughout the region [23].

8.4 Regenerating Upland Oak Forests in the Southern Appalachians

Regeneration harvests are the most common silvicultural activity conducted on public and private lands. Clearcutting was used extensively during the mid- to late-twentieth century to create open conditions that were thought to favor oak over less economically valuable shade-tolerant and intolerant species. Decades of research indicate that clearcutting on all but the most xeric sites fails to regenerate oak [24]. More recently, regeneration harvests on public lands have predominantly implemented a two-aged silvicultural system to meet multiple-use objectives. In a typical two-aged system, often referred to as an extended irregular shelterwood, overstory removal cuts are heavy (2–6 m² ha⁻¹ of residual basal area), and dispersed or aggregated reserve trees are often maintained throughout the rotation of the developing cohort to provide wildlife habitat, structural diversity, and eventually deadwood in the regenerating stand.

Development of large advance oak reproduction prior to substantial reductions in overstory density is critical to successful regeneration and recruitment of oak. In mixed-oak forests, a midstory removal treatment conducted approximately 10 years prior to a regeneration harvest (i.e. oak shelterwood) [14] is a critical step in any silvicultural prescription. The midstory removal treatment reduces stand basal area from below by 20–30% using herbicides to inhibit vigorous sprout competition [25]. The reduction in density provides an ephemeral increase in light in the understory [26], which can provide sufficient resources for mid-tolerant oak and hickory seedlings to develop beneath the intact overstory [27]. These treatments simulate burning that can effectively promote the fire-tolerant oaks over mesic fire-intolerant competitors.

Group selection, an uneven-aged silvicultural method, is implemented on public lands, though it is often not the most economical option for hardwood management (Figure 8.5). Although used successfully in other hardwood forest types where it resembles the natural disturbance patterns and subsequent regeneration process [28], when group selection is implemented in mixed-oak stands, yellow-poplar outcompetes oak and hickory even in small openings (>0.07 ha). Single-tree selection, which reduces diversity and favors shade-tolerant species, is not practiced. Exploitive diameter-limit harvesting or “high-grading” is common on private lands.

Prescribed fire has been promoted for regenerating oaks, but only recently have more silvicultural prescriptions been developed and tested. Understory burning in mature stands does promote oak



Figure 8.5 Multi-aged oak-hickory forest, Bent Creek Experimental Forest, North Carolina, USA (forest matrix, 12-year-old gap, and recent harvest area/gap in view).

regeneration, but the oak fails to reach competitive sizes without repeated burns which is often difficult to achieve. In Piedmont oak-dominated hardwood stands, a prescription that combines shelterwood harvest and repeated prescribed fire has successfully promoted oak regeneration to competitive size in the understory. The shelterwood-burn method [29] has incorporated the understanding that fires of sufficient intensity are required to significantly set back competitors such as yellow-poplar, but additional vegetation control is required to ensure oak is a significant portion of the stand.

8.5 An Ecologically Based Silvicultural System for Mixed-Oak Ecosystems

Differences in regeneration strategies among the most frequent and abundant species demand careful design and implementation of silvicultural treatments that favor the regeneration and recruitment of mid-tolerants, without simultaneously making growing conditions favorable for competitors. The template for such a design may come from our growing understanding of the multiple canopy disturbances – across space and time and of variable intensity – that were necessary for the successful regeneration and recruitment of the oak and hickory in contemporary canopies.

Based on the natural developmental model of mixed-oak forests and regeneration dynamics of the important species, we propose that an expanding-gap irregular shelterwood may best create conditions similar to the natural developmental sequence in mixed-oak forests that are needed to successfully regenerate and recruit mid-tolerant species (Table 8.2). This silvicultural system is largely implemented in the mature forest stage, so the developmental sequence is at the gap scale with gap expansion creating a mosaic of developmental stages at the stand level. These actions would result in conditions characteristic of the old forest stage of the natural development model. However, actions implemented in the preforest and young forest stages will work to increase the likelihood of successful regeneration in later stages.

8.5.1 Disturbance and Legacy Creation

An irregular group shelterwood regeneration method [30, 31], seeks to create multi-cohort stands over space and time. The initial entry is similar to a group selection harvest, but subsequent entries expand the gap created with the initial entry instead of creating new independent gaps. This pattern reflects the mosaic of gap-scale conditions across a landscape affected by intermediate disturbance.

Table 8.2 An ecological silvicultural system for southern Appalachian mixed-oak forests.

Stage	Years	Potential actions	Outcome
Disturbance/ Legacy creation	0	Initial harvest for an irregular shelterwood expanding-gap system (occurs in Mature or Old Forest); create snags and leave deadwood	Continuity of structure; initiate preforest stage
Preforest	1–10	Site preparation to remove non-merchantable stems following harvest Midstory removal treatment	Midstory removal treatments are important for manipulating understory conditions to favor development of mid-tolerant species
Young forest	10–40	Competition control; crown-touch release treatments	Increase competitiveness of established mid-tolerants
	40–70	Pre-commercial thinning; continued competition control; midstory removal	
Mature forest	70–120	Initial harvest followed by expansion entries every decade up to four times; additional entries to regenerate new areas; site preparation and competition control between entries	Increase growth and canopy heterogeneity; add microsite variability; establish new cohorts; release oak and hickory regeneration with subsequent entries; create 5 age classes
Old forest	100+	Oak and hickory should represent ≥30% of stand composition; expand natural gaps or initiate new harvest sequence	Enrich species, maintain structurally complex and diverse conditions

An initial harvest entry creates gaps similar to those that result naturally from both small-scale endogenous and exogenous events and intermediate-scale disturbance events. Gaps characterized following Hurricane Opal had a median size of 0.4 ha and ranged from the size of a single canopy tree to approximately 4 ha [32]. An experimental demonstration of the expanding-gap system, selected entry sizes of 0.1 and 0.4 ha based on the natural developmental model, operability, and economics, with the initial entry removing 25% of the area.

Each entry releases growing space for trees, some of which will be captured by shade-intolerant competitors, but along edge conditions, the mid-tolerants will establish and remain competitive. These entries across the landscape create patches of species diversity and variation in forest structure similar to gap dynamics underlying the natural development model for the ecosystem. Gaps can be located adjacent to existing advance regeneration to create advantageous edge effect. Retention can be incorporated within the initial entries or expansions, depending on intentions.

8.5.2 Preforest Stage

Silvicultural activities during a preforest stage would focus on-site preparation and control of competitive saplings and invasive shrubs and vines that fill in quickly. A midstory removal treatment, as described earlier, can create the open understory conditions characteristic of the landscape

before fire suppression policies and land abandonment in the early to mid-1900s. Competition control may be accomplished using prescribed fire, chemical treatments (injections or targeted sprays), or mechanical methods.

8.5.3 Young Forest Stage

Silvicultural actions during the young forest stage are similar to the preforest stage. Efforts would focus on developing oak and hickory seedlings into competitive saplings. Early in this stage, competition control around the developing regeneration is required to ensure continued presence. Crown-touch release treatments can be used to increase growing space around desirable trees.

Later, a pre-commercial thinning could provide a modest early economic return, but more to free resources for desirable species. Prescribed fire is avoided at this stage when species are most susceptible to damage. Mechanical or chemical treatments are used to control invasives.

8.5.4 Mature Forest Stage

The gap expansion entries are similar to patterns of border-tree mortality documented following gap-forming disturbances [33] and are designed to take advantage of the large advance reproduction that develops naturally within the periphery of created gaps. In addition, the expanding-gap system maintains the economic advantages of even-aged methods by reusing harvesting infrastructure established during the initial entry and provides landowners the opportunity for periodic income.

The expansions create openings of irregular patterns, modeled after natural gaps that are often more elliptical in shape than circular. Working towards an irregular shape promotes freedom to take advantage of any advance oak development in the periphery after gap creation. Wider expansions can be marked around gaps where favorable advance reproduction has developed but, smaller expansions or even delaying expansion for another cycle along gaps where advance reproduction has failed to develop. Both site preparation and competition control may be needed before or after each additional entry. Gap-level live tree retention could be incorporated as this would be expected in a downburst or hurricane patch.

The cutting cycle and the amount removed during each entry are flexible. While the baseline gap formation rate is minimally 1% per year from small disturbances, it can extend to nearly 40% of the total land area following less-frequent intermediate intensity disturbances. Using the baseline natural gap formation rate alone as a guide, entries might be designed to remove 10% of the stand every 10 years for a 100-year rotation. However, entries of this size may not produce enough volume to be economically or operationally feasible, so the entry schedule and area treated can be customized accordingly.

Each expansion entry will result in the production of an age class; if for example, four entries removing 25% of the stand each are planned, four age classes will result from each regeneration harvest, and the fifth age class will be the result of retention trees throughout the stand (e.g. inoperable or riparian areas). No harvesting is planned following the fourth entry for approximately 60 years. If timber production is among the management objectives, commercial harvest may occur at 60+ years. Initial entries would start the expanding gap cycle again, creating legacy conditions to promote regeneration of shade mid-tolerant and intolerant species.

8.5.5 Old Forest Stage

This old forest stage could be reached if stands are managed for alternative ecosystem services instead of timber production. Management for these stands may focus instead on wildlife habitat, biodiversity, carbon storage, watershed protection, resistance, and resilience to disturbances. Silviculture will focus on adding structure and maintaining or restoring species that had decreased in abundance. Activities might include prescribed fire or mechanical control of competing species in gaps where regeneration is focused. If harvesting is desired in the old forest stage, trees are marked so as to release advance regeneration of desirable species occurring near natural or prior harvested areas.

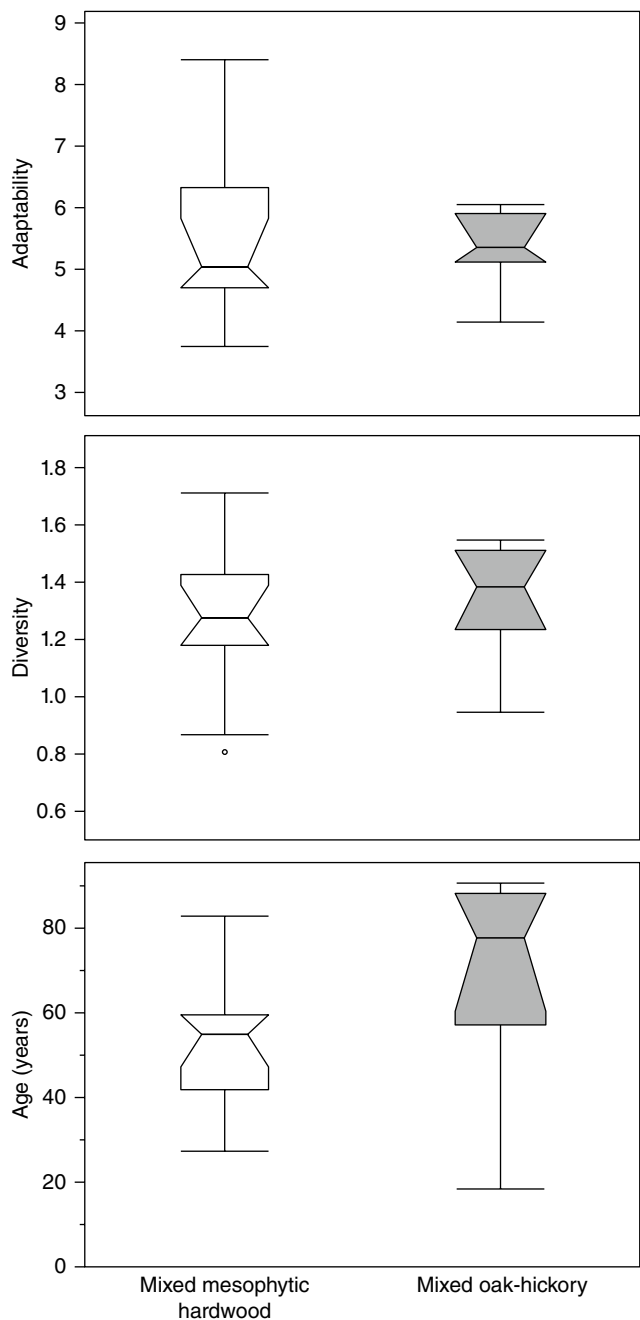
8.6 Climate Change Considerations

Oak-hickory forests already require active restoration strategies due to the altered disturbance regime under which they are established. Mixed oak-hickory forests are desirable as they have more consistent and greater adaptability and species diversity relative to mixed mesophytic forests (Figure 8.6). The compounding effects of a warmer and drier climate and range expansions of forest pests and pathogens may favor oaks over the long term [34], though various oak species will respond differently. In general, species in the white oak group are relatively more shade tolerant, longer-lived, slower growing, and more drought tolerant than species in the red oak group, resulting in higher adaptability scores for the white versus red oak group [35, 36]. Experimental evidence also indicates that two important white oak species (chestnut and white oak), when in dominant and codominant canopy positions, are not sensitive to stand density, stem size, or site productivity [37] indicating they will likely be less affected by future climate change. Management activities focusing on the regeneration, establishment, and retention of white oak versus red oak species may be a viable strategy for sustaining the growth and productivity of oak species with climate change. Ecologically based management that includes prescribed fire and thinning would reduce wildfire hazards and create more desirable oak forests.

8.7 Summary

Alternative silvicultural approaches will be necessary to ensure mixed-oak forests that provide a wide range of ecosystem services, remain an important component of southern Appalachian hardwood forests. By increasing the structural diversity of the current second-growth mixed hardwood forests, multi-cohort silvicultural systems based on the natural development model for these forests will increase floral and faunal diversity while enhancing disturbance and drought resilience. The design of the silvicultural system we present is based on the natural developmental model of the forest type, creating multiple entries of different shapes and sizes, and placed to expand off a previous entry to release the desirable mid-tolerant species that often successfully naturally regenerate in gap edge conditions. The variable-aged adjoining entries create a mix of microhabitats promoting species diversity and developing into a structurally diverse forest system. Gap-based silviculture offers an ecologically justifiable, operationally feasible, and publicly acceptable approach to upland hardwood regeneration. Such attributes are desirable to public land managers and the growing number of private landowners managing their forests to balance conservation, recreation, aesthetics, and production objectives.

Figure 8.6 Estimates of forest stand age, adaptability score, and Shannon-Weiner diversity calculated from FIA data from 825 stands in the southern Appalachians of North Carolina. FIA data were collected between 2011 and 2021 and represent plots with diverse ownership, last land-use history, and site conditions. Stand and stock data were used to calculate basal area-weighted stand-level adaptability, similar to the methods described in Kabrick et al. [39]. Adaptability scores range from 0 to 10, with a low score indicating lower capacity to tolerate or respond to predicted changes. *Source:* Adapted from Kabrick et al. [39].



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