Chapter 2
Gap-Scale Disturbances in Central Hardwood Forests with Implications for Management

Justin L. Hart

Abstract All forest ecosystems are subject to canopy disturbance events that influence species composition and stand structure, and drive patterns of succession and stand development. Disturbances may be categorized by a variety of characteristics, but they are most often classified along a gradient according to their spatial extent, magnitude, and frequency. This gradient spans from broad-scale, stand-replacing events where most of the overstory is removed to fine-scale events which result from the removal of a single canopy individual or a small cluster of trees. The disturbance regimes of most stands in the Central Hardwood Region are characterized by fine-scale events. At the stand scale, these localized and asynchronous events can create a patchwork mosaic of microsites comprised of different tree species, ages, diameters, heights, crown spreads, and growth rates. Through the modification of fine-scale biophysical conditions, these localized canopy disturbances promote heterogeneity and biodiversity in forest ecosystems. Forest management based on natural disturbance processes should consider elements of the gap-scale disturbance regime, such as frequency, size, shape, and closure mechanisms, and the historical range of variation associated with these characteristics. Silvicultural prescriptions are available for gap-based management designed to promote oak regeneration and mimic natural disturbance processes.

Keywords Canopy gap • Disturbance • Silviculture • Succession • Stand development

2.1 Introduction

All forests are subject to disturbance events which influence forest composition and structure and thus, drive successional and developmental pathways. Forest disturbances may be categorized by a variety of characteristics, but are most often

J.L. Hart (✉)
Department of Geography and Program in Environmental Science,
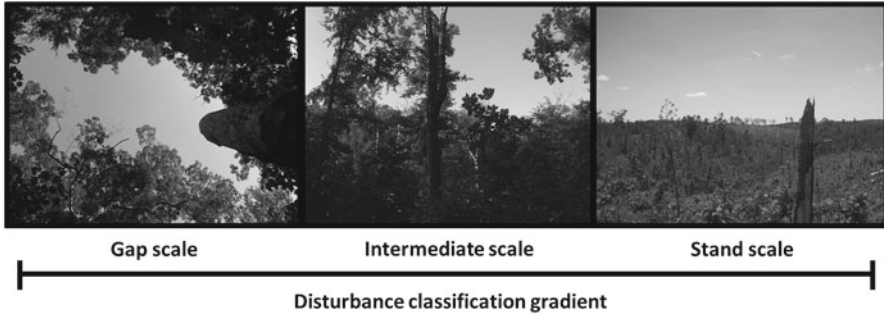University of Alabama, Tuscaloosa, AL 35487, USA
e-mail: hart013@ua.edu

Fig. 2.1 Disturbance classification gradient based on spatial extent and magnitude of a discrete disturbance event (Photographs by author)

classified according to spatial extent, magnitude, and frequency, and occur along a gradient that spans from fine-scale events that result from the loss of a single canopy tree or a small cluster of individuals to broad-scale, stand-replacing events when most of the overstory is removed (Fig. 2.1; Oliver and Larson 1996). The disturbance regimes of most hardwood stands in the Central Hardwood Region (CHR) (Greenberg et al. Chap. 1, Fig. 1.1) are characterized by fine-scale events (Lorimer 1980; Barden 1981; Runkle 1981, 1982, 1996, 2000; Cho and Boerner 1991). At the stand-scale, these localized canopy disturbances create a patchwork mosaic of microsites which may be comprised of different tree species, ages, diameters, heights, and crown spreads (Runkle 1981, 1985; Canham and Marks 1985; Phillips and Shure 1990). By modifying fine-scale biophysical conditions, these gap-scale canopy disturbances may increase heterogeneity and biodiversity in forest ecosystems (Putz 1983; Abe et al. 1995).

Canopy gaps are typically defined as visible void spaces in the main forest canopy within which gap stems are shorter than a specified threshold (e.g., 20 m) or shorter than a percentage of the canopy trees surrounding the void (e.g., <75 % canopy height), and a gapmaker tree or trees are present (Yamamoto 2000; Richards and Hart 2011). The area directly beneath the canopy void is typically considered to be the canopy gap (sometimes called the true gap, light gap, or observed gap). However, because this void area changes with time since gap formation, and insolation and other abiotic variables are not limited to the area directly underneath the canopy void, canopy gaps can also be described as the total terrestrial area below the gap and extending to the bases of the canopy trees surrounding the gap. This is termed the expanded or extended gap (Fig. 2.2; Runkle 1981). Canopy gaps may be characterized by a range of different physical parameters, but the metrics most commonly measured are canopy gap formation mechanisms, gap formation frequency, gap size and shape distributions, fraction of land in gaps, gap closure mechanisms, and advanced reproduction within gaps. In this chapter, I attempted to synthesize information on these characteristics from studies conducted throughout the CHR and provide recommendations for management based on natural gap-scale disturbance processes.
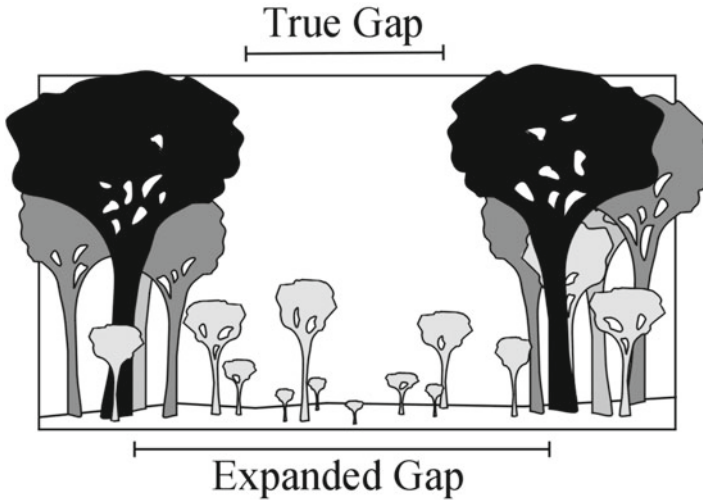
Fig. 2.2 The true gap (also called observed or light gap) and expanded gap (also called extended gap) environments. The *black* trees represent canopy dominants along the periphery of the gap

2.2 Gap Formation Mechanisms

Canopy gaps occur on sites where partial or total death of one or a small cluster of canopy individuals has occurred (Watt 1947; Runkle 1981, 1985). As such, canopy gaps may be caused by a variety of disturbance agents such as strong winds and insect outbreaks. Individual canopy gaps are formed by trees that have been uprooted (root network uplifted), stems that have been snapped (bole broken below the crown), or snags (standing dead trees with crowns mostly intact; Putz 1983; Clinton et al. 1993; Yamamoto 2000; Richards and Hart 2011).

Tree uprooting typically results from strong winds and may be related to soil depth where trees are not firmly anchored (Schaetzl et al. 1989), soil saturation which reduces soil cohesion and shear strength (Beatty and Stone 1986; Schaetzl et al. 1989), or biotic factors such as infection by the fungus *Armillaria mellea*, which weakens root systems (Williams et al. 1986). Uprooting may also be caused by crown asymmetry, which occurs as gap neighbors benefit from adjacent canopy gaps and undergo lateral branch growth to fill the void from the side, unequal crown growth of trees at different elevations on steep slopes, and/or twig loss and abrasion from wind (Young and Hubbell 1991; Rentch et al. 2010; Peterson et al. Chap. 5). In mesic hardwood stands of the CHR, wind-induced mortality is the predominant gap formation mechanism (Barden 1979; Runkle 1981, 1982, 1996). Snapped stem-formed gaps may be caused by strong wind events when the stem fails above ground level (Quine and Gardiner 2007) or by trees that first formed as snags that subsequently snapped. Snag-formed gaps are common in upland stands of the CHR (Clinton et al. 1993, 1994; Richards and Hart 2011). In this region, snag-formed

gaps are most typically found on xeric sites where water can be limiting and are hypothesized to often result directly or indirectly from water stress (McComb and Muller 1983; Hart and Kupfer 2011; Hart et al. 2012). Standing dead trees are often removed by mild to severe wind events and this process complicates formation-specific gap investigations because the category likely represents a combination of gaps that formed directly by stem snapping and those that first formed as snags. Snags that are eventually snapped likely create distinct microenvironmental conditions and the response of residual trees may differ between these gaps and those that are formed rapidly (Krasney and Whitmore 1992; Clinton et al. 1994).

Biophysical gap characteristics may be influenced by the formation mechanism and thus, gap environments and gap-phase processes may differ according to mode of tree mortality (Krasney and Whitmore 1992; Clinton et al. 1994; Himes and Rentch 2013). Gaps caused by uprooting may be larger in size and more elliptical in shape relative to snag-formed gaps that are often comparatively small and circular (Hart and Grissino-Mayer 2009). Gaps formed by uprooting are also more likely to involve two or more canopy trees compared to snag-formed gaps as the fall of an uprooted gapmaker has a greater probability of removing neighboring individuals (Yamamoto and Nishimura 1999). Snag gaps are typically smaller in size and they release growing space more gradually as they shed limbs rather than instantaneously. I note however, that once the snag is barren of leaves the majority of the growing space has been released as woody material restricts a relatively small proportion of insolation. Additionally, composition of gaps created by uprooting events may differ significantly from that in gaps created by snags or snapped stems (Hart and Kupfer 2011). Such patterns may be attributed to the physical alteration of the gap environment by the uprooting process as intra-gap heterogeneity caused by uprooting canopy trees (e.g., pit and mound topography) has been shown to be an important determinant of species composition in gaps (Hutnik 1952; Putz 1983; Runkle 1985). However, gap formation is coupled with other factors. For example, soils, slope aspect, and steepness influence the gap formation mechanism and the gap formation mechanism in turn influences gap size. Hart and Kupfer (2011) found that snag-formed gaps were most common on south-facing slopes on soils with low moisture holding capacity on the Cumberland Plateau in Tennessee. Species composition of these gaps differed from that of gaps caused by tree uprooting; however, tree uprooting was largely restricted to north-facing slopes on soils with higher moisture holding capacities. Thus, although forest community response to a disturbance event is constrained by the physical environment, the disturbance regime itself may also be strongly influenced by the physical setting.

2.3   Gap Formation Frequency

Disturbance regimes and forest response to discrete events vary by forest developmental stage attributed largely to differences in species composition, stand structure, and tree age distributions (Table 2.1). Exogenous disturbance events are stochastic

**Table 2.1** Typical canopy gap characteristics in relatively young and old central hardwood forest stands

Characteristic	Young	Old
Gap frequency	High	Low
Gap size	Small	Large
Gap duration	Short	Long
Gap fraction	–	–
Gap closure	Lateral crown expansion	Sub-canopy height growth

and not related to stand age, but responses of residual trees to these discrete events may differ (e.g., some old trees may be less likely to respond to increased resources and growing space compared to younger, more vigorous individuals).

Although gap formation frequency varies through time (because of the stochastic nature of exogenous disturbance) and by stage of development (because of the factors listed above), estimates on the rate of canopy gap formation have been developed. For hardwood stands in the CHR, the canopy gap formation rate is typically 0.5–2 % per year (Runkle 1982, 1985). Based on these values, the average time between natural canopy disturbances for a given site is 50–200 years (Runkle 1985). However, some recent research indicates that exogenous canopy gap formation rates may have declined over the past 400 years in white oak (*Quercus alba*) stands of the eastern USA (Buchanan and Hart 2012). The authors speculated this pattern may have been attributed to changes in drought frequency and intensity, changes is anthropogenic land-use patterns, and the extinction of Passenger Pigeon (*Ectopistes migratorious*) (Greenberg et al. Chap. 12). Thus, the estimated gap formation rate (i.e., background mortality) of 0.5–2 % per year may be slightly lower than that of centuries prior because of changes in the frequency of exogenous disturbance events. I stress that this pattern has not been found in all canopy disturbance reconstruction studies in the region. For example, Rentch et al. (2003) did not find differences in canopy gap formation frequency in five old-growth oak stands across the 1700s, 1800s, or 1900s. More research on potential changes in canopy gap formation in central hardwood forests is warranted.

The proportion of stands in the eastern USA in the complex stage of development at European settlement was estimated to be much higher than at present (Whitney 1994; Lorimer 2001). In complex stage stands canopy tree heights and crown volumes are more highly variable, which creates more complex canopy topography (Oliver and Larson 1996). Stands with old trees and with more complex canopy topography are more likely to experience damage (i.e., localized tree mortality) from strong wind events (Runkle 1985; Foster 1988; Quine and Gardiner 2007). Thus, a single storm event may influence stands differently across stages of development, with stands in the complex stage being the most sensitive to wind-induced damage. Although the frequency and intensity of severe wind events in the eastern USA may not have changed over the past few centuries, the conversion of stands throughout the CHR to more simple structures may have reduced the frequency of localized canopy disturbances in these systems, which may in turn have influenced regeneration patterns.
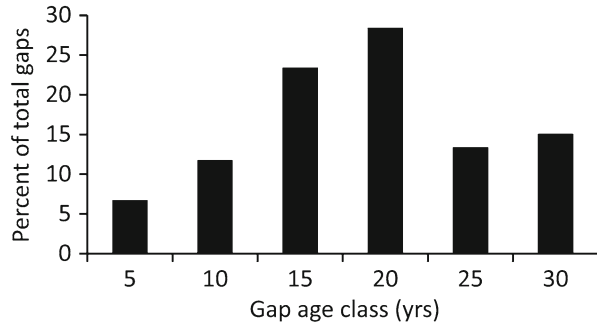
If the gap closure rate approximates the gap formation rate in a stand, gap fraction is considered to be in dynamic equilibrium (Himes and Rentch 2013). If gap formation and gap closure are in equilibrium, the gap age distribution should reveal a high frequency of young gaps and the number of gaps should decline with increased age. However, superimposed over the natural background mortality rate are exogenous disturbances; events which may create a high frequency of localized, gap-scale disturbances throughout a stand. These punctuated events may cause the gap age distribution to become irregular (Fig. 2.3).

The most commonly used disturbance classification terminology is based on spatial extent and magnitude of damage caused by a discrete event (Oliver and Larson 1996). However, for some events it may be the timing of formation that dictates the disturbance classification (e.g., gap-scale v. intermediate-scale disturbances). For example, strong wind events may remove trees singularly or in small groups (i.e., create localized canopy disturbances) throughout a stand. The size of individual canopy disturbances may be of the scale that constitutes a gap, but if the gaps were created across a broad area of the stand the disturbance may in fact have removed enough basal area to be considered of the intermediate scale. In such instances it would be gap formation rate that determines the disturbance classification. Disturbance history reconstructions using tree-ring records and forest inventory data have been conducted in some hardwood stands of the CHR. The common convention in these studies is to classify gap-scale disturbances that removed trees from at least 25 % of the stand as stand-wide events. The return interval of these stand-wide events was typically 20–40 years (Nowacki and Abrams 1997; Ruffner and Abrams 1998; Hart and Grissino-Mayer 2008; Hart et al. 2012). At the stand scale, these disturbance events may have removed enough basal area to be considered intermediate-scale disturbances, but the mortality was localized (i.e., gap scale) throughout the stands.

2.4 Canopy Gap Sizes and Shapes

Canopy gap size is highly variable and is influenced by factors such as the number of trees removed, the height and crown volume of removed trees, and the gap formation mechanism. The range of gap sizes reported from hardwood stands in the CHR

ranges from 5 m^2, in gaps that are just about to close, to greater than 4,000 m^2 (Barden 1980; Clinton and Baker 2000; Hart and Grissino-Mayer 2009). Some authors have suggested that canopy disturbances exceed the size of canopy gaps (i.e., they are not gap scale, but intermediate- or stand-scale events) if the canopy void space exceeds 1,000 m^2 (Yamamoto 2000). Nonetheless, gap-scale disturbance studies from the central hardwood forests have typically found true canopy gaps to range from 30–140 m^2 and expanded canopy gaps to typically range from 200–500 m^2 (Barden 1980, 1981; Runkle 1981, 1982, 1990; Runkle and Yetter 1987; Clinton et al. 1993, 1994; Hart and Grissino-Mayer 2009; Richards and Hart 2011; Himes and Rentch 2013). Gap size may also be expressed in relation to adjacent canopy tree height by comparing gap diameter to mean canopy height (D:H). Such comparisons in central hardwood forests have found that the D:H of most gaps is <1.0 (Runkle 1985; Richards and Hart 2011).

Canopy gap shapes typically range from circular to elliptical, but gap shape varies and the patterns can be blocky rather than elliptical (Lima 2005). However, the majority of gap-based research in central hardwood forests has noted elliptical shapes (Runkle 1982, 1992; Clinton et al. 1993; Hart and Grissino-Mayer 2009, Richards and Hart 2011). Gap shapes may be quantified by calculating the gap length (longest axis of the gap) to gap width (longest distance perpendicular to length) and analyzing the length-to-width ratio (L:W; Hart and Grissino-Mayer 2009; Rentch et al. 2010; Richards and Hart 2011). The gap formation mechanism may be a strong determinant of gap shape. Snag-formed gaps tend be more circular in shape and have L:W of about 1.0. In contrast, gaps formed by uprooted and snapped stems tend to be more ellipsoidal with L:W of >2.0 (Hart and Grissino-Mayer 2009).

2.5   Canopy Gap Fraction

Canopy gap fraction is the percent of a stand that is within a true or expanded canopy gap. Gap fraction in central hardwood forests for true gaps typically ranges from 3–25 % and for expanded gaps often ranges from 8–30 % (Romme and Martin 1982; Runkle 1982; Runkle 1985; Keller and Hix 1999; Busing 2005; Hart and Grissino-Mayer 2009; Himes and Rentch 2013; Weber 2014). Although gap frequency and size vary by stage of stand development, gap fraction may be rather similar. Hart and Grissino-Mayer (2009) found gap fraction in upland oak stands on the Cumberland Plateau at age 80 years approximated the values reported from much older stands throughout the region. Thus, the percentage of land area in gap environments in relatively young and old stands was similar, but the distribution of the gap area was quite different (Table 2.1). Young stands are characterized by a high frequency of small gaps and older stands are characterized by a relatively small number of large gaps.

2.6 Gap Closure and Structural Development

Hardwood stands during the stem exclusion and understory reinitiation phases of development are characterized by high densities of relatively small individuals of similar age (Oliver and Larson, 1996). Intense competition for resources and self-thinning in developing stands result in a high frequency of localized canopy disturbances (Clebsch and Busing 1989; Hart and Grissino-Mayer, 2009). In such systems, when a canopy individual dies residual neighboring stems are able to quickly capture the released growing space and close the canopy void via lateral crown extension, thereby altering tree size, tree architecture, and stand structure (Hart and Grissino-Mayer 2008). Conversely, during the complex stage of development stands contain fewer individuals and have reduced competition and mortality rates resulting in a reduced frequency of endogenous canopy disturbance events (Zeide 2005). Most canopy trees in complex stage hardwood stands have comparatively large crowns and when one of these individuals is removed from the canopy, a relatively large void is created and peripheral trees are often incapable of closing the gaps through lateral crown extension (Tyrell and Crow 1994; Yamamoto 2000). These larger gaps should require relatively long periods to close because of their size, which increases the probability of a new individual recruiting to a dominant or codominant position through subcanopy ascension (Runkle 1985; Rentch et al. 2003; Webster and Lorimer 2005; Zeide 2010). These comparatively large gaps in old stands may also allow for the establishment of new individuals and may therefore promote multi-aged stands. In the absence of exogenous disturbance events, structural changes with maturity are driven by these localized canopy disturbances (Johnson et al. 2009). Indeed, it is gap-scale disturbance processes that create the complexity that defines old-growth structure in hardwood systems (Oliver and Larson 1996; Frelich 2002; Richards and Hart 2011).

2.7 Gap-Phase Succession

Forest community responses to gap-scale disturbances are influenced by a range of gap characteristics such as size (Runkle and Yetter 1987), age (Brokaw 1985), formation frequency (Canham 1989), formation mechanism (Putz 1983; Clinton et al. 1993), distance from edge (Kupfer et al. 1997), topographic position (Clinton et al. 1994; Abe et al. 1995) and orientation (Poulson and Platt 1988) among others. Throughout the CHR, light is commonly the most limiting factor (Oliver and Larson 1996) and gap characteristics are important because of their direct influence on understory light regimes (Canham et al. 1990). Gap-scale disturbances influence all forest strata, but the biophysical changes caused by local canopy removal are typically most evident in the regeneration layer (Brokaw and Busing 2000; Yamamoto 2000). Responses in this stratum are important because saplings represent the pool of species likely to recruit to larger size classes, so sapling composition in gaps is

often an important determinant of future canopy composition in stands with disturbance regimes dominated by gap-scale processes (Wilder et al. 1999; Taylor and Lorimer 2003).

Gaps are stochastic and favor species in the understory or midstory of the gap environment. Without competition from shade-tolerant mesophytes, oaks have the physiological capability for long-term survival beneath an oak-dominated canopy, and may be considered a gap-phase genus (Orwig and Abrams 1995; Abrams 1996; Rentch et al. 2003) as these trees are able to persist in low light conditions and maintain the ability to respond to increased resources associated with canopy disturbance in their vicinity. During the twentieth century, the understory strata of oak-dominated stands across a variety of site types came to support a high density of shade-tolerant individuals, principally red maple (*Acer rubrum*) and sugar maple (*Acer saccharum*) (i.e., the oak-to-maple transition; McEwan et al. 2011). The driver of this widespread understory composition shift may vary according to site, but was likely a function of climate change, herbivore population density fluctuation, loss of American chestnut (*Castanea dentata*) and Passenger Pigeon (*Ectopistes migratorious*) (Greenberg et al. Chap. 12), changes in land-use patterns, and modification of the fire regime (Lorimer 1993; Abrams 2003; Nowacki and Abrams 2008; McEwan et al. 2011; Grissino-Mayer Chap. 6). When a canopy gap forms in a stand exhibiting the oak-to-maple transition, the probability of a shade-tolerant individual being in the gap environment is greater than the likelihood of a shade-intolerant or moderately-tolerant species being in the gap. Furthermore, small canopy gaps typically close quickly by lateral crown expansion and may not permit enough time for even fast growing shade-intolerant species to colonize the gap environment and then ascend to the canopy prior to gap closure. For these reasons, gap-scale disturbances typically favor shade-tolerant species. As canopy oaks die in oak-dominated stands, the gaps formed provide a mechanism for shade-tolerant stems that are abundant in the understory to recruit to larger size classes and to ascend to canopy positions. This gap-scale process is driving the observed successional replacement of oak by maple throughout central hardwood forests.

2.8   Gap-Based Management

In recent decades, there has been a fundamental philosophical change in the management of forest resources. Increasingly, managers are utilizing approaches that emulate natural ecological processes including natural disturbance regimes (Franklin and Johnson 2012; Hanson et al. 2012; Zenner Chap. 14). This approach emphasizes creating structures and community assemblages through silviculture that are similar to those that were historically produced by natural disturbance processes (Seymour and Hunter 1999). Wind is the most common and arguably the most influential canopy disturbance agent in hardwood forests of the eastern USA (Runkle 1996). The goal of natural disturbance-based management is not to mimic the actual disturbance event (i.e., trees are not typically felled by winching to

emulate the effects of strong winds), but rather to use the effects of such events (e.g., the altered light regime) as models for individual and cumulative silvicultural treatments with the goal of minimizing the structural, compositional, and functional disparities between managed and unmanaged stands. The rationale for such an approach is that emulation of natural events restores and/or maintains resilience to a range of environmental challenges, critical ecosystem functions, and native forest biodiversity (Long 2009). The success of this management approach requires clear and tangible guidelines that are based on quantitative data from stands that are situated in similar biophysical settings and are therefore appropriate analogues (Seymour et al. 2002; Franklin et al. 2007).

Uneven-aged management approaches have commonly relied upon single tree and group selection systems (Nyland 2002). Removing trees singly or in small groups will certainly emulate the sizes of naturally formed canopy gaps. However, through much of the CHR, markets have historically not supported such an approach. As a consequence, operators are often not experienced with single tree and group selection harvests. In addition, single tree and small group selections typically promote shade-tolerant species, and with few exceptions, this approach has not worked to maintain strong components of moderately-tolerant taxa such as oak and hickory (*Carya* spp.) in the CHR (Nyland 2002; Johnson et al. 2009).

A gap-based silvicultural approach that utilizes even-aged treatments applied in groups rather than evenly throughout an entire stand may be sufficient to maintain dominance of moderately-tolerant taxa such as oak and hickory, be economically viable throughout central hardwood forests, and fall within the historical range of variation of the disturbance regime. Oak stands in this region are most often managed with an even-aged approach; by modifying the size and spatial arrangement of even-aged treatments, managers may be able to fulfill multiple management objectives: commodity production, oak maintenance, and entries that fall within the historical range of variation.

I emphasize that there is no specific gap size that is guaranteed to promote oak recruitment (Lhotka 2013). Rather, gap size should be viewed based largely on the D:H. Oak reproduction will usually grow well if stems receive 20–50 % of full sunlight, which is typically met in gaps with a D:H of about 1.0 (Marquis 1965). Gaps of this size may be slightly larger than most naturally formed single tree fall gaps of central hardwood forests (Runkle 1985), but may still fall within the historical range of variation and may approximate the size of natural multi-tree fall events. In addition, such approaches should be placed strategically around existing oak advanced reproduction. The return interval of stand-wide, canopy disturbance events reported from hardwood stands through the CHR is 20–40 years. This return interval may be used to help guide the timing between entries in a single stand. Subsequent entries could create new group selection openings or could expand the size of the gaps created prior (i.e., femelschlag; Lhotka and Stringer 2013). I also note that the canopy gap formation rate of 0.5–2 % per year reported from the region may be somewhat low compared to centuries prior (Buchanan and Hart 2012) although more data are needed to verify this claim. Nonetheless, larger or more frequent harvest-created gaps may not be outside the historical range of variation in the disturbance regime.

For those who wish to adopt a management approach that emulates natural disturbance processes, it is important to recognize that many of the contemporary oak-dominated stands that occur throughout the CHR of the eastern USA were not the result of natural disturbance events (Cowell 1998, Foster et al. 2002). Managers that wish to maintain oak dominance and adhere to a natural disturbance-based management approach will likely need to make a compromise between a silvicultural system designed to emulate natural disturbances and one designed to maintain desired species assemblages. Oak regeneration failure has been reported widely across all but the most xeric site conditions throughout the CHR (Abrams 1992, Lorimer 1993, Nowacki and Abrams 2008, McEwan et al. 2011). Although variability exists at the species-level, oak are generally considered only moderately tolerant of shade, and canopy disturbance events that increase insolation in the understory are required for regeneration (Dey 2002). These canopy disturbances must be sufficiently large to provide adequate light levels for small oak, but not so large that they allow for the establishment of shade-intolerant species that can outcompete oak in high light environments (Runkle 1985, Grayson et al. 2012). Thus, gap opening size and the density and size of oak and its competition are critical factors to be considered in developing a silvicultural prescription to maintain oak dominance. In stands with a significant component of shade-tolerant mesophytes in the understory and where the management objective is to maintain oak, entries designed to release advanced oak reproduction should be implemented in conjunction with competition reduction measures such as fire or herbicide application (Loftis 1990, Schweitzer and Dey 2011, Hutchinson et al. 2012, Brose et al. 2013). Oak seedlings are often abundant in successional stands with abundant shade tolerant stems in the understory, but most of these oak seedlings will not recruit to sapling or small tree size classes and may be considered ephemeral (i.e., the oak bottleneck). Without competition reduction measures, advanced oak reproduction will be sparse, and oak reproduction should be in place before overstory trees are removed (Johnson et al. 2009). Although competition removal may fall outside the historical range of variation, these actions may be essential to maintain oak dominance in stands with strong maple or other shade tolerant components. Competition reduction is not without its problems. For example, many managers have found that prescribed fire is not an effective control measure for a prolific sprouting species like red maple and herbicide can be cost prohibitive.

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