STUDY PLAN
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An expanding gap version of group selection (Irregular shelterwood, Femelschlag) to regenerate oak and restore complexity on productive sites in the southern Appalachian Mountains

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Tara L. Keyser and Jason A. Rodrigue

1. Background

Goals and objectives associated with forest management on public lands have evolved over the past few decades from primarily timber production and extraction to those associated with ecosystem-based management (e.g., conservation of biodiversity, sustaining ecological integrity, etc.). The underlying premise of 'ecological' forestry is to manage forests in such a way that management practices create and/or maintain forest structure, function, and composition within limits defined by the historic range of variability prior to human alteration of the landscape (Seymour and Hunter 1999). The goals associated with this approach to forest management are common across forest types (e.g., maintain within-stand complexity, conserve biological legacies, restore species diversity, conserve biodiversity, etc.). However, because specific silvicultural prescriptions used to achieve these common goals under guides of ecological forestry are designed to emulate a system's natural disturbance regime, treatments vary significantly not only among, but also within forest types (e.g., Franklin et al. 1997, Wilson and Puettmann 2005, Seymour 2005, North and Keeton 2008). By using the natural disturbance regime as a guide, this disturbance-based approach to forest management attempts to recreate the conditions that promoted the conservation of biodiversity and complexity in ecosystem structure and function proposed to exist prior to human influence (Seymour and Hunter 1999, North and Keeton 2008).

Prior to Euro-American settlement, upland hardwood forests of the southern Appalachian Highlands were diverse and complex at both the stand- and landscape-level. Topography and associated variability in resource availability and disturbance regimes across the southern Appalachians created a diverse pattern of forest types across the landscape ranging from those dominated by yellow pines [Virginia (*Pinus virginiana* Mill.), shortleaf (*P. echinata* Mill.), pitch (*P. rigita* Mill.), Table Mountain (*P. pungens* Lamb.) pine] at lower elevations and south- and west-facing slopes (Stanturf et al. 2002) to spruce/fir (*Picea rubens* Sarg./*Abies fraseri* (Pursh) Poir.) and northern hardwood forest types at higher elevations. Bounded by these communities, were forest types dominated by a mixture of oak (*Quercus*) and hickory (*Carya*) species along with mixed-mesophytic (i.e., cove hardwood) forests.

In the southern Appalachians, most active forest management occurs in mid-elevation forests where mixed-oak forests dominate the landscape. Stand reconstruction studies conducted in old-growth temperate hardwood forests suggests the structure and composition prior to Euro-American settlement in these mixed-oak forests was complex, with high levels of heterogeneity at both the stand- and landscape level (Rentch et al. 2003a, b). Widespread exploitative logging and other factors associated with Euro-American settlement (e.g., land clearing and subsequent land abandonment, wildfires, grazing, etc.), combined with widespread clearcutting on public lands in the mid- to late 20th century effectively homogenized species composition in many places (e.g., conversion of mixed-oak stands to pure yellow-poplar) and reduced the structural complexity at both the stand- and landscape levels (Lorimer 1989, Runkle 1982, Rentch et al. 2003a, b).

1.1.Natural disturbance regime

Although the natural (i.e., without human influence) disturbance regimes of temperate hardwood forests, including upland mixed-oak forests, have not been fully quantified, it appears the disturbance history is similar to that of other eastern US forest types, including mixed-mesophytic throughout the Central Hardwood Region and northern hardwood forests (Lorimer 1989). This disturbance regime was dominated by frequent, small-scale disturbances punctuated by intermediate disturbances of moderate extent and frequency (Rentch et al. 2003a,b). Estimates from stand reconstruction studies by Runkle (1982) suggest canopy gaps in old-growth mesophytic forests form at an average rate of one percent per year on an area basis (range 0.5 to 2 percent/yr), and are primarily caused by single-tree mortality, with an average rotation of 100 yrs (range 50 to 200 yrs). These estimates are similar to those reported by Lorimer (1980) who found canopy gap creation due to age- or competition-related mortality occurs at a rate of 0.06 percent per year, but an additional 0.06 to 0.08 percent per year occurs due to exogenous (e.g., drought, wind, insects/disease) disturbance events. A recent study in second-growth upland mixed-oak forests in the southern Appalachians suggests a slightly higher annual rate of mortality than observed in old-growth forests with mortality rates of oak species alone occurring at rates of one percent per year due to oak decline and small-scale wind events (Greenberg et al. 2011). Gap sizes created by endogenous or exogenous disturbance events vary from as low as ~25 m^2 (Runkle 1982) to >1000 m^2 (Romme and Martin 1982, Rentch et al. 2003a), with most gaps <200 m^2 in size (Rentch et al. 2003a).

These small-scale background disturbances occur frequently on the landscape and represent the background disturbance rate for temperate hardwood forests. Superimposed on this background disturbance regime are intermediate disturbances; the effects of which have simply not been sampled during past stand reconstruction efforts due to the temporal and spatial stochasticity of these events. Intermediate disturbances are characterized by a lower frequency of occurrence, often create a larger range of gap sizes, and occur with longer return intervals than observed during small-scale, gap dynamics. Despite variability in the intermediate disturbance regime, recent studies suggest tree mortality following a single intermediate disturbance can equivalent to that which occurs during one to three decades of background (i.e., small-scale gap creation) mortality (Woods 2004)

Intermediate disturbances common to the southern Appalachians include hurricane-related wind and rain events, downbursts, and ice storms. These types of disturbance events occur at a regional scale upwards of every 20 years (McNab et al. 2004, Whitney and Johnson 1984), but may occur less frequently at a localized or stand-level scale (Wooten et al. 2008, White et al. 2011). Although return intervals are difficult to quantify because of the stochastisity of these events, relatively frequent return intervals at a stand or watershed level have been observed. For example, in the Appalachian Mountains of Virginia, four major ice storms occurred in a single stand between 1914 and 1998 (Lafon and Speer 2002) while the remnants of three hurricanes affected stands within portions of the Blue Ridge Mountains in western North Carolina between 1995 and 2004 making the mean return interval for these disturbances 21 and 3 years, respectively. Similarly, two major ice storms that affected vast areas of eastern Kentucky were recorded between 2003 and 2009 (mean return interval of 3 years) suggesting intermediate disturbances may not be as uncommon as suggested by stand reconstruction efforts in old-growth forests (e.g., Busing 2005). Gaps created during these events often have high-levels of within-gap complexity, defined by the amount of overstory canopy that remains following these disturbances (e.g., Mou and Warrillow 2000, Lafon and Speer 2002, Hanson and Lorimer 2007). Gap sizes created during intermediate disturbances vary greatly ranging from as small as a single-tree fall gap (e.g., <100 m^2) to 10 ha (Hanson and Lorimer 2007, McNab et al. 2004, Mou and Warrillow 2000) and can affect forests at the stand, watershed, and landscape level (**Fig. 1**). For example, in the case of a single hurricane-related wind event in western North Carolina, as much as 15% of the forested areas of the Nantahala National Forest were severely affected by blowdown events (William Culpepper, personal Communication, sensu Elliott et al. 2002) emphasizing the role these intermediate disturbances have in controlling stand dynamics at multiple spatial and temporal scales. Although intermediate disturbances greatly affect ecosystem structure and function (e.g., Greenberg and McNab 1998, Elliott et al. 2002, Hanson and Lorimer 2007), data that describes the various components of this disturbance regime (e.g., frequency, extent, rotation length, etc) are, for the most part, lacking due to the stochastic nature of these disturbance events (Beverly Collins, *personal communication*).

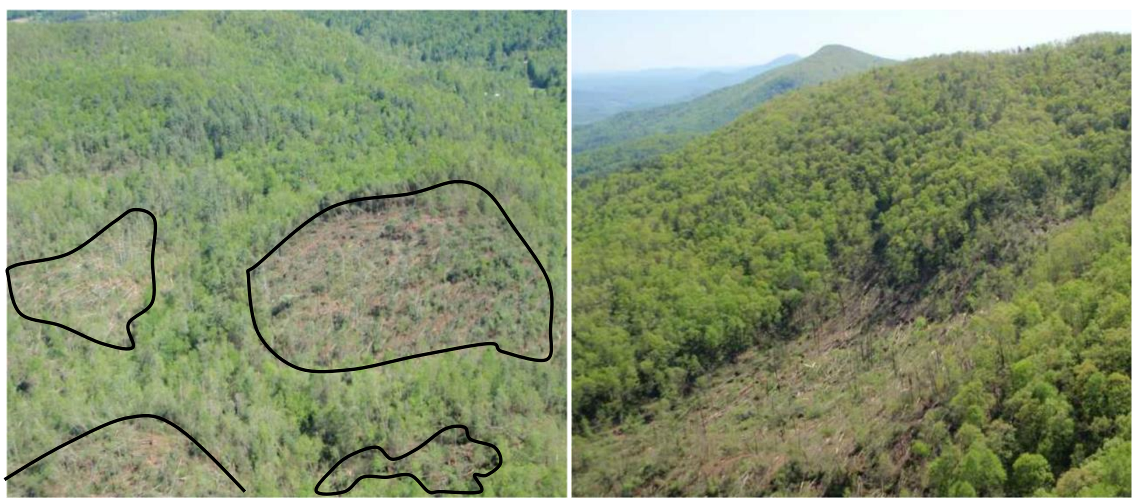

Figure 1. Wind-related disturbance in mixed—hardwood forests of northern Georgia. Photos from Pat Hopton, USDA Forest Service, Chattahoochee-Oconee National Forest.

The influence of disturbances on forest structure and composition is widely recognized (Pickett and White 1995). Prior to Euro-American settlement, small-scale gap dynamics coupled with intermediate disturbances created and maintained a mutli-aged structure dominated by oaks (and chestnut (*Castanea dentata*) prior to introduction of the chestnut blight). Abundant evidence suggests burning by Native Americans was prevalent at a regional scale across the southern Appalachians, and likely served as an additional exogenous disturbance event controlling species composition and stand structure (Delcourt and Delcourt 1997). For example, Brose et al. (2001) have hypothesized that repeated low intensity fire may have been key to the maintenance of mid-tolerant oak species [and American chestnut (Delcourt and Delcourt 1998)] prior to Euro-American settlement and subsequent fire suppression efforts by eliminating more shade-tolerant and less fire-resistant species, such as red maple.

Although natural, lightning-caused (i.e., natural) fires were of importance in maintaining yellow-pine dominated systems [e.g., Table Mountain/pitch pine (Williams 1998, Brose and Waldrop 2006)], anthropogenic burning was likely the predominant source of fire in oak/pine and upland mixed-oak forests (Brose et al. 2001, Hoss et al. 2008). The fire regime of dry oak and oak/pine systems appear to have been dominated by low-intensity, frequent surface fire (Harmon 1982, Hoss et al. 2008, Alrich et al. 2010). However, in the southern Appalachians, fire behavior/fire intensity and, consequently, fire effects are substantially affected by topographic/moisture/productivity gradients, with xeric ridge-tops generally experiencing substantially greater fire intensity and more severe fire effects than forest stands situated on mid-slope and lower-slope positions (Elliott et al. 1999). The exact role of fire in controlling structure and composition likely varied across the topographically complex landscape of the southern Appalachians. Using paleoecological records, Delcourt and Delcourt (1998) correlate an increase in oak during pre-EruoAmerican settlement time periods with an increase in fire in the southern Appalachians. However, this increase in oak did not occur with a concomitant decrease in fire-intolerant species (e.g., red maple), suggesting forests on lower slopes (i.e., cove hardwoods and/or mixed-mesophytic forests), where these more fire-intolerant species are found, experienced a different fire regime than forests located on ridge-top or upper-slope positions (i.e., oak and oak/pine) and/or forests located around settlements near alluvial bottoms (Delcourt and Delcourt 1997, 1998). Recent stand-level evidence does suggest periodic fire did occur in cove hardwood forests and more mesophytic oak forests prior to EuroAmerican settlement (Fesenmyer and Christensen 2010). Specifics regarding the components of the fire regime in these forest types (e.g., the extent, severity, behavior, and frequency of fire at the stand-level) have not been quantified, but fire was likely less frequent and less severe than in forests located on ridge-top and upper slope positions.

In regards to controlling structure and stand dynamics, disturbances can regenerate a new cohort and/or alter the competitive position of individual regeneration sources in the surrounding, undisturbed forest (Oliver and Stephens 1977). A myriad of disturbance, including natural and anthropogenic fire, small-scale gap dynamics, and intermediate disturbance events contributed to the maintenance and dominance of mid-tolerant oak species across the pre-EuroAmerican landscape. However the relative importance of each of these disturbance events in maintaining ecosystem structure and composition has not been quantified. It is in small, frequently created gaps where overstory recruitment of oak species occurred prior to Euro-American settlement (Rentch et al. 2003b). However, it is likely that, especially around population centers where fire was most frequent (Guyett et al. 2006), that anthropogenic burning facilitated the recruitment of oak into canopy positions within the context of small and intermediate disturbance events by controlling more shade tolerant competition in the understory (e.g., Abrams 1992). Similarly, intermediate or moderate-severity events, such as wind storms and ice storms, likely had a substantial role in maintaining mid-tolerant species, such as oak throughout the Central Hardwood Region by modifying structure and resource availability, not only within disturbance-created gaps (e.g., Woods 2004, Hanson and Lorimer 2007), but with the surrounding forest matrix as well (Oliver and Stephens 1977).

1.2. Ecology and silviculture of upland oak forests in the southern Appalachians

In the southern Appalachians, forest management efforts are often centered on the restoration of structure, function, and species composition of upland hardwood stands of mixed species composition, with a particular emphasis on regenerating oak species. Coupled with restoration efforts to regenerate and restore species composition are objectives associated with the sustainable production of high-value hardwood sawtimber. Species assemblages in upland hardwood forests are complex with over 90 arborescent species native to the Region. Although oak is a primary species of interest for management because of its ecological significance, mixed-species stands on sites of moderate to high productivity possess high levels of diversity and often contain a mixture of oak along with numerous other species, including hickory (*Carya* spp.), ash (*Fraxinus americana* L.), basswood (*Tilia heterophylla* Vent.), magnolia (*Magnolia* spp.), etc. A common trait among these target or 'desirable' tree species is that they are all mid-tolerant of shade and have a persistence reproductive study; meaning in order to be successful occupants (here defined as occupying the overstory in a dominant or co-dominant canopy position) of a new cohort, advance reproduction of sufficient size and quantity must be present prior to and persist through the disturbance (whether that disturbance is natural or silvicultural).

For these persistent-strategy species, and oak in particular, successful regeneration is a multi-step process that includes acorn production, seedling establishment, development of seedlings into stems that can compete following release (i.e., large advance reproduction), and the release itself (Johnson et al. 2002). Because oaks are intermediate in shade tolerance, moderate overstory or midstory disturbance that alters light levels at the forest floor is, in most cases, required for development of competitive, or large, advance regeneration (Loftis 1990a). This oak understory ultimately forms an overstory after release, thus sustaining oak (and other persistent-strategy species) as a dominant canopy tree species. Lack of disturbance prevents oaks from developing into competitive advance reproduction and allows more shade-tolerant species to replace oak and eventually dominate the overstory canopy later on moderate to good quality sites (e.g., Spetich and Parker 1998).

At the landscape-level, the presence of large, competitive advance reproduction of these desirable persistent strategy species is rare. Although oaks remain a prominent component of the overstory, the midstory (i.e., sapling layer) of most stands is often dominated by shade-tolerant species, such as red maple (*Acer rubrum* L.), sugar maple (*Acer saccharum* Marsh.), dogwood (*Cornus florida* L.), blackgum (*Nyssa sylvatica* Marsh.), and sourwood (*Oxydendrum arboretum* L. (DC.). Advance oak reproduction, on the other hand, while often abundant in the regeneration layer, is generally small (<0.3 m in height). Regeneration treatments that dramatically reduce the forest canopy without the development of competitive oak regeneration sources result in oak regeneration failure because shade-intolerant competitors such as seedling origin yellow-poplar (*Liriodendron tulipifera* L.) quickly outcompete the small oak and other persistent-strategy species (Loftis 1990a, Shure et al. 2006).

Currently, regeneration treatments on National Forest lands in the Appalachian region are centered on the implementation of the two-aged silvicultural system (e.g., shelterwood and clearcutting with reserves) (Smith et al. 2007). Establishment cuts are heavy and leave approximately 2-4 m^2/ha of residual basal area. Residual trees are held on-site indefinitely, thereby creating a two-aged structure, and serve as an important source of mast, wildlife habitat, structural diversity, and a future source of coarse woody debris. Although shelterwood systems successfully regenerate southern Appalachian hardwood stands, on average to high quality sites (Loftis 1983), whether or not the new cohort is of mixed-species composition is dependent upon the amount and size distribution of persistent-strategy species, including oaks, prior to regenerating the stand (Sander 1972, Loftis 1990b).

Other regeneration methods used to regenerate oak in the Appalachian region include the oak shelterwood method (Loftis 1990a), which is best described as a classic two-step shelterwood. Here, the establishment cut is a non-commercial removal of ~30% of the stand basal area from below, and is performed via herbicides to inhibit re-sprouting of removed individuals. This effectively removes the competing shade-tolerant midstory, increases light at the forest floor, and results in the development of large advance oak reproduction without creating a light environment conducive to the establishment and growth of yellow-poplar. After sufficient time has elapsed to allow for the development of small advance oak reproduction into large (>1.4 m), competitive advance reproduction (approximately 10 years), the overwood is removed down to a residual basal area of ~2 m^2/ha.

Although the resultant age-structure of stands treated under these two-aged silvicultural systems is multi-aged, and therefore represents a deviation from the predominantly even-aged landscape, this system does not necessarily mimic the age structure and within-stand complexity common to upland hardwood forests prior to Euro-American settlement. Furthermore, unless steps are taken, well in advance of regenerating a stand to develop large advance reproduction (i.e., oak shelterwood method), oak species along with other persistent-strategy species are unlikely to be a substantial component of the regenerated cohort (Loftis 1990b).

1.3. Designing a disturbance-based silviculture treatment to regenerate oak

The switch from managing for primarily timber to managing for the full range of services and values provided by forest ecosystems (e.g., wildlife habitat, biodiversity, watershed protection, resistance and resilience to disturbance, etc.) has caused silviculturists to re-examine the efficacy of using traditional silvicultural practices to meet current goals and objectives associated with ecosystem-based forest management; namely the conservation of biodiversity and ecosystem complexity (Seymour and Hunter 1999). Group selection is an uneven-aged silvicultural method that is promoted as an alternative to traditional even-aged silvicultural systems. Group selection is thought to be a more ecological approach to managed regeneration because it is believed to more accurately represent natural disturbance patterns and the subsequent regeneration process (e.g., gap creation), and should allow for the regeneration of species both intolerant and mid-tolerant of shade (Coates and Burton 1997).

Although group selection creates a multi-aged stand, and therefore increases within-stand complexity, the efficacy of using this silvicultural method to regenerate stands of mixed-species composition (of which oak is a substantial component) in upland hardwood forests is questionable. Unlike studies of group selection in northern hardwoods where the resultant species composition consists of a mixture of shade-tolerant and/or shade-intolerant species (e.g., Leak 1999, Webb and Scanga 2001), on moderate to high quality mixed-oak forests, most groups openings become dominated by shade-intolerant species (e.g., Weigel and Parker 1996, Jenkins and Parker 1998, Bent Creek Experimental Forest, unpublished data). Within the range of yellow-poplar, group selection generally results in an increase in the overstory importance of yellow-poplar as compared to other mixed-hardwood species, essentially converting stands once dominated by mixed-oak species to a stands dominated by yellow-poplar (Weigel and Parker 1997, Jenkins and Parker 1998). The lack of an oak component in these stands prior to the creation of group openings suggest that if oak were present in the regeneration layer prior to harvest, the population as a whole was dominated by small, non-competitive stems (Loftis 1990b). Had large advance reproduction of desirable species (e.g., oak) been present prior to the group selection harvests, species composition likely would have been of a mixed nature (Sander 1972, Loftis 1990a).

In an undisturbed forest, light levels can be as low as 1-2% of full-sunlight (Canham and Burbank 1994), which significantly retards the growth of advance oak reproduction. Advance oak reproduction benefits from intermediate-level disturbances that increase light levels to 12-15% of full-sunlight (David Loftis, *unpublished data*). At these light levels, advance oak reproduction that is capable of competing with species like seedling-origin yellow-poplar following overstory removal develops (Lofits 1990a). Resource availability, in particular light, decreases along a gradient from the center of a gap to the edge, and beyond into the undisturbed matrix (e.g., York et al. 2003, McNab 1991). Disturbances such as inducing mortality in the midstory tree layer via herbicide (i.e., oak shelterwood method) is one method used to modify the light environment at the forest floor and develop large advance oak reproduction (Loftis 1990a). Other disturbances, however, alter light levels within a stand, including prescribed fire (although this increase in light is transient as re-sprouting of fire-killed individuals occurs even after multiple fires) (Chiang et al. 2005) and the creation of gaps via natural (Hanson and Lorimer 2007) or silvicultural means (York et al. 2003). Although light availability diminishes from the center of a group opening out through to the edge of an opening (York et al. 2003), a significant and prolonged increase in tree growth associated with increased light availability in the undisturbed matrix can occur.

Subtle differences in resource availability following a disturbance event can dramatically alter the relative position of regeneration sources within the canopy, and therefore alter competitive interactions within and among species (Oliver and Stephens 1977). Evidence from stand reconstruction studies suggests the primary method by which mid-tolerant oak species regenerated was though the process of small- to moderate-scale canopy gap formation (Rentch et al. 2003a,b, Hanson and Lorimer 2007). The exact process by which mid-tolerant oaks were able to compete with both shade-intolerant (yellow-poplar) and shade-tolerant (e.g., red maple) species following the creation of canopy gaps is unclear. In the presence of a yellow-poplar seed source, on moderate to high quality sites, oak must exist as large advance reproduction prior to a release event if they are to be a component of the new age cohort (Lofits 1990b). Similarly, light levels in an undisturbed forest setting limit the growth of small advance oak reproduction and favor the growth of shade tolerant competitors (Kolb et al. 1990, Lorimer et al. 1994, Hodges and Gardiner 1993). Native American burning was likely an important disturbance (Guyette et al. 2006) that limited or removed competition from shade-tolerant species such that oaks were in a position to recruit into canopy position following the creation of canopy gaps (Abrams 1992, Brose et al. 2001). However, stand dynamics associated with the creation of small- and moderate-sized gaps was likely a key process by which mid-tolerant oaks were able to develop into large advance reproduction and, and through with future canopy disturbance(s) persist as a dominant overstory tree species.

Regardless of the specifics surrounding the past (pre-EuroAmerican settlement) disturbance regime, it is unlikely the relatively homogenous landscape of today; one dominated by even-aged forests with little variation in the age-class distribution across the landscape, reflects the complexity in forest structure that existed prior to settlement (Lorimer 1980, Runkle 1982, Rentch et al. 2003a,b). The conditions under which pre-EuroAmerican forests developed can never be recreated. However, a silvicultural system that is based, in part, on the disturbance regime under which species evolved may recreate some of the environmental conditions that promoted the conservation of biodiversity and complexity in ecosystem structure and function (Seymour and Hunter 1999, North and Keeton 2008). Using the strict definition of natural disturbance regime, that is without human influence (Seymour and Hunter 1999), in the mixed-oak forests of the southern Appalachians, a disturbance-based silvicultural system would rely heavily on the artificial creation of small and medium-sized canopy gaps over extended periods of time (e.g., a 100 year rotation) to create mutli-cohort stands characterized by high levels of compositional and structural diversity at variable spatial and temporal scales. In terms of silvicultural prescriptions, this process of repeated gap formation is most similar to the goals and objectives of group selection. Once canopy gaps are formed, evidence from past stand reconstruction efforts indicates that areas within close proximity to the original gap become more susceptible to subsequent gap formation (Runkle 1984, Foster and Reiners 1986, Runkle 1990). Therefore, in contrast to the traditional approach to group selection where new, independent canopy gaps are created during at each cutting cycle, a disturbance-based approach to group selection would expand on the initially created gaps during each subsequent cutting cycle.

The expansion of gaps, as opposed to the creation of new gaps is an intriguing concept in terms of regenerating mixed-oak stands. Relative to the interior forest, forest edge habitats possess greater light and soil moisture availability (McNab 1991, Chen et al. 1995). Increased resource availability in edge environments can greatly affect tree growth, composition, herbaceous layer diversity, and future forest structure. Tree species that are of particular interest in the southern Appalachians, including oak species, have been found in increased abundance in terms of both density and basal area in the overstory and midstory layers (Whitney and Runkle 1981) at depths of 10 to 20 m from the original canopy gap edge (Wales1972). Mature trees up to 10 m from the edge of gaps created during group selection can display a significant and prolonged increase in radial growth (York and Battles 2008), which has important implications regarding the timber production and economics of future cutting cycles.

In the southern Appalachians, where the successful regeneration of desirable tree species on moderate to high quality sites is dependent on the presence of large advance reproduction, the effects of gap creation on the regeneration layer is especially important. While the interior of natural or silvicultural created gaps are largely dominated by seedling origin yellow-poplar (Jenkins and Parker 1994, Berg and Van Lear 2004), advance reproduction of a variety species near the gap edge environment experience a substantial increase in the density, survivorship, and growth (Chen et al. 1992, Berg 2004, Bent Creek Experimental Forest, *unpublished data*). The depth of edge influence on regeneration dynamics following gap creation in the southern Appalachians has not been quantified, but based on previous efforts in other systems could be anywhere between 10 (Ranney et al. 1981, Chen et al. 1992) and 137 m from the gap edge (Chen et al. 1992). If increased resource availability into the forest matrix following the creation of gaps allows for the development of large advance oak reproduction (along with the development of large advance reproduction of other desirable, persistent strategy species), a system that takes advantage of the presence of this advance oak reproduction, i.e., an expanding gap system under the guides of group selection, should work to not only regenerate oak and other persistent-strategy species, but also create structural and compositional complexity over multiple spatial and temporal scales.

Proposed here is a natural disturbance-based approach to regenerating mixed-oak stands in the southern Appalachians. Using information about the natural disturbance regime from a variety of sources (e.g., Lorimer 1980, Runkle 1982, Lorimer 1989, Rentch 2003a,b, McNab et al. 2004) this system, which can be termed irregular group selection, group shelterwood, or oak Femelschlag (German for irregular shelterwood), will seek to create multi-cohort stands using an area-controlled form of group selection. Unlike the traditional group selection system, this system will mimic natural gap formation processes by expanding the area created around artificially created gaps during each entry as opposed to creating new, independent gaps. Unlike the oak shelterwood method (Loftis 1990a), which uses herbicides to promote the development of advance oak reproduction, this system will take advantage of the large advance reproduction that develops naturally within the periphery of artificially created gaps. This system, based, in part, on the natural disturbance regime of southern Appalachian mixed-oak forests is an alternative to the current two-age system commonly used on National Forest lands in the Appalachian region. Although the historic landscape can never be recreated due to societal pressures, land ownership patterns, and among other factors, the loss of keystone species due to the introduction of non-native diseases and insects (e.g., American chestnut), this system, in theory, should promote the development of complex stand structures of mixed-species composition that were likely common prior to widespread Euro-American settlement.

2. Justification

Goals and objectives associated with forest management on public lands have evolved over the past few decades from primarily timber production and extraction to those associated with ecosystem-based management (e.g., conservation of biodiversity, sustaining ecological integrity, etc.). Currently, regeneration treatments on National Forest lands in North Carolina are centered on the implementation of the two-aged silvicultural system (Smith et al. 2007). Although shelterwood systems successfully regenerate southern Appalachian hardwood stands, on average to high quality sites (Loftis 1983) whether or not the new cohort is of mixed-species composition is dependent upon the amount and size distribution of persistent-strategy species, including oaks, prior to regenerating the stand (Sander 1972, Loftis 1990b). Although the resultant age-structure of stands treated under these two-aged silvicultural systems is multi-aged, and therefore represents a deviation from the predominantly even-aged landscape, this system does not necessarily mimic the age structure and within-stand complexity common to upland hardwood forests prior to Euro-American settlement. Furthermore, unless steps are taken, well in advance of regenerating a stand to develop large advance reproduction (i.e., oak shelterwood method), oak species along with other persistent-strategy species are unlikely to be a substantial component of the regenerated cohort (Loftis 1990b).

The switch from managing for primarily timber to managing for the full range of services and values provided by forest ecosystems (e.g., wildlife habitat, biodiversity, watershed protection, resistance and resilience to disturbance, etc.) has caused silviculturists to re-examine the efficacy of using traditional silvicultural practices to meet current goals and objectives associated with ecosystem-based forest management; namely the conservation of biodiversity and ecosystem complexity (Seymour and Hunter 1999). Group selection is an uneven-aged silvicultural method that is promoted as an alternative to traditional even-aged silvicultural systems. Group selection is thought to be a more ecological approach to managed regeneration because it is believed to more accurately represent natural disturbance patterns and the subsequent regeneration process (Coates and Burton 1997).

In the southern Appalachians, where the successful regeneration of desirable tree species on moderate to high quality sites is dependent on the presence of large advance reproduction, the effects of gap creation on the regeneration layer is especially important. While the interior of natural or silvicultural created gaps are largely dominated by seedling origin yellow-poplar (Jenkins and Parker 1994, Berg and Van Lear 2004), advance reproduction of a variety species near the gap edge environment experience a substantial increase in the density, survivorship, and growth (Chen et al. 1992, Berg 2004, Bent Creek Experimental Forest, unpublished data). The depth of edge influence on regeneration dynamics following gap creation in the southern Appalachians has not been quantified, but based on previous efforts in other systems could be anywhere between 10 (Ranney et al. 1981 sensu Chen et al. 1992) and 137 m from the gap edge (Chen et al. 1992). If increased resource availability into the forest matrix following the creation of gaps allows for the development of large advance oak reproduction (along with the development of large advance reproduction of other desirable, mid-tolerant species), a system that takes advantage of the presence of this advance oak reproduction, (i.e., an expanding gap system), should not only regenerate oak species, but also increase within-stand structural and compositional complexity.

Proposed here is a natural disturbance-based approach to regenerating mixed-oak stands in the southern Appalachians. Using information about the natural disturbance regime from a variety of sources (e.g., Lorimer 1980, Runkle 1982, Lorimer 1989, Rentch 2003a,b, McNab et al. 2004) this system, which can be termed an irregular shelterwood, group shelterwood with reserves, or a Femelschlag system (Appalachian Femelschlag) patterned after the Bavarian Femelschlag (see Seymour 2005, Puettmann et al. 2008, or Raymond et al. 2009 for a more detailed description of the Femelschlag system and its history, will seek to create multi-cohort stands using an area-controlled form of group selection. Unlike the traditional group selection system, this system will closely mimic natural gap formation processes by expanding the area created around artificially created gaps during each entry as opposed to creating new, independent gaps. Unlike the oak shelterwood method (Loftis 1990a), which uses herbicides to promote the development of advance oak reproduction, this system will take advantage of the large advance reproduction that develops naturally within the periphery of artificially created gaps.

This system, based, in part, on the natural disturbance regime of southern Appalachian mixed-oak forests is an alternative to the current 2-aged system commonly used on National Forest lands in western North Carolina. Although the historic landscape can never be recreated, this system is expected to promote the development of complex stand structures of mixed-species composition that were likely common prior to widespread Euro-American settlement and may promote the resistance and resilience to a variety of current and emerging natural resource-related problems.

3. Materials and Methods

3.1. Study area

The study area will be located within the Blue Ridge Physiographic Province of the southern Appalachian Mountains in North Carolina. Terrain is generally mountainous with steep slopes. Geology is predominantly felsic to mafic high-grade metamorphic biotite and granitic gneisses. Soils are Inceptisols and Ultisols that are shallow to very deep, well drained, moderately to extremely acid, and range in texture from coarse-loamy to clayey; stones are scattered on the surface of some sites. The climate is characterized by warm summers and cool winters. Average monthly minimum and maximum temperatures are 3.9 and 18.9 °C. Precipitation averages 1200 mm annually and is evenly distributed throughout the year. Vegetation consists of mature, second-growth upland mixed-oak forests. Oak species (*Quercus rubra* L., *Q. velutina* Lam., *Q. coccinea* Muenchh., *Q. alba* L., *Q. prinus* L.), hickory species (*Carya* spp.), and yellow-poplar (*Liriodendron tulipifera* L.) are the predominant overstory trees. Species composition in the midstory consists primarily of shade-tolerant species including sourwood (*Oxydendrum* *arboretum* (L.) DC.), flowering dogwood (*Cornus florida* L.), blackgum (*Nyssa sylvatica* Marsh.), and red maple (*A. rubrum* L.). Site productivity generally varies with topographic position with mesic lower slopes more productive than xeric ridge top locations. Site index (SI; base-age 50) for mixed oaks varies with the topographic gradient ranging from 17 m (56 ft) to 29 m (95 ft). This study will be located on more productive sites where SI is ≥21.3 m (70 ft).

3.2. Study design

5.2.a. Treatments:

1) **Small-gap:** This gap treatment simulates small-scale gap dynamics. Target gap size will be 0.1 ha, which is at the upper limit of gap sizes documented to occur as a result of small-scale endogenous and exogenous gap creating events in old-growth forests. Using the average rate of gap formation rate reported by Runkle (1982) (1 percent of the total land area per year) and a 10 year cutting cycle, 10% of the stand should be regenerated in each entry (based on a 100 year rotation). However, to make this treatment operational, 25% of the stand will be regenerated during each of the 4 entries (40 years), with no harvesting occurring during the last 60 years creating an effective rotation length of 100 years (Arseneault et al. 2011). This treatment will result in the production of five age classes; four age classes will result from the 0.1 ha regeneration harvests and the fifth age class will be the result of retention trees throughout the stand (e.g., inoperable areas, riparian areas). Unlike traditional group selection, after the initial entry, gaps will be expanded to more closely mimic the natural processes of gap formation (**Fig. 2**).
    a. Target gap size = 0.1 ha (0.25 acres)
    b. Number of entries = 4
    c. Cutting cycle = 10 years
    d. Rotation length = >100 years for late structural habitat; 80+ years for commercial oak production
    e. Desired age classes: 5 (5th age class being residual trees)

2) **Large-gap**: This gap treatment simulates intermediate-scale gap dynamics. Return intervals and gap formation rates under an intermediate disturbance regime have not been quantified due to the spatial and temporal variability of these disturbance events (White et al. 2011). However, these disturbance events were nonetheless important in shaping pre-settlement structure and function, and can be used as a guide towards managing mutli-cohort stands (Woods 2004, Hanson and Lorimer 2007). Gap data from the most recent hurricane event to significantly affect the southern Appalachians (i.e., Hurricane Opal) suggests gap sizes from these events can range from that of a single tree fall to ~4 ha (McNab et al. 2004) with a median gap size of 0.4 ha. Consequently, target gap size under this treatment the will be 0.4 ha, which is the upper limit of opening sizes suggested in the Forest Plan. It should be noted this 0.4 ha opening size is within the limits of gap sizes created during other intermediate disturbance events, such as ice storms, in the region (Mou and Warrillow 2000).

    Cutting cycle and rotation length will be similar to the small-gap treatment (10 year cutting cycle and 100 year rotation length). During each entry, 25 percent of the stand will be regenerated during the initial four entries (40 years), with no harvesting occurring during the last 60 years creating an effective rotation length of 100 years (Arseneault et al. 2011). Similar to the small-gap treatment, the large-gap treatment will create and maintain five age classes. After the initial entry, gaps will be expanded during each subsequent entry (**Fig. 2**). This treatment will result in the production of five age classes; four age classes will result from the 0.1 ha regeneration harvests and the fifth age class will be the result of retention trees throughout the stand (e.g., inoperable areas, riparian areas).

   a. Target gap size = 0.4 ha (1 acre)
   b. Number of entires = 4
   c. Cutting cycle = 10 years
   d. Rotation length = >100 years for late structural habitat; 80+ years for commercial oak production
   e. Desired age classes: 5 (5^{th} age class being residual trees)

3) **Un-harvested control:** No treatments/vegetation manipulation will occur in the control stands.

NOTES:

(1) Natural gaps tend to be more elliptical in shape than circular (McNab et al. 2004). Consequently, in both treatments 1 and 2, the shape of openings will be irregular (as opposed to circular). The key is to ***NOT*** have circular or donut-shaped gaps that result in a decreasing width of groups during each expansion, but an irregular shape that takes advantage of any and all advance oak development in the periphery after gap creation.
(2) Standard FS protocols (pre- and post-entry) will be utilized to control the presence and spread of non-native, invasive species, particularly Oriental bittersweet.
(3) If shade tolerant, undesirable species, especially red maple, are present in large numbers and/or in the large seedling size classes (>1.4 m in height), control methods, including herbicide treatments, will be conducted either throughout the stand or around the periphery of each gap in the years prior to future entries and gap expansion. The decision to treat undesirable species will be made by the PIs and District Silviculturists. If needed, the treatment of undesirables will follow standard FS protocols.

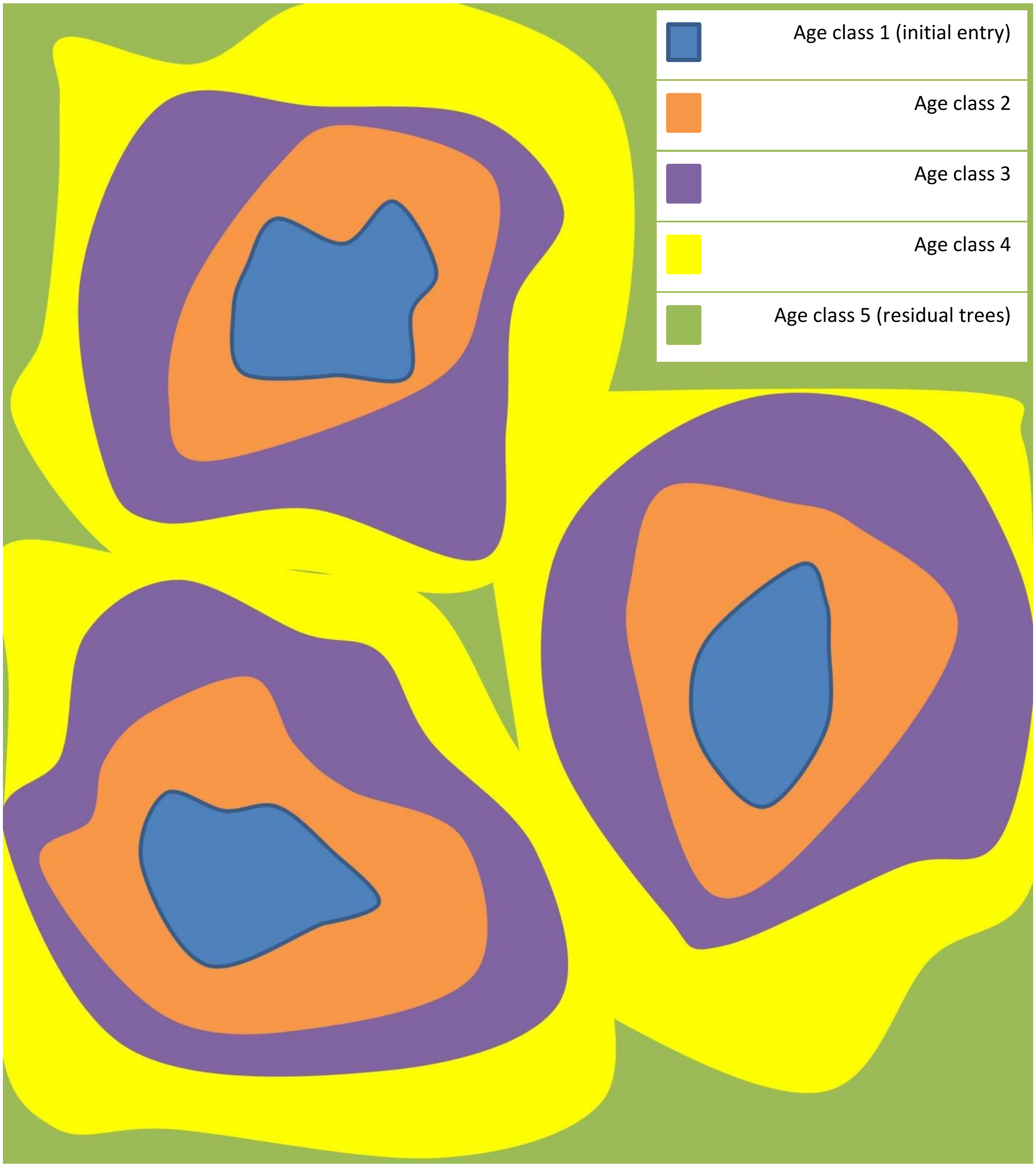

Figure 2. Schematic depicting the installation of an irregular group selection to regenerate mixed-hardwood (oak) forests in the southern Appalachians. Different colors represent the age classes created during each of four entries under the small- and large-gap treatment.

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