RESTORING OAK FOREST, WOODLANDS AND SAVANNAHS USING MODERN SILVICULTURAL ANALOGS TO HISTORIC CULTURAL FIRE REGIMES

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Variability in historic fire regimes in eastern North America resulted in an array of oak savannahs, woodlands and forests that were dominant vegetation types throughout the region. In the past century, once abundant savannahs and woodlands have become scarce due to conversion to agriculture, or development of forest structure in the absence of fire. In addition, the future dominance of oak forests is uncertain due to chronic low regeneration potential of oak across the region and insufficient overstory recruitment.
Restoration of oak savannahs and woodlands, and sustaining oak forests are primary goals for land management agencies and conservation organizations. Insights learned from fire history research can be used to guide silviculture prescriptions to achieve these goals. Restoration of oak savannahs and woodlands requires a long-term regimen of prescribed burning, but it takes a combination of prescribed fire, timber harvesting and forest thinning to efficiently produce desired structure and composition. Sustaining oak savannahs and woodlands requires an occasional longer fire-free period to allow for replacement of the overstory by recruitment of trees from the reserve of oak sprouts that have accumulated in the understory.
Prescribed fire is useful for sustaining oak forests, but it must be used judiciously to minimize timber damage and decreases in value. Integrating fire in a silvicultural prescription that uses the shelterwood regeneration method to promote competitive oak reproduction has been successfully applied in the eastern US to sustain oak forests.
Restoration of oak ecosystems is possible but requires innovative combinations of traditional practices, including prescribed burning.

Keywords: sustainability, silviculture, fire, regeneration, recruitment.
Parole chiave: sostenibilità, selvicoltura, fuoco, rigenerazione, selezione.

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1. Introduction

Today, the high level of concern for conservation and restoration of oak-dominated ecosystems may seem odd given that oak occurs on 78.5 million hectares of forest lands in the eastern U.S. and accounts for 51% of all such land (Smith *et al.*, 2009).
However, the widespread recognition of oak regeneration failure is sounding the alarm for the continued loss and inability to sustain this genus that is highly prized both for its economic and ecological values. Oak forests, woodlands and savannahs are important for conserving the biodiversity of plants and animals and to ensure ecosystem resilience to future biotic outbreaks and environmental stresses.
Since the commencement of fire suppression on a national level beginning in about the 1930s (1) oak regeneration failures have been increasingly and widely reported, (2) succession to other species is common in managed or preserved (old growth) oak forests, and (3) declines in landscape diversity are ongoing due to the dramatic loss of oak savannahs and woodlands, and increase in maturing forests.
There are less than 1% of the original oak savannahs remaining (Nuzzo, 1986) and woodlands are greatly diminished due to conversion to agriculture and succession to forest structure wrought by increasing tree density and development of multi-storied tree canopies in the absence of fire (Hanberry *et al.*, 2014).
There is an urgent need for silvicultural prescriptions for sustaining oak forests and restoring oak savannahs and woodlands in the eastern U.S.

2. History of fire and development of modern oak forests

Historic fire regimes in eastern North America have been intricately linked with humans and climate, and resulted in an array of oak savannahs, woodlands and forests distributed for thousands of years throughout eastern North America (Beerling and Osborne, 2006; Guyette *et al.*, 2002, 2012). The abundance of oak was greatly increased about 4,000 years ago following the development of agriculture in the eastern U.S., promoted by the increasing influence of Native American populations and their use of fire (Delcourt and Delcourt, 1997, 1998). There was substantial spatial variability across the U.S. in the frequency of fire in the historic period that was modified by climate (Guyette *et al.*, 2012). Over much of the modern range of oak species, fire was frequent (annual to every 20 years) in the historic period (circa 1650-1850). Historic fire also varied temporally being influenced by changing human land use and culture, topography, and vegetation (Guyette *et al.*, 2002).

General characteristics of fire history over the past 350 years include (based on e.g., Dey and Guyette, 2000; Guyette and Spetich, 2003; Guyette *et al.*, 2003; Stambaugh *et al.*, 2006; Stambaugh *et al.*, 2011; Brose *et al.*, 2013):

– during the latter Native American period:
  -relatively frequent fire (5 to 20+ years) with variable (e.g., 1-40 years) fire-free periods,
  -dormant season fires (i.e., August to March),
  -mixed-severity fire regimes dominated by low intensity surface fires, with less frequent (every 10-30 years) moderate to high severity fires that probably burned in droughty years;
– during the early European settlement period:
  - increased fire frequency (e.g., annual to 3 years) with decreased variability in fire-free periods;
  - dormant season fires (i.e., August to March):
  - mixed-severity fire regimes dominated by low intensity surface fires,
  - greater portions of the landscape burning in any given year;
– during the modern European period:
  - significant reduction in fire occurrence following adoption of fire suppression programs,
  - low intensity, small-scale wildfires in dormant season (August to April),
  - extremely long fire-free periods that exceed the maximum longevity of dominant tree species,
  - infrequent use of prescribed burning largely for ecosystem restoration on smaller parcels,
  - it is during this period that most modern oak forests began to advance into maturity.

3. Fire regime and woody structure of ecosystems

The frequency, intensity and seasonality of fire are major determinants of woody structure in the eastern U.S. Annual to near-annual fires are necessary to retard development of woody structure and maintain prairies (Anderson, 1983, 2006; Nelson, 2010). Fire-free periods of from 10 to 30 years permit trees to grow large enough in diameter and develop sufficient bark thickness to make them resistant to mortality or topkill of the shoot by fire. Savannah structure develops with decreasing fire frequency and intensity, and increased variability in fire-free periods, including extended periods without fire. Woodlands (both open and closed) develop with continued decreases in fire frequency and intensity, and increased frequency and duration of fire-free periods. Forest structure occurs on portions of the landscape that burn infrequently enough to permit development of high stem density and multiple canopy layers. Landscapes that once were intricate mosaics of diverse natural communities that spanned the structural gradient from prairie to forest have become more homogeneous after decades of fire suppression in the eastern U.S. (Schulte *et al.*, 2007; Hanberry *et al.*, 2012, 2014a,b,c). The region is dominated by maturing forests where lands have escaped development (Shifley and Thompson, 2011; Shifley *et al.*, 2012).

Low intensity fires are usually able to cause mortality or topkill in hardwood stems < 12 cm dbh, almost regardless of species (Arthur *et al.*, 2012). A single fire of this intensity is able to eliminate the midstory canopy layer and may cause single tree gaps in the main canopy (Hutchinson *et al*., 2005). Higher intensity fires, or fires that occur when woody plants are actively growing (late spring-early summer) are more lethal than those that burn in the dormant season (Hutchinson, 2006; Brose *et al.*, 2013). They are needed to kill the stems of larger diameter hardwoods. Thus, low intensity fires are effective for creating a closed woodland structure, but more severe fires are needed to create open woodland or savannah structures. Fire severity can be increased by burning when weather and fuel conditions foster higher temperatures of longer duration, especially when plants are more vulnerable.

4. Oak's adaptations to fire

Oak species have several traits that promote their survival and competitiveness where fires are part of the disturbance regime. Oak cotyledons and numerous dormant buds at the root collar are often buried in the soil, which protects them from the heat of fire because soil is a poor conductor of heat (Iverson and Hutchinson, 2002; Iverson *et al.*, 2004).

Acorns are desired food for several species of wildlife such as squirrels (*Sciurus* sp.) and blue jays (*Cyanocitta cristata*) that cache seed in the soil, increasing the likelihood that acorns will be protected from fire by soil burial. Oak seedlings preferentially allocate carbohydrates to root growth (Johnson *et al.*, 2009), which increases the probability that there will be a ready energy supply to support rapid sprout growth in the event that the parent stem is killed by fire. Therefore, through repeated cycles of shoot topkill and resprouting in the presence of adequate light, oak seedlings can develop large root systems and increase their competitiveness when a regeneration releasing disturbance does occur.

However, acorns and small oak seedlings (e.g., <10mm in basal diameter) are highly susceptible to death by even low intensity fires (Johnson, 1974; Auchmoody and Smith, 1993). As oak seedlings grow into the sapling, pole and sawtimber size classes, their bark increases in thickness relatively more rapidly and to greater thicknesses than many competing species, which confers greater protection to cambial tissues from the heat of fire (Harmon, 1984; Sutherland and Smith, 2000). Species in the white oak group (Section *Quercus*) are also known for their superior ability to compartmentalize fire injuries and limit decay development (Smith and Sutherland, 1999; Sutherland and Smith, 2000). In contrast, red oak group species (Section *Lobatae*) are relatively susceptible to decay following fire injury (Nelson *et al.*, 1933; Berry, 1969; U.S. Forest Service, 1967).

Oaks have several adaptations that indirectly favor their dominance because they allow oaks to persist on droughty sites of low fertility. These sites are more prone to burning, both historically and under prescribed conditions, and they are more restrictive to oak's competition.

5. Fires purpose and use varies by management goal

Oak ecosystem management can be categorized into two classes that differ in their strategic goals and outcomes. Oak ecosystems can be managed as forests that are meant to produce a variety of ecological services and traditional economic commodity products such as sawtimber and veneer, or they can be managed to restore historic natural communities such as woodlands and savannahs.

In the first case, fire is not needed to sustain forest systems, but it may have a beneficial and ecologically relevant role in managing oak forests. In forest management, fire can be thought of as a tool that may promote oak regeneration and recruitment into the overstory if it occurs at a strategic time in stand development. Fire at the wrong time has the potential to cause high levels of damage to trees, product devaluation, and failure to achieve major management goals. In the latter case, fire is an essential element of the disturbance regime that is necessary for the creation and maintenance of oak natural communities. The emphasis here is more on ecosystem goods and services and values such as landscape diversity, native biodiversity, wildlife habitat quality and ecosystem resilience. In woodland and savannah management, fire damage to trees and devaluation of wood products is of lessor concern, although prudent managers will not wantonly cause unnecessary damage to trees that may have adverse impacts on the economic viability of restoration prescriptions or that may cause negative ecological consequences such as excessive mortality of overstory trees.

The strategic management direction determines whether using fire is appropriate and defines the specific timing and nature of fire required to produce desirable outcomes.

6. Combining fire and regeneration methods

When regenerating oak in forests it is essential that competing vegetation be controlled so that oak seedlings can development into competitive individuals capable of achieving codominance at the time of canopy closure, i.e., the beginning of the stem exclusion stage of development in the new forest. Oak stump sprouts are highly competitive and often account for the majority of dominant oaks in the stem exclusion stage (Beck and Hooper, 1986; Gould *et al.*, 2002; Morrissey *et al.*, 2008), but not all oak stumps that result from harvesting produce sprouts (e.g., Johnson, 1977; Weigel *et al.*, 2011), which is why emphasis is placed on development of large oak advance reproduction in the understory to sustain desired oak stocking in the future stand (Johnson *et al.*, 2009).

In general, the single-tree selection method is not recommended for oak regeneration (Johnson *et al.*, 2009). It usually accelerates succession toward and dominance of species more shade tolerant than oaks. There is some evidence on xeric sites that uneven-aged management may be able to sustain oak forests, primarily those dominated by the more shade tolerant white oaks (Section *Quercus*) (Johnson *et al.*, 2009). Prescribed burning as a method to promote oak seedling development by control of competing vegetation has limited usefulness in combination with the single-tree selection method, which simultaneously regenerates oak seedlings while promoting recruitment into the overstory through development of saplings and pole-sized trees. Oaks in the sapling and pole-size classes are vulnerable to basal stem wounding by fire, have reduced diameter growth and, hence, slower wound closure rates in the shade of a partial overstory, and wounded trees have higher probability of extensive decay development in the lower log because they exist in stands for decades before they are large enough to be harvested. The use of the group selection method is more likely to regenerate oak if large oak advance reproduction are present at harvest and competing vegetation is controlled. Prescribed fire with this method has limitations because burning the group openings, which are scattered in a matrix of forests managed by single-tree selection, is complicated and expensive. There are more efficient and affordable mechanical or chemical methods of controlling competing vegetation in group openings.

Even-aged methods are more commonly recommended for managing oak forests, but without control of competing vegetation they often result in oak regeneration failure. Clearcutting is only done when the combined regeneration potential of oak advance reproduction and stump sprouts is sufficient to achieve desired oak stocking levels. Prescribed burning after clearcutting is an excellent way to control competing vegetation and improve the relative dominance of oak reproduction. Small oak seedlings (<6mm basal diameter) are susceptible to fire mortality, but larger oak seedlings have increasing higher probabilities of responding to fire topkill of the shoot by vigorous sprouting (Dey and Hartman, 2005). Repeated prescribed burning (e.g., every 3 to 5 years) can be used to promote oak regeneration competiveness in open environments. When oak reproduction is sufficiently competitive and competing vegetation has been reduced, then a fire-free period is needed to allow oaks to recruit into the overstory.

Monitoring the status of oaks during the stem exclusion stage may indicate that stand thinning is required to maintain desired stocking of dominant oaks. Prescribed burning to thin sapling-sized stands is a poor choice because fire is indiscriminant in what trees are topkilled, there is less control over stand stocking and spatial arrangement of surviving trees, fire can scar residual trees, and it is difficult to conduct prescribed burns in such stands. There are limited times during the year that dense sapling stands can be effectively burned due to undesirable fuel conditions, i.e., low fine fuel loading, and unfavorable weather conditions, i.e., high fuel moisture content, high humidity, and low wind speeds within these stands. Mechanical or chemical thinning using the crop tree system (Miller *et al.*, 2007) is a good way to maintain oak dominance in maturing stands.

Many oak forests in the eastern U.S. have low oak regeneration potential because large diameter (>25cm dbh), mature (>80 years old) oak trees are less likely to produce stump sprouts, and oak advance reproduction is absent or small (e.g., 4-6mm basal diameter and 15 cm in height). In such situations, the shelterwood method is often recommended to develop adequate densities of large oak advance reproduction (Johnson *et al.*, 2009). The method is flexible and can be adapted to differing site conditions and mixes of competing species, and is capable of providing a wide range of microclimate in the regeneration layer by regulating overstory density and stand structure. Prescribed burning is useful for controlling high density, small-diameter competing woody vegetation. Brose *et al.* (2008, 2013) provided guidance for combining prescribed burning with the shelterwood method to promote oak regeneration. The role of fire in implementing the shelterwood method is limited to control of competing vegetation in the regeneration layer, it is a poor tool for managing overstory density as it takes substantially higher fire intensity to kill overstory trees, and there is less control over residual stand stocking and spatial arrangement of surviving trees. Managing overstory structure is best conducted by timber harvesting or application of herbicides by stem injection. Harvesting permits recovery of wood products and generation of revenues to help offset the cost of site preparation and competition control. The timing of prescribed burning is important in promoting oak regeneration. Acorns and small oak seedings are vulnerable to fire mortality. Fire can be applied in mature stands that lack oak advance reproduction and before acorn dispersal to prepare the site for oak seedling establishment by reducing overly thick litter layers, reducing seed bank supply and decreasing woody competition in the mid and understory. In the presence of small oak advance reproduction, the initial shelterwood harvest increases light in the understory and stimulates growth of oak advance reproduction, as it does the competition. For 2-3 years, oak reproduction benefit from increased light and develop larger root systems, increasing in sprouting capacity.

Fire may be used at this time to release the oak reproduction from competition if oak seedlings are large enough in basal diameter (e.g., >10mm). Otherwise, removal of the shelterwood provides an additional mechanical release that may be followed by prescribed burning in 2-3 years when oak seedlings are larger. Hotter, more intense fires conducted in the growing season, i.e., late spring-early summer, improve relative oak competitiveness when there is adequate large oak reproduction (Brose *et al.*, 2013).

7. Restoration of oak savannahs and woodlands

Restoration of oak savannahs or woodlands usually begins with a forest state because of the densification of these former natural communities in the absence of fire (Hanberry *et al.*, 2012, 2014a,b,c). The main objectives in savannah and woodland restoration are to reduce tree density and reintroduce fire. The greatest positive response in native ground flora diversity is when stand density is reduced significantly in conjunction with prescribed burning (Hutchinson *et al.*, 2005; Hutchinson, 2006; Waldrop *et al.*, 2008; Kinkead *et al.*, 2013). Prescribed burning with low intensity dormant season fires is effective for creating closed woodland structure and improves the native diversity of ground flora (Kinkead *et al.*, 2013). More intense fires are needed to kill enough overstory trees to restore open woodland or savannah structure. Generally, this is more effectively done by timber harvesting using the shelterwood method. In a traditional forestry context, the shelterwood is meant to create a favorable environment for desirable tree reproduction without aggravating the level of competition to the detriment of the desired tree species. In the restoration of savannahs and woodlands, regulating density of the shelterwood is driven by the environmental needs of the desired ground flora species. The shelterwood canopy may be reduced in stages through several harvests but the final desired stocking for a savannah or open woodland is retained for long periods. Fire is a recurring necessary disturbance in maintaining savannahs and woodlands and the specifics in fire prescriptions is driven by controlling encroachment by woody species and by the ecological and physiological needs of the desired plant species indicative of the natural community. For example, grass dominated ground flora require low tree canopy cover (<50% crown cover) and frequent to annual burning (Anderson *et al.*, 1999; Nelson, 2010; Mayer and Khalyani, 2011; Starver *et al.*, 2011). Forbs and legumes can be favoured by summer burning (Nelson, 2010). Increasing tree crown cover favours more shade tolerant species. Maximum plant diversity often occurs in the heterogeneous environments characteristic of savannahs (Leach and Givnish, 1999; Peterson and Reich, 2008).

8. Conclusion

Prescribed fire can be incorporated with traditional silvicultural practices to mimic historic disturbances that once promoted oak natural communities (savannah, woodland, forest). The role of fire varies by management goal, i.e., forest management for commodity products and other ecological and social amenities, or natural community management for conserving native biodiversity, increasing landscape resilience, diversifying ecosystem goods and services and improving wildlife habitat. In forest management, fire has a lessor role than in the past and can be viewed more as a tool that is used at judicious times in preparing for regeneration and ensuring oak's dominance through stand initiation. It has a historical and ecological basis in promoting oak dominance, but other modern treatments are more efficient and effective in managing the overstory and producing forest products. A variety of traditional silvicultural regeneration methods are able to emulate natural fire-driven stand disturbances and dynamics. Fire still has a role to play in preparing sites for oak seedling establishment and in controlling competing vegetation as oak regeneration develops the ability to maintain its dominance in young stands. However, once oak is able to maintain its dominance in maturing stands, then fire becomes a liability because it increases the risk of volume and value loss due to wood decay following fire injury or mortality. In contrast, recurring fire is essential in the creation and maintenance of oak savannah and woodland communities. It is needed to retard the encroachment of woody species, and to promote the diversity, abundance and reproductive capacity of native ground flora that are dependent on fire. Knowledge of fire history combined with an understanding of ecological requirements and competitive stand dynamics are integral for developing detailed silvicultural prescriptions for specific site conditions and range of management goals. Monitoring the vegetation is key to adapting silvicultural practices and use of fire to achieve the desired outcomes in forest, woodland and savannah management.

RIASSUNTO

Restauro delle savane e dei boschi di quercia utilizzando le moderne conoscenze derivanti dalla ricerca sulla storia degli incendi

Nel corso della storia il regime variabile degli incendi nell'America nord-orientale ha provocato la formazione di una serie di savane a quercia, che nel passato rappresentavano il tipo forestale dominante in tutta la regione. Nel secolo scorso, queste formazioni si sono rarefatte sia per la conversione del suolo all'agricoltura sia per l'evoluzione della struttura forestale in assenza di incendi. Il futuro di queste formazioni è inoltre incerto per la scarso potenziale di rinnovazione naturale della quercia. Per questi motivi la conservazione e il restauro delle savane e dei boschi di quercia sono obbiettivi primari per gli enti di gestione del territorio e le agenzie per la conservazione della natura. Le conoscenze derivanti dalla ricerca sulla storia degli incendi possono essere usate per definire linee guida selvicolturali per raggiungere questi obbiettivi. Il restauro delle savane e dei boschi di querce richiede un regime di fuoco prescritto di lungo termine, associato a prelievi legnosi e diradamenti per indirizzare la foresta verso la struttura e la composizione desiderata. È poi necessario un periodo esente da incendi occasionali, per consentire il reclutamento di nuovi individui dalla riserva di polloni che si sono accumulati nel piano inferiore. Il fuoco prescritto è utile ma deve essere usato razionalmente per ridurre al minimo i danni al soprassuolo. Associato a schemi selvicolturali basati sul trattamento a tagli successivi, il fuoco prescritto è stato impiegato con successo per la conservazione e la promozione delle foreste di quercia degli Stati Uniti orientali.

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