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The devil is in the small dense saplings: A midstory herbicide treatment has limited effects on short-term regeneration outcomes in oak shelterwood stands

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ABSTRACT

On intermediate quality sites, where oak advance regeneration often accumulates, we tested whether a low-intensity herbicide treatment of shade-tolerant saplings and poles (injection of stems >5 cm DBH with glyphosate), conducted just prior to a shelterwood harvest, could increase the proportion of oak (and hickory) in the regeneration layer after the harvest. Control and herbicide units were established at four study sites in southern Ohio. Advance reproduction was measured before and 4–6 years after a shelterwood harvest that reduced basal area by 50%. Before the harvest, shade-tolerant species, mainly red maple, blackgum, and sourwood, dominated the sapling layer but established oak-hickory seedlings were present at moderate densities. After the harvest, the proportion of oak-hickory did not change significantly on either control or herbicide units and non-oaks were dominant in the majority of plots. However, larger oak-hickory regeneration (>70 cm height) developed on nearly 50% of the sampling units (2-m radius subplots) and oak-hickory regeneration was dominant on a greater proportion of subplots in the herbicide units (26%) than in the control units (13%). Herbicide effects were limited due to the large number of smaller non-oak stems (<5 cm DBH) that were not treated and also the ineffectiveness of glyphosate to prevent red maple stump sprouting. The heavy shelterwood first removal cut stimulated the growth of both oak seedlings and competing stems, and the herbicide treatment resulted in very limited improvements in the competitive position of the oaks. However, because the oaks did survive and grow, additional treatments may still change the outcome on these sites.

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1. Introduction

Poor oak regeneration is a widespread problem in the central hardwoods region, with important ecological and economic implications (McShea and Healy, 2002). In mature, unmanaged oak (*Quercus* L.) dominated stands on intermediate and mesic sites, shade-tolerant trees typically occupy the midstory and understory strata, creating low light levels on the forest floor. These conditions reduce survival of oak seedlings and prevent the accumulation of larger oak advance reproduction (seedlings, seedling sprouts, saplings), which is necessary for successful oak regeneration after a timber harvest or natural disturbance (Johnson et al., 2009). As sites become more mesic, oak seedlings increasingly fail to persist and accumulate due to high mortality caused by competition for growing space by non-oaks (Johnson et al., 2009; Kabrick et al., 2014).

Scientists have proposed and tested variants of the shelterwood regeneration system to address oak regeneration challenges. The most successful outcomes (e.g., Loftis, 1990; Brose and Van Lear, 1998) have occurred when small oak seedlings are abundant before treatments are applied. A preliminary treatment, which we will call a shelterwood first removal cut, removes the midstory and a portion of the overstory to increase oak seedling survival and growth, and the final shelterwood removal cut takes place when there are abundant large oak seedlings. This system has also been shown to have wildlife habitat advantages by creating early successional habitat and maintaining overstory structure for a period of time (Perry et al., 1999; Bellocq et al., 2005). Thus, early- and late-successional wildlife species both occupy shelterwood stands (Newell and Rodewald, 2012).

However, without additional understory treatments (e.g., herbicide, fire), oak seedlings are often outcompeted after a

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shelterwood first removal cut by sprouts from shade-tolerant stems (Hill and Dickman, 1988; Martin and Hix, 1988), newly established but fast-growing shade-intolerant species (Loftis, 1983), or a mixture of both (Brose and Van Lear, 1998). Because oak seedlings invest more growth to roots than shoots, they become overtopped and shaded by competitors that concentrate growth aboveground. The success of the shelterwood system for sustaining oaks is dependent on several factors: (1) the initial density and size of oak advance reproduction, (2) the composition, abundance, and size of competing species in the understory, and (3) the effectiveness of additional treatments (e.g., herbicide, fire, fencing) to reduce the dominance of competing non-oak species and/or favor the survival and growth of oak (Brose et al., 2008).

On mesic northern red oak sites in southern Appalachia, intensive single-stem pre-harvest herbicide applications that treat midstory trees and also small stems of yellow-poplar (*Liriodendron tulipifera* L.) (<5 cm DBH down to 60 cm height), have been shown to effectively reduce competition and increase the survival and growth of oak advance reproduction that was abundant before the treatment (Loftis, 1990; Kass and Boyette, 1998). However, studies in West Virginia (Schuler and Miller, 1995) and Wisconsin (Povak et al., 2008) have reported poor to moderate oak regeneration even after intensive pre-harvest herbicide treatments of shade-tolerant species such as sugar maple (*Acer saccharum* Marsh); both of these studies began with low densities of oak advance reproduction. Other factors such as the effectiveness of the herbicide and the intensity of deer browsing may also affect regeneration outcomes. When small shade-tolerant stems occur at high densities, individual stem herbicide treatment may be very costly (Kochenderfer et al., 2004).

The shelterwood burn method has been tested as a cost-efficient and effective method to promote oak regeneration. Brose and Van Lear (1998) studied mixed oak stands in Virginia with abundant regeneration of small oak seedlings and other species. They found that a first removal shelterwood cut followed several years later with a single prescribed fire favored oaks as the fire caused higher mortality rates in competing understory species such as yellow-poplar and red maple (*Acer rubrum* L.) than among the oaks. The oaks gained the greatest advantage from moderate- to high-intensity fires conducted during the growing season.

In many stands, however, prescribed fire is not a management option. Even where prescribed fire can be used, growing-season burns may not be feasible due to fuel and weather conditions or may not be allowed due to concerns about the impacts of fire on wildlife. For example, on lands owned by the Ohio Division of Natural Resources, any prescribed fire conducted after 15 April requires a survey the previous year to determine whether the federally endangered Indiana bat (*Myotis sodalis*) may be present in the burn unit (ODNR, 2013).

In mature oak stands on intermediate quality sites (Oak SI $\sim$ 18–21 m), oak advance reproduction often accumulates in the understory but remains relatively small and is typically overtopped by shade-tolerant saplings and poles. Under these conditions, we tested whether a moderate-intensity herbicide treatment of shade-tolerant saplings and poles (injection of stems >5 cm DBH), conducted just prior to a shelterwood harvest, could increase the proportion of oak (and hickory, *Carya* L.) in the regeneration layer after the shelterwood harvest. We hypothesized that the late-growing season herbicide treatment would increase the proportion of oak-hickory through reduced sprouting of competitors. We also hypothesized that greater densities of large oak-hickory reproduction would develop after the shelterwood harvest in herbicide-treated units, due to less competition from stump sprouts of competitors.

2. Methods

2.1. Study area

Four study sites of 26–43 ha are located in southeastern Ohio, in the Unglaciated Allegheny Plateau. All sites are on State Forests owned and managed by the Ohio Department of Natural Resources, Division of Forestry. The Ball Diamond (39°11′16″N, 82°24′27″W) and Wolf Oak (49°10′42″N, 82°23′27″W) sites are on the Vinton Furnace State Forest (VFSF), in Vinton County. The Zaleski (39°20′2″N, 82°18′33″W) and Richland Furnace (39°10′20″N, 82°36′24″W) sites are located on nearby Zaleski and Richland Furnace State Forests, in Vinton and Jackson Counties, respectively.

The physical setting and land use history are generally similar for all sites. Topography is dissected with steep slopes and narrow valleys. Elevations range from 200 to 300 m. Bedrocks are predominantly sandstones of Pennsylvanian age, with some siltstones and shales. The highly weathered soils are fairly similar among sites and are characterized as moderately deep (50–100 cm to bedrock) sandy loams and silt loams that are acidic and have low available water capacity; the primary soils are the Steinsburg–Gilpin Association (Wolf Oak and Zaleski), the Germano–Gilpin Complex (Ball Diamond), and the Rarden–Wharton Complex (Richland Furnace) (Kerr, 1985; Lemaster and Gilmore, 2004). Steinsburg soils are coarse-loamy, mixed, active, mesic Typic Dystrudepts. Gilpin soils are fine-loamy, mixed, active, mesic Typic Hapludults. Germano soils are coarse-loamy, mixed, active, mesic Aquultic Hapludalfs. Wharton soils are fine-loamy, mixed, active mesic Aquic Hapludults. The average temperature, precipitation and growing season length at VFSF are 11.3 C, 1024 mm, and 158 days, respectively (Sutherland et al., 2003). Each site is located on former "furnace lands" which were clearcut in the mid- to late-1800s to provide charcoal to fuel nearby iron furnaces.

Stands were even-aged: dominant trees were 80 years old at Richland Furnace, 100 years at Zaleski, and 130 years at Ball Diamond and Wolf Oak. Among the four sites, tree basal area averaged 22–29 m^2/ha, of which 74–85% was oak-hickory. White oak (*Quercus alba* L.), chestnut oak (*Q. montana* Willd.), and black oak (*Q. velutina* Lam.) were dominant species in the overstory. Site index (black oak) of mid- to upper-slopes, where plots were located, ranged from 18 to 21 m (Carmean, 1965). White-tailed deer (*Odocoileus virginianus* Zimm.) populations are estimated at 5–7 deer/km^2 after hunting season; at these densities, browsing does not have a large impact on the density or composition of advance reproduction (Apsley and McCarthy, 2004).

2.2. Experimental design and treatments

The experimental design is a randomized complete block. At each of the four study sites (blocks), the entire 26–43 ha area would receive a shelterwood harvest. Four 5–12 ha treatment units were established at each site, two control (shelterwood harvest only) and two herbicide (herbicide + shelterwood harvest) units. There were four units at each site in order to incorporate a future (post-shelterwood) prescribed fire treatment on two of the units: one shelterwood + prescribed fire treatment and one herbicide + shelterwood + prescribed fire unit per site.

In 2005, prior to the shelterwood harvest, stem-injection herbicide treatments were applied in late summer and fall. Herbicide treatment dates were August 11–29 at the Ball Diamond, Richland Furnace, and Zaleski sites, and October 3 and 4 at the Wolf Oak site. For all tree species other than oaks and hickories, all stems >5.0 cm DBH were injected with glyphosate (54% active ingredient) (Kochenderfer et al., 2012), within each sample plot (see below) and also within a 10 m buffer surrounding each plot. From our