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Northern red oak regeneration: 25-year results of cutting and prescribed fire in Michigan oak and pine stands

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ABSTRACT

Overstory and understory treatments were established in natural oak stands and red pine plantations in Michigan in 1991 to test the hypotheses that (1) oak seedling survival and growth would be greater in pine than oak stands and (2) removal of competitors would enhance oak seedling performance. Late spring prescribed fires were implemented in 2002 and 2008 to investigate their effectiveness in controlling understory red maple. Performance of planted northern red oaks has been monitored since 1991 and the abundance of naturally regenerating oak and red maple seedlings and sprouts in different size classes has been documented since 2001. A subset of oaks has been protected against deer browsing since planting. Results suggest partial competitor removal enhances oak seedling and sprout performance, whereas complete removal increases mortality from browsing and frost. Increases in red maple abundance and decreases in oak abundance were documented after the prescribed fires in 2015. Greater growth and survival of planted oaks was observed in the pine stands, provided they were protected from browsing. Based on these results, the most viable management scenario for maximizing survival and growth of oak seedlings and sprouts in the study region would include protecting oak seedlings from deer in 25% canopy cover shelterwoods in pine plantations. Opportunities exist for developing systems involving alternating rotations and mixtures of oak and pine.

1. Introduction

Increasing recognition of oak (*Quercus* spp.) regeneration problems stimulated several studies, reviews, and conferences focused on identifying causes and potential solutions in the 1980s and early 1990s (Abrams, 1992; Abrams and Nowacki, 1992; Crow, 1988; Laursen and DeBoe, 1991; Loftis and McGee, 1993; Lorimer, 1993, 1985). Of the potential mechanisms underlying regeneration failures, increased competition between oaks and species less adapted to fire such as red maple (*Acer rubrum* L.), sugar maple (*Acer saccharum* Marshall), yellow-poplar (*Liriodendron tulipifera* L.), and American beech (*Fagus grandifolia* Ehrh.) was forwarded as a predominant factor. It was hypothesized that fire exclusion over much of the 20th Century increased the abundance of these competitors throughout the eastern United States (Abrams, 2016, 1992; Crow, 1988; Lorimer, 1993; Nowacki and Abrams, 2008). Oak regeneration failures due to the competitive effects of other hardwoods are thought to be more common on productive sites than on intermediate and poor sites (Loftis and McGee, 1993). Multiple studies established in several states in the 1980s and 1990s focused on reducing overstory and understory competitors through cutting, herbicide application, and prescribed fire (e.g., Brose et al., 2001, 1999a, 1999b; Brose and Van Lear, 1998; Crow, 1988; Loftis, 1990a; Reich et al., 1990; Ross et al., 1986; Will-Wolf, 1991). More recently, McEwan et al. (2011) and Arthur et al. (2012) have pointed out that changes in climate, predators, herbivores, keystone plant species, and land use have also occurred within the same time period as changes in fire regimes and declines in oak regeneration. Deer browsing, late spring frost, and seed predation were also implicated in oak regeneration failures in the

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1990s, but were considered to be aggravating or contributing factors because their importance varied from region to region (Lorimer, 1993). Browsing and frost damage have been addressed in several oak regeneration studies and publications (Marquis et al., 1976; Miller et al., 2017; Thomas-Van Gundy et al., 2014), although competition has remained the primary focus of most projects.

Shared interest in developing techniques for enhancing oak regeneration on the part of the Michigan Department of Natural Resources (DNR) and USDA Forest Service, North Central Forest Experiment Station resulted in support for a long-term, replicated oak regeneration study established in 1991 in northern Lower Michigan (Buckley et al., 1998). The principal aims of this project were to examine the effects of canopy manipulation treatments, understory manipulation treatments, and two prescribed fires on artificial and natural oak regeneration in natural northern red oak (*Quercus rubra* L.) and planted red pine (*Pinus resinosa* Sol. Ex Aiton) stands.

Fossil pollen records indicate long-term co-occurrence of upland oaks and pines in the region, with changes in oak species dominance relative to pines throughout the past 10,000 years (Jacobson, 1979; Webb, 1974). Inventory data collected within the region and additional observations revealed patterns including oak seedlings and saplings in the understory of mature pine stands, and also young pines in the understory of mature oak stands, suggesting a potential for cyclical replacement of oaks and pines (Crow, 1988; Johnson, 1992; Sarnecki, 1990). Based on this evidence and the tendency for oak to follow pine in successional sequences, it was hypothesized that oak regeneration would be enhanced in pine stands relative to oak stands, although the exact mechanisms were unknown. Sarnecki (1990) documented abundant oak regeneration beneath red pine canopies at relatively low levels of canopy cover, suggesting that pines may provide favorable conditions for oak regeneration, while hindering other hardwood competitors. Specific objectives were to (1) test the hypothesis that northern red oak seedlings would be more successful in pine than oak stands, (2) evaluate overstory canopy treatment effects on long-term oak regeneration, (3) evaluate understory treatment effects on long-term oak regeneration, (4) evaluate oak regeneration before and after prescribed fire, and (5) test the hypothesis that woody understory competitors would be reduced with prescribed fire.

2. Materials and methods

2.1. Sampling area

Study sites were established on state forests in southern Roscommon County (84°41′ W, 44°14′ N, elevation 300 m) and southern Crawford County (84°45′ W, 44°31′ N, elevation 400 m) in Michigan. Both counties are within the Grayling Outwash Plain of the Highplains District of the northern Lower Peninsula (Albert, 1995). Soils are characteristic of sandy, mixed, frigid, Alfic Haplorthods developed in pitted outwash. Excavation of soil pits indicated that physical and chemical properties of soils were comparable among sites (Kim et al., 1996). Slopes were ≤5%. Stands utilized in the study were either second-growth natural oak, or unthinned planted red pine stands. The study sites were intermediate in productivity. Site index for northern red oak according to curves for the Lake States region was 17–18 m at a base age of 50 years (Carmean et al., 1989). Site index for red pine was about 17.2 m at age 50, based on curves for red pine in Minnesota (Gevorkiantz, 1957). The oak stands were 88–100 years old and the pine stands were 59–75 years old (Buckley et al., 1998). Deer densities for Roscommon County and Crawford County are estimated at 12–18 deer/km^2 and 6–12 deer/km^2, respectively (Quality Deer Management Association, 2017). Deer population densities between 2006 and 2015 remained stable in Roscommon County (Michigan Department of Natural Resources, 2017a) and were stable, if not increasing in Crawford County (Michigan Department of Natural Resources, 2017b).

In 1991, the herb layer (0–25 cm above ground) was dominated by grasses, sedges, blueberry (*Vaccinium angustifolium* Ait. and *Vaccinium myrtilloides* Michx.), and red maple seedlings. The shrub layer (≥25 cm above ground to stems 2.54 cm in diameter at breast height (dbh)) was predominantly comprised of bracken fern (*Pteridium aquilinum* (L.) Kuhn) and red maple saplings. Witch hazel (*Hamamelis virginiana* L.), beaked hazel (*Corylus cornuta* Marsh.), black cherry (*Prunus serotina* Ehrh.) saplings, and trembling aspen (*Populus tremuloides* Michx.) saplings were also present in the shrub layer. Extensive presettlement forests of eastern white pine (*Pinus strobus* L.), red pine, jack pine (*Pinus banksiana* Lamb.), oak-pine mixtures, and northern hardwoods covered the uplands of Crawford and Roscommon counties (Whitney, 1986). Presettlement stands of large eastern white and red pine on pitted outwash often contained oak in the subcanopy (Whitney, 1986). Following turn of the 20th century logging and repeated burning, extensive areas of both counties were replanted with eastern white pine, red pine, and various mixtures of eastern white, red, and jack pine between 1900 and 1956 (Stone, 1958). Red pine plantations were selected for this study, as natural pine stands of sufficient size and density for experimentation no longer existed in the study region.

2.2. Experimental design

Three replicate oak blocks and three replicate pine blocks measuring 1.74 ha each were subdivided into four 66 × 66 m plots measuring 0.44 ha each. One of four canopy cover treatments (0% residual canopy, 25% residual canopy, 75% residual canopy, or uncut control, hereafter referred to as 0%, 25%, 75%, and 100%, respectively) was randomly assigned to each plot (Buckley et al., 1998). A minimum 20 m-wide buffer zone was established between each treated area and adjacent access roads. Stands receiving canopy cover reduction treatments were cut from fall 1990 to early spring 1991. Partial canopy cover treatments were performed by initially cutting subcanopy trees ≥ 2.54 cm dbh from below, then cutting additional canopy trees as needed to meet the required treatment objective. In all treatments, red maple and suppressed red pine in subordinate canopy positions were cut first. In 0% treatments, all woody plants ≥ 2.54 cm dbh were cut. Soil compaction and understory vegetation disturbance were minimized by restricting logging equipment to the buffer zones. Woody debris was cleared from planting areas by hand.

Four 15 × 15 m understory treatment subplots (0.02 ha each) were arranged in a square pattern at the center of each canopy treatment plot (Buckley et al., 1998), which resulted in an 18 m buffer between understory subplots and the edge of the canopy treatment plot. Four understory treatments were randomly assigned to the understory treatment subplots within each canopy treatment: Shrub Layer Removal (S) (herbs, shrubs, and saplings ≥ 25 cm tall up to 2.54 cm dbh), Herb Layer Removal (H) (herbs, shrubs, and seedlings < 25 cm tall), Litter Removal down to humus layer (L), and Control (C). All treatments were completed with hand tools just prior to planting in 1991 and were maintained periodically from 1992 to 2001. No maintenance of understory treatments occurred between 2001 and 2015.

Northern red oak acorns and nursery seedlings were planted for comparison of treatment effects on seedlings at different stages of development. As outlined by Buckley et al. (1998), all acorns for direct seeding were collected from 20 to 30 dominant trees growing on a range of sites in October of 1990 at the University of Michigan Biological Station (UMBS), located in Cheboygan County, Michigan. Nursery seedlings (2–0) were acquired from Wyman State Tree Nursery in Manistique, Michigan.

Acorns and nursery seedlings were planted 2 m apart on a 10 × 10 m grid within each 15 × 15 m understory treatment plot in late April of 1991. Twenty grid points were randomly selected to receive acorns, 12 were randomly selected to receive nursery seedlings, and four were reserved for related studies (Zhou et al., 1998; Zhou and Sharik, 1997). In total, 5760 acorns and 1152 nursery seedlings were planted. Three acorns were planted at each direct seeding location,