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Four-year response of underplanted American chestnut (*Castanea dentata*) and three competitors to midstory removal, root trenching, and weeding treatments in an oak-hickory forest

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ABSTRACT

American chestnut (*Castanea dentata*) has been killed or reduced to recurrent stump sprouts throughout its range following the importation of multiple pathogens in the 19th and early 20th centuries. Understanding what drives chestnut growth and survival would aid the development of appropriate silvicultural guidelines for restoring the species once blight resistant stock is available. Here we compare the response of planted American and hybrid chestnut seedlings to that of important competitors, northern red oak (*Quercus rubra*), sugar maple (*Acer saccharum*) and red maple (*A. rubrum*), under treatments designed to evaluate the effects of various sources of competition on seedling growth and survival. After four years, American and hybrid chestnut was significantly taller in trenched plots (181.8 ± 12.4 cm; mean ± SE) compared to untrenched plots (127.5 ± 7.9 cm), weeded plots (174.5 ± 12.7 cm) compared to unweeded plots (130.1 ± 6.5 cm) and in midstory removal plots (156.6 ± 7.8) versus full canopy (88.8 ± 11.7 cm), and had outperformed the other species in most competitive environments. Chestnut was the only species to respond to every treatment with significant growth increases, displaying a notable ability to capture growing space when it became available. We suggest that American chestnut restoration may be more successful where early stand management provides chestnut a brief period of reduced competition. Specifically, midstory removal can increase survival and growth of underplanted American chestnut, and when combined with multi-stage shelterwood removals of the overstory and some amount of competition control, may constitute a viable restoration strategy for chestnut in many of the eastern oak-hickory forests where it was originally dominant.

1. Introduction

American chestnut (*Castanea dentata* (Marsh.) Borkh.) was a dominant hardwood species in eastern North America prior to the importation of two pathogens: cinnamon root rot (*Phytophthora cinnamon* Rands.) in the 1860s and chestnut blight (*Cryphonectria parasitica* (Murr.) Barr.) in the 1900s (Anagnostakis 2012; Foster et al., 2002). The two pathogens caused widespread and near complete mortality of the species, respectively leading to a range contraction in the southern US and to functionally extirpating the species elsewhere. On *Phytophthora*-free sites, American chestnut now only exists as recurrent stump sprouts which rarely reach sexual maturity (Paillet, 2002). Consequently, American chestnut been replaced on the landscape by a variety of other tree species, most prominently oaks (*Quercus* spp. L.; Paillet, 2002; Vandermast and Van Lear, 2002).

American chestnut has little to no natural resistance to either pathogen. Although tree breeding efforts to confer resistance to *Phytophthora* has only recently started, a long history of backcrossing by the U.S. Forest Service, the Connecticut Experiment Station and, most recently, The American Chestnut Foundation has produced putatively blight-resistant hybrids of American chestnut and Asian species; these are being field tested for eventual restoration in plantings across the former range (Anagnostakis, 2012; Jacobs et al., 2012; Worthen et al., 2010). The current scarcity and expense of this planting material necessitate a shift in research focus away from describing the ecophysiology of American chestnut (Bauerle et al., 2006; Joesting et al., 2009; Latham, 1992; Wang et al., 2006), and toward developing nursery, planting and silvicultural protocols that will lead to high survival (Clark et al., 2012a,b; Jacobs et al., 2012). Reintroduction strategies for planted American chestnut in intact forests and other natural settings is

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strongly needed, yet this research remains uncommon (Gauthier et al., 2013; McCament and McCarthy, 2005; Rhoades et al., 2009).

While many studies have described American chestnut in afforestation plantings (e.g., Gauthier et al. 2013; Jacobs and Severeid, 2004), particularly on mine reclamation sites, relatively few have looked at reintroduction in existing forests (Clark et al., 2012a; McCament and McCarthy, 2005). The numerous benefits of reintroducing American chestnut in understory environments likely include lower competitive pressure, fewer environmental extremes, and lower browse pressure (Comeau et al., 2005; Motsinger et al., 2010; Paquette et al., 2006). Underplanting often requires minimal site preparation as canopy shade has suppressed shrub and herbaceous growth, expedites the development of mature forest characteristics, and maintains high levels of forest-based ecosystem services (Comeau et al., 2005; Paquette et al., 2006). Finally, underplanting systems are advantageous on sites following overexploitation, local extirpation, or any other causes of insufficient natural regeneration of the desired species (Dey and Parker, 1997; Lhotka and Loewenstein, 2013; Paquette et al., 2006). Plantings need not cover a large area nor be at high densities; given the goals of restoration, introducing a new species through dispersed, low density planting which mimic natural forest succession may be preferable to classic plantation establishment.

Though American chestnut's performance has rarely been compared to competitor species in the understory, historical writings and paleoecological pollen records indicate that chestnut was found across a wide range of environments (Foster et al., 2002; Wang et al., 2013). Underplanting chestnut in oak-dominated stands may be an effective means of capitalizing on American chestnut's competitive ability and intermediate shade tolerance to increase its dominance relative to competing species (Clark et al., 2012a; Griscom and Griscom, 2012; Joesting et al., 2009; Rhoades et al., 2009). Many oak stands require control of shade-tolerant midstory stems preceding an overstory harvest in order to increase light availability and promote establishment of oak advance regeneration (Bailey et al., 2011; Lhotka and Loewenstein, 2013; Lhotka and Zaczek, 2003; Motsinger et al., 2010). These midstory removal treatments are now commonly used as a first stage in shelterwood regeneration systems in eastern oak forests rather than a traditional establishment cut that would otherwise encourage the encroachment of less desirable, shade-intolerant species (Loftis, 1990; Lhotka and Loewenstein, 2013; Motsinger et al., 2010). Maintaining partial canopy cover and, thereby, excluding fast-growing, intolerant species should increase the growth and survival of planted American chestnut seedlings (Clark et al., 2012a; Latham, 1992; McCament and McCarthy, 2005; Rhoades et al., 2009; Wang et al., 2013).

In addition to directly altering light competition, silvicultural treatments indirectly alter belowground competition. Reduction of root competition can improve seedling performance as much as the increased light availability resulting from crown thinning (Barberis and Tanner, 2005; Coomes and Grubb, 2000). Even herbaceous vegetation can provide sufficient competitive pressure to negatively impact seedling growth (Davis et al., 1998). Unfortunately, the degree to which root competition limits aboveground growth still remains poorly understood (Barberis and Tanner, 2005; Coomes and Grubb, 2000). The rooting habits of American chestnut in particular have not been extensively studied, although the species is hypothesized to have tendencies similar to co-occurring oak species which invest heavily in belowground structures early in development (Clark et al., 2012b; McCament and McCarthy, 2005; Wang et al., 2006). This may be a tenuous assumption as American chestnut grows more quickly in height and stem diameter than oak across a variety of light levels and competitive environments (Jacobs and Severeid, 2004; Latham, 1992; Wang et al., 2006).

The objectives of this study were to compare the growth and survival of underplanted American and hybrid chestnut to three common competitors, northern red oak (*Quercus rubra* L.), red maple (*Acer rubrum* L.) and sugar maple (*A. saccharum* Marsh.), under a range of competitive conditions produced by combinations of midstory removal, trenching and weeding. Using a blocked, split-split plot design that juxtaposed midstory removal, trenching and weeding treatments with full canopy and untreated controls, we isolate sources of competition affecting seedling survival and growth and make inferences on restoration strategies for the species in intact, natural forests. We predicted that the shade-tolerant maple species would survive better and grow faster than chestnut or oak in the heavily shaded control treatments, but that all species' survival and growth would increase after midstory removal. We also predicted that due to the reduction of competition resulting from weeding and trenching treatments, all species would respond to those treatments with increased growth. Finally, due to its potentially high growth rates, our final hypothesis was that chestnut would more readily respond to increased growing space resulting from midstory removal, trenching and weeding treatments.

2. Materials and methods

2.1. Study sites

This study was conducted on two Purdue University properties in north-central Indiana: the Cox–Haggerty Property (40°25.7′N, 86°58.2′W) and Meigs Research Farm (40°17.3′N, 86°52.5′W). Both sites are in the Central Till Plain, Beech-Maple Section (McNab et al., 2005), and have a mean annual temperature of 10.9 °C and annual precipitation of 105.4 cm (NCDC, 2012). Monthly precipitation is slightly higher in the spring and summer months (maximum: May, 11.3 cm avg.), than in the fall and winter months (minimum: February, 5.8 cm avg.; NCDC, 2012). The region has relatively short, mild winters and long, hot summers. Average day of last freeze is April 22 and average day of first freeze is October 16 (NCDC, 2012).

The Cox–Haggerty canopy is dominated by white oak (*Q. alba* L.) and red oak (*Q. rubra* L.) as well as several hickory species (*Carya* spp. Nutt.), with a midstory of primarily sugar maple, sassafras (*Sassafras albidium* Nutt.), Ohio buckeye (*Aesculus glabra* Willd.) and the invasive exotic Amur honeysuckle (*Lonicera maackii* Rupr.). The understory at Cox–Haggerty is somewhat sparse and consists primarily of regenerating sugar maples, various grasses, and Amur honeysuckle. Average overstory basal area is 36 $m^2\ ha^{-1}$ with a site $index_{50}$ for upland oaks of 24–26 m (Bailey, 2011; NRCS, 2014). Soils are Miami silt loam grading into the clay loam Strawn-Rodman complex. Both are well-drained and derived from loamy glacial till (NRCS, 2014). Planting blocks were located in areas that minimized the effects of topography, usually in areas below 20% slope.

The Meigs canopy is dominated by hickory, elm (*Ulmus* spp. L.) and black cherry (*Prunus serotina* Ehrh.), with the midstory layer dominated by elms and hackberry (*Celtis occidentalis* L.). Meigs is a very productive site with a thick understory consisting of a variety of herbaceous species, including poison ivy (*Toxicodendron radicans* (L.) Kuntze), mayapple (*Podophyllum pelatumi* L.) and wood nettle (*Laportea canadensis* (L.) Weddell). Average overstory basal area is 26 $m^2\ ha^{-1}$ with a site $index_{50}$ for upland oaks of 24–28 m (Bailey, 2011; NRCS, 2014). Soils range from Crosby-Miami silt loam complex to Richardville silt loam; both soils are derived from loess over loamy glacial till (NRCS, 2014). The site lacks major topographical relief (i.e., slopes between 0% and 2%) and adjoins a restored wetland area, with soils at or above field capacity during much of the growing season in most years.